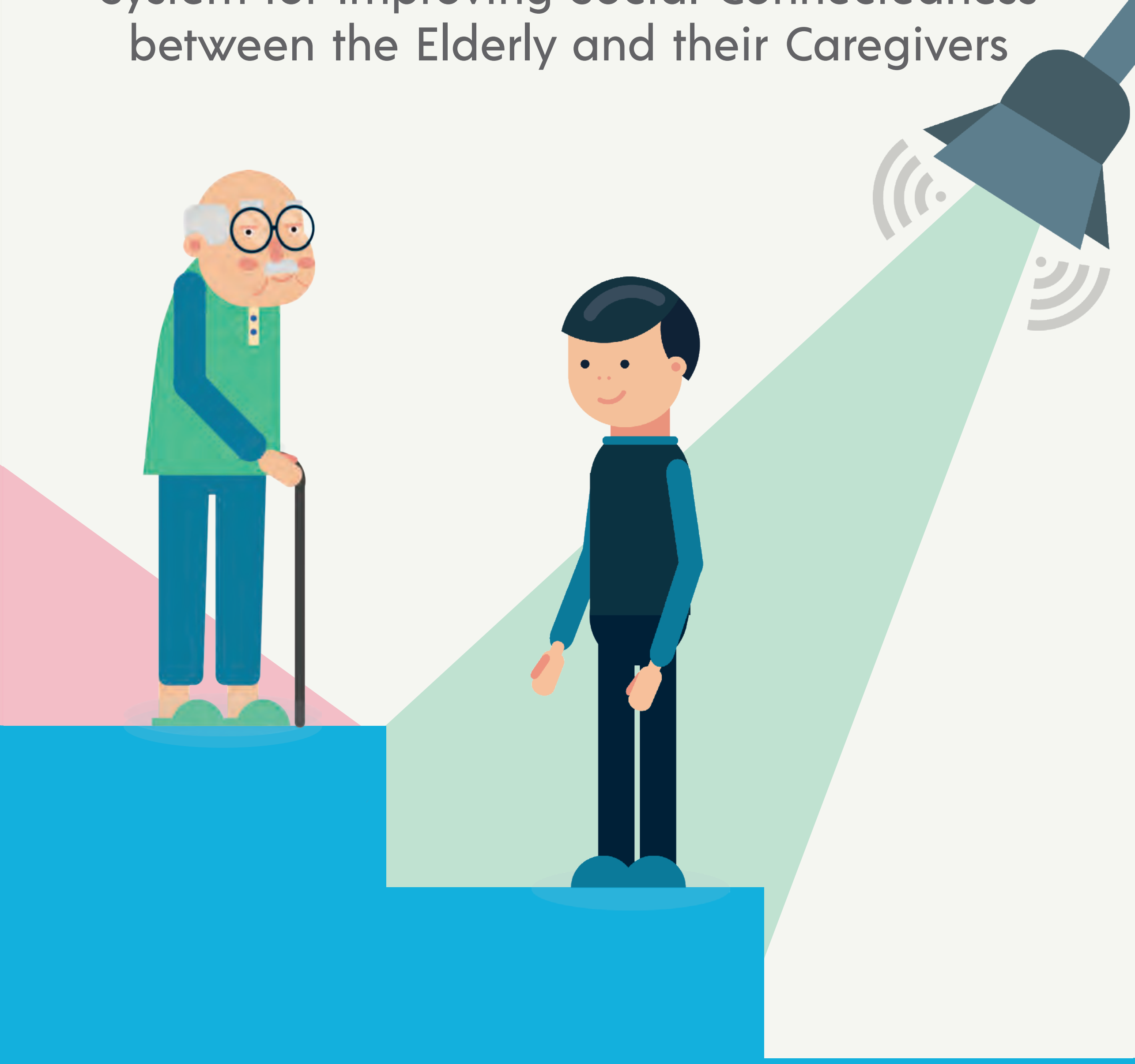
# Social Hue

A Bidirectional Human Activity-Based System for Improving Social Connectedness between the Elderly and their Caregivers



Kadian Alicia Davis

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A Bidirectional Human Activity-Based System for Improving Social Connectedness between the Elderly and their Caregivers

PROEFSCHRIFT

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door

Kadian Alicia Davis

geboren te St. Andrew, Jamaica

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TECHNISCHE UNIVERSITEIT EINDHOVEN

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*"There is gold, and a multitude of rubies: but the lips of knowledge are a precious jewel."*

—Proverbs 20:15

*"Ti koro nko agyina" Translation – One head does not hold council.*

—Akan Proverb

*This work is dedicated to the One my soul loves, my dear and loving husband, my beloved parents, delightful brother, nurturing grandmother, close relatives, and friends.*

# Summary

Nowadays, people are living longer, which is primarily influenced by improved sanitation and hygiene, access to food, clean water, and modern medicine. However, the elderly are sometimes challenged with social isolation and loneliness while caregivers are often worried about their elderly loved ones. In truth, ageing is a reality for all of us, although ‘daunting’ it provides a unique opportunity to design and develop state-of-the-art technologies for promoting healthy and active ageing and improving social connectedness between the elderly and their caregivers.

In recent years, we have seen a massive growth in smartphones and wearable technologies. Remarkably, sensors embedded in these devices are capable of capturing vast amounts of data related to location, activities of daily living (ADL), and health. Human activity recognition (HAR) is widely adopted within the ambient assisted living (AAL) domain by leveraging ubiquitous sensors to recognize ADLs for health monitoring and enhancing the elderly’s quality of life. Moreover, the exchange of activity cues between the elderly and their caregivers could trigger emotional responses and reveal pertinent information concerning their health, moods, and habits.

However, most assisted living technologies focus on the use of sensors for ambulatory monitoring of emergency cases, in particular, fall detection with little progress toward improving interpersonal relationships between the elderly and their caregivers. Also, existing AAL tools which enable context-awareness are often unidirectional (i.e., only providing elderly-contextual information to relatives and not vice-versa) giving rise to obtrusiveness and violations of privacy and dignity rights among the elderly population.

Besides, understanding the nature of users in their physical environments, their needs and expectations are challenged by readily available computer simulation tools, which often ignore the challenges (cognitive impairments, motor and physical disabilities, social isolation, and loneliness) faced by the ageing population. In addressing the design and validation of AAL solutions, it often appears as though researchers are more focused on features of technicality and functionality at the expense of designing to ensure usable and acceptable products, which easily integrate into the users’ daily lives.

This dissertation employs a user-centered design approach within a multidisciplinary framework, which includes aspects of human-computer interaction, social psychology, cognition, signal processing, and pervasive computing for the design, development, deployment, and validation of bidirectional activity peripheral displays to support social connectedness. Throughout this dissertation, we exploit a human-centered approach to actively involve impending ageing and caregiver users in our design, development, and validation process. Traditional ethnographic techniques such as interviews and observation, accompanied by contemporary techniques such as co-constructing stories were applied to acquire a holistic understanding of the users in context and assist prospective users to imagine user requirements and envision future usage possibilities within AAL environments.

Within this framework, we exploited the smartphone's inertial sensors (accelerometer and gyroscope) and advanced HAR algorithms to identify six basic activities (standing, sitting, laying, walking, walking upstairs, and descending the stairs) of the elderly and their caregivers. A hybrid multi-class support vector machine (SVM) and hidden markov model (HMM) algorithm was developed to detect users' activities with a very small margin of error. This hybrid model was evaluated against standalone classical multi-class SVM, and artificial neural network (ANN) classifiers applied to data collected from prospective elderly and caregivers, with the hybrid model demonstrating the best classification performance. Subsequently, our dataset was made publicly available for use by the machine learning community.

The aforementioned basic activities later served as inputs to a bidirectional activity-based ambient display system for increasing social connectedness between the target groups. Subsequently, a real-time activity-based two-way lighting system consisting of waist-mounted smartphones, a central HAR server, Philips Hue light orbs, a Led walking cane, and a Led wallet were designed, implemented, and deployed within a living lab environment. Overall, six different experimental studies were conducted to investigate the following:

- Obtain an understanding of the users' context in order to enrich the design of connectedness oriented solutions in AAL.

- Examine the relevance of accurate presentation of activity information with ambient displays.

- Develop a more robust and reliable human activity recognition model for the AAL context, while taking usability issues such as end-user acceptance and privacy into account.

- Explore ambient lighting properties suitable for an unobtrusive exchange of activity information.

- Investigate the implications of the receipt of activity information via ambient lighting on cognition (problem solving, implicit memory and attention), subjective social connectedness, arousal, and valence.
- Probe how the exchange of activity information between interaction partners could influence interpersonal activity synchrony.

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# Chapter 1

# Introduction

*"Age is an issue of mind over matter. If you don't mind, it doesn't matter."*

—Mark Twain

## 1.1 Population Ageing: A Global Phenomenon

In the last century, global life expectancy has considerably increased. In 1900, the average life expectancy in the developed world was estimated between 40 and 50 years while today, the predicted life expectancy is 80 years (UNFPA, 2012). A continued rise in life expectancy will yield a major increase in old-dependency ratios, i.e., the proportion of elderly persons not in the labour force to those of working age (Debes et al., 2016). Following this trend, the World Health Organization predicts that the number of persons aged 60 and over will be more than double its size going from 901 million in 2015 to nearly 2.1 billion in 2050 (World Health Organization, 2015). This unprecedented phenomenon is driven by improved nutrition, access to sanitation, increased access to education and advances in medicine, primarily in the diagnosis and treatment of diseases (UNFPA, 2012). Although this is a sign of progress, there are many concerns associated with population ageing, which are yet to be addressed.

Primarily, population ageing can impose considerable economic cost and social implications. These include increased public spending on health and long-term care, the shortage of formal caregivers (e.g., nurses/care-home personnel), and increased taxation for the working-age population to support pension schemes. Moreover, population ageing imposes pressure on informal caregivers (e.g., family/friends/neighbours living apart, who maintain social contact with the elderly once or twice per week) trying to strike a balance between the re-

This chapter is partly based on selected paragraphs from the following publications (Davis, Feijs, Hu, Marcenaro & Regazzoni, 2016; Davis, Hu, Feijs & Owusu, 2015; Davis, Owusu, Bastani et al., 2016; Davis, Owusu, Hu et al., 2016; Davis, Owusu, Marcenaro et al., 2016; Davis, Owusu, Marcenaro, Hu et al., 2017; Davis, Owusu et al., 2015; Davis, Owusu, van den Boomen et al., 2017; Davis, Owusu, Marcenaro, Feijs et al., 2017).

sponsibility of taking care of their elderly loved ones and their own personal and professional lives.

### 1.1.1 Social Isolation, Loneliness, and Medical Issues as Risk Factors

Social support is a critical component of healthy and active ageing. Notably, caregivers whether family, friends, neighbours, or professional helpers are key pillars of social support for older adults. In fact, Hazer and Boylu (2010) assert that caregivers are instrumental in alleviating the sense of alienation brought about by old age and ensuring that older adults still feel ‘needed’ and ‘valued’. While social isolation and loneliness are common among all age groups, the elderly are more prone to experience this social phenomenon (Halmos, 2013; Sheldon et al., 1948). An account of these concepts and their essential indicators by Shahtahmasebi and Scott (1996) is given below.

- *Social isolation* – refers to the objective state of infrequent or the nonexistence of communication with others. It is identifiable by a wide range of indicators, namely;
  - living alone,
  - having little or no social participation,
  - perceived lack of social support,
  - and feelings of loneliness.
- *Loneliness* – ascribes to the subjective state of repugnant emotions affiliated with social isolation, limited contact than desired and the deprivation of companionship.

Some gerontological studies suggest that social isolation and loneliness have precarious health risks commensurable with smoking and obesity in older adults (Cornwell & Waite, 2009). In fact, social isolation has often been held accountable for increased mortality in older adults (Cornwell & Waite, 2009; Steptoe, Shankar, Demakakos & Wardle, 2013).

Besides social isolation and loneliness, increased longevity is associated with heightened susceptibility to several medical issues, including cognitive disorders, cardiovascular and mental health diseases, and motor and physical disabilities (Helal, Mokhtari & Abdulrazak, 2008; Steptoe et al., 2013). Despite the elderly’s increased vulnerability to social isolation, chronic illnesses and disabilities, the majority of westernised older adults are in favour of living independently and remaining in the comfort of their own homes (Farber & Shinkle, Dec. 2011; Maeda & Ishikawa, 2002), a concept more formally coined as *"ageing in place"* (Wiles, Leibing, Guberman, Reeve & Allen, 2011). However, many homes in their current state, are unfit for accommodating the mobility limitations of older adults. Thus, prompting the demand for safer, smarter, and more adaptable homes.

To address these challenges, policy makers, non-profit organizations, and major industry partners have sparked heightened interest in the development of cutting-edge interventions directed toward sustained well-being and independent living while lowering the costs associated with elderly care. More specifically, social participation has been incorporated into the research and public policies of ageing societies as shown by the Guide to Social Innovation report (Regional and Urban Policy, 2013). For example, the National Foundation for the Elderly[1] is a Dutch charity organization, which aims to promote quality of life and prevent isolation among older adults. Such associations enable social cohesion through active involvement in volunteering services, clubs, and organizations. In turn, this fosters a sense of belongingness and also influences the quality of life, which is critical for the sustainable development of ageing societies. Altogether, the work in this dissertation is set against the backdrop of population ageing and is situated within the wider context of ambient assisted living (AAL), a framework which will now be discussed.

## 1.2 Ambient Assisted Living – A Framework for Promoting Ageing in Place

With the goal of meeting the day-to-day needs of older adults, AAL[2] is an interdisciplinary field, which aspires to develop innovative technical solutions for preserving health, functional independence, and enhancing social interaction among older adults. Ambient Intelligence (AmI), the backbone of AAL, aspires to detect people's state and adaptively respond to their needs and behaviours through the integration of ubiquitous technologies in their environment (Vasilakos & Pedrycz, 2006). Drawing from disciplines such as artificial intelligence, human computer interaction, pervasive/ubiquitous computing, and computer networks, AmI systems can sense, reason, and adapt to offer personalized services based on the user's context, intentions, and emotions (Acampora, Cook, Rashidi & Vasilakos, 2013; D. J. Cook, Augusto & Jakkula, 2009). In this way, such systems, also known as context-aware systems (Schilit &

[1] `https://www.ouderenfonds.nl/`
[2] `http://www.aal-europe.eu/about/`

Theimer, 1994), can be integrated into AAL environments to provide better care and support for the elderly living independently.

### 1.2.1 Motivation – Why Human Activities?

There are a wide array of applications geared toward remote monitoring, indoor localization, fall risk assessment, and fall detection to provide context-awareness by notifying caregivers and emergency services of anomalous occurrences in the homes of the elderly and provide safety, and autonomy for the elderly (Bennett, Wu, Kehtarnavaz & Jafari, 2016). In particular, monitoring activities of daily living (ADL) (Katz, 1983), are critical to determining the elderly's functional mobility and their competence to live independently. As a result, human activity recognition (HAR) has become a critical feature of AAL, to support physical activity monitoring and fall detection (Rashidi & Mihailidis, 2013b). Generally, physical activity data has been studied in relation to health benefits, e.g., for motivating people to exercise. However, Consolvo, Everitt, Smith and Landay (2006) indicate that the exchange of physical activity information between peers can create awareness and influence social cohesion in technology-mediated environments. This finding serves as an added motivation to drive our decision to use physical activity information within our proposed AAL system.

In perceiving human activity, we rely on several information sources from various modalities including sensory, motor, and affective processes (Blake & Shiffrar, 2007). Specifically, the human visual system appears to play a significant role in understanding human actions and intentions. Furthermore, it is extremely sensitive to human movement, and as such, it can extract socially relevant details (Troje, 2002). This implies that human motion could provide reliable information for discerning affect (Blake & Shiffrar, 2007). For instance, Visser et al. (2011) confirmed that movement information shared between two remote users gave a sense of peripheral presence and interpersonal awareness; thus stimulating social connectedness. Therefore, this dissertation considers the idea that the perception of the activities of others can improve social connectedness. Imagine the following scenario:

*You have an information display showing your distant elderly mother's activities, which runs in the background while you read a book in your living room. Suddenly, you discern that something is wrong and you are prompted to call your mother. Could you recognize specific patterns in the daily activities of your mother? Could you sense that something was wrong based on the dynamics of the visualization in the absence of direct communication? Would this improve social connectedness between yourself and your elderly parent?*

To support our idea that this is possible, we will examine the processes and paradigms necessary to support indirect activity awareness and a subtle sense of connectedness and presence in AAL environments.

## 1.3 Context-Aware Systems for Social Connectedness

Mark Weiser described his vision for ubiquitous computing in his seminal work entitled *The Computer for the 21st Century* (Weiser, 1991). In his narrative, Weiser envisaged a world where technology would silently reside in the background or periphery of the user's attention and is available at a glance when needed. Consequently, the allocation of minimum attentional resources would enable peripheral interaction with a system as suggested in the following statement. "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it" (Weiser, 1991, p. 1). To this end, ubiquitous computing aims to enable calm technology (Weiser & Brown, 1997), whereby information is transported easily between the center and periphery of attention.

The notion of context-aware computing (Schilit & Theimer, 1994), i.e., the adaptation of a system's behaviour in response to the sensed physical environment, is therefore, a derivative of Weiser's vision of ubiquitous computing. Though earlier research on context-aware computing was more focused on location-aware applications and remote monitoring for fall detection, the domain is evolving to also support interpersonal awareness between the elderly and their caregivers within AAL. In fact, the emergence of social awareness technologies is a catalyst for a paradigm shift from direct communication channels such as social media, Skype, and email to maintain awareness of people around us indirectly (Markopoulos, Ruyter & Mackay, 2009).

Recall that context-awareness is a central theme in the field of AmI and therefore, it is of paramount importance to enable the sharing of health and well-being information between remote caregivers and their elderly relatives. Such information can be provided through direct notifications to users or using their peripheral senses. To achieve the latter, ambient displays, a sub-discipline of AmI, generally refer to systems intended on portraying various types of context information, e.g., weather, stock prices, or the presence or activities of others in the periphery of the users' attention (Pousman & Stasko, 2006). By deploying ambient displays, Tomitsch, Kappel, Lehner and Grechenig (2007) claim that ambient information can be presented through standalone or a combination of visual (Ambient Devices, 2002), audio (Mynatt, Back, Want, Baer & Ellis, 1998) , olfactory (Kaye, 2001), and or tactile modalities (Ishii et al., 1998). However, Tomitsch et al. (2007) assert that most ambient displays operate in the visual modality while auditory, olfactory, and tactile modalities are scarcely exploited. Following these findings, researchers such as Müller et al. (2012) contend that light and colour are two important properties, which unobtrusively transmit ambient information while simultaneously enhancing the environment. Within the AAL domain, some studies (Chang, Resner, Koerner, Wang & Ishii, 2001; Consolvo, Roessler & Shelton, 2004; Dadlani, Markopoulos, Sinitsyn & Aarts, 2011; Dadlani, Sinitsyn, Fontijn & Markopoulos, 2010; Metaxas, Metin, Schneider, Markopoulos & De Ruyter, 2007; Mynatt, Rowan, Craighill & Jacobs, 2001; Rowan & Mynatt, 2005; Sellen, Eardley, Izadi & Harper, 2006; Visser et al., 2011) have demonstrated benefits associated with aesthetically pleasing and informative ambient displays to enable contextual awareness and strengthen social interaction. In light of these studies, the potential advantages of ambient displays serve as a motivation for us to approach the problem of sensing both the caregivers' and elderlys' activity data to provide indirect awareness of each other's context and enhance interpersonal connectedness.

## 1.4 Problem Statement

Although AAL technology has provided overarching benefits through enhanced personal assistance, prolonged independent living, and improved quality of life (D. J. Cook et al., 2009; Mynatt et al., 2001; Rodríguez-Martín, Samà et al., 2015; Rowan & Mynatt, 2005; Visser et al., 2011), there are some open research problems in need of further exploration by the AAL community, which are listed below.

1. Most conventional AAL tools are intended for emergency/anomaly detection (Bennett et al., 2016) with limited motivation towards improving social connectedness i.e., *"the experience of belonging and relatedness between people"* (Van Bel, Smolders, IJsselsteijn & de Kort, 2009, p. 67).

2. The majority of context-aware systems are unidirectional, i.e., they provide a context information in one direction from the elderly to the caregiver, e.g., (Consolvo et al., 2004; Mynatt et al., 2001), which raises trust and privacy concerns.

3. To a great extent, earlier studies, e.g., (Matviienko et al., 2015; Müller et al., 2012) exhibit a lack of consistency in their guidelines for encoding activity information relevant for AAL contexts.

4. The cognitive implications of ambient display studies were in most cases unaccounted for by earlier studies, e.g., (Consolvo et al., 2004; Mynatt et al., 2001; Visser et al., 2011) deploying ambient displays within AAL.

5. A substantial amount of studies deploying ambient displays in AAL environments are deficient of portability, which by extension can affect the acceptability of such systems as suggested by Wallbaum, Matviienko, Heuten and Boll (2017).

6. Most activity recognition studies are evaluated under controlled laboratory conditions, which might not be representative of the real-life behaviour of the intended users resulting in system reliability and accuracy concerns. For instance, Rodríguez-Martín et al. (2015) raised concerns regarding this observation.

7. In some cases, the process by which some context-aware systems, e.g., (Dadlani, 2016) extract meaning (e.g., human activity patterns) from complex sensor data is not clearly explained and therefore, it becomes difficult to argue their reliability and reproducibility.

Overall, most AAL practitioners when addressing the design and validation of AAL solutions, are ostensibly more focused on technical features and functionality to support the frailty of the elderly at the expense of designing to ensure that products are acceptable and beneficial to both the elderly and their caregivers.

Based on these observations, a bidirectional AAL solution for supporting mutual activity awareness and promoting social connectedness may be helpful to the elderly and caregivers. Remarkably, such a tool might be useful for those who are bounded by time constraints, separated by geographical distance, and for those who require more indirect means of communicating with their loved ones. Accordingly, to achieve interpersonal awareness and to offer a more intuitive form of communication that seamlessly blends into the users' environment, it is important that rigorous quantitative and qualitative studies are conducted to answer the following research questions.

1. *How a better understanding of the users' context can better support the design of connectedness oriented solutions in AAL?*

   (a) *What are the means in place for social support for both the elderly and their caregivers and how can they be complemented by appropriate design?*

   (b) *What are the daily routines of the users (caregivers and elderly), the elderly's functional abilities, and independent living skills and how can they be supported through appropriate design?*

2. *What are the general attitudes, preferences, expectations, and concerns regarding the potential use of AmI technologies for context sensing and increasing social connectedness in AAL environments?*

   (a) *Are potential caregivers and elderly users willing to use subtle ambient technologies to obtain situational awareness and enhance their social interactions?*

(b) *What are the design preferences of the potential users for sensing and indicating context information within the AAL domain?*

(c) *What are the key factors that affect user acceptance of AmI technologies, focusing on stimulating context-awareness and improving social interaction in AAL environments?*

3. *How to design and develop bidirectional activity-based displays for promoting social connectedness and context-awareness in AAL?*

   (a) *What are the user preferences regarding the visual modality for ambient displays and how can they be exploited to encode activity information?*

   (b) *How to design and develop a robust and accurate human activity recognition model suited for AAL environments?*

   (c) *How to design to exploit everyday objects to support portability and an 'always connected' service for AAL contexts?*

4. *What are the implications of the deployment of bidirectional activity-based displays within AAL on the following*:

   (a) *context-awareness?*

   (b) *implicit and explicit social interaction?*

   (c) *cognition, moods, and behaviour?*

   (d) *coordinated actions?*

   (e) *adoption for future usage?*

To address these questions, this dissertation employs a multidisciplinary approach, which includes aspects of human computer interaction, social psychology, cognition, signal processing, and pervasive computing to create a rich tapestry for the design and evaluation of a subtle bidirectional activity-based ambient display for enhancing social connectedness. In addition, we propose the next generation of AAL systems and research aimed to:

1. Explore various constructs of interpersonal relationships in AAL environments.
2. Provide a holistic understanding of the users' personal experiences and social context, their needs, perceptions, and insights relating to context-aware connectedness oriented technologies in AAL.
3. Maximize on the opportunistic sensing capabilities of the smartphone, to avoid intrusive camera-based sensing and to deploy as few sensors as possible.
4. Provide a more robust and accurate activity recognition approach for connectedness oriented systems to better support a realistic representation of the users' context in AAL.
5. Encourage equal communication and acceptance in both directions via a bidirectional human activity-based ambient display system to improve social connectedness and context-awareness between the elderly and their caregivers.
6. Add to the existing knowledge base that informs the design for activity-based peripheral displays for an AAL context.
7. Provide useful insights into the potential cognitive and behavioural implications of the deployment of bidirectional ambient displays in AAL environments.
8. Offer portability and always on connectivity for ambient displays in AAL.

## 1.5 Research Approach and Concept Design

Within an AAL context, there are two user groups to be considered, i.e., the elderly and their caregivers whether familial or professional. Notably, each constituent group has its own needs, preferences, and expectations. In particular, older adults are extremely diverse, with multifarious differences regarding physical and cognitive abilities, societal values, social networks, religious beliefs, living arrangements, and technological expertise and acceptance. On the other hand, younger adults are in general more abreast with technology and tend to have busier lifestyles.

In this dissertation, a user centered design (UCD) approach has been deployed to uncover insights into the users' context, tasks, values, needs, and expectations from the users' perspective. Particularly, it intertwines classical ethnographic-based techniques (O'reilly, 2012) and contemporary participatory design techniques, such as those based on theatrics (Kanis et al., 2011) or storytelling principles, e.g., constructing stories (Buskermolen & Terken, 2012) to offer a more centralized focus on the user.

These techniques together with research and expert advice are then used in the initial designs of components of our bidirectional human activity-based ambient display system as shown in figure 1.1.

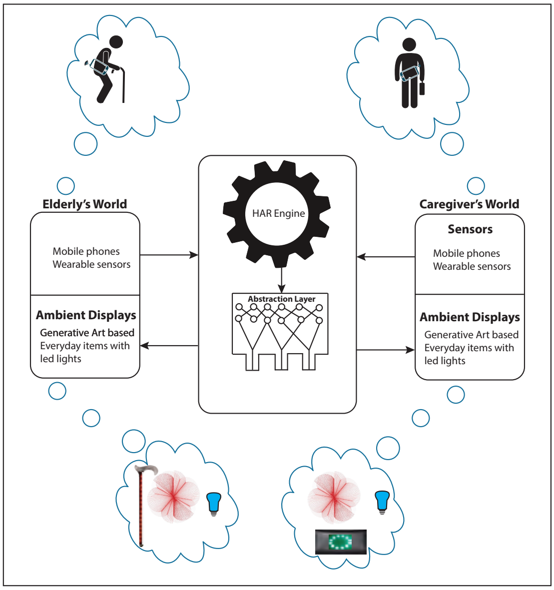


Figure 1.1 Our bidirectional activity-aware system for improving social connectedness.

The envisioned bidirectional connectedness system is comprised of four main components:

- *Wearable sensors (smartphones)* – These collect information on six basic ADLs (walking, walking upstairs and downstairs, sitting, standing, and laying) by means of their in-built accelerometer and gyroscope sensors, which are sent to a server responsible for extracting meaning from the data.
- *A HAR engine* – This is responsible for detecting the activities performed within a sequence of time, from the sensor data received from the wearable mobile phones.
- *An abstraction layer* – This component transforms the outputs of the HAR classifier into activity levels, which in turn serves as input to the ambient displays.

- *Ambient displays* – Exploiting everyday objects, activity levels are projected with a Philips Hue lamp, LED wallet, and walking cane, and a screen-based visualization, which renders this information based on predefined patterns of light, colour, motion, and speed.

Subsequently, the system and its components then go through an iterative process of testing and improvement based on user feedback. Figure 1.2 describes the UCD process.

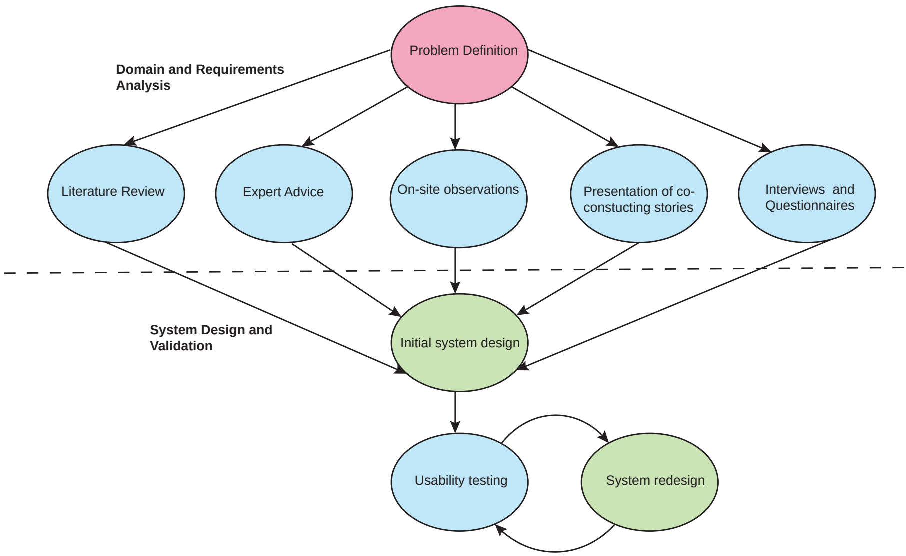


Figure 1.2 A user-centered design process.

## 1.6 Structure of Dissertation

This dissertation is divided into ten chapters, and the outline is presented as follows.

- Chapter 2 provides a review of the topics and related works relevant to the proposed bidirectional solution.

- Chapter 3 introduces the Social Hue and illustrates our first case study evaluating prospective users' perceptions and acceptance of wearable devices and ambient displays for enabling context-awareness and augmenting social connectedness. A list of design opportunities and implications primarily relating to ambient lighting were derived from the analysis of the qualitative results.

- Chapter 4 portrays our first iteration of the bidirectional activity-based system and describes the results and design implications of a real-life exploratory study within an AAL context.

- Chapter 5 examines the development of a hybrid of the Support Vector Machine and Hidden Markov Model (SVM-HMM) for improving activity recognition accuracy for connectedness oriented systems in AAL. The developed HMM-SVM is compared to two mainstream models: a multi-class SVM and Artificial Neural Networks (ANN). This chapter also features the related work on sensing technologies and classification models for activity recognition.

- Chapter 6 illustrates two exploratory studies on ambient lighting displays situated within an AAL context. The first study explores how parameters of ambient lighting (e.g., hue and brightness) can be used to communicate meaningful activity information. The second study examines the psychological effects of peripheral activity awareness through ambient lighting. This chapter concludes with a series of design guidelines and sensitivities for designing activity-based ambient lighting displays in AAL environments.

- Chapter 7 presents the design and development of an "always connected" activity-based system aimed at enabling the real-time viewing of bidirectional activity states between the elderly and their caregivers. Essentially, we exploit a set of everyday objects to provide always on connectivity within AAL environments.

- Chapter 8 outlines our final experimental study, which investigates the behavioural and social connectedness implications of our bidirectional activity-based system and its acceptance. Here, the construct of interpersonal activity synchrony is explored in more detail. The study results are thoroughly described along with additional design considerations for bidirectional activity-based displays in AAL.

- Chapter 9 states the research conclusions, limitations, and options for future work.

- This dissertation culminates in chapter 10, with a memoir describing my observation of the behaviours and attitudes, routines, artefacts, social interaction and support structures, and conversational interviews with older adults and their caregiver counterparts during my research. Lastly, I give an account of the experimental challenges faced during my research.

# Chapter 2

# Theoretical Background

*"Men generally agree that the highest good attainable by action is happiness, and identify living well and doing well with happiness."*

—Aristotle

## 2.1 Introduction

This chapter describes five key aspects and related guidelines that form the theoretical basis of the work presented in this dissertation. These components are listed below.

1. *Social well-being and related measures*
2. *Cognitive processes for social connectedness in AAL environments*
3. *Psychophysical effects of light and colour*
4. *Ambient intelligence*
5. *Ambient information systems*

To begin with, it is necessary to understand the notion of social well-being as a critical aspect of 'ageing in place'. Also, it is imperative to explore how a remote sense of presence and a feeling of belongingness can be stimulated in mediated AAL environments.

This chapter is partly based on selected paragraphs from the following publications (Davis, Feijs et al., 2016; Davis, Hu et al., 2015; Davis, Owusu, Bastani et al., 2016; Davis, Owusu, Hu et al., 2016; Davis, Owusu, Marcenaro et al., 2016; Davis, Owusu, Marcenaro, Hu et al., 2017; Davis, Owusu et al., 2015; Davis, Owusu, van den Boomen et al., 2017; Davis, Owusu, Marcenaro, Feijs et al., 2017).

Following this, human consciousness, i.e., an individual's state of awareness in response to a stimulus (Velmans & Schneider, 2008) is an intriguing topic, which has gained much attention in human computer interaction research to explore how this phenomenon affects changes in behaviour (Nardi, 1995). More specifically, human cognition, an important aspect of human consciousness is concerned with a number of mental processes including perception, attention, and memory (Matlin, 2005). These cognitive processes are described as the next component since, this dissertation is primarily based on the concept of peripheral awareness, which is exemplified by, "our ability to maintain and constantly update a sense of our social and physical context" (Pedersen & Sokoler, 1997, p. 51). Therefore, it is needful to understand the human cognitive abilities to support the design and evaluation of a bidirectional activity-based system for sustaining peripheral awareness and connectivity between the elderly and their caregivers.

Moreover, designing for conscious human interaction has been widely studied, and as such, we have chosen to examine the role of the unconscious in the development and deployment of AAL applications. The unconscious is explained by Bargh and Morsella (2010) as, "the unintentional nature of the behaviour or process, with an associated lack of awareness not of the stimuli themselves, but of the influence or consequences of those stimuli" (p. 6). This model of the unconscious has been viewed by designers as a fundamental factor for understanding the user's behavioural processes (Kamil & Abidin, 2013). Thus, we will explore the psychophysical influences of light and colour on human behaviour and physiology.

Furthermore, in an AAL setting, the control of lighting through sensors and the Internet can realize systems that go beyond illumination. This is mostly driven by ambient intelligence (AmI), a critical aspect of AAL. In particular, "smart" connected lighting systems are capable of sensing and communicating vast amounts of information about the environment. Thus, light has huge potential for enabling context-awareness and enhancing well-being. Thus, it is essential to learn how light and colour can be used to transmit activity information while simultaneously evoking a sense of presence and connectedness.

Revisiting Weiser's notion of calm technology (Weiser, 1991), AmI draws inspiration from calm computing to design technologies that are not disruptive to daily life, but instead, are seamlessly interwoven to empower peripheral attention. Therefore, this chapter is intended to investigate how ambient information systems (a subset of AmI and another component of AAL) can be used to indirectly raise awareness and social connectedness for an AAL setting. Finally, we provide a synopsis of the general insights gained from this theoretical background, relevant for the design and development of activity-based peripheral technologies to promote awareness and social interaction in mediated environments.

## 2.2 Social Well-being and Related Measures

Social well-being has become a central topic in gerontological research (Jivraj, Nazroo, Vanhoutte & Chandola, 2014; Steptoe, Demakakos & de Oliveira, 2012) and is defined by Keyes (1998) as "the appraisal of one's circumstance and functioning in society" (p. 122). According to Abraham Maslow's hierarchy of needs (see figure 2.1), love and a sense of belonging are vital for human functioning, which transcends to the primal need for intimacy, family, and friendship (Maslow, 1954). In Maslow's hierarchy, once physiological and safety

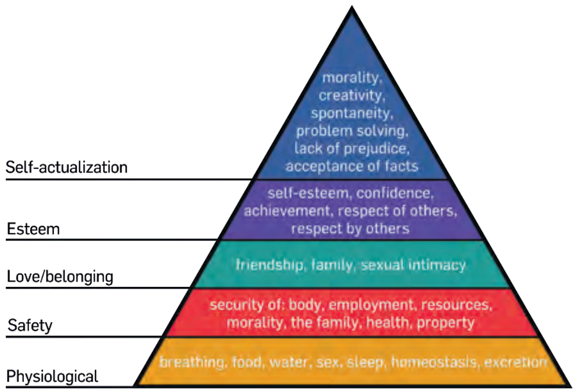


Figure 2.1 Maslow's hierarchy of needs adapted from (Maslow, 1954).

needs are met then a person can strive to satisfy the need for love and belonging, which is essential to fulfil esteem needs and if possible attain a state of self-actualization. Therefore, sociality is crucial for well-being, as human beings are naturally driven by an inherent desire to belong and maintain strong and lasting bonds (Baumeister & Leary, 1995). Accordingly, this need is satisfied through regular and positive interactions with long-term social contacts (Baumeister & Leary, 1995).

Throughout the past decades, several researchers in psychology and social sciences have documented substantial empirical evidence on the impact of social relationships on promoting health, longevity, and optimal physical functioning in older adults (Lyyra & Heikkinen, 2006; Y. C. Yang, Schorpp & Harris, 2014). In particular, socially active senior citizens are often physically and mentally healthier when compared to those who are socially isolated (Cornejo, Favela & Tentori, 2010; Wells, 2012). However, the absence of close family ties and fulfilling social relationships may cause undesirable implications such as loneliness and depression in older adults (Singh, 2015).

With the onset of better employment or educational opportunities, geographical distance between family members has become a primary barrier for effective communication and the provision of care for older adults (Bian, Logan & Bian, 1998). Essentially, while living apart, it is crucial to stay connected and keep abreast of each others' activities. Although the proliferation of computer-mediated technologies such as instant messaging, free or relatively cheap Voice over IP calls, and email can augment communication, such technologies are sometimes intrusive and require more attentional resources for communication. As such, this dissertation explores the concept of social connectedness through peripheral technology designed to facilitate awareness and improve interaction between the elderly and their caregivers in mediated environments. To reduce disturbances in daily life activities, we believe that an indirect means of awareness of each other's context and activities can sustain close connections and reduce the risks of social isolation and loneliness among older adults.

### 2.2.1 Social Connectedness

Social connectedness is conceptualized as a sense of "belongingness and relatedness between people" (Van Bel et al., 2009, p. 1). Van Bel, IJsselsteijn and de Kort (2008) discuss the importance of understanding the temporal aspects of belongingness, which can be experienced on two levels, i.e., the (i) 'momentary' or (ii) 'continuous' feeling of connectedness. However, Van Bel et al. (2008) gave precedence to the long-term experience, which is more distinctive in relatively stable interpersonal relationships. Whereas, the short-term experience of connectedness can be influenced by a person's current emotion, their present assessment of their sense of belongingness or their interactions with another individual. Other factors such as age, context, gender, personality traits, culture, individual preferences, and previous relationship experience can also affect how people experience social connectedness (Global Council on Brain Health, 2017).

Altogether, a sense of belonging appears to be embodied in the concept of social connectedness, such that an increase in social connectedness can lead to the positive feeling of having enough social contacts and support the personal assessment of being a valued member of a group. To determine a person's social connectedness with others, Van Bel et al. (2009) suggest the following five dimensions:

1. Relationship Salience – The continued sensation of presence and togetherness with another despite being in different locations.

2. Contact quality – The subjective assessment of the quality of interaction with others in a person's social network.

3. Shared understanding – having common interests, ideologies, and perspectives with people in one's social network.

4. Knowing each others' experiences – becoming emotionally aware of each other's subjective feelings along with recognizing and understanding the counterpart's experience and how they think.

5. Feelings of closeness – examines the intensity of the attachment with one person against all other relationships. Also, assesses the quality of communication and emphasizes confidentiality and openness in relationships.

To raise awareness and stimulate feelings of connectedness in mediated environments, Kuwabara, Watanabe, Ohguro, Itoh and Maeda (2002) introduced the notion of connectedness oriented communication, which facilitates the symbolic exchange of information related to presence, feelings, and context between relationship partners. Moreover, to cultivate a sense of social connectedness, Kuwabara et al. (2002) assert that consideration should be given to sensing modalities that detect the sender's contextual information and precedence should be given to how this information is presented to the recipient.

Awareness systems build on the construct of connectedness oriented communication, which is closely aligned with the exchange of affective and relational information aimed at maintaining relationships and promoting a strong sense of connectedness (Markopoulos et al., 2009). Since awareness systems can improve social well-being and lead to more satisfying and positive interactions, the concept of social connectedness seems to be a suitable metric for evaluating the sense of belonging between relationship partners in mediated AAL environments. Basically, social connectedness assesses the emotional experience of belongingness and can be measured qualitatively by determining heightened feelings of closeness, commonalities between relational partners, and the mutual expression of feelings and thoughts (Van Bel et al., 2009). The construct can be approached quantitatively by assessing how one perceives their social situation (i.e., social appraisal) and their personal evaluation of relationship salience (i.e., the presence of another) (Van Bel et al., 2009).

While the notion of social connectedness is difficult to measure, the design community has noticed its relevance to tailor novel socially aware technologies to facilitate a sense of belonging in mediated environments (Visser et al., 2011). However, there are other applicable measurements (e.g., social presence) related to this phenomenon that will be addressed in this dissertation.

### 2.2.2 Social Presence

Social presence has been traditionally studied in relation to communication media in collaborative learning environments (Gunawardena, 1995; Weinel & Hu, 2007) and the relevance of avatars in online environments (Ning Shen & Khalifa, 2008). However, there has been growing interest in studying how awareness systems can evoke social presence (De Ruyter, Huijnen, Markopoulos & Ijsselsteijn, 2003; A. K. Dey & de Guzman, 2006).

The original theory of social presence was developed by Short, Williams and Christie (1976) to examine the effects of communication media, e.g., (face-to-face discussions, video conferencing, or synchronous/asynchronous audio) on social behaviour in mediated environments. Building on previous work in areas such as psychology and human communication, Short et al. (1976) conceptualized social presence as, "the degree of salience of the other person in the interaction and the consequent salience of the interpersonal relationships" (p. 65), including elements such as intimacy (Argyle & Dean, 1965), immediacy (Mehrabian, 1968), and media richness (subjective rating of the media's attributes) as key components of this construct. In communication scenarios, intimacy is characterized by a combination of several features including eye-contact, physical proximity, the personal nature of the topic, and body language. Whereas, immediacy (Mehrabian, 1968) is defined in relation to the perceived distance between the sender and the receiver, transmitted by verbal and non-verbal cues. Basically, Short et al. (1976) defined social presence as a "quality of the medium itself" (p. 65), whereby the degree of social presence of the media is measured along dimensions such as cold–warm, impersonal–personal, and unsociable–sociable.

Both media richness (Daft & Lengel, 1984) and social presence (Short et al., 1976) theories are contingent upon the core premise that the use of different media may have varying implications on how social cues are conveyed (IJsselsteijn, van Baren, Markopoulos, Romero & de Ruyter, 2009). Moreover, the idea that different media types encompass different degrees of experienced social presence is not only suggested by Short et al. (1976) but also shared by scholars such as Weinel and Hu (2007). Following this view, some works suggest that face-to-face communication is ranked the highest along the social presence continuum (Newberry, 2001; Short et al., 1976), with text-based media having the lowest degree of social presence (Newberry, 2001). In fact, richer media are rated more positively as they enable prominent non-verbal cues, e.g., intonation, gestures, and facial expression, which reveal the sender's true feelings and desires at a given moment (Daft & Lengel, 1984).

Despite many attempts to define social presence, the scientific community has not yet reached a consensus on its definition. A more concrete view is formulated by Biocca and Harms (2002), where they define social presence as a "sense of being with another in a mediated environment" (p. 10), not only replicating face-to-face interactions but also considering the mediated experience of human and non-human intelligence (e.g., artificial intelligence). This shorthand definition further elaborates on the "moment-to-moment awareness of co-presence of a mediated body and the sense of accessibility of the other being's psychological, emotional, and intentional states" (Biocca & Harms, 2002, p. 10). Therefore, social presence is categorized into three distinct levels as explicated by Biocca and Harms (2002) below.

1. *Level one (the perceptual level)* – one becomes aware of the co-presence of the mediated other.

2. *Level two (the subjective level)* – is comprised of four dimensions describing the perceived accessibility of the mediated other's:

    - attentional engagement
    - emotional state
    - comprehension
    - behavioural interaction

3. *Level three (the intersubjective level)* – assesses the degree of symmetry or correlation between one's own feeling of social presence and their impressions of the mediated other's psychological sense of social presence. It goes further to examine concepts such as interdependent actions e.g., reciprocity/motor mimicry in mediated environments, which is closely related to the notion of interpersonal activity synchrony (Cirelli, Einarson & Trainor, 2014), a concept generally known to foster socially cohesive behaviours in relationships that will be investigated later in this dissertation.

While most of the early pioneers of social presence (Short et al., 1976) have explored the construct with reference to the characteristics of the media, more recent works (Biocca & Harms, 2002) have considered the subjective emotional experience of social presence as well as the perceived behavioural response. However, other scholars, e.g., Van Baren and IJsselsteijn (2004) have proposed more objective psychophysiological and behavioural indicators for evaluating social presence in virtual or remote environments. Van Baren and IJsselsteijn (2004) described psychophysiological measures including examples such as changes in: (i) heart rate (Slater, Brogni & Steed, 2003), (ii) skin temperature and skin conductance (Meehan, Insko, Whitton & Brooks, 2002), and (iii) facial electromyography (EMG) (Ravaja, 2002). Regarding the objective behavioural measures of social presence, Van Baren and IJsselsteijn (2004) proposed more 'naturalistic' behaviours exhibited in real environments as indicators of presence. Examples include, facial expression (Huang &

Alessi, 1999) and social responses, e.g., interpersonal distance (Bailenson, Blascovich, Beall & Loomis, 2003), which have been investigated only in a few studies so far.

Although an objective approach to social presence through psychophysiological signals appears to portray the user's automatic response without conscious thought and deliberation (Van Baren & IJsselsteijn, 2004), it is not without challenges. For instance, they can be easily confounded by extraneous factors such as exposure to (i) an unexpected stimulus or (ii) stimuli that produce the same systemic changes in a user's physiology (Riva, Davide & IJsselsteijn, 2003). Moreover, the causal effect of social presence on psychophysiological responses appears to be inconclusive (Biocca & Harms, 2002). However, it might be beneficial to combine both objective and subjective indicators of social presence as demonstrated in (Järvelä, Kätsyri, Ravaja, Chanel & Henttonen, 2016).

### 2.2.3 Synopsis

In summary, there are marked differences between social presence and social connectedness. To further illustrate these differences, IJsselsteijn et al. (2009) articulate that the experience of social presence (i.e., the imagination of being with the other and sharing the same space) appears to be relatively short-lived (i.e., it appears to end immediately when contact is discontinued) whereas, the experience of social connectedness is not bounded by time. Instead, social connectedness places more emphasis on the affective experience including sensations of not being alone, being in touch, sharing, belonging and intimacy (IJsselsteijn et al., 2009). Despite their differences, both constructs aim to support social well-being in technology mediated environments. In this sense, awareness of others can stimulate social connectedness and social presence and initiate communication through other media (Markopoulos et al., 2009; Romero et al., 2007), which is practically relevant to AAL environments.

## 2.3 Cognitive Processes for Social Connectedness in AAL Environments

The access to information is critical for enabling awareness and stimulating social connectedness in AAL environments. In 'real' communication scenarios, one must perceive and pay attention to available cues, in order to discern the 'states' and 'traits' of another (Bodenhausen & Hugenberg, 2009). However, this becomes more difficult in mediated communication as multiple stimuli are competing for the perceiver's attention, which might affect the quality of the interaction. Consequently, a number of cognitive processes including perception, attention, and memory (Matlin, 2005) were examined to inform the design of ambient displays for an AAL context. Moreover, C. A. Wisneski (1999) brings to the fore the need to understand human cognitive abilities as they are believed to be highly relevant to tailor how the display content is presented, with much attention given to the 'channel capacity' limitations of the human perceptual system.

### 2.3.1 Perception

According to Styles (2005), perception is a sensory process whereby sense organs (e.g., eye, nose, ear, etc.) transmit 'physical energy' detected from the world around us, which is encoded and dispatched to the brain through sensory neurons for analysis by the perceptual system. Styles (2005) describes a typical example of visual perception as follows.

*When light patterns enter the eye, it is encoded by the photoreceptors (i.e., via the rods and cones) in the retina, this information is then relayed via the pathways that handle visual input and is later transferred to the cortical regions of the brain primarily responsible for colour, shapes, movement, etc. perception.*

Basically, Styles (2005) suggests that the preliminary stages of perception are mostly governed by automatic and unconscious processes (i.e., executed without conscious awareness). Bodenhausen and Hugenberg (2009) more clearly explain the perceptual experience as the process where stimuli sensed from the outer world, are received by the observer who later converts these signals into more meaningful representations that define their inner feelings, sensations or thoughts of the outside world.

Psychologists distinguish between two approaches to perception namely: top-down and bottom-up processing (Engel, Fries & Singer, 2001). The top-down approach requires conscious awareness and refers to the process whereby stimuli are interpreted based on prior knowledge or experience (Gregory, 1970). Consequently, the top-down process is conceptually driven, such that one's expectations of the incoming sensed data may influence how the information is perceived (Styles, 2005). A number of perception theorists (Gregory, 1970; Henle, 1989; Rock, 1983) assume the significance of top-down mechanisms, for instance, to trigger the recollection of stored memories (Engel et al., 2001). However, the bottom-up viewpoint implies unconscious processing and suggests that perceptual processes are 'stimulus' or 'data' driven by incoming data received from sense organs (Rollinson, 2008; Styles, 2005).

### 2.3.2 Attention

Attention is considered a necessary process to facilitate perception (Bodenhausen & Hugenberg, 2009; Styles, 2005). James (1890) a 19th-century psychologist and philosopher, defined attention as follows:

*"Every one knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration, of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others" (p. 403).*

In essence, James (1890) suggests that attention is a conscious process, which is inherently selective, whereby irrelevant details are filtered, to interpret and analyze only one item at a time. Theories of selective attention, e.g., Broadbent's filter theory (Broadbent, 1958) and Treisman's attenuation theory (A. Treisman, 1964) are often classified as filter theories, whereby certain stimuli are attended to while irrelevant stimuli are eliminated or attenuated. This assumption implies that the human perceptual system is unable to simultaneously process all incoming stimuli due its limited capacity channels (Pashler & Sutherland, 1998). However, Neisser (1967) proposed a counter theory to describe the selectivity of attention through his analysis-by-synthesis theory. He believed that attention is functionally divided between two processes: (i) pre-attentive and (ii) focal-attentive processing (Neisser, 1967).

- *Pre-attentive processing* – occurs in parallel across the visual field (A. M. Treisman & Gelade, 1980) i.e., the brain's ability to process several stimuli at once. According to Wyer (2014), it is characterized by salient features such as:

  - rapid
  - effortless
  - unconscious
  - automatic

  In essence, pre-attentive processes perform preliminary sorting and organization of sensory data for further analysis by focal-attentive processes. Also, it facilitates the interpretation of physical features such as colour, orientation, brightness, the direction of movement, and controls the perceptual grouping of stimuli (A. M. Treisman & Gelade, 1980). Furthermore, this construct underpins and supports gestalt principles (Banerjee, 1994) such as figure and ground, similarity, closure, symmetry, etc., which enable visual perception in pattern recognition scenarios. From a design standpoint, Ware (2004) pointed out that pre-attentive attributes such as colour, form, spatial position, speed, and motion are relevant to trigger perception at a glance, a salient feature of this dissertation.

- *Focal-Attentive processing* – the movement of information occurs serially (A. M. Treisman & Gelade, 1980) i.e., attention can solely be attuned to one task at a time. It is considered to be slow, controlled, and comes after pre-attentive processing.

Divided attention theories examine the notion of multi-tasking in which multiple attentional tasks are executed in parallel. However, Kahneman (1973) in his theory of divided attention, implies that only a limited number of mental resources are available for distribution across different tasks, so the number of activities that can be executed concurrently is constrained. Thus, in multi-tasking activities, mental resources are allocated based on the degree of complexity of the task.

To gain a deeper understanding of divided attention, both controlled and automatic information processing (Shiffrin & Schneider, 1977) must be taken into account. As previously examined, *controlled* processes require conscious awareness and can only be executed one item at a time while *automatic* processes are fast, unconscious and can be executed in parallel. Spaulding (1994) argues that automatic processes develop with time and practice; thus preventing cognitive overload by reducing the amount of mental effort required. This is reflected in the following example.

*In controlled activities such as when we first learn to ride a bicycle, the activity of riding demands conscious awareness and a substantial amount of mental effort. Basically, one has to concentrate on learning how to balance, pedal, brake, stop, switch gears, etc. Thus, these activities cannot be performed in parallel with others. However, with time, practice, and experience riding becomes automated or habituated (requiring less mental effort). Consequently, it can be executed in parallel with other activities such as steering, enjoying the environment, and reacting to anomalies in vehicular traffic.*

Revisiting the theory of divided attention, Kahneman (1973) believed that the allocation of mental effort is based on the following four factors: (i) involuntary action (e.g., the allocation of mental resources to unusual signals or abrupt changes in movement), (ii) momentary intentions (e.g., like deciding the switch the channel from a cooking show in order to watch the news), (iii) evaluation of demands (e.g., whenever the request from two activities exceeds more resources than available, then only one is executed), and (iv) effects of arousal (heightened arousal will more likely increase attention to controlled processes, e.g., being highly engaged in watching an exciting motion picture).

Basically, by exploring the theory of divided attention, it is apparent that we can multitask to a certain extent. As mentioned earlier, one of the main goals of this dissertation is to support perception at a glance. Fundamentally, this is achieved through peripheral interaction, which according to Hausen (2014), is aimed at "divided attention and thus multitasking but with the specific goal of moving tasks to the periphery of attention (visual and cognitive)" (p. 22). Furthermore, Buxton (1995) underscores the importance of the periphery in supporting awareness and communication in the field of computer-mediated environments. More specifically, Buxton (1995) differentiates between foreground and background interactions such that:

- *Foreground activities* – are 'intentional' or 'pre-mediated', requiring consciousness, much focus, and concentration, e.g., having a conversation on a mobile phone.
- *Background activities* – are undertaken in the periphery of consciousness, e.g., being aware of someone cooking in the kitchen while one reads this dissertation in another room.

Essentially, Buxton's notion of the background is invaluable for enabling peripheral interaction in mediated environments. Primarily, through the filter mechanisms embodied in selective attention, it is feasible to maintain awareness of information on the periphery of one's attention (Vogel, 2005). This is achieved through habituation (i.e., repeated exposure to a stimulus generates reduced reactions, which eventually fades into the background) and dishabituation (speedy recovery of a response, which was previously debilitated by habituation) (J. A. Gray, 1975; Vogel, 2005). However, Vogel (2005) argues that certain circumstances can cause sudden or unexpected changes to background stimuli; thus, triggering dishabituation. Following the preliminary operations on background stimuli, if a stimulus is detected as highly relevant, then it is selected for complete attentive processing. Thus, supporting the seamless transition between the foreground and background attentional processes, which is a primary goal of peripheral interaction. Moreover, since, peripheral interaction aspires to reduce the user's cognitive mental effort, then habituation could be useful in peripheral interactions (Hausen, 2014).

Overall, this dissertation assumes the relevance of the study of human attentional abilities for the following reasons:

1. pre-attentive mechanisms can inspire the processing of background information in AAL environments,
2. further insight into the filter mechanisms involved in focal-attentive processes may help us to design to avoid distraction from irrelevant stimuli in AAL environments, and

3. to obtain a deeper understanding of the relevance of focal attention in detecting important states, which is fitting for pattern recognition in AAL domains (Matthews, Dey, Mankoff, Carter & Rattenbury, 2004).

### 2.3.3 Memory

Cognitive psychologist, Nathan Spreng implies that memory is the cornerstone of social behavioural processes (Spreng, 2013). Specifically, Spreng (2013) outlines how memory is utilized within a social context in the statement below.

*"In navigating the social world, we must often retrieve, maintain, manipulate, and update the information we have about other people" (p. 1).*

Generally speaking, memory involves three main processes where information is: (i) encoded, (ii) stored, and (iii) retrieved (Atkinson & Shiffrin, 1968). It is further categorized into three sub-components, which are summarized by (Styles, 2005) below.

1. *Sensory memory* – This is the shortest form of memory and is determined by the ability to retain traces of a stimulus even when it has ended. When visual traces are retained, this is known as iconic memory, e.g., when you still see the camera flashing even though it is turned off.

2. *Short-term/working memory* – acts as the temporary storage of sensory information, which has already been processed for recall from long-term processing, is limited in processing capacity and requires conscious awareness.

3. *Long-term memory* – This is an information storehouse for prolonged periods of time. It further decomposed into the following types memory:

    - *explicit memory* – requires conscious effort to enable recollection,
    - *implicit memory* – is automatic and unintentional, i.e., does not require conscious awareness for task execution,
    - *declarative memory* – facilitates the recollection of facts or events – requires conscious awareness,
    - *procedural memory* – enables recollection for demonstration of proficiency and task execution activities – is an unconscious process,
    - *episodic memory* – ability to recall personal experiences, self-identity, and life-history – requires conscious awareness, and
    - *semantic memory* – ability to recall facts – requires conscious awareness.

Considering this dissertation explores social connectedness in AAL domains, we assume the relevance of memory on social behaviour. However, close attention should be paid to memory decline limitations in older adults (Caselli et al., 2009) for AAL scenarios. Small (2002) argues that mental activity can enhance memory performance and retard cognitive decline in older adults. While, E. Gray and Tall (2007) claim that abstraction is inherent of mental activity processing. Thus, it might be interesting to explore interventions that signify abstraction in AAL domains.

### 2.3.4 Synopsis

Overall, this dissertation considers the relevance of visual perception, attention, and memory to decode activity information received from the outer world through peripheral technology. This is achieved by filter mechanisms, which enable divided attention and support interaction in the attentional periphery. Furthermore, Kahneman (1973) implies that attention and arousal are tightly coupled. Therefore, to support awareness and enhance the sense of belongingness in AAL environments, there is a need for a transition medium that can propagate visual signals through abstraction, while evoking a sense of presence, causing minimal distraction and support peripheral interaction. Accordingly, a closer look into the physiological and behavioural effects of light and colour will shed light on how these visual features can be used to offer interaction on the periphery of attention.

## 2.4 Psychophysical Effects of Light and Colour

Light is essential for visual perception. Moreover, behavioural lighting research documents positive influences of light and colour on physiology and moods (Gerard, 1958; Küller, Ballal, Laike, Mikellides & Tonello, 2006).

### 2.4.1 Physiological Effects of Light

Cajochen (2007); Yasukouchi and Ishibashi (2005) demonstrate that light can affect various physiological aspects such as:

- alertness,
- arousal levels,
- body temperature,
- sleep, and

- circadian rhythm.

Notably, both melatonin (i.e., hormone that regulates sleep) and cortisol (i.e., an adrenal hormone released in response to stress and low blood-glucose concentrations) play critical roles in assessing the effects of light on circadian clock disruption (Cajochen, 2007), which may cause depressive symptoms and poor sleep quality. Furthermore, Thapan, Arendt and Skene (2001) state that short-wavelength light (blue light) is known to suppress melatonin levels. Melatonin suppression can be ameliorated by deploying longer wavelengths of light toward yellow, orange and red (Pauley, 2004). Moreover, bright light therapy has been proven to alleviate symptoms associated with mood and sleep disorders (Shikder, Mourshed & Price, 2012).

### 2.4.2 Psychophysical Effects of Colour

Colour hue, saturation, and brightness have been shown to have positive effects on emotions. For example, Jacobs and Hustmyer (1974) deduced from physiological measurements such as galvanic skin response, heart, and respiration rates, that red is remarkably more arousing than either blue and yellow, while green induces greater arousal levels than blue. Additionally, by using the pleasure, arousal, and dominance scale, Valdez and Mehrabian (1994), have found hues such as blue and blue-green evoked more pleasant feelings while yellow and yellow-green were least pleasant. Furthermore, red was ranked at an intermediate value of pleasantness. Similar pleasantness ratings were obtained by Kwallek, Woodson, Lewis, Sales et al. (1997), which investigated the impact colour on mood and worker performance.

Another case in point is illustrated by Gerard, who while using psychophysiological measures reported that the higher arousal levels associated with red are triggered by unpleasant associations of red light with blood, injuries, fire, aggression, and danger whereas the low arousal levels associated with blue are induced by the association of blue with serenity, the skies, and friendliness (Gerard, 1958). Conflicting impacts of the colour red on psychological behaviour are demonstrated by Hevner (1935) where red is associated with happiness and excitement. In addition, Ou, Luo, Sun, Hu and Chen (2012) demonstrated affective implications of lighting colour using colour emotion scales such as “passive” or “active”. The more reddish the colour yielded the more “active” colour emotion response by both elderly and younger adults while higher variations of blue were in most instances ranked as more passive by both user groups. Essentially, Olsen (2010) argues that the meaning of colour is based on ‘learned associations’ coupled with the physiological responses. Moreover, varied interpretations on colour are heavily reliant on culture, age, and situational context.

### 2.4.3 Behavioural Effects of Light

Added to the physiological effects, many researchers have accrued evidence that light can affect well-being (Kuijsters, Redi, de Ruyter & Heynderickx, 2015), interpersonal communication (Gifford, 1988), social and emotional functioning in older women (Grandner, Kripke & Langer, 2006), improved performance on a variety of cognitive task and interpersonal behaviour (Baron, Rea & Daniels, 1992), time estimation (Delay & Richardson, 1981) and create an inviting and pleasant atmosphere (Custers, De Kort, IJsselsteijn & De Kruiff, 2010). Whereas, other scientists have failed to identify significant influences of light on moods (Baron et al., 1992; Knez, 2001) and a variety of cognitive tasks (Boray, Gifford & Rosenblood, 1989; Veitch, 1997).

### 2.4.4 Synopsis

Altogether, a general inference can be drawn on the potential influence of light, especially coloured light on interpersonal relationships, mood, and performance on various cognitive tasks. Still, a deeper understanding of the implications of coloured lighting is needed to facilitate the design of intelligent lighting interventions relevant for an AAL context (Kuijsters, Redi, de Ruyter, Seuntiëns & Heynderickx, 2015). In retrospect, a large majority of lighting experiments were conducted with relatively young people aged $18-35$ years as discussed by Kuijsters, Redi, de Ruyter, Seuntiëns and Heynderickx (2015). Thus, the vision problems of older adults, which influence their perception of light were often overlooked. Despite these challenges, light's non-visual effects could be advantageous especially for elderly people, who tend to struggle with alertness and loneliness. Therefore, the design dimensions discussed by Philips Research (2008) such as variations in: (i) brightness, (ii) colour rendering, (iii) direction, and (iv) patterns could enhance user experience in AAL settings. In essence, light's aesthetic qualities along with its dynamic properties present an opportunity to explore how coloured lighting can be integrated into AAL environments to create a sense of awareness while simultaneously enhancing social well-being, thereby positively impacting the quality of life of the elderly and their caregivers.

## 2.5 Ambient Intelligence

To facilitate social connectedness in technology mediated AAL environments, this dissertation builds and combines a variety of concepts related to the ubiquitous computing and AmI paradigms. According to Greenfield (2010), ubiquitous computing (UbiComp) describes the notion that computers are embedded into everyday objects to support constant and 'everywhere' access to information. Examples include smart buildings, smart televisions, and smart clothing among others. The AmI concept is enveloped in the field of UbiComp (Raisinghani et al., 2006) and was drafted in 2001 by ISTAG (Ducatel, Bogdanowicz, Scapolo, Leijten & Burgelman, 2001), an EU advisory group, to demonstrate a novel approach to designing intelligent environments with a human-centered focus on enhancing the quality of life. An excerpt from the ISTAG mantra, describes an AmI world where, *"People are surrounded by intelligent intuitive interfaces that are embedded in all kinds of objects and an environment that is capable of recognising and responding to the presence of different individuals in a seamless, unobtrusive and often invisible way" (Ducatel et al., 2001, p. 1).*

Zheng and Stahl (2012) characterize AmI as having the following features:

- *embedded* – all sensing and interconnected computing devices are distributed and seamlessly integrated into the user's environment,
- *interconnected* – All system components, e.g., sensors and information and communication technology (ICT) systems are networked via wireless communication to form a large scale ubiquitous system,
- *adaptive* – the amount of service offered is dependent on the quantity of information available and the accessibility of external services,
- *personalized* – tailored to suit the user's needs and preferences,
- *anticipatory* – the system can detect the user's desires and regulates itself accordingly, and
- *context-aware* – the ability to sense and recognize situational context and adapt to the user's needs and context.

Clearly, from the above description, the internet of things (IOT) and sensing devices are enabling technologies for AmI. Leveraging wireless technologies, IOT is defined by Giusto, Iera, Morabito and Atzori (2010) as follows:

*"the pervasive presence of a variety of "things" or "objects", such as RFID, sensors, actuators, mobile phones, which, through unique addressing schemes, are also able to interact with each other and cooperate with their neighboring "smart" components to reach common goals" (p. 5).*

Context-aware systems typically employ one of two approaches using vision or wearable sensors (Bennett et al., 2016). Camera-based sensors are usually considered intrusive and suffer from disturbances in the line-of-sight. To support unobtrusive sensing, sensors have been embedded into a variety of devices including watches, glasses, smart textiles, and jewellery (Rashidi & Mihailidis, 2013b; Wright & Keith, 2014). Although these devices provide endless possibilities for AAL, they are expensive while simultaneously challenged by privacy and security risks surrounding their deployment (Steele, Lo, Secombe & Wong, 2009). Regarding AAL, some studies (Bourke, O'brien & Lyons, 2007; Suryadevara & Mukhopadhyay, 2014) have confirmed the use of sensors and actuators to improve the quality of life of the elderly who are living independently by providing notification to caregivers. Specifically, elderly remote monitoring systems employ wearable and ambient sensing technologies to unobtrusively detect health and emotional states, and identify patterns in activities of daily living (Martínez-Rodrigo, Zangróniz, Pastor, Latorre & Fernández-Caballero, 2015; Patel et al., 2012). In addition, these ambient sensors are capable of detecting a range of physiological, movement, and environmental data including blood glucose (BGL), blood pressure (BP), respiration (R), cardiac activity (ECG), brain activity (EEG), muscle activity (EMG), eye movement (EOG), blood oxygen saturation (SpO2), galvanic skin response (GSR), body temperature (T), acceleration, orientation, sound, light-intensity, humidity, floor pressure, and door opening and closing (Rashidi & Mihailidis, 2013b; Steele et al., 2009).

In total, these features and enablers have been applied within the AAL domain to show positive implications for improving the health and well-being of older adults (Emiliani & Stephanidis, 2005). This implies that AmI provides an opportunity for older adults to sustain their independence, provide awareness of their situational context, in concert with receiving social support from caregivers and, by extension, improve their quality of life.

Although AmI appears to be beneficial, it is not without limitations. For instance, D. J. Cook et al. (2009) outlines critical concerns of AmI such as, it is subject to surveillance issues ("big brother syndrome"), violations of data protection rights and reliability, handling and installation errors as it pertains to sensing devices. However, Pedersen and Sokoler (1997), suggested a "kind of shielding" of personal activity information through abstraction, utilizing features such as visual or auditory cues to enable "non-attentional demanding awareness". Systems such as the InfoCanvas system enabled its users to create abstract representations of their contextual information using artistic renderings of various scenes (Stasko, Miller, Pousman, Plaue & Ullah, 2004). Similarly, the Tableau Machine senses human activity and generates inexplicit representations of home activities (Pousman, Romero, Smith & Mateas, 2008). Accordingly, this presents new possibilities for researchers and designers to explore the design space efficiently and identify ways to address the privacy and reliability concerns, while subtly raising context-awareness and promoting a feeling of social well-being in AAL domains.

## 2.6 Ambient Information Systems

Ambient information systems, which include a collection of AmI technologies commonly referred as: (peripheral displays (Matthews et al., 2004), ambient displays (Mankoff et al., 2003), awareness systems (Markopoulos et al., 2009), or notification systems (McCrickard, Chewar, Somervell & Ndiwalana, 2003) are rooted on the premise of peripheral awareness, where information is subtly portrayed in the periphery of one's attention (Pousman & Stasko, 2006). In fact, users can perform their primary tasks in the foreground, while context information can be perceived outside of focal attention (Hazlewood, Connelly, Makice & Lim, 2008). For the purposes of this dissertation, the terms peripheral displays and ambient displays are used interchangeably. A crucial feature of ambient displays is their capacity to be perceived at a quick glance, which triggers pre-attentive processing to minimize the number of mental resources utilized by a user. Thus, demonstrating the relevance of divided attention to facilitate peripheral interaction while using ambient displays (Matthews et al., 2004).

In a digital era, people are often inundated with information, from emails to an assortment of social media applications (Müller et al., 2012). Ambient displays can remarkably reduce the amount of information mentally processed by providing an aesthetically pleasing overview of the content, "manifesting itself as subtle changes in form, movement, sound, color, smell, temperature, or light" (C. Wisneski et al., 1998, p. 2). Typically, aesthetic features are largely motivated by the field of information art, which focuses on how traditional art pieces, e.g., paintings can be augmented, or amplified and made to render meaningful information (Redström, Skog & Hallnäs, 2000). We will now explore the design guidelines relevant for the design of ambient displays.

### 2.6.1 Design Guidelines

A considerable amount of work has been published on guidelines (A. Dey, Mankoff & Dey, 2003; Pousman & Stasko, 2006; Tomitsch et al., 2007) for the design and assessment of ambient displays (Mankoff et al., 2003; Matthews, Hsieh & Mankoff, 2009).

Pousman and Stasko (2006) analyzed a wide array of ambient displays and derived a taxonomy based on four dimensions:

1. *Information capacity* – "the number of discrete information sources that a system can represent."

2. *Notification Level* – "the degree to which system alerts are meant to interrupt the user."

3. *Representational Fidelity* – “describes a system’s display components and how the data from the world is encoded into patterns, pictures, words, or sounds.”

4. *Aesthetic Emphasis* – “the relative importance of the aesthetics of the display.”

Additional design dimensions were discussed by Tomitsch et al. (2007) while Mankoff et al. (2003) suggested a number of heuristics for evaluating ambient displays. Altogether, these design guidelines and heuristics will be used to set the initial requirements for the ambient displays that will be designed in this dissertation. However, they were still too general and more specificity would better assist designers to tailor ambient lighting solutions to encode physical activity information.

In an attempt to fill this gap, Matviienko et al. (2015) derived a set of guidelines for encoding lighting parameters. Yet, these guidelines were not matching the intended outcome of our overall research, i.e., not only to provide context-awareness but also to enhance the social connectedness experience through the use of coloured lighting. Therefore, the specific colour choice should not only convey activity information but also evoke a subtle sense of remote presence based on the elder’s current activity level. In fact, the derived lighting patterns for presenting situations by (Matviienko et al., 2015), are not sufficient for raising awareness while simultaneously triggering a sense of connectedness as the authors recommended different colours for status information classes showing presence and physical activity data. Consequently, there is a need for a colour scheme that could achieve both outcomes. Thus, it might be prudent to review example ambient lighting displays to find the right inspiration and ideas for designing activity-based ambient lighting displays.

### 2.6.2 Ambient Lighting Displays

As mentioned previously, light has enormous potential for enabling context-awareness and enhancing well-being. Also, the varying visual properties of light, e.g., colour, brightness, saturation, position, and frequency of changes (Müller et al., 2012) make it ideal for encoding and sharing physical activity information.

Previous studies have exploited lighting features for conveying physical activity information using different encodings. For instance, ActivMON is a wrist-based ambient display, which uses coloured lighting to inform users about their activity levels (Burns, Lueg & Berkovsky, 2012). In addition, a pulsing light is used to convey information about the activity levels of others. ActivMON uses a colour fade from red-to-green, where red shows no daily activity while green demonstrates that the user’s daily activity goal is achieved. A fast pulsing light indicates high physical activity levels for other users while a slow pulsing light shows their inactivity. The HealthBar (Mateevitsi, Reda, Leigh & Johnson, 2014) is an ambient lighting display, deployed in working environments to counteract the effects of prolonged sitting. The HealthBar exploits a light tube placed at the user's desk, which fades from green-to-red. A fully charged HealthBar is initially set to green and gradually fades to red to prompt the user to take a break. If the break is not initiated, a pulsing light is used as a break reminder. Similarly, ambient light was deployed through the Movelamp (Fortmann, Stratmann, Boll, Poppinga & Heuten, 2013) to stimulate increased movement in office environments. Using a Philips Living Colours lamp, the Movelamp was positioned in the user's peripheral vision. It changed using a colour fade from green-to-red with increasing brightness. Green shows periods of physical activity while red displays no activity, the brightness was a medium to alert the user's attention (Fortmann et al., 2013). The Pediluma ambient display is a shoe accessory that uses one colour (green), with varying intensities to visualize the wearer's physical activity (B. Y. Lim, Shick, Harrison & Hudson, 2011). More physical activity is reflected with a brighter glow, encouraging users to increase their activity levels.

Overall, we observed that colour, brightness, position, and a pulsing light are the four most common combination of lighting parameters to encode activity information. However, within an AAL context, a pulsing light would be more relevant to convey an emergency or crisis situation, which is not an intended goal of this research. As an aside, most of the earlier studies on ambient light displays, encoding activity information, have focussed primarily on how the receipt of information influenced the receiver's activity states and levels. Quantitative evidence showing how people perceive the visual information received is largely left unexplored. As mentioned earlier, ambient displays are meant to trigger pre-attentive processing, an intuitive process often based on instinct, snap judgements, and gut feelings as mentioned by (Gladwell, 2007). As Gladwell (2007) argues, rapid cognition is not always correct, which in this case, can be harmful within an AAL setting. Consequently, opening up the problem space for researchers to explore whether the caregiver's perception of activity encodings at a glance, matches with the physical reality of the elder's activities.

In the next subsection, we will discuss the state of the art ambient displays supporting context-awareness and social connectedness especially relevant to an AAL context.

### 2.6.3 Connectedness-Oriented Ambient Displays

The following examples will illustrate a range of ambient displays that support peripheral interaction in the AAL field. These studies mainly exploit the visual periphery using features such as light and colour, through physical artefacts such as photo frames, clocks, bowl, lamps, and a snow-globe, which all blend seamlessly into the users' surroundings. Furthermore, these ambient technologies mainly combine both implicit interactions (i.e., context information is perceived without focal attention) and explicit (if the user wants to exchange a social gesture then he or she must consciously touch or turn on the device) interaction. A more detailed account of these systems is given below.

The Digital Family Portrait (Mynatt et al., 2001; Rowan & Mynatt, 2005) is a prototypical example providing substantive evidence of the implicit use of ambient displays for enabling peace of mind of remote family members worried about their elderly relatives living independently. To illustrate a qualitative sense of a senior's daily activities, location and

Figure 2.2 An illustration of the Digital Family Portrait adapted from (Rowan & Mynatt, 2005).

activity information are rendered to a caregiver using a photo frame (see figure 2.2) entwined beautifully with their surroundings. Caregivers may acquire more details concerning their elderly relative's activities by touching one of the icons displayed. The results of the field trial between an elderly mother and her adult son, attest to the caregiver's appreciation of the system's monitoring capabilities for detecting unusual events, while not raising privacy concerns for the elderly parent. At the same time, the elderly parent expressed satisfaction with the system, emphasizing that the notion of someone *'looking in'* made her feel *'less lonely'* (Mynatt et al., 2001; Rowan & Mynatt, 2005).

Similarly, visual-based studies such as the Carenet Display (displays elderly-contextual information e.g., calendar, activities, moods, medication, falls, meals, and outings) (Consolvo et al., 2004), Aurama (portrays the elderly' situational context e.g., sleep and weight trends, cognitive ability, weight patterns, and an overview of well-being) (Dadlani et al., 2011, 2010) (both were augmented picture frames, built upon information received from sensing devices), Daily Activities Diarist (Metaxas et al., 2007) (the narrative presentation of the elderly's activities of daily living (ADLs) and the MarkerClock (Riche & Mackay, 2007) (facilitates the sharing of activity information through a clock) rely on the automated capture and display of elderly contextual information for enabling remote monitoring, and supporting connectedness and peace of mind of caregivers.

Other systems such as the Whereabouts clock (Sellen et al., 2006), enable the exchange of location information by exploiting everyday devices such as a clock and the smartphone. Placed in the home, e.g., in the kitchen or living room, users can explicitly receive information regarding their family member's location such as (*'home', 'work', 'school'*). The qualitative results of a longitudinal study suggested affective benefits of the system while it simultaneously provided a sense of connectedness and reassurance to family members while confirming the normality of the other person's situation.

On the other hand, ambient displays exploiting decorative objects examples include the following: GustBowl (Keller, van der Hoog & Stappers, 2004), Lumitouch display (Chang et al., 2001), Casablanca Intentional Presence Lamp (IPL) (Hindus, Mainwaring, Leduc, Hagström & Bayley, 2001), and the SnowGlobe (Visser et al., 2011). Notably, all four displays trigger explicit tangible interactions, to support the virtual exchange of social gestures, e.g., using touch or a nudge to communicate affection and facilitate remote presence. In particular, the GustBowl (Keller et al., 2004) supports remote sharing of daily actions between a mother and son. When the son places an object into the bowl, a snapshot is taken, which is transported remotely to the mother's home. Thus, stimulating sentiments of closeness and presence, while suggesting that the son has arrived home. Also, the Lumitouch display (Chang et al., 2001) conveys emotional information through a pair of interactive photo frames using light patterns, such that a glow is reflected when the other person's photo frame is touched. The Casablanca Intentional Presence Lamp (Hindus et al., 2001), enables two remote users to convey presence information by turning on the device, which is explicitly controlled by the user, using varying colours and images. Perhaps, the Snowglobe (Visser et al., 2011) is most comparable to the work executed in this dissertation. The Snowglobe (Visser et al., 2011), exploits features such as brightness to encode movement information in an AAL context, for creating interpersonal awareness between two remote persons. In this design, movement information is rendered using a measure of purple light and fluttering snowflakes. When communication was initiated by one person, the other person's Snowglobe reflects a bright orange light accompanied by fluttering snowflakes. Additionally, users can virtually exchange social gestures by shaking the device. A pictorial representation of the Snowglobe is portrayed in figure 2.3.


Figure 2.3 An illustration of the Snowglobe adapted from (Visser et al., 2011).

### Connectedness-Oriented Ambient Displays: A Closer Look

Even though earlier connectedness oriented systems (Digital Family Portrait, CareNet, Diarist, etc.), demonstrated promising early results on aspects of connectedness, e.g., sentiments of safety and reassurance, there is a lack of empirical evidence surrounding an understanding of the acceptance and perceptions of the elderly and their caregivers. In particular, these studies lacked the relevant measurement instruments to quantitatively assess or objectively quantify the user experience. In addition, only a few systems were evaluated in a real-life context or for an extended period. Thus, warranting further confirmation through an increased number of participants and or longer trial durations.

In addition to the level of user acceptance, a fundamental problem with earlier connectedness oriented systems is that they were in most cases unidirectional. Generally speaking, the elderly party was mainly observed to determine situational awareness e.g., daily routines, medications, or anomaly cases while the caregiver acted as an *'observer'*, to provide care and support when needed, while simultaneously gaining a peripheral sense that everything is happening as anticipated with their elderly counterpart. This unbalanced communication channel could have considerable implications especially concerning the violations of privacy and dignity rights for the elderly. On the contrary, in cases where bidirectional deployment was attempted, it was difficult to obtain equal acceptance of the system. This was evident in the Aurama display (Dadlani et al., 2011), whereby the elderly was allowed to marginally inspect the caregiver's information while the caregiver was capable of observing more details with respect to their elderly loved one. Overall, bidirectionality was not equally supported or appreciated as caregivers were more accepting of this feature while the elderly believed it was more relevant to caregivers.

Also, in most cases, ambient displays were positioned as decorative objects (ambient photo frames, lamps, snow globe, clocks, bowl, etc.) in a fixed location inside the users' homes. Thus, prohibiting access to the counterpart's context information outdoors. To facilitate an "always connected" communication channel between the elderly and their caregivers, designers can explore how ubiquitous technologies and the Internet of things can be leveraged to create pervasive interactive devices.

Furthermore, from the literature review, a considerable number of connectedness oriented studies assessed the elderly's activities of daily living by deploying sensors in and around the home. However, the number and type of sensors deployed were too many and in some cases obtrusive. Specifically, the Digital Family Portrait (Rowan & Mynatt, 2005) deployed a wide array of 16 sensors ranging from wearable Radio-frequency identification (RFID) tags to wireless motion detectors. In hindsight, noisy signals and instability of the detection field with respect to motion sensors were some of the issues raised by Rowan in his Digital Family Portrait study. Also, in some instances, the use of intrusive camera-based sensing to support activity recognition was observed, e.g., in (Dadlani, Gritti, Shan, de Ruyter & Markopoulos, 2014). Consequently, prompting the need for gerontological studies to provide motion sensing technologies that provide long-term detection stability and noise reduction while simultaneously respecting the elderly's privacy needs through the avoidance of camera-based sensing technologies and deploying as little sensors as possible.

Due to the emphasis placed on sustaining the elderly's health within AAL, careful consideration should be given to the accuracy and reliability of the sensing infrastructure and by extension the overall system performance. This is necessary to build system trust, guarantee the authenticity and validity of the information received, and thwart undue stress on the part of the caregiver. It should be noted that earlier deployments of connectedness oriented systems suffer from limitations surrounding the reliability and accuracy regarding the interpretations of the sensed data. For example, in the case of the Diarist Metaxas et al. (2007), an erroneous system caused regular misdetection resulting in needless distress for the caregiver. Also, with respect to system performance, to the best of our knowledge, only one connectedness oriented system (Dadlani, 2016) minimally discussed their activity recognition approach and its performance. In fact, overall system accuracy reported, was 73% percent, which is moderately low for an AAL context. A part of the work in this dissertation attempts to bridge this gap, through the use of wearable smartphone sensing and machine learning algorithms to support the development of robust activity recognition technologies.

## 2.7 Conclusion

This chapter aspired to develop a theoretical basis, for designing peripheral technologies to support interpersonal communication in mediated AAL environments. By exploring these existing theories, we gained further insights into the following: (i) the intrinsic need for love and belongingness to promote well-being along with the related measures for assessing social connectedness and social presence in mediated AAL environments, (ii) the human cognitive processes to support peripheral interaction in mediated AAL domains, (iii) the psychophysical and behavioural effects of light and colour on well-being, and (iv) AmI and its potential for AAL and examples of existing ambient information systems supporting awareness and social connectedness in AAL environments. Going forward, these concepts may be used as a reference to lay the foundation for the design and evaluation of bidirectional activity-based displays for improving social connectedness between the elderly and their caregivers. In the next chapter, we present the early stages of the requirements elicitation and design of our bidirectional activity-based system.

# Chapter 3

# Requirements Elicitation in Ageing Societies: A Case Study

*"Get closer than ever to your customers. So close that you tell them what they need well before they realize it themselves."*

—Steve Jobs

In the foregoing chapter, we provided a theoretical background of the fundamental concepts relevant to this dissertation. The ability to maintain a high cognitive function, autonomy, and social support are key factors to promote "successful" ageing. Thus, we began with an understanding of the basic human need for love and belonging, which is often challenged by geographical constraints, work responsibilities, and mobility-impairment in AAL environments. Therefore, impeding the timing and frequency of face-to-face visits in AAL contexts. We studied how we could maintain interpersonal awareness and feelings of connectedness in mediated environments. Subsequently, examining the human cognitive abilities, which form the basis for interacting with ambient information systems in the periphery of our attention. As discussed previously, there has been a move towards embracing the use of technology to enhance the quality of life of senior citizens mostly in the context of home care. Researchers in AAL environments exploit a set of ubiquitous and pervasive technologies to provide context-awareness, facilitate independent living, and improve the health and well-being of the elderly population. However, many AAL applications tend to focus on technical requirements such as reliability, accuracy, and computational complexity, neglecting the elderly's context, needs, and expectations (Bennett et al., 2016).

This chapter is largely based on the following publications (Davis, Feijs et al., 2016; Davis, Owusu, Marcenaro, Hu et al., 2017).

In this chapter, we attempt to bridge this knowledge gap through the incorporation of a user centered design approach, which could reduce development cost, and increase the ease of use and trust in our system. To achieve this, we adopt a participatory design approach to gain a shared understanding of the users' context, their perspectives on ambient lighting technologies and wearable sensing, privacy concerns, and acceptance of a system to promote social interaction. We obtained detailed accounts of our elderly participants' social support structures and their interactions with their caregivers. Moreover, our exploratory results suggest important design requirements to realise the first iteration of our bidirectional activity-based ambient display system; we refer to as the Social Hue. The Social Hue is envisioned to create feelings of social connectedness and social presence by leveraging socially discreet and non-invasive pervasive technologies over mediated environments.

## 3.1 Introduction – The Relevance of User Centered Design in AAL

Don Norman, a pioneer in user centered design, highlights the importance of understanding human behaviour to positively influence technological designs (Norman, 2013). He further argues, that people are not responsible for the complexities that arise from the use of technology, but instead, can be largely determined by the technology itself. Quite often, we see this translated into the design and development of interactive technologies for older adults, such that solutions are far more *'data centric'* rather than *'user supportive'*.

User-centered design is a human centered process, with a primary focus on users and their tasks, paying keen attention to an empirical assessment of adoption and technology use, while predominantly deploying an iterative design approach, whereby a product is designed, modified, and tested repeatedly (Rubin & Chisnell, 2008). Thus, from the very onset, both designers and engineers need to establish an explicit understanding of the users' context, tasks, values, needs, and expectations from the users' perspective. As a consequence, researchers can gain deeper insights into future usage scenarios to tailor solutions, which can be incorporated into the users' daily practice and environments.

Participatory design is a human centered approach, whereby users are involved in the conception, design, and development of products (Schuler & Namioka, 1993). Traditionally, participatory design methods include but are not limited to the following classical ethnographic-based techniques: (i) on-site observations, (ii) audio and video recordings, (ii) self-report questionnaires, (iv) in-depth interviews, (v) contextual inquiries, (vi) surveys,

(vii) focus groups, (viii) note-taking, (ix) artefact analysis, and (x) diary collection (O'reilly, 2012).

The contextual inquiry, i.e., a mixture of interviewing and observation techniques deployed with real users in their natural environments, is an invaluable tool for soliciting user requirements for existing and potential product use (Holtzblatt & Jones, 1993). In fact, the contextual inquiry is known to reveal the *'invisible'* details of the stakeholder's environment and is viewed as an enabler for co-design and creating stronger collaborations between the users and designers (Holtzblatt & Jones, 1993).

Within AAL, the potential difficulties of older adults to understand the fundamental concepts of novel ambient technologies could hinder their imagination and acceptance of such systems (Kanis et al., 2011; Tang & Kao, 2005). Thus, providing more contemporary participatory design techniques, such as those based on theatrics (Kanis et al., 2011) or storytelling principles could be more beneficial. For instance, co-constructing stories (Buskermolen & Terken, 2012) could help older adults to imagine user requirements and envision future usage possibilities of AAL technology.

As the design cycle evolves, participatory design techniques such as low-fidelity mock-ups and prototyping could be helpful to designers, to discover measurable user experiences and usability criteria (Abras, Maloney-Krichmar & Preece, 2004). These include but are not limited to the following criteria (i) ease of use, (ii) effectiveness, (iii) efficiency, (iv) safety, (v) pleasure, (vi) utility, (vii) attention, (viii) learnability, and (ix) memorability (Abras et al., 2004; Rogers, Sharp & Preece, 2007). At this point, the potential problems can be identified, thus prompting further redesign to ensure that the system addresses the stakeholders' needs.

In summary, by paying close attention to the aforementioned user centered design approaches, it is possible to deploy a set of participatory design techniques to infer user requirements and gather rich qualitative data on usability experiences of both the elderly and their caregivers in order to develop systems to support social connectedness. In this chapter, we put these techniques into action. Properties such as sensing technologies and lighting features of a context-aware ambient lighting system, the Social Hue are evaluated. Moreover, we present the findings from a case study conducting qualitative research into the perceptions, perspectives, and attitudes of elderly persons and their caregivers toward the system and its application in daily life. The co-constructing stories design paradigm (Buskermolen & Terken, 2012) was applied to determine whether the elderly and their caregivers perceived the envisioned system as a viable resource for enabling context-awareness and supporting social interaction. This chapter presents three contributions to the gerontechnology community, which are summarized below.

- A bird's eye view of the social situation of our users in context and their expectations and preferences for sensing and context-aware ambient intelligent solutions.
- Understanding how our proposed system could influence social connectedness, perception and unconscious human behaviour.
- Implications for designers in tailoring ambient lighting displays to support subtle context-awareness and social interaction.

In the next sections, we elaborate on the characteristics of the proposed Social Hue application. Then we discuss the details of the user study and demonstrate the results. Thereafter, we discuss our findings and state our conclusions.

## 3.2 The Social Hue Design

The Social Hue is a lighting system to support peripheral mutual context-awareness and enhance social connectedness between the elderly and their caregivers. This chapter seeks to gather deeper insights into the user requirements at the early design phase. The Social Hue consists of three components:

1. remote sensing,
2. activity detection, and
3. a glanceable display that resides in the participants living rooms and office spaces.

In this case, the Philips hue lighting system renders aesthetic representations of the elderly's physiological information to the caregiver and vice versa. The smartphone's embedded sensors such as the accelerometer and gyroscopes are used for activity recognition.

The phases of the design and requirements elicitation process are described as follows: (a) brainstorming sessions with potential users for idea-generation concerning the lighting design space, (b) Social Hue service images were constructed to support conversations with the stakeholders regarding the envisioned ambient display, and (c) the co-constructing stories participatory design method (Buskermolen & Terken, 2012) was applied to elicit feedback and suggestions about the design concept.

### 3.2.1 Concept Generation

Brainstorming sessions were conducted with 12 participants, including researchers from various disciplines such as electrical engineering $n = 2$, computer science $n = 3$, biomedical engineering $n = 1$, industrial design $n = 4$, and psychology $n = 2$. Our participants were asked to describe how ambient lighting could discreetly support intimacy and context-awareness between the elderly and their caregivers and to freely think of the parameters that could influence the lighting space design. Conceptual ideas were generated using whiteboards and note-taking. Key lighting parameters to promote intimacy and show context information are demonstrated in Figure 3.1. These factors were considered in our design of the Social Hue ambient display.

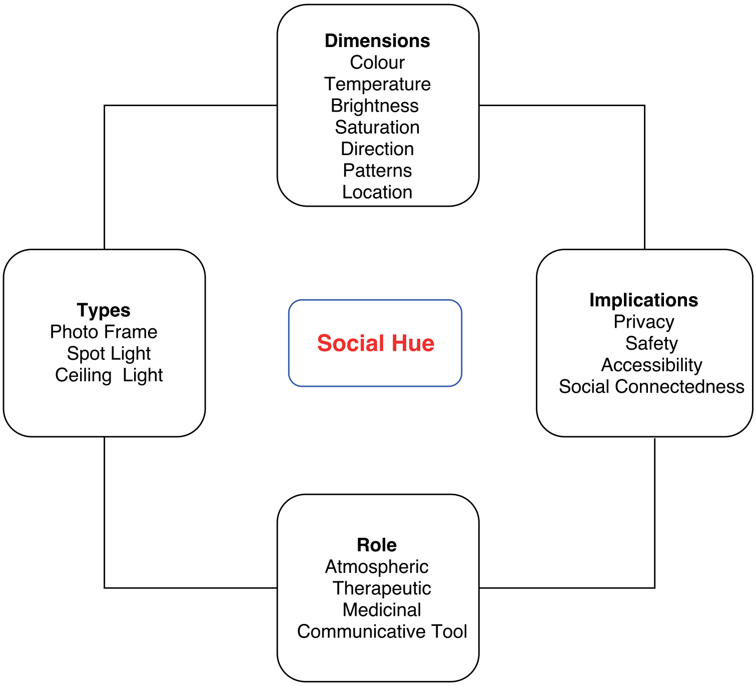


Figure 3.1 Lighting parameters to support intimacy and context-awareness.

## 3.3 The User Study

We conducted a qualitative user study to determine (i) the users' needs, (ii) social context, (iii) their expectations, and (iv) perspectives and insights concerning peripheral ambient technologies on awareness and supporting social interaction. Our multidisciplinary team involved a range of professionals including (i) a cognitive psychologist, (ii) a medical doctor, (iii) a computer scientist, and (iv) an industrial designer, who all served as experimenters in

Table 3.1 Demographic characteristics of participants

| Group | Name | Age | Gender | Nationality | Marital Status |
|---|---|---|---|---|---|
| A | Abigael | 53 | F | Dutch | Divorced |
| | Alexander | 31 | M | Dutch | Married |
| | Johanna | 48 | F | Dutch | Single |
| | Abraham | 54 | M | Dutch | Married |
| | Aletta | 25 | F | Dutch | Common-law |
| | Addler | 32 | M | German | Married |
| | Emma | 28 | F | Belgian | Single |
| | Adam | 27 | M | Dutch | Common-law |
| | Catharina | 27 | F | Dutch | Common-law |
| | Antoon | 42 | M | Dutch | Single |
| B | Piet | 66 | M | Dutch | Married |
| | Saskia | 65 | F | Dutch | Married |
| | Coby | 60 | M | Dutch | Divorced |
| | Agna | 71 | F | German | Married |
| | Aleit | 66 | F | German | Single |
| | Carla | 82 | F | German | Widowed |
| | Carlene | 74 | F | German | Widowed |
| | Adalwolf | 71 | M | German | Single |
| | Achmed | 75 | M | German | Married |
| | Esmeralda | 77 | F | Canadian | Single |

this study. The aim of this experiment was to derive additional requirements for the Social Hue, explore the users' perception and acceptance of context-aware technologies, and to explore the design implications of subtle ambient lighting displays in AAL environments as a means of enhancing interpersonal relationships between the elderly and their caregivers.

### 3.3.1 Participants

A total of 20 participants (mean age = 53.7 and standard deviation = 19.6) were briefed on the main objectives of the study and assured of the confidentially measures in place to secure anonymity. In keeping with the non-disclosure agreement, pseudonyms were adopted throughout this study. After that, participants completed their demographic information and signed an informed consent on all aspects of the study. Participants were recruited through social media and personal networks. Overall, we recruited 10 caregivers (Group A) and 10 elderly volunteers (Group B) whose demographic information is presented in table 3.1. To accommodate our elderly Dutch and German participants, this study was also conducted using the Dutch and German language, respectively.

Our caregiver sample reflected a gender balance while the females dominated the elderly sample by 20%. This is not astonishing given the evidence reported by Waldron and Johnston (1976) showing higher male mortality rates. Moreover, marital status was more varied among the elderly subjects, with 60% being single, divorced, or widowed.

### 3.3.2 Sensitising Phase: Co-constructing Stories Method

To set the stage for discussion and sensitize users to the positive and negative aspects of ageing, participants read a storyboard for 10 minutes, which displayed the social and health context surrounding an elderly parent Mrs. Visser and her son Steven, separated by geographical distance, which is narrated below.

*Mrs. Audria Visser is a retired* 75 *year old store keeper who lives independently in an elderly apartment in Eindhoven, The Netherlands. Her Husband Mr. Roy Visser, died five years ago. Mrs. Visser's only child, Steven Visser is* 45 *years old and is a software developer in Groningen. He is married to Tamoi Visser with children Elizabeth and Jonathan,* 8 *and* 13 *years, respectively. Mrs. Visser suffers from mild hypertension and has bi-weekly visits from the doctor. She cooks, cleans, goes grocery shopping, and occasionally does her own gardening. Mrs. Visser's social ties include her neighbours, her church family members, and her lifelong friend Mrs. Karole Abbes who lives in a neighbouring community. Moreover, she is in contact with her sister Ms. Cheryl Aarts and her son Steven and his family. Mrs. Visser keeps in touch with her family via the telephone and has irregular visits from Cheryl and Karole. Distance and high job demands have restricted regular visits from Steven and his family limiting them to telephone conversations 1-2 times per week. Steven is worried about his mother's psychological and physiological well-being and desires to be more aware of her activities. Although his mother's hypertension is seemingly controlled, Steven is fearful that she lives alone and would like to be informed in the case of eventualities.*

Next, participants were asked a number of questions geared toward eliciting real-life experiences by helping the participants to remember concrete accounts of their experiences with their relatives and elaborate on their social support structures. Participants also discussed their ideas concerning the factors for improving social connectedness, their willingness to provide physiological information to their relatives, their preferences for wearable sensing devices, and the preferred modality to receive awareness information. During this study, all responses were audio-taped.

Mrs. Visser's living room.

Steven's living room.

Figure 3.2 Service image snapshot showing combination of lights in two remote living rooms.

### 3.3.3 Co-constructing Stories

The continuation of the sensitising story was illustrated through Social Hue service images. The envisioned system illustrated a lighting social intervention strategy for Steven and Mrs. Visser. Service images were demonstrated using warm (yellow) and cold (blue) colour temperatures to exhibit key lighting features demonstrated in Figure 3.1. The proposed system displays movement and emotional information through its glow on the edge of a photo-frame, ceiling or wall, or a combination of all three. Figure 3.2 illustrates a snapshot of the combination of lights in Mrs. Visser's and Steven's living room.

Following the illustration, we investigated through in-depth interviews the preferences regarding the lighting temperature, colour, combination, and location. Thereafter, we made inquiries concerning the perceived social connectedness and awareness benefits of the lights based on indirect and direct observation. This was done to evaluate the users' perception on the subtlety of the envisioned ambient display. Note well that there was no mention of the word unconscious throughout this experiment. Instead, phrases like 'without dedicated attention', 'in the periphery', or 'in the background' were used to capture the users' perceptions of the notion of the subtle awareness. Later, we briefly examined the awareness and interpersonal benefits of light pulsing in emergency phases. On average, each session took 30 minutes for caregivers and 45 minutes for elderly participants.

### 3.3.4 Analysis

Audio-taped responses were transcribed, Dutch and German responses were translated to English by the principal researcher, a graduate assistant, and a professor. We conducted a thematic analysis (Braun & Clarke, 2006) to identify patterns in how stakeholders perceived their social interactions, their preferences for lighting characteristics, sensor options, and their perceptions on subtle awareness and connectivity through ambient lighting. We adopted the QSR-NVivo software, to facilitate extensive coding and identification of themes.

## 3.4 Findings

In this section, we discuss the major themes and concepts identified, which demonstrate the social context of our participants and their perceptions and acceptance of assistive technologies for social interaction and context-awareness.

### 3.4.1 Factors Contributing to Loneliness and Social Isolation

Notably, the caregiver participants acknowledged loneliness and social isolation as serious problems of old age and were in favour of finding solutions to combat these issues. However, loneliness was not readily reported among the elderly participants. In retrospect, deeper insights into their subjective feelings of loneliness were acquired with further questioning from the investigator. These concepts will now be discussed.

#### Sickness

Almost all caregivers attributed sickness and cognitive disorders as causative factors for social isolation and loneliness among their elderly relatives. For example, this is reflected in the following statement.

*"When it is a close elderly relative you will always be worried about them. We think my grandma she is having a bit of dementia and we are wondering if she can handle it alone. So we are thinking to move her to a retirement home [...]"* – Emma

In hindsight, those caregivers who were concerned about their elderly loved one's ill health were more in favour of the idea to place them in a nursing home.

#### Death of Friends and Family

All of the caregivers assumed the loss of friends and loved ones were contributing factors to loneliness and social isolation among the elderly. An example statement is given below.

*"I think my boyfriend's grandpa misses his deceased wife and to hear some more people in the house he wouldn't feel so alone. Also, he used to walk with five friends but each year the group lessens when one of them dies. Now, he's alone and he doesn't have anyone to go with."* – Catharina

#### Denial

Denial was observed among a few elderly participants demonstrating the unpleasant realities of loneliness and social isolation. For instance, Carla, aged 82, confessed to experiencing loneliness after initially denying the risk factor of old age.

*"Well, I feel alone sometimes. My two children have their own families and are not so far away. I use the phone more due to the distance. I don't like this town a lot and I don't have any real friends [...]"* – Carla

Adalwolf, aged 71, angrily painted his sister's loneliness as follows:

*"She is so stupid, she has retreated from life. When we drink coffee, she doesn't come. She thinks it is repetitive and nothing comes of it. That is so stupid! Stupid! She is a hermit in her apartment."*

However, further discussions with Adalwolf implied that he also could have been suffering from experienced loneliness. In addition, he demonstrated that independence is highly esteemed among the elderly and depicted his reliance on technological tools to support independence when he stated the following.

*"My disease I must deal with. You have to deal it on your own, and cannot pass it further to someone else. I have 90% severe disability, and it is also not good to me. I have a device that helps me with daily living. I don't want to be a burden."*

### 3.4.2 Social Support

In retrospect, several elderly participants suggested that they were able to reduce the feelings of loneliness through their involvement in a variety of sport and support groups. We will now describe the social structures of both user groups.

#### Support Groups

Social structures for caregivers generally included family, friends, college-mates, and colleagues. However, Johanna solely mentioned, *"my family"* while Alexander stated, *"my work is my social life."*

On the basis of the findings, maintaining communication and strong social networks were paramount for sustaining social relationships between the elderly and their caregivers. Among the elderly participants, common social support were family, friends, religious groups, and neighbours. Esmeralda, aged 77, mentioned the following.

*"I try to make myself busy at times. I am involved in church and I go to prayer meetings. My children call and visit me often."*

Moreover, neighbours were deemed important for sustaining social interaction and mutual dependence in crisis situations. This is reflected in Carlene's (aged 74 years) statement below.

*"I can always ask my neighbours for help. With one of them I go on vacation sometimes."*

Finally, involvement in sports e.g., gymnastics, swimming, biking, and dancing were contributing factors toward infrequent loneliness tendencies among our elderly participants.

#### Feelings of Guilt

A few caregivers became emotional as they articulated their concerns. In particular, feelings of guilt emerged as some caregivers spoke about interactions with their frail elderly relatives. For example, Alexander indicated his discomfort by saying the following.

*"I think I sometimes feel like a bad grandchild. The last time I was there was about a half a year ago and I only visit her twice per year because I am always busy."*

#### Caregiver's Overestimation of Loneliness

In general, the caregivers perceived their elderly relatives as sad, lonely, and socially isolated, which are common ageism stereotypes of the ageing process as discussed by Thornton (2002). However, the elderly participants' responses showed otherwise as the majority were very active and indicated that they did not have much in common with Mrs. Visser's lonely character. For instance, Agna, aged 71, stated the following.

*"My situation is not comparable to Mrs. Visser's as I have a lot of friends. At any time I can call someone to do something together. I feel sorry for Mrs. Visser."*

#### The Emergence of a Generation of Caregivers Among the Elderly

Some elderly participants indicated that they were responsible for taking care of their feeble elderly relatives and friends. For example, Coby, aged 60, mentioned the following:

*"I cannot relate to Mrs. Visser, as I am more involved visiting people with disabilities (De Zonnebloem) and the elderly in my apartment building."*

Similarly, this was reiterated by Aleit, aged 66, in the following expression.

*"I can definitely relate to Steven's situation as I worry for my mother as well. My mother has some illnesses, so I know how it feels [...]"*

### 3.4.3 Perceptions and Attitudes Toward Context-Aware Technologies

Concerning the receipt of physiological updates, participants were generally concerned about the privacy implications and felt that sensory data was prone to false positives, which could cause unnecessary worrying.

#### Ethical Issues Associated with Sensor Technology

Privacy and security were major concerns as it relates to the receipt and sharing of physiological information among the participant majority. Abigael, a caregiver participant highlighted the following.

*"It's a matter of privacy. We don't have to know every heartbeat, change in muscle tension or breathing rhythm if people want you to worry they would tell you to worry. I think people should be able to decide for themselves what they want to share with the people around them."*

While another caregiver, Addler argued as follows.

*"Is it that only my mother can see it? The light goes through the windows so, what about the neighbours wouldn't they also be aware? Also, hacking, anyone could get access to my data and know what I am doing all day. Maybe also knowing nothing is happening so I am probably not at home could be a motivation for burglars to break in."*

#### Who Should Receive Physiological Information?

One participant implied that nurses were deemed more adequate than family members concerning the receipt of physiological information. Achmed, aged 75, communicated his perceptions in the statement below.

*"I don't know whether this is wise, I don't know. If there is a nurse that needs to know exactly what is going on yes, but otherwise, no."*

#### System Reliability

Some participants expressed concern regarding the accuracy and reliability of the sensors. For example, the following expression demonstrates concerns regarding false alarms.

*"With real time data you might see the fluctuations, which might cause unnecessary worrying."* – Abraham

#### Tension Reduction and Defense Mechanisms

Anna Freud posited in (Freud, 1992), that humans are driven towards tension reduction as a means of reducing emotional anxiety. In this user study, reality anxiety, i.e., the avoidance or removal of one's self from a threatening situation (Freud, 1992) was demonstrated by one caregiver participant. This anxiety often triggers the activation of defense mechanisms, which often occurs unconsciously to reduce psychological trauma. This is evident in the statement below.

*"For me, definitely not because my mother is really sick. I don't want to get a message repeatedly every day saying, oh no, she is dying right now! Actually, that's why I am distancing myself a bit because I don't want to always know how she is feeling because I know she is feeling really bad and I would worry all the time [...]"* – Addler

**Acceptance**

Wearable sensors were acceptable to most participants provided that they did not provide continuous sensing and measures to maintain privacy and confidentiality were in place. In addition, our analysis revealed the desire for an unconscious interaction with sensor devices. For instance, this reflected in Abraham's statement below.

*"If it's not really live updates only average values that are sent after a couple of minutes then maybe yes."*

In addition, Catharina communicated the following.

*"I can imagine you could wear it and get used to it and then maybe don't feel it at all. Considering a watch or a bracelet you would always have to be careful if you take a shower or something. It would be fine to wear a sensor but I don't want to consciously wear it the whole day."*

A few participants were more appreciative of sensing devices to enable family members to be recipients of their physiological data sets. Johanna indicated her concerns along these lines.

*"I would agree to wear it just to make my sister feel safer, I live alone and I am not elderly but anything is possible as I could have a heart attack [...]"* – Johanna

Various elderly participants found sensor technology useful for the elderly with greater levels of frailty than themselves. For example, Carla, aged 82, articulated her opinion in the statement below.

*"Yes, they could possibly be advantageous especially if you really have a problem and you are no longer able to call an ambulance. But I would not be particularly captivated by them, as I'd feel even older than I already am."*

## 3.4.4 Sensor Design Preferences

Sensor preferences were based on subtlety, unobtrusiveness, and how well they could be integrated into daily life.

**Embedded Sensors**

Sensor options such as rings, bracelets, and smart undergarments emerged during the discussions. Also, the provision of comfort, non-visibility, and the ability to affect consciousness repeatedly presented themselves during the conversations. Emma expressed the following.

*"Maybe something like a watch that collects the readings not something that stands out that I am wearing a sensor but something regular [...]"*

While Addler quoted his desire for 'seamless design' in the following statement.

*"I would choose something that is not obtrusive and something that I would have to wear anyway like a sock, shoe, pants, insole or something that is not visible and I wouldn't notice as well. I would not wear the watch, which is a fashion object, I would rather choose my own fashion."*

### 3.4.5 Preferences for Lighting Features

Colour preference was based on aesthetic appeal, the calming effects of warmer colour temperatures, and the alerting effects of colder color temperatures. However, the unobtrusive nature of the light source was the basis for the preference among the participant majority.

#### Colour Temperatures

Six of ten elderly participants expressed their preference for warmer colour temperatures e.g., yellow for seniors' living rooms while the others considered colder temperatures, e.g., blue more suitable for the caregivers. Esmeralda articulated her preference as follows.

*"I prefer blue, because it is brighter than yellow, the yellow may affect Mrs. Visser's eyesight. I like yellow for Steven because he is younger and may have better vision."*

Specific colours that were mentioned by both generations included light green, orange, and softer tones to evoke feelings of presence, happiness, and warmth. Furthermore, subtle changes of light were also encouraged to induce a sense of remote presence, which in turn could trigger social connectedness.

#### Type of Light Sources

Three light sources were evaluated, namely a ceiling light, a wall spot light, and an enhanced picture frame light. Caregivers generally preferred the picture frame light due to its inconspicuous nature.

*"I prefer the picture frame, it is not as present as the rest, it's quieter, and you can see if something is wrong but it doesn't immediately announce itself [...]"* – Johanna

Most caregivers appreciated the ceiling light while the vast majority described the wall light as invasive and overdone. However, Addler was concerned that the picture frame light would solely enhance the picture itself and not the loved one's context information; thus impeding its awareness function. Consequently, he expressed his preference for the ceiling and wall combination. In addition, Adam another caregiver advised that the wall light could be useful only for elderly mood enhancement. Similarly, the wall light was appreciated among some elderly participants for its illuminating effects, and a few participants referred to its ability to augment visibility.

In contrast, some elderly participants highlighted the atmospheric and therapeutic benefits of the ceiling light to reduce loneliness. Carlene suggested that awareness information through the ceiling light could produce an empathetic response and reduce loneliness when she stated the following.

*"You are reassured, and you have peace of mind that you are not alone any more. If you see everything is all right with the family you are reassured."*

Additional places and lighting types were suggested such as beneath furniture and desk lamps to support subtle awareness in addition to being integrated one's home environment. Overall, both the elderly and their caregivers were more in favour of the ceiling and picture frame combinations to support mutual awareness and social interaction.

### 3.4.6 Design Considerations

We will now discuss the design considerations for the Social Hue.

#### Provide an On Demand Service

Notwithstanding the advantages of the light's inconspicuousness some participants were still concerned about privacy violations and were interested in having more control of the lighting installation.

Alexander, highlighted the importance of installing an on-demand lighting system in the statement below.

*"So if you want you can ignore it and otherwise you can pay attention. I could see if the light is automatic inside your house then it can be intrusive even though it's intended to be unobtrusive, understated and very unconscious but then it would feel more intrusive because you don't have your own life any more, you have a shared life."*

#### Design Based on User's Context

A number of participants suggested that colour temperature could be activated based on activities and context. This is reflected in the example statement below.

*"So blue light could be used if you have to concentrate on something such as reading. You could use the warmer colours with anything that could be social [...]"* – Addler

#### The Value of the Unconscious

To improve connectedness, some caregivers indicated that colour temperature could activate certain thoughts and memories from the past. In this case, existing knowledge of a loved one's favourite colour could modulate the other person's memory, perceptions, expectations, and behaviours without being aware of it. Aletta, a caregiver participant, mentioned the following.

*"If Steven likes green and something lights up in Mrs. Visser's apartment with the colour green then this could facilitate connectivity because she knows that's his favourite colour from childhood. She could possibly reconnect childhood memories of Stephen as a child through this method."*

Besides, some participants discussed that subtle changes in colour could evoke meaningful emotional information unconsciously and consequently improve connectedness. An example statement is given below.

*"If there are small changes in light, that's something you may not pick up consciously, but if you connect a certain shade of the lighting colour to a certain feeling, that may evoke positive emotions that could improve connectedness. Even though it might not even be connected to the real activity that the family member is doing."* – Abigael

**Risks and Emergency Management**

The value of emergency notifications was a recurring theme in this study. To alert the users' attention, a red light was most preferred among the participants. Also, certain participants suggested better ways of supporting care coordination and management through intermediaries such as neighbour aid and medical intervention to assist in emergency cases.

*"Given they are three hours away from each other then its better if she has a home alert system that could alert the medical personnel or a neighbour or friend who is living close by."* – Abigael

### 3.4.7 Attitudes Toward Subtle Ambient Displays for Social Interaction

Our findings revealed mixed reactions toward the Social Hue. Some participants were certain about the social connectedness benefits of the envisioned system suggesting the pleasantries of light, especially in winter months for mood enhancement, to increase social presence and create assurance. While others remained neutral suggesting that indirect updates could be less daunting for caregivers while it could simultaneously be distracting especially for those working at home. On the contrast, a few participants cynically indicated that the implementation of technological solutions to combat loneliness is reflective of a societal problem.

### 3.4.8 Cynicism

Piet, aged 66, sarcastically gave the following remarks.

*"I think everyone is waiting on the applause for this improvement in the social aspect of the lonely elderly. You hear how extremely sceptical I am about this, particularly because I think its at the level of "giving the dog a pat". If you give the dog a pat then the loneliness is gone again? I think human communication should have a higher quality than giving a pat, with or without nice light. So we have to attack the root of the problem [...]"*

Upon further interrogation by the interviewer, Piet chronicled the root of the problem as follows.

*"People should improve their own communication instead of having technological tools to do it for them."*

### 3.4.9 Relevance to Frail Elderly

Most participants perceived that the light would be more relevant for the frail elderly to provide their children with awareness information. For example, Saskia, aged 65, stated the following.

*"Not me. But I don't know how my state will be* 10 *to* 15 *years from now. Now, I don't need it. But I still live with someone. Many people are visiting me (my children etc.). I do not feel vulnerable now, no not yet [...]"*

Furthermore, participants commented on the mutual social interaction benefits through subtle cues and demonstrated the need for such a system.

*"I think they would feel closer to each other because they know someone is watching the other and that would be a positive thing."* – Adam caregiver

## 3.5 Discussion

In this section, we discuss the following: (i) the social context and its implications for designing subtle awareness systems for social connectedness, (ii) the implications for designing context-aware technologies, (iii) the implications for designing ambient lighting displays, (iv) the role of the unconscious in design for social connectedness, and (v) the limitations of the current study.

### 3.5.1 The Social Context and its Implications for Designing Subtle Awareness Systems for Social Connectedness

Our findings suggest that the elderly participants were consistently in pursuit of social interaction through their involvement in volunteering services, sporting activities, and visits and outings with family and friends. Therefore, our senior participants were much more socially involved than anticipated and in most cases defied the loneliness ageism stereotype conjectured by traditional gerontological theories (Becker et al., 1998; Steptoe et al., 2013).

In contrast, denial of loneliness and projection onto others were observed among a few elderly participants. Moreover, our naive idea that there are three generations, i.e., grandparents, parents, and children was inaccurate as we observed the emergence of a fourth generation among our elderly participants who deemed themselves caregivers due to their responsibilities for taking care of their frail elderly loved ones.

As confirmed in previous studies, caregivers maintained a busy work life; thus awareness of the need for social contact was insufficient to initiate a social behavioural change especially concerning their frail elderly relatives such as grandparents, aunts, and uncles.

Considering physical barriers (i.e., being in different locations) to communication between the elderly and their caregivers, the Social Hue was generally perceived as a means not to replace face-to-face communication but as a tool to augment the users' desire to improve social interaction. On the other hand, as suggested by most of our elderly participants our envisioned system would be more helpful for the frail elderly to reduce their loneliness, create deeper intimate connections, and monitor their health.

### 3.5.2 Implications for Designing Context-Aware Technologies

Taking account of the perceived barriers to mainstream adoption and deployment of sensing infrastructure in AAL, we gathered detailed accounts of the participant's acceptance and perceptions of such technologies to support ageing in place. This we believe is a valuable design tool for researchers and practitioners to enable user-involvement and understand the challenges surrounding user-satisfaction with respect to sensing devices in AAL environments.

During the sensitising phase, a few participants were sceptical regarding wearable sensors while the remaining participants recognized the value of these sensors for monitoring cases of fall-induced injuries or cardiovascular diseases for the frail elderly and to facilitate the involvement of family members in the care of their loved ones living alone irrespective of their age. Consequently, our results confirm the studies of Consolvo et al. (2004); Metaxas et al. (2007); Mynatt et al. (2001), which all depicted evidence of the benefits of contextual information. Therefore, our results can inform practitioners in the field of AAL on the perceived value of wearable sensor deployment and its relevance to the elderly and their loved ones.

Most participants saw the need for a balance to be struck between inconspicuousness and comfort for wearable devices. Revisiting the phrase *"I don't want to consciously wear it the whole day,"* suggests that wearable sensors require conscious effort especially concerning switching on and off the devices and its ability to seamlessly integrate into everyday life is critical for preventing discomfort among users. This provides an opportunity for designers to consider how to seamlessly interweave sensor technologies into the tapestry of daily routines (e.g., in undergarments).

Moreover, the notion of privacy was considered threatening especially for the caregivers as they were generally concerned about the type of information they wanted to share with their elderly relatives. Thus, it is imperative that designers allow selective-content control as shown by Consolvo et al. (2004), for elderly dignity preservation purposes and to respect the caregivers' desire to live "separate" lives from their elderly counterparts.

The exchange of physiological information is a very delicate topic, which raised concern for some participants. Furthermore, securing the information alone was considered insufficient, as burglaries based on the receipt of awareness information were also a concern for a few participants. Considering the complexities involved in preventing unrestricted access by others, e.g., burglars and hackers, it is critical for AAL practitioners to consider new and innovative ways for the seamless integration of physical and cyber security structures to protect against data violation and victimization in AAL environments.

Overall, presenting context information is extremely challenging when designing solutions to support the elderly who are living independently. For instance, sensor deployment increases the risks of missing detections and false alarms (Chong & Kumar, 2003). It is therefore critical to carefully select the sensors to support context-awareness and to apply robust pattern recognition techniques to improve system reliability.

In addition, it is imperative that designers provide discreet and comprehensive representations based on average values to prevent worrying and distraction between both user groups. Furthermore, we suggest that designers consider an additional layer of abstraction into a format that ensures privacy preservation of sensor data, which is of utmost importance within the AAL domain.

### 3.5.3 Implications for Designing Ambient Lighting Displays

Our work suggests that ambient lighting solutions for assisted environments need to be inconspicuous, accurate, reliable, and therapeutic while providing bidirectional awareness information to caregivers and their elderly loved ones.

In the case of assisted living, pervasive and ambient technologies should discreetly focus on both the caregiver's and their elderly counterpart's well-being and provide opportunities to strengthen social interaction. Moreover, exploiting existing lighting characteristics, such as colour temperature, location, and lighting type among others provide unique opportunities for supporting emotional and awareness needs. Also, due to age-related visual decline, ambient lighting technologies should stimulate alertness and provide visual support for the ageing population.

Although participants were more in favour of warmer colour temperatures due to its atmospheric and therapeutic benefits, it was generally implied that colour temperature should be customizable, i.e., based on personal preference and the overall design of the living space.

### 3.5.4 The Role of the Unconscious in Design for Social Connectedness

Discussions with participants revealed that colour temperature could trigger a change in behaviour without being consciously aware of it. In essence, participants envisioned that perception of the Social Hue could support reflection or retrieval of preserved memories detailing past interactions with family and friends.

On a different note, illuminated awareness information through the Social Hue could reflect a symbolic interaction between the elderly and their caregivers. This symbolic interaction could trigger perception of awareness cues from a loved one's environment, which could influence unconscious behaviour, e.g., prospective users can be led to be more mindful of each other and increase their social interaction.

On the other hand, the Social Hue is anticipated to trigger physiological responses, e.g., changes in alertness and arousal levels, which is projected to reflect the view of the unconscious by Bargh and Morsella (2010) i.e., being aware of the stimulus with a lack of awareness of the influences/effects of the triggering stimulus. Furthermore, the Social Hue through its lighting features, e.g., colour, location, brightness, and saturation is projected to be a promising tool to reduce anxiety among its target users.

### 3.5.5 Limitations

There are a few limitations in this study. Firstly, increasing our sample size could make our results more generalizable to the population at large. Secondly, participants were relatively highly educated, which could influence their perceptions on ambient interventions to support awareness and social interactions. Thirdly, the study was conducted in individualistic societies whereby a person should only look after himself or his immediate family (Hofstede, 2011), which might have culturally influenced the perception of our envisioned system.

## 3.6 Conclusion

This chapter has explored the social context and perspectives of ambient technologies to support awareness and social interaction between caregivers and their elderly relatives. By adopting the co-constructing Stories (Buskermolen & Terken, 2012) approach, we were able to identify a range of social behavioural tendencies and perceptions on ambient technologies for awareness information and social connectedness, especially concerning ambient lighting. In particular, the sensitising story was beneficial for exposing users to the ageing problem, promoting reflection and determining how users identified with the characters. Thereafter, during the elaboration phase, participants viewed service design images of the proposed technology, which led to active discussions on their acceptance of wearable devices and ambient displays for enabling context-awareness and improving social connectedness. Given the promising findings of our exploratory study, we demonstrate the potential for designing subtle ambient interventions to support assisted living and improve social connectedness between the elderly and their caregivers.

From this study, it can be concluded that in designing tools for awareness and social connectedness in AAL, that designers should critically assess the social environment and methods for social interaction for both caregivers and their elderly counterparts. Moreover, the physical barriers to communication and the perceived barriers for adoption towards the value of context-aware technologies and ambient displays should be taken into account. Furthermore, identifying the users' implicit needs such as unobtrusiveness of the sensing device or the 'hidden' or 'quiet' nature of the ambient display should be considered in AAL product design. In retrospect, our findings suggest that users were more in favour of a type of 'invisible technology', which can be easily integrated into their daily lives. In addition, the contributions of the users' insights and perspectives of sensing infrastructure and ambient tools, could predict a range of anticipated behaviours with respect to product experience, e.g., the system's capability to trigger reflection on past interactions and convey a sense of reassurance to the intended user groups. In subsequent chapters, by considering the acquired user and system requirements, we aspire to develop the Social Hue system and empirically assess its usefulness against the insights and expectations presented in this chapter. More specifically, in the next chapter, we conduct field research with real users in their natural environments, which investigates the potential of activity data in facilitating the implicit sharing of activity information through peripheral awareness.

# Chapter 4

# Real-life Social Connectedness: The Case of an Independent Living Facility in Canada

*"All our knowledge begins with the senses, proceeds then to the understanding, and ends with reason. There is nothing higher than reason."*

—Immanuel Kant

In the former chapter, we unveiled the insights and perceptions of prospective users regarding sensing and ambient lighting technologies to support social connectedness and awareness in AAL environments. Moreover, through in-depth participatory methods, we gathered first-hand knowledge regarding the users' context, their daily practices, and acceptance of connectedness oriented solutions. Towards the design of a bidirectional activity-based platform, in this chapter, we developed an activity-based ambient display prototype enabling the asynchronous viewing of activity levels to create awareness and enhance social connectedness. This iteration demonstrates the significance of human cognitive processes such as perception, attention, and memory to support peripheral awareness and explored the effects of a bidirectional peripheral display system, which is aimed at raising awareness and integrating the activity sensing capabilities of the smartphone to support social connectedness and presence. While presenting a rich understanding of the participant's experiences, this chapter also presents the value in understanding how culture plays a role in affecting the acceptance of connectedness oriented technologies in AAL environments. Moreover, this chapter could provide insights into the user and technical requirements for the design of connectedness oriented technologies for AAL environments. As such, the research findings

This chapter is largely based on the following publications (Davis, Owusu, Hu et al., 2016; Davis, Owusu, Marcenaro, Hu et al., 2017).

may help interaction designers tailor AAL solutions for increased social interaction and context-awareness.

## 4.1 Introduction

Existing research in AAL confirms the success of context-aware applications in conveying feelings of connectedness and creating a sense of co-presence. Awareness of an elder's activities could trigger emotional responses and reveal pertinent information concerning their health, moods, and habits. As previously discussed in chapter 2, earlier works, e.g., the Digital Family Portrait (Mynatt et al., 2001; Rowan & Mynatt, 2005) and the Diarist system (Metaxas et al., 2007) have already demonstrated how pervasive technologies can be exploited to enable peripheral awareness between remote families to facilitate social connectedness and support independent living. Although previous peripheral awareness systems highlighted aspects of social connectedness and social presence, there is little empirical evidence surrounding their acceptance. Moreover, these earlier investigations were often unidirectional only providing elderly-contextual information to caregivers. What is lacking is an understanding of the implications of the receipt of caregiver awareness information for the elderly participants.

This work extends the previous chapter, which investigates the potential of activity data in facilitating implicit sharing of activity information through peripheral awareness. Our primary goal is to examine how the bidirectional perception of activity levels can aid in improving social connectedness between the elderly and their caregivers. To accomplish this, we employed machine learning and pattern recognition techniques to detect users' activity states and levels. An activity state in this context refers to the actual activities executed, e.g., sitting, walking, and standing whereas, an activity level refers to the categorization of activity states into low and high levels. This activity information serves as an input for the bidirectional ambient display platform.

Inspired by the work of Redström et al. (2000), activity data was visualized using curve stitching patterns to allow the elderly to dynamically share subtle cues related to their activity levels with their caregivers and vice versa without disclosing the details of the specific activities performed. The main contributions of this chapter are threefold:

- we present a design approach to realize a bidirectional system to promote social connectedness of the elderly and their caregivers based on activity information obtained from smartphones and a visualization that abstracts from concrete activities;

- we compare how a smart versus a naive way of presenting activity data, affect the reported social connectedness experience within an AAL environment;
- we show that peripheral awareness of the elderly and their caregivers can stimulate/facilitate social connectedness and social presence.

In the subsequent sections, we discuss our research approach, illustrate our findings, and give our concluding remarks.

## 4.2 Methodology

Our experimental approach can be described in two phases: a design and realization of a bidirectional peripheral activity awareness system and a field trial of an experience prototype[1] to investigate how users perceived and interacted with the system and the overall effect on social connectedness. Our research goals are discussed below.

- Investigate how the proposed bidirectional peripheral activity awareness system influences self-reported relationship closeness and social presence between caregivers and their elderly counterparts.
- Investigate how the approach to classifying (naive versus smart) and presenting activity data affect social connectedness.
- Understand the conscious and unconscious meanings attributed to the visual presentation of activity levels.
- Assess the social context of the participants and conduct an ADL assessment for the elderly living independently.

### 4.2.1 Design and Realization of the Awareness System

Our awareness system can be decomposed into two main components; an activity state and level detection module (ASLDM) and a peripheral display module (PDM). The ASLDM is responsible for detecting and classifying users' activity states and levels at regular intervals of time while the PDM handles the presentation of dynamic visual patterns on a peripheral display based on the input received from the ASLDM. Figure 4.1 illustrates the components of the activity awareness system.

[1]The experience prototype is a service design tool particularly useful for demonstrating and evaluating a solution through active stakeholder participation, see `http://www.servicedesigntools.org/tools/21` (accessed 1 December 2015).

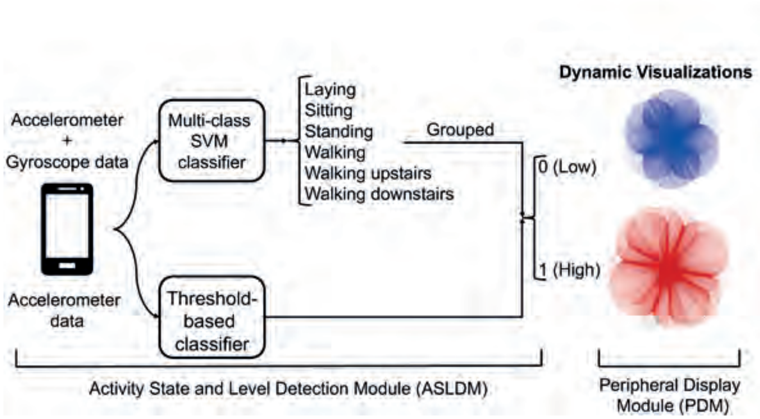


Figure 4.1 Components of the activity awareness system.

### Data Collection

Participants were asked to execute their daily tasks, while wearing a smartphone around their waist, in their home and working environments without restricting the set of activities (walking, walking upstairs, walking downstairs, standing, sitting, and laying). The state of the art in data collection for activity recognition reveals the intrusive use of wearable sensors. For instance, Suutala et al. (2007) obtrusively collected data by placing wearable sensors on various parts of the body, e.g., thighs, wrist, and neck. Therefore, our objective was to deploy as few body-worn sensors as possible and to exploit the smartphone's sensing modalities for enabling human activity recognition in AAL due to its portability, in-built inertial sensors (accelerometer and gyroscope), communication features (WIFI, 3G, and Bluetooth), and inexpensive cost (Anguita, Ghio, Oneto, Parra & Reyes-Ortiz, 2012; Ustev, Durmaz Incel & Ersoy, 2013). Figure 4.2, shows a participant with a waist-mounted smartphone.

We implemented an Android application, which logged the phone's accelerometer and gyroscope readings at a frequency of 50Hz. These readings will later serve as input to two human activity state/level classifiers based on machine learning and threshold based classification techniques.

### Human Activity Recognition and Classification

To recognize the activity level of a person at any point in time, we exploited the multi-class Support Vector Machine (SVM) for human activity recognition (HAR) presented in (Anguita et al., 2012; Reyes-Ortiz et al., 2016), which allowed the recognition of six common activity

Figure 4.2 Example of a participant wearing a waist-mounted smartphone for collecting experiment data.

states (sitting, laying, standing, walking, walking upstairs, and walking downstairs) using inertial sensor data from a smartphone. Detected activity states were then grouped into activity levels (low or high) based on naturalistic observation, which were later validated by the users themselves.

The SVM was trained with a smartphone activity dataset consisting of 30 people obtained from the UCI Machine Learning repository (Anguita, Ghio, Oneto, Parra & Reyes-Ortiz, 2013). The data was collected in a manner similar to the collection approach described earlier. The collected sensor time signals were segmented in windows of 2.56 seconds (with a 50% overlap) and associated with a unique label from the six activities available. For each window, a set of features in time and frequency domain were extracted. The labels together with the extracted features were subsequently used to train the SVM. The approach used was one-vs-all in which 6 binary linear SVMs were trained, each one representing one of the available activities against the rest. Basically, the prediction of activities consisted of finding the SVM with the highest prediction score.

The SVM model gave an overall accuracy of 96% on the labelled public test data from the UCI repository while it gave an overall accuracy of 77.4% on the labelled test data collected from 11 persons in our experiment. This reduction in accuracy was due to differences in the experimental context (different smartphones and positions of the phone around the waist, and different stairway structures on which the public data was collected).

To map an activity state to an activity level (high or low), we observed our participants in their homes and work environments. Our observation revealed that sitting and laying mapped to a low physical activity level as participants mainly rested in these states. Standing, walking, ascending and descending the stairs were consequently mapped to a high physical activity level. This direct observation/consultation was necessary to accurately decide, which activity state belongs to which activity level based on users' job and activity patterns.

With only two activity groups, the SVM model gave an overall accuracy of 94.4% as shown in Table 4.1, as errors were introduced only when a low physical activity was misclassified as a high physical activity and vice versa.

Table 4.1 Confusion matrix after grouping activity states into low or high activity levels

| Activity level | Low | High | Recall % |
|---|---|---|---|
| Low | **535** | 35 | 93.9 |
| High | 57 | **1003** | 94.6 |
| Precision % | 90.4 | 96.6 | **94.4** |

In a control condition, the activity levels were obtained based on the patterns in the raw accelerometric data as shown in figure 4.3. The goal of the control was to compare the effects

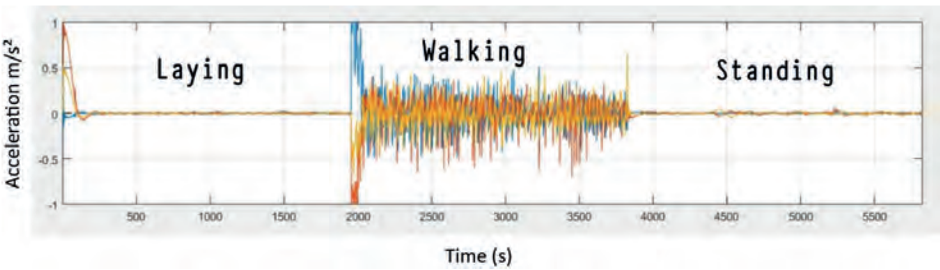


Figure 4.3 Observable patterns in the raw accelerometric data.

on social connectedness of the machine learning based approach coupled with the context mapping of activity states, against a naive classification based approach.

Accelerometers measure the acceleration of an object, which is the object's acceleration relative to free-fall (g-force). Therefore, the accelerometer of the waist-mounted smartphone can detect the rate of movement of the body, "as acceleration is directly proportional to the muscular force being exerted" (Kang, 2008, p. 56). The accelerometric readings were used to detect the activity levels with no explicit detection of the actual activity states. In this threshold-based classification, the accelerometric data was sectioned into non-sliding windows of 1.28 seconds. Then, given a window $w_i$ of $n$ three-dimensional data points where a data point $a_{ij}$, is represented in equation 4.1,

$$a_{ij} = (x_{ij}, y_{ij}, z_{ij}) \tag{4.1}$$

where $i$ identifies the window and $j = [1 \dots n]$

we calculated the sum of the magnitude of all data points as illustrated in equation 4.2:

$$s_i = \sum_{j=1}^{n} |a_{ij}| \tag{4.2}$$

where

$$|a_{ij}| = \sqrt{(x_{ij}^2 + y_{ij}^2 + z_{ij}^2)}$$

Assuming we have $k$ windows, we calculated the mean (to be used as a threshold) of all window sums as shown in equation 4.3:

$$\bar{s} = \sum_{i=1}^{k} s_i / k \tag{4.3}$$

Then for each $s_i$, we obtained the level of activity, $l_i$ as shown in equation 4.4:

$$l_i = \begin{cases} 0 & s_i < \bar{s} \\ 1 & s_i \geq \bar{s} \end{cases} \tag{4.4}$$

**Peripheral Display Module**

To arouse the feeling of connectedness, we exploited vision; man's most powerful sense. For a quicker perception of visual information, Ware (2004) pointed out that the pre-attentive attributes of visual perception namely: color, form, spatial position, and motion should be used. Furthermore, Redström et al. (2000) also argued that effective information art pieces should facilitate the perception of the intended information at a glance and promote concentration and reflection. Thus, to create awareness and stimulate reflection, we also considered the notion of *calm Technology* (Weiser & Brown, 1997), whereby information is easily transitioned between the center and periphery of attention. Like Ishii et al. (1998), we envision that users can interact with the ambient information through their peripheral senses, focusing on a primary task while subconsciously perceiving their loved ones' activities. The information may move its way into consciousness in one of three ways:

1. if the user consciously decides to check on their relative's activities,

2. a shift in focus from the primary task, and
3. in the case of an anomaly.

A heuristic evaluation with six usability specialists indicated their preference for animated curve stitching patterns to display activity data over the proposed pulse waves. The reason is that animated curve stitching patterns combine motion, form (length of lines), and color to present the activity data. Moreover, curve stitching patterns (Michalowicz & Boole, 1996) (also known as string art) are aesthetically pleasing as they give the illusion of curves even though only straight lines are used while the pulse waves appeared monotonous to the specialists. To this end, the proposal in figures 4.4 and 4.5 to present the activity data using simple pulse waves was abandoned. Moreover, we believe that the display of activity information using line graphs could be misleading for amateurs as they might require domain-specific knowledge for interpretation.

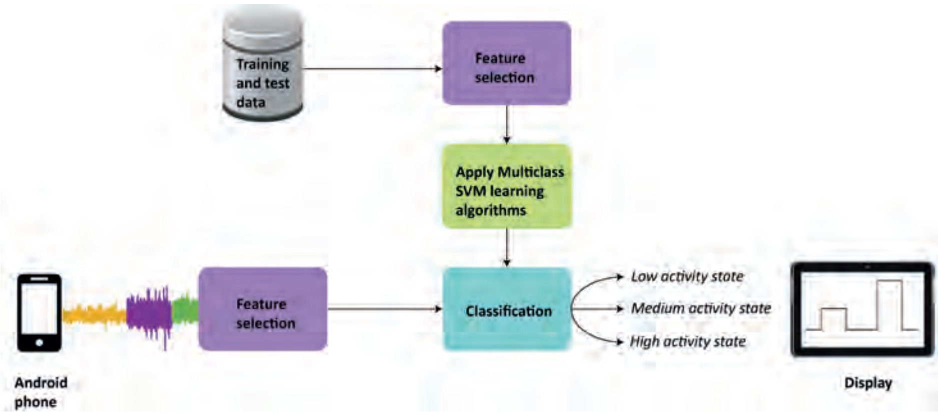


Figure 4.4 Set-up I showing the machine learning approach adapted from (Davis, Owusu et al., 2015).

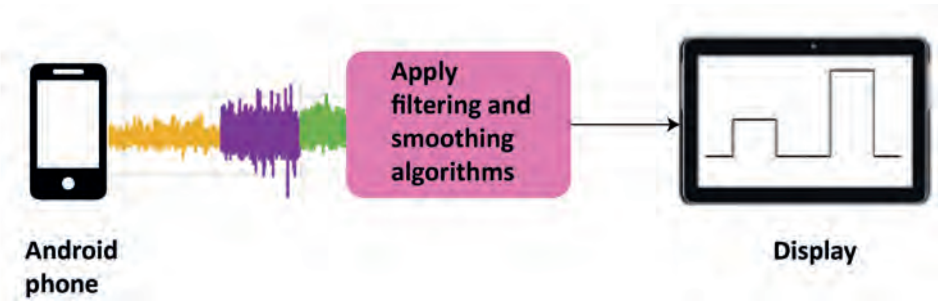


Figure 4.5 Set-up II showing the naive approach adapted from (Davis, Owusu et al., 2015).

As explained in the previous section, a participant's activity level (input data point for the visualization) was detected every 1.28 seconds. For each classified data point, the visualization module stitched lines according to the activity level of the data point. In a high activity level, longer red lines were stitched at a constant rate of 0.02 seconds per data point. In contrast, shorter blue lines were stitched at a constant rate of 0.2 seconds per data point during a low activity level. Figures 4.6 and 4.7, illustrate transitions of the pattern stitching during high and low activity levels, respectively.

Wexner (1954) suggested a positive correlation between colour and moods. For example, red is commonly associated with excitement and blue with tranquillity and comfort. Thus, red and blue colours were used to represent high and low activity levels, respectively. With reference to form discussed by Ware (2004) we varied line length and size in the curve stitching patterns according to the level of activity performed. Moreover, the speed of the

Figure 4.6 Dynamic fast stitching curves showing high activity.

Figure 4.7 Dynamic slow stitching curves showing low activity.

animation (stitching at different rates for low and high activity levels) aided in the illusion of motion to convey the impression of high and low activity levels.

### 4.2.2 Field Trial

The field trial consisted of the actual deployment of our system and the collection of both quantitative and qualitative data. Approval for the study was obtained from the property manager of an independent living facility in Canada. Participants were obtained through personal networks and door to door recruitment with the following criteria (i) elderly subjects should be living independently and alone and should be able to execute basic activities of daily living, (ii) the elderly should not be severely cognitively impaired, which would limit their ability to evaluate their experiences, and (iii) both the elderly and their caregivers should be living apart. Participants' descriptive statistics are presented in table 4.2. The caregiver

Table 4.2 Table showing participants' descriptive data

| Characteristics | Elderly | Caregivers | Total (%) |
|---|---|---|---|
| Gender | | | |
| Male | 0 | 2 | 16.7 |
| Female | 6 | 4 | 83.3 |
| Age | | | |
| 30-49 | - | 1 | 8.3 |
| 50-64 | - | 5 | 41.7 |
| 65-79 | 4 | - | 33.3 |
| 80+ | 2 | - | 16.7 |
| Marital Status | | | |
| Single | 1 | - | 8.3 |
| Married | - | 5 | 41.7 |
| Div./Sepd./Wd. | 5 | 1 | 50 |
| Self-reported Health | | | |
| Healthy | 5 | 6 | 91.7 |
| Unhealthy | 1 | - | 8.3 |

participants ranged in age from 49 to 58 years while the elderly participants were between 72 to 93 years. Two caregivers were male while the remaining caregiver and elderly participants were female. Moreover, the participant majority were Canadian by naturalization, having deep cultural heritage and traditions from the Caribbean. At the end of the study, participants were compensated through a dinner party, which included joint activities e.g., games with both user groups.

**Procedure**

The bidirectional ambient display platform was deployed in a two-week field trial with 6 elderly-caregiver pairs; the same sample size used in a similar comprehensive and exploratory study by Visser et al. (2011). Plans for deployment were centered around the availability of the participants. The three-stage experiment lasted for five days per participant.

In stage 1 (day 1), the participants were briefed on the objectives of the study and were assured of the non-disclosure of their identities after which they signed an informed consent form. Subsequently, activity data was collected within the context of the participants' home and work environments for 3 hours. During this three hour period, participants were encouraged to perform basic activities, which included the detectable activity states (walking, sitting, etc.), which were later verified. Also, for privacy control reasons, participants were adequately informed during the briefing that they could stop the application at any point during the data collection. Using a notebook, we tabulated all the activities performed and their timings, which were compared with the accelerometric and gyroscopic data.

In stage 2 (day 2), the displays were introduced into the living rooms of the elderly and work environments of the caregivers.

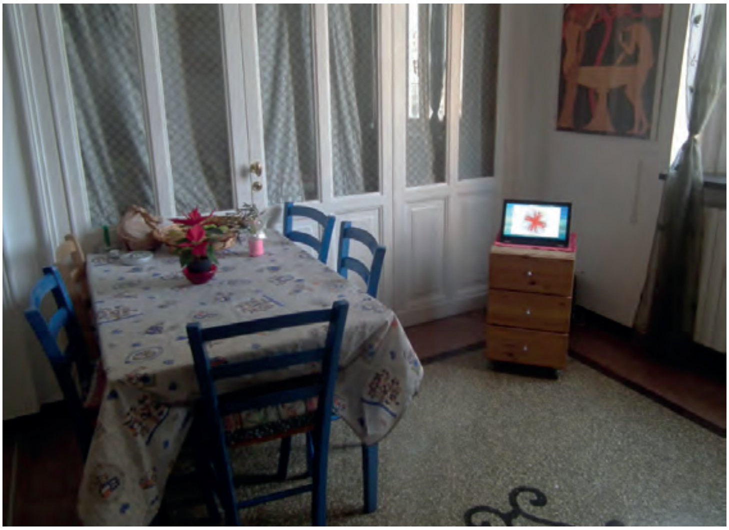

Figure 4.8 Example showing the setup in an elderly participant's home.

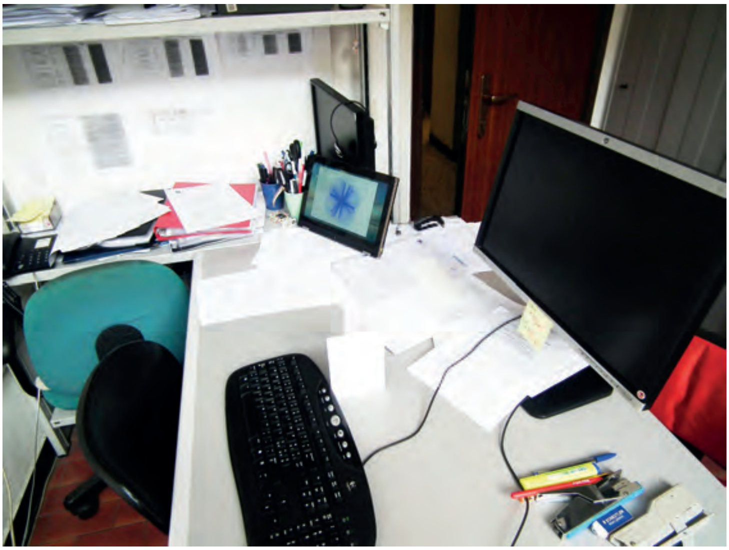

Figure 4.9 Example showing the setup in a caregiver's working environment.

In particular, the display was positioned like a photo frame in the periphery of the user's attention, taking into consideration the participants' home/work environments and daily routines, which were acquired through observation and interviews. Figures 4.8 and 4.9, demonstrate examples of the activity awareness display in an elderly participant's home and a caregiver's working environment. Recall, there were two set-up conditions in our experiment, i.e., the machine learning based activity display versus the threshold based activity display.

We applied the within subjects experimental design method and the sequence of the displays was counterbalanced using an AB-BA format (Gergle & Tan, 2014). In this approach, each participant was randomly assigned to one of two groups. This implies that testing was done in an AB form (machine learning input condition followed by threshold-based input condition) for group one and a BA form (threshold-based input condition followed by machine learning input) for group two. Based on the condition assignment, there was a gap of two days before the other set-up was shown (stage 3, day 5). Next, participants were left uninterrupted and were advised to continue their regular routines while the display was positioned like a photo frame using an Ultrabook's 13.3-inch display with a resolution of 1600 x 900 pixels. Note that the experimenter did not provide the details of the actual activities performed to the participants. Instead, the explanation given was that the display was related to their loved one's activities emphasizing that blue patterns suggested low periods of activity and red patterns implied high activity levels.

**Measurement Instruments**

Pre- and post- tests were carried out for each experimental condition of the experiment. During the pre-test, participants completed the UCLA loneliness questionnaire (D. W. Russell, 1996). The UCLA loneliness scale (D. W. Russell, 1996) is widely recognized as a 'gold standard' for measuring subjective feelings of loneliness and social isolation. It comprises of 20 items, examining the rate of recurrence of feelings of being alone and being misunderstood, lack of companionship, social inclusion, and relationship closeness. Every item is followed by a four point Likert scale ranging from one = *never* to four = *always*. Scores range from 20 to 80 with higher scores indicating greater degrees of loneliness. In this chapter, our evaluation of the UCLA loneliness scale is inspired by the view that social isolation and loneliness, are objective indicators of the extent to which a person is socially connected (Tomaka, Thompson & Palacios, 2006).

Next, we applied the Lawton Instrumental Activities of Daily Living Scale (IADL) (Graf, 2008). This investigation is done to assess an older adult's functional abilities and their instrumental activities of daily living (IADL), i.e., the skills needed for living independently (e.g., housework, laundering, and meal preparation). The Lawton IADL scale is a standard instrument for measuring self-care and is well-validated in geriatric communities (Elsawy & Higgins, 2011). It consists of 8 IADL items ranging from 0 (low function) to 8 (high function) assessing the degree of dependence in telephone use, mobility, grocery shopping, meal preparation, housekeeping, laundry, medication, and financial management. Within AAL, the results of an IADL assessment may serve as an early indicator of functional decline (Graf, 2008).

Within this study, we were motivated to understand the social relationship between the elderly and their caregivers. The instrument, the Inclusion of Other in the Self Scale (IOS) developed by Aron, Aron and Smollan (1992), is one of the most highly cited measures of the perceived closeness of relationships. Subsequently, participants ranked the perceived intimacy of their loved ones through this scale. The IOS scale is a 7 point pictorial measure of closeness using two overlapping circles, whereby a closer intersection, indicates stronger sentiments of love and companionship. Moreover, to gain deeper insights into their social connectedness, we asked participants to elaborate on the elements of their social network.

During post-trial evaluations, the perceived levels of social presence for each condition were determined through the use of a questionnaire adapted from the Institute for Perception Social Presence Questionnaire (IPO-SPQ) (De Greef & Ijsselsteijn, 2001; IJsselsteijn, van Baren & van Lanen, 2003). For the IPO-SPQ, two different approaches were adopted for measuring social presence. First, the semantic difference technique from (Short et al., 1976), which measures affective qualities of the medium. Second, subjective attitude statements for evaluating the experience using a 7 point agree-disagree scale. The post-test questionnaire used the items from the semantic differential approach while items from the subjective attitude scale were slightly adapted to suit the needs of the experiment. We also included from the IPO-SPQ, the questions on system usability and general acceptance. Later, the IOS scale was repeated to determine perceived closeness after each condition. Finally, we interviewed participants to get feedback relating to their perceptions and experience with the system.

### Qualitative Interviews

For each set-up, the experimenter administered post-qualitative interviews (elderly and caregiver separately) to further understand their impressions on perception, usability, social presence experience, preference, and changes in social interaction throughout the deployment. The following questions were intended to provide qualitative evidence during the post-test interviews as demonstrated in (Davis, Owusu et al., 2015).

- Did the bidirectional ambient display trigger social behaviour?

- What are the privacy implications of activity awareness stemming from the use of bidirectional ambient displays for activity awareness?
- How are both displays perceived and what are the preferences of both user groups to obtain activity awareness?
- Were caregivers able to recognize certain activity patterns pertaining to their loved ones and vice versa?
- When participants observed the displays what are their perceptions of their loved one's activities?

## 4.3 Results

In this section, we describe our findings organizing them into four main categories: (i) what are the participants' social context and the elderly's functional abilities and how does this relate to their social well-being, (ii) how the bidirectional display is expected to affect social connectedness and presence, (iii) what are the overall impressions of the system and how social interaction changed throughout the study, and (iv) how did the means of classifying activity levels affect the social connectedness experience?

### 4.3.1 Participants' Social Context and Functional Abilities

The pre-test findings showed that caregivers maintained a busy work schedule and had very little time for social interaction. Their social networks included members of their immediate family, colleagues, and friends. On the other hand, some elderly participants had very few friends and family members living within close range. Two elderly participants reported that church members were all they had while the remaining four participants were in close contact with friends and family.

The mean UCLA loneliness score among the participants was 38, with a standard deviation of 7.73 and scores ranging from $24-48$. However, the elderly majority admitted during the qualitative interviews that they were involved in community-based exercise programs suggesting that exercise can have positive effects on the social well-being as posited by McAuley et al. (2000). Also, our elderly participants demonstrated high levels of subjective social well-being, which can be attributed to their involvement in church activities, prayer, and bible reading sessions several times per day. Thus, supporting a positive correlation between religion and subjective well-being in later life as demonstrated by Koenig, George and Titus (2004); Krause (2003).

With respect to functional ability, the elderly participants had very high scores (mean 7.83 and standard deviation 0.41). Subsequent discussions with the property manager confirmed their involvement in senior exercise programmes for health and wellness and their quest to maintain a healthy and balanced lifestyle.

### 4.3.2 Social Connectedness

Overall, the awareness of activity levels gave a sense of increased closeness for both target groups. Using the General Linear Model for repeated measures in SPSS 23.0, the analysis of the IOS scale (Aron et al., 1992), which is a measure of social connectedness demonstrated significant differences between the no visualization condition and the displays based on the machine learning and threshold based algorithms.

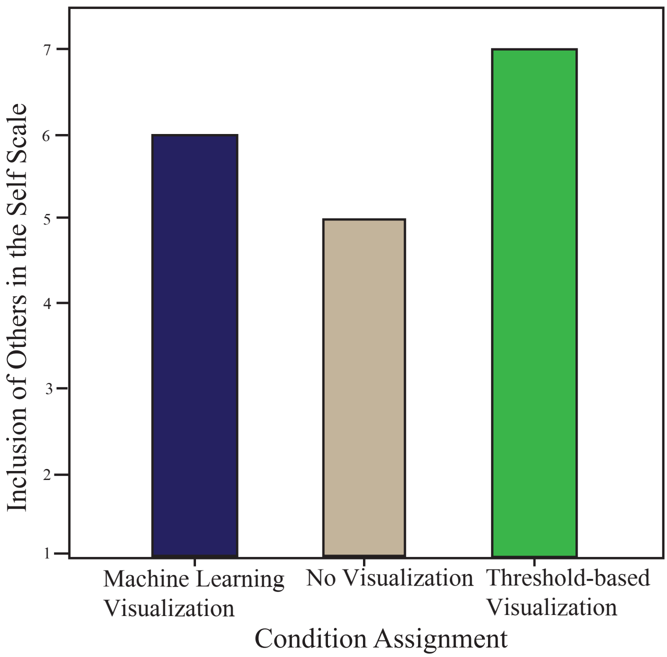


Figure 4.10 Estimated marginal means and effects of the type of visualization on social connectedness using the IOS scale.

The within subjects effect for social connectedness shows the following results: $F = 9.34$, $p < 0.001$. Pairwise comparisons of the ratings of closeness with the no visualization condition versus the machine learning based and the threshold based visualizations show $p <$

0.035 and $p < 0.013$, respectively. However, there was no significant difference between the IOS results when both machine learning and threshold based visualizations were compared, i.e., $p > 0.660$. This shows that awareness of activity data induces social connectedness irrespective of the approach to classification. Figure 4.10, illustrates the estimated marginal means of each condition and the effects on social connectedness.

### 4.3.3 Social Presence

There was no significant difference in experienced social presence between the machine learning and threshold based visualization conditions.

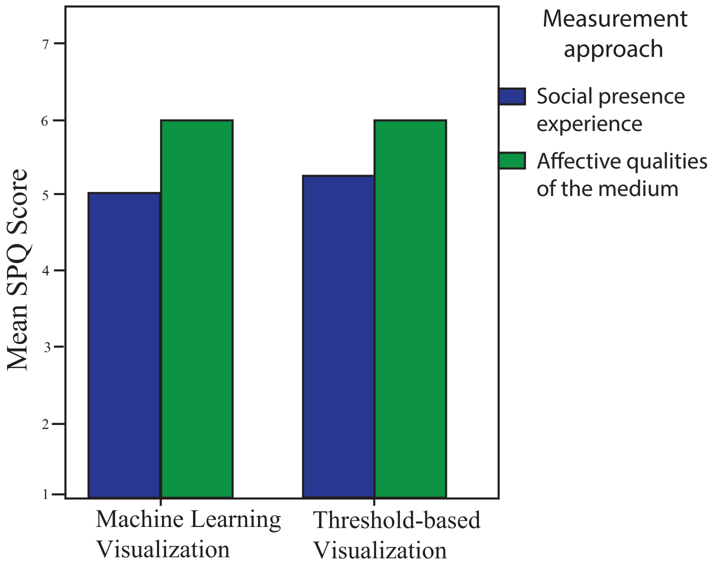


Figure 4.11 Estimated marginal means and effects of the visualization type on participants' assessment of experienced social presence versus the affective qualities of the display using the IPO-SPQ.

The within subject effect on experienced social presence with respect to the type of visualization showed $F = 0.247$ and $p > 0.629$. Furthermore, the said measure demonstrated no significant effect on the aesthetic qualities of both displays with $F = 0.149$ and $p > 0.707$.

From figure 4.11, we see that activity awareness induces social presence despite the classification approach used. However, the participants placed more value on the affective qualities of the bidirectional ambient display platform instead of the social presence experience. Examples of affective benefits conjectured by IJsselsteijn et al. (2003) include the sense of not being alone, being in touch, sharing, belonging, and intimacy.

### 4.3.4 Qualitative Analysis

The qualitative data suggest that the bidirectional ambient display platform triggered social interaction and positively improved relationship closeness between the target groups. Moreover, the bidirectional communication channel was significantly appreciated, with participants often expressing increased feelings of connectedness through the indirect knowledge of their loved ones' activity levels. Notably, some participants reported increased social contact the during the experiment.

#### Activity Awareness and Social Connectedness

The findings suggest that peripheral awareness of activities enables participants to feel closer to their loved ones by enhancing their perception of each other's activity patterns. In addition, the caregiver majority were astounded by the high activity levels of their elderly counterparts, which corresponds to their high functional ability scores using the IADL scale (Graf, 2008).

Overall, the data suggest that higher activity levels were more appreciated to elicit increased affective responses between older adults and their caregivers. Not surprisingly, the machine learning based visualization (inputs: the classified activity states grouped into high/low levels) was highly preferred by nine participants over the threshold based visualization (inputs: high/low activity levels solely based on the observable patterns of the raw accelerometric data), which was favoured by only one participant because the machine learning based visualization showed more periods of high activity than its contender. This was due to the fact that threshold-based algorithm classified steady standing states as low activity levels while standing was mapped to a high activity level in the machine learning based display. The remaining two participants reported neutrality with both displays. Despite this general preference, three participants indicated that the threshold classification was relevant for showing a balanced lifestyle as it demonstrated more restful activity states. Although trends in activity data could provide feedback on the other person's activity levels, nine participants, indicated that the accuracy of the visual mappings is vital to avoid false positives and avoid unnecessary worrying, especially for caregivers if extended periods of low activity levels were consistently observed.

Despite the social connectedness benefits of the system, four caregiver participants mentioned that they were more interested in monitoring inactive periods to determine emergency situations such as fall detection for their elderly loved ones as confirmed by (Bourke et al., 2007). This can be attributed to age factors, e.g., one participant was 93 and was susceptible to falling coupled with the family history of two other elderly participants who were also prone to falling. For instance, one caregiver stated:

*"The display makes me feel more peaceful and connected. This application is necessary because my mother and grandmother fell and were at home helpless all day. Back then, no one was aware or informed."*

Similarly, one elderly participant appreciated the peripheral information to determine if everything was okay with her son. Participants generally expressed that the bidirectional ambient display platform not only provided social connectedness benefits but indirectly gave a sense of peace of mind to caregivers who were worried about their elderly loved ones and also provided comfort and reassurance for the elderly in knowing that their caregivers were active and well.

**Engagement**

The results suggest that indirect activity awareness may enhance the level of engagement, which might enrich perceived intimacy. Often when participants were engaged in viewing the display, they became curious to identify trends in their loved one's activity patterns by actively trying to imagine what they were doing. Specific activity patterns perceived by caregivers included restful states (sleeping, television, toileting, and reading among others) and periods of high activity (cooking, ironing, laundry, cleaning, and baking). Alternatively, the elderly imagined manual labour, computer activities, shopping, and house work as high activity periods for their caregivers and deemed relaxation for short periods as a low activity level.

Moreover, two elderly participants likened their experiences to that of a puzzle/game and mentioned that the system's additional layer of abstraction promoted mental stimulation, which could improve cognitive function for the frail elderly as confirmed by Small (2002); Weisman (1983). However, further experimentation is needed to prove this claim. In retrospect, participants noted that such intuition of activity states was based on the colour, pattern, and speed of the visualization and their prior knowledge of their loved one's daily activities, which was confirmed by the experimenter through activity labelling, thinking-aloud (Lewis, 1982), and verbal probing methods. In most cases, the mental map conjectured by participants matched the actual activities of their loved ones. Altogether, an increased amount of interpersonal awareness through the bidirectional display prompted participants to call or visit each other more frequently. Furthermore, the bidirectional display was deemed as a trigger to promote personal reflection of being highly active in younger years for some elderly participants.

*"The display brought me back to my younger days, back then I was moving as fast as my caregiver, and I was able to accomplish all the tasks I had to do."* – Elderly participant

Additionally, like the researchers in (Visser et al., 2011) the view that the other person was 'far away' gradually disappeared through increased sentiments of closeness and social presence. For example, when asked about the co-presence effects of the machine learning visualization, one caregiver exclaimed:

*"The red makes me feel as if my mother is right here with me. It feels as if she was doing her stuff all around me. I found myself looking at the visualization to see if she would stop as she often times overdoes it [...]"*

*"I felt his presence. Yeah the system gave me an idea of his routine and made me look forward to his visits [...]"* – Elderly participant

In contrast, most participants expressed feelings of social distance during periods of inactivity.

*"Whenever it is blue, I feel my caregiver is not with me."* – Elderly participant

Some participants were appreciative of its artistic effects and articulated the following:

*"From an artistic perspective, I realized that I could identify patterns and use lines and movement to create something beautiful."* – Caregiver

*"It was good to see my son moving, it's like watching a TV programme about him. It is very interesting!"* – Elderly participant

In general, the bidirectional display was equally fascinating for both parties, which was mainly attributed to its aesthetic appeal. In addition, two elderly participants expressed that the visual patterns stimulated self-reflection on their higher activity levels during their youth. Meanwhile, others reflected on notable past social experiences with their caregivers and highlighted their caregivers' admirable strengths and qualities.

**Privacy and Control**

When people are engaged in activity sharing, privacy and control are critical factors. Notably, two elderly participants expressed discomfort as they believed they were being watched or recorded during the study. In addition, one elderly participant articulated that she appreciated the receipt of her child's activity information but was unsure if such systems would respect the privacy needs of caregivers.

*"This system gave me an idea of his activities. He is a very busy man but what if I want to know and he does not want me to know?"*

Moreover, the participant majority appreciated the abstraction of their activity levels, which gave them a sense of control as the other party was unable to explicitly ascertain the exact activities of their loved ones. Furthermore, participants found the idea of wearing a mobile phone around their waist interesting and less obtrusive as they could easily remove it when necessary.

**Accessibility and Affordability**

Two elderly participants expressed satisfaction that context-aware solutions were now affordable and accessible as in the past it was merely accessible to incredibly wealthy people. An example statement is given below.

*"Back then, I would never dream that something like this could be in my own living room. Actually, in those times only rich people could afford these technologies."* – Elderly Participant

## 4.4 Discussion

Overall, we demonstrated that activity data relayed in an ambient display was possible for eliciting feelings of closeness between the elderly and their caregivers in the absence of direct communication. In conveying their impressions and experiences with the bidirectional ambient display platform, participants generally had positive reviews concerning its deployment unlike some of the participants from the previous study in chapter 3. This could be attributed to cultural differences between both sets of participants. As mentioned earlier, participants in this study were mostly naturalized Canadian citizens who originated from the Caribbean. Chioneso (2008) argues that most Caribbean immigrants maintain a collectivist culture, i.e., a closely knit framework where a person expects his family or other members in his/her social network to take care of them, which is ultimately rewarded with loyalty (Hofstede, 2011). This notion of collectivism could have been a contributing factor to the current participants' acceptance for the sharing of activity information, and embracing the bidirectionality of the intervention and the sense of subconscious presence it gives.

Our findings suggest that activity perception varied between the target groups and encompassed the discovery of activity patterns based on their preconceptions of their loved ones, past knowledge of the other person's activities, and observation of certain visual cues including; colour, speed, and motion. Furthermore, the artistic rendering of activity cues was praised among participants as a rich channel for creating a fascinating interaction and a sense of the activities and presence of remote loved ones.

Quantitatively, awareness of activity data induces a sense of presence irrespective of the approach to classification. However, a paradoxical effect was reflected in the qualitative reviews. Specifically, the exit interviews revealed that the participant majority viewed the machine learning based visualization as a better resource for communicating activity information and supporting feelings of presence. This can be attributed to the experimenter's mapping of activity states to levels based on observation and user-confirmation of the participants' activity patterns. In safety critical environments such as AAL, it is imperative that the visual display corresponds to the users' actual activity patterns — though challenging, it is essential to accurately classify the user's activity states.

Although monitoring and surveillance were not intended research goals, they were recurring themes throughout this experiment. For instance, the qualitative analysis signals the usefulness of the proposed bidirectional display as an 'indirect' type of monitoring application. Also, despite already existing market solutions to support emergency cases in AAL environments, participants mentioned technical requirements such as system accuracy and reliability during the discussions. Therefore, the threshold based classification approach was too naive to quantitatively satisfy these users' needs. Whereas, the machine-learning classifier could serve as a better resource for enabling system accuracy and reliability.

While our strategy worked for only two activity levels, assistive environments could benefit from more robust machine learning algorithms for accurately detecting the users' actual activities and generating mappings based on their context and needs. Therefore, the hybrid support vector machine and hidden markov model algorithms could result in improved activity recognition performance, which is investigated in the subsequent chapter.

### 4.4.1 Design Implications

Generalizable implications, which might be useful for interpersonal awareness systems in AAL environments to support social connectedness between the elderly and their caregivers are discussed below.

#### Understanding the Users in Context

Before designing connectedness oriented systems, it is non-trivial to understand the users in context. In this case, we assessed their social situation and the elderly's functional ability. Concerning social structures, the mechanisms for social cohesion and social connectedness to achieve well-being among our elderly participants included; community-based exercise programmes, involvement in religious activities coupled with frequent visits/telephone calls from loved ones. The acquired information was useful for determining the user's needs and expectations and evaluating the social connectedness implications of the ambient display.

#### Implications for Designing Ambient Displays for Social Connectedness in AAL

The bidirectional ambient display platform is designed as a medium to strengthen interactions and to create a sense of togetherness between the target groups. In addition, the system is meant to be a quick reference for busy caregivers and a fascinating and informative experience for the elderly. Therefore, the information on the display needs to be reliable, accessible, relaxing, and easily absorbed. Moreover, ambient displays should be aesthetically pleasing. However too many details make it more complicated and difficult to read, which can harmful in AAL domains.

Considering the many activities completed within a day, it might be prudent to exploit the abstraction of activity information through aesthetic ambient displays, which have been proven to promote personal engagement and implicit interactions with the system. Furthermore, abstraction can be useful to discreetly support privacy, promote a sense of mysteriousness stimulating users to make sense of the information presented. In light of age-related cognitive decline, the processing of abstract information could boost memory function and promote mental agility among the elderly as suggested by E. Gray and Tall (2007); Small (2002) (cf. chapter 2). Also, the perception of activities could activate top-down processing (Engel et al., 2001), through subjective interpretations of a loved one's activities or encourage self-reflection on past social interactions drawing from their episodic memory as discussed in chapter 2.

Bidirectionality affects not only contextual awareness but also social connectedness within AAL environments. Our findings indicate that the bidirectional effects can evoke more positive social behaviours between the elderly and their caregivers and in this case, bidirectionality was in most cases, equally appreciated by both user groups. However, one elderly participant was concerned about the privacy implications for her child. As a consequence, this opens the design space for AAL designers to explore additional ways to handle the privacy implications of the bidirectional presentation of activity information.

As an aside, bidirectional ambient displays could facilitate the transition from implicit to explicit interaction with a loved one. For example, if the system conveys worrisome information, a participant could initiate social contact with their loved one.

### 4.4.2 Limitations

We acknowledge that a larger sample size could further enhance our understanding of the social connectedness implications and the statistical significance of the proposed system, which we hope to resolve in future experiments. Caregiver recruitment proved difficult given the geographical distance between both user groups and the extensive time required for the experiment. Moreover, the short length of the trial coupled with the fact that the sensor device had to be worn “consciously” could have created an increased awareness of the mobile application itself. Such self-awareness can impact user behaviour, and a longer trial is needed to remove any such effects.

Although none of the participants explicitly reported negative distraction from the presence of the bidirectional ambient display platform, we acknowledge that more attentional resources were utilized in our study. This could be related to the novelty of the display as several caregivers were often intrigued to determine when their elderly loved-one would be less active. We expect that a long-term study would stabilize user interest and lead to habituation in order to overcome the effects of novelty over time as confirmed by Shen, Moere, Eades and Hong (2008).

While the study duration was relatively short, we consider this study as a crucial first step towards the implications of a bidirectional activity awareness display to achieve context-awareness and social connectedness. We hope our findings and methodological approach will benefit the future evaluation of ambient displays to enhance social connectedness within an AAL context. Toward the end of this dissertation (chapter 8), we will objectively investigate these implications through behavioural measures.

## 4.5 Conclusion

The purpose of this study was to gain an understanding of how the deployment of a bidirectional peripheral activity awareness system could influence social presence and relationship closeness between elderly-caregiver pairs. Although previous works were mostly unidirectional e.g., (Consolvo et al., 2004; Metaxas et al., 2007; Mynatt et al., 2001), this study showed that bidirectionality was useful for the following: (i) enhancing situational awareness, (ii) eliciting social presence, and (iii) motivating some participants to improve their social contact, e.g., extrinsically through increased visits or telephone contact and intrinsically via self-reflection on past social interactions with the partner, thereby improving social connectedness. The study culminated with a series of design implications, which are summarised as follows. First, we discussed the value of a user centered design approach. Then, we highlighted the benefits of the display for strengthening interactivity and social presence. Subsequently, we discussed critical features relating to information access, e.g., reliability and ease of interpretation. Later, we emphasized the benefits of aesthetics for enhancing the users’ experience and promoting engagement. Thereafter, we discussed the notion of abstraction as a useful resource for sustaining privacy and promoting cognitive flexibility among older adults. Finally, we discussed in more detail how the bidirectionality of the intervention can promote and enhance positive social behaviour between the pairs. Moreover, we discussed how bidirectional awareness can affect the transition between implicit and explicit social interactions in AAL environments.

While the intervention appeared to be useful, it was not without limitations, e.g., its attention demanding nature, limited participants, etc. Like the participants in chapter 3, caregivers generally highlighted the value of highly reliable and accurate information sources to avoid false positives within AAL environments. Thus, prompting the need for a more robust activity classification technique to serve as input for the bidirectional display. In the next chapter, we discuss human activity recognition in more detail and introduce a robust activity recognition system as a means to support peripheral awareness and social connectedness in AAL environments.

# Chapter 5

# Activity Recognition Based on Inertial Sensors for AAL Environments

*"The goal is to turn data into information, and information into insight."*

—Carly Fiorina

As demonstrated in the previous chapter, this dissertation employs activity recognition as the oil that powers the peripheral display engine, geared towards improving interpersonal awareness and social connectedness in AAL environments. This is further supported by exploiting the pre-attentive features discussed by Ware (2004), namely colour, form, spatial position, and motion to provide a richer and better abstraction of activity data to support bidirectional presence and improve interactivity.

Generally speaking, the safety of older adults living alone is a critical requirement of AAL applications to avoid system failure detection (Memon, Wagner, Pedersen, Beevi & Hansen, 2014). As such, algorithms deployed in this domain should maintain high reliability. Chapters 1 and 2 definitively illustrate that systems investigating activity recognition in assisted living scenarios were more focused on elderly ambulatory monitoring for emergency detection. Although emergency notification is not the primary objective of this research, the results of both preliminary studies in chapters 3 and 4 emphasized the need for reliability and accuracy of the information shown on the display. Thus, to satisfy user requirements, the purpose of this chapter is to provide a more robust activity recognition system as a means to raise situational awareness and support social interaction in mediated AAL environments. Accordingly, this chapter presents an activity recognition system that opportunistically exploits motion data from the smartphone's accelerometer and gyroscope sensors to infer

This chapter is largely based on the following publications (Davis, Owusu, Bastani et al., 2016; Davis, Owusu, Marcenaro, Hu et al., 2017).

six basic activities (walking, ascending the stairs and descending the stairs, sitting, standing, and laying) of the elderly and their caregivers in their natural environments. Specifically, three activity recognition approaches were investigated, which form part of the broader empirical studies, whereby the elderly and their caregivers perceive each others' activity states through subtle bidirectional ambient displays to raise awareness and enrich perceived intimacy. The best performing activity recognition model is used to drive our bidirectional activity-based system for subsequent empirical studies, which can be broadly extended to support context-awareness in AAL domains.

## 5.1 Introduction

As demonstrated in chapter 4, human activity patterns can convey a wealth of information with respect to health, moods, and behaviour. Within the AAL domain, the monitoring of activities of daily living (ADLs), e.g., bathing, dressing, housekeeping, and food preparation is essential for explicitly exploring the physical activity patterns for sustaining autonomy and quality of life among older adults. More specifically, various researchers have demonstrated the benefits of ADL monitoring for (i) recognizing ADLs (Philipose et al., 2004), (ii) fall detection (Bourke et al., 2007), and (iii) monitoring physical activity levels (Najafi et al., 2003). In addition, ADL monitoring can facilitate early diagnosis of a variety of diseases including (i) Alzheimer's (Debes et al., 2016; Galasko et al., 1997; Nygård, 2003), (ii) Parkinson's (Muro-de-la Herran, Garcia-Zapirain & Mendez-Zorrilla, 2014), and (iii) Dementia (Barberger-Gateau et al., 1992; Debes et al., 2016) and in turn, divulge reliable information concerning an elder's ability to live on their own.

Since the manual assessment of ADLs is largely impractical within this context (Debes et al., 2016), there is the need for automatic recognition of physical activities – generally known as human activity recognition (HAR). Common activities typically exploited, include (i) walking, (ii) walking upstairs, (iii) walking downstairs, (iv) sitting, (v) standing, and (vi) laying (Capela, Lemaire & Baddour, 2015; Ortiz, 2015).

A smart home, commonly defined as a residential facility, augmented with technology to provide comfort, energy efficiency, and safety to its occupants (Debes et al., 2016; Rashidi & Mihailidis, 2013a), is a test bed for analysing HAR models. Within AAL, smart homes have been utilized to assess the psychological and physical health of its occupants. For instance, D. Cook, Schmitter-Edgecombe, Crandall, Sanders and Thomas (2009) through the CASAS project employed machine learning algorithms to support remote health monitoring of the elderly.

Within a smart home, sensors initiate the data acquisition process, by gathering data on ADLs, so that signal processing algorithms can learn and make inferences from the data. A variety of sensing devices have been deployed to facilitate HAR, ranging from video cameras (Bastani, Marcenaro & Regazzoni, 2015; Fiore et al., 2008), wearable sensors (Patel et al., 2012), and wireless sensor networks (Corchado, Bajo, Tapia, Abraham et al., 2010). In particular, (i) accelerometers, (ii) gyroscopes, (iii) global positioning system (GPS), (iv) magnetometers, (v) radio frequency identification (RFID), and (vi) microphones to detect changes in location and movement (Chernbumroong, Cang, Atkins & Yu, 2013; Debes et al., 2016). Moreover, emerging trends in recent research, show that accelerometers have been combined with gyroscopes and magnetometers to improve recognition performance (Ustev et al., 2013).

Sensing technologies can be categorized into two groups namely, (i) non-wearable and (ii) wearable sensors. Non-wearable sensing devices are usually installed in stationary locations of the smart home. This is done to predict changes in location, gait, and activity patterns (Debes et al., 2016; Muro-de-la Herran et al., 2014). Within AAL, examples of non-wearable sensing technologies for ADL classification include, infrared (PIR) sensors for motion and human presence detection (Skubic, Alexander, Popescu, Rantz & Keller, 2009), vibration sensors for fall detection (Zigel, Litvak & Gannot, 2009), pressure sensors for detecting human presence and falls (J.-H. Lim, Jang, Jang & Park, 2008), cameras for activity recognition (Fleck & Straßer, 2008), and audio sensors for detecting door opening and closing (Popescu, Li, Skubic & Rantz, 2008). Based on the reports in (Chernbumroong, Atkins & Yu, 2010), the use of camera-based monitoring might not be applicable in AAL due to greater concerns toward the privacy constraints.

On the other hand, wearable sensors are body-worn devices, which enable the collection of context data, by embedding electronic technology into everyday objects (e.g., watches, smartphones, jewellery, or clothing) to measure motion or physiological characteristics, e.g., blood glucose, blood pressure, and cardiac activity) (Debes et al., 2016; Rashidi & Mihailidis, 2013a). Within the AAL domain, wearable sensors are in most cases used for ADL monitoring and classification. Primarily, wrist-worn sensors including wrist-watches, bracelets, and magnetic sensors are used for activity recognition (Debes et al., 2016). Although wearable sensors have shown much potential for ADL monitoring, they are often sold at exorbitant cost and are frequently challenged by their privacy and security vulnerabilities.

Remarkably, the smartphone is comparable to hand-worn sensing devices for enabling HAR. Housing a myriad of miniature sensors, e.g., accelerometer, gyroscope, GPS, magnetometer and a microphone, the smartphone is capable of supporting the acquisition of rich datasets as demonstrated by Debes et al. (2016); Kwapisz, Weiss and Moore (2011); Ortiz

(2015). Moreover, it is equipped with a variety of components including WIFI, 3G/4G, and Bluetooth, which enable communication with other services (Anguita et al., 2012; Ustev et al., 2013). Signals recorded by mobile accelerometers and gyroscopes are typically represented in the form of time-series, i.e., a sequence of data points usually collected at regular intervals (Liao, 2005). Specifically, common activities such as walking, standing, and laying, etc. are generally represented by time-series patterns, useful for assessing physical and cognitive well-being in ambient assisted living (AAL) environments.

Although smartphones offer great potential for HAR, there are some hardware-related challenges, such as battery life, processing power, and memory capacity constraints. Thus, it might be challenging to compute resource-intensive machine learning algorithms on phones (Ustev et al., 2013). This problem can however be overcome by using the smartphone only for sensor data collection and then performing other HAR resource intensive tasks on a remote server. Also, the smartphone's portability, affordable cost, and ubiquity make it ideal for supporting the convenient, continuous and unobtrusive monitoring of physical activities, without imposing many restrictions in one's home. For example, Dai, Bai, Yang, Shen and Xuan (2010), developed a fall detection system using the inbuilt smartphone accelerometer. Our proposed HAR hybrid model advocates the use of the smartphone, placed on the users' belts for sensor data collection.

To facilitate the successful adoption of pervasive sensing technologies in AAL, user comfort with respect to the amount and location of deployed sensors must be carefully considered as it directly affects the acceptance of the system (Chernbumroong et al., 2013). In fact, sensors placed in certain positions or deployed in multiple locations might negatively influence the users' ability to perform activities normally and comfortably within AAL.

Also, HAR models used in AAL should be accurate and reliable to prevent misdetection and false alarms as false positives may cause excessive anxiety and result in unnecessary worrying, in particular for caregivers. Therefore, the need arises for being able to explore very accurate HAR models suitable for deployment within AAL. With the motivation of achieving the highest possible classification accuracy among all classes, we exploited the Support Vector Machines model described by Reyes-Ortiz et al. (2016) with the use of smartphone sensors (accelerometer and gyroscope). Furthermore, a hybridization of the Support Vector Machine (SVM) and Hidden Markov Model (HMM) algorithms and Artificial Neural Networks (ANNs) were also explored. Experimental results on real-life data show classification performances of over 90% for all three approaches with the hybrid SVM-HMM model achieving the highest detection accuracy. This offers a lot of potential for increasing the precision and accuracy of our context-awareness system for improving context-awareness and social connectedness for older adults and their loved ones over mediated environments.

This chapter is organized as follows. We first summarize the related work. Then, we describe the procedure and the proposed methodologies. Later, the results are discussed. Finally, we present the insights gained and our future research directions.

## 5.2 Related Work

There is a wide spectrum of approaches toward sensor-based human activity classification and recognition ranging from simple pattern recognition models, e.g., threshold-based classification methods (Shin, Park, Kim, Hong & Lee, 2007), to more advanced machine learning classification models. The most common models employ supervised learning techniques (Rodriguez-Martin et al., 2013), conditional random field (Zhao, Wang, Sukthankar & Sukthankar, 2010), rule-based reasoning (Paganelli & Giuli, 2011), artificial neural networks (Lubina & Rudzki, 2015), and probabilistic modelling (Duong, Bui, Phung & Venkatesh, 2005; Patterson, Fox, Kautz & Philipose, 2005). In addition, unsupervised learning methods have been proposed for HAR (Kwon, Kang & Bae, 2014).

Although these methods have shown progress in the field of sensor-based activity recognition, it has been difficult to achieve very high accuracies within the AAL domain due to the challenges listed below.

1. The inconsistency of ADLs i.e., different people perform activities in different ways and sequences (Rashidi, Cook, Holder & Schmitter-Edgecombe, 2011).

2. Sensor data tends to be noisy or ambiguous thereby affecting classification results. The more unobtrusive, the more noise, and calibration problems.

3. A large majority of previous activity recognition experiments were conducted using data from relativity young people. This data might not be truly representative of activity characteristics of older adults (Chernbumroong et al., 2013).

Notwithstanding these challenges, generative models have been reported to successfully handle these uncertainties (Jurek, Nugent, Bi & Wu, 2014). Generative models estimate the joint probabilities of observed samples, which are used to predict the likelihood of a class to which a new sample belongs. More importantly, Hidden Markov Models (HMM), have shown solid potential for addressing the ambiguities of interpretation within the AAL domain (Patterson et al., 2005). Hidden Markov Models (HMM) are mostly useful for activity recognition by virtue of their ability to exploit the temporal and sequential characteristics of activity data; thereby enabling the prediction of future states from current observation data. Though HMMs have demonstrated notable success, they are not without limitations (Kim, Helal & Cook, 2010). To begin with, it struggles in representing concurrent or interleaved activities, which can be problematic when modelling continuous activities which occur in the AAL domain. Second, its strict independence assumptions make it inadequate for the capturing of transitive dependencies of observations. Moreover, it is not feasible to model the feature vector extracted from accelerometer and gyroscope sensors.

As opposed to generative models, discriminative models estimate the conditional probability distribution of labelled sequences given the observations. A feasible solution to overcome the shortcomings of HMMs is to use a discriminative model such as the Support Vector Machine (SVM) to determine the emission probabilities of an HMM, which can then be combined with the dynamic temporal features of the HMM to give improved classification accuracy. In particular, it has been demonstrated that the hybrid SVM-HMM model achieves better performance when contrasted with stand alone SVM and artificial neural network (ANN) classifiers (Ordóñez, de Toledo & Sanchis, 2013). Nonetheless, this improvement in recognition accuracy was achieved using a network of binary sensors, which is different from the goal of deploying as few sensors as possible. In addition, by using the HMM-SVM technique Suutala et al. (2007) recorded an overall accuracy of 96% for activity recognition using wearable devices. However, the method used for data collection was quite invasive as participants wore many wearable sensors on various parts of the body including the thigh, both wrists and neck. For user comfort, in this dissertation, we advocate the deployment of as few sensors as possible for activity recognition. Moreover, hybrid SVM-HMM approaches have been successfully applied to other domains such as speech recognition (Ganapathiraju, Hamaker & Picone, 2004), speech emotion recognition (Lin & Wei, 2005), and analysis of facial expressions (Valstar & Pantic, 2007).

The biologically inspired Artificial Neural Networks (ANNs) are commonly presented as a collection of interconnected neurons grouped in layers, which are capable of automatic learning based on experience and approximating a non-linear combinations of features for pattern recognition (Ye, Dobson & McKeever, 2012). Artificial Neural Networks are shown to perform well by J.-Y. Yang, Wang and Chen (2008); Ye et al. (2012) for learning static (e.g., standing) and dynamic activities (e.g., walking) using a wrist-worn wireless sensing triaxial accelerometer. From this, we see that ANNs provide an efficient, robust, and well-suited design methodology for pattern recognition and classification involving uncertain and complex data. However, they have some limitations, including the requirement of a large volume of training data and the difficulty of deriving an explicit model as the underlying reason for high recognition validity is often unknown (Ye et al., 2012).

Moreover, several studies (Anjum & Ilyas, 2013; Kwapisz et al., 2011; Liang, Zhou, Yu & Guo, 2014; Martín, Bernardos, Iglesias & Casar, 2013; Ortiz, 2015; Ronao & Cho, 2017; Óscar D. Lara, Pérez, Labrador & Posada, 2012) have proposed in recent years to take advantage of the powerful in-built sensors of the smartphone to recognize physical activities using a combination of different learning techniques discussed above. In table 5.1, we present an overview of the state of the art approaches to activity recognition using smartphone sensors. It describes the relevant components, e.g., (sensors, classifiers, sampling rate, accuracy, and the number of experimental participants) that were employed in each approach. From table 5.1, it can be inferred that the type of sensors used, the classification methods, sample sizes, and sensor position/locations were quite varied among researchers. Noticeably, the authors applied a broad range of machine learning classification approaches including (i) decision trees (DT), (ii) decision tables (DTA), (iii) logistic regression (LR), (iv) additive logistic regression (ALR), (v) ANN, (vi) naïve bayes (NB), (vii) hierarchical HMM, (viii) HMM, (ix) SVM, (x) k-nearest neighbour (KNN), (xi) bayesian network (BN), (xii) multilayer perceptron (MLP), (xiii) base-level and meta-level classifiers (bagging and boosting), and (xiv) random forest (RF). In this dissertation, we evaluated standalone SVM and ANN classifiers, and developed a hybrid SVM-HMM model in order to select the most accurate human activity classification model for our AAL context and varied participant demographics.

## 5.3 Experimental Protocol

The Samsung Galaxy S II smartphones, with inbuilt accelerometer and gyroscope sensors, were used to conduct our experiment as illustrated in chapter 4. Our mobile sensing application was developed using Android Development tools. Signal pre-processing, feature extraction, feature selection, and classification were implemented using Matlab.

### 5.3.1 Data Collection and Feature Extraction

In addition to publicly available smartphone activity datasets, we collected our own datasets in order to reduce the uncertainties of the former. We received 5744 samples from 31 healthy volunteers, ranging from 22 to 79 years from 14 countries, namely Russia, Italy, The Netherlands, Germany, Iran, China, India, Pakistan, Nigeria, Ghana, Tunisia, Lebanon, Jamaica, and Colombia. Like it was done by Anguita et al. (2013) and in chapter 4, users were asked to perform six basic activities (walking, walking up and downstairs, standing, sitting, and laying) while wearing a waist-mounted smartphone belt on their left or right side. Each activity was performed for one minute in the context of the elderly's homes

Table 5.1 Summary of existing smartphone-based activity recognition studies

| Citation | Sensor/s | Sampling Rate | Location/Position | Movement/s / Activity Level/s | Classifier/s | Accuracy (%) | Number of Participants |
|---|---|---|---|---|---|---|---|
| (Kwapisz et al., 2011) | accelerometer | 50Hz | pocket | walking, jogging, ascending stairs, descending stairs, sitting, standing | DT, LR, multi-layer ANN | 91.7 | 29 |
| (Óscar D. Lara et al., 2012) | accelerometer, vital signs | 50Hz | chest | walking, running, sitting, ascending stair, descending stairs | NB, BN, DT, MLP, ALR, boosting, bagging | 95.7 | 8 |
| (Anjum & Ilyas, 2013) | accelerometer, gyroscope, GPS | 8Hz | hand, pants pocket, shirt pocket, handbag | walking, running, ascending stairs, descending stairs, driving, cycling, being inactive | NB, DT, KNN, SVM | 95 | 10 |
| (Martín et al., 2013) | accelerometer, gyroscope, magnetometer | 6.25Hz | hand, texting, talking, front and back trouser pockets, shirt and jacket pockets, a short-strap and long-strap bag, in a backpack, armband, waist case, | walking at different paces (slow, normal, rush), running, sitting, standing | NB, DTA, DT | 92.94 | 16 |
| (Liang et al., 2014) | accelerometer | 0.5Hz, 2Hz, 10Hz, 20Hz | pocket | standing, sitting, laying (prone), laying (supine), driving, walking, running, ascending stairs, descending stairs, cycling, jumping | DT | 89.1 | 24 |
| (Ortiz, 2015) | accelerometer, gyroscope | 50Hz | waist | walking, ascending stairs, descending stairs, sitting, standing, laying | SVM | 96.5 | 30 |
| (Ronao & Cho, 2017) | accelerometer, gyroscope | 50Hz | waist | walking, ascending stairs, descending stairs, sitting, standing, laying | hierarchical HMM | 93.18 | 30 |

and the caregivers' working environment simulating a semi-naturalistic environment. Also, accelerometric and gyroscopic data were collected at a sampling rate of 50Hz.

To reduce the biases associated with using our own dataset, we merged our collected dataset with the public dataset for HAR using smartphones (Anguita et al., 2013), which was collected in a similar manner and at the same frequency. In total, 16043 samples were available for training, cross-validation, and testing. Our dataset is publicly available on Github and the UCI Machine Learning repository.

A method similar to (Anguita et al., 2013) has been employed for extracting features from the accelerometer and gyroscope data collected. Features were computed on a fixed length sliding window of 2.56 sec with 50% overlap. The raw signal data per window were filtered using a median filter and a 3rd-order low-pass Butterworth filter of 20Hz corner frequency. The jerk of the angular velocity, body, and gravity acceleration were derived before computing standard statistical measures described in table 5.2 and demonstrated by Reyes-Ortiz et al. (2016). Overall, 561 features were extracted per window.

Table 5.2 The list of measurements for the computation of feature vectors adapted from (Reyes-Ortiz et al., 2016)

| **Function** | **Description** |
|---|---|
| mean | Arithmetic mean |
| std | Standard deviation |
| mad | Median absolute deviation |
| max | Largest value in array |
| min | Smallest value in array |
| skewness | Frequency signal skewness |
| kurtosis | Frequency signal kurtosis |
| maxFreqInd | Largest frequency component |
| energy | Average sum of the squares |
| sma | Signal magnitude area |
| entropy | Signal entropy |
| iqr | Interquartile range |
| autoregression | 4th order Burg autoregression coefficients |
| correlation | Pearson correlation coefficient |
| meanFreq | Frequency signal weighted average |
| energyBand | Spectral energy of a frequency band |
| angle | Angle between signal mean and vector |

### 5.3.2 SVM and HMM

The original SVM developed in 1990s is a binary classification method (Cortes & Vapnik, 1995). Later, two strategies were developed to extend SVM in multi-class problems: 1) *one-against-all* strategy, which uses one SVM for each class and 2) *one-against-one* strategy, which uses a SVM for each pair of classes. Here the *one-against-all* strategy is used, which has shown superiority for multi-class classification problems (Anguita et al., 2012; Rifkin & Klautau, 2004). As described by Hsu and Lin (2002); Ortiz (2015) the one-against-all approach consists of constructing $k$ SVM models where $k$ is the number of models. The $ith$ model is then trained with all data samples belonging to class $i$ as positive points and all other samples as negative points. Consequently, the classification of new instances is formulated using a winner-takes-all scheme given by equation 5.1, where $f_i$ represents the $ith$ classifier.

$$f(x) = arg\,max_i\, f_i(x) \tag{5.1}$$

The multi-class SVM is trained with a 561 (dimension) feature vector extracted from the measurements of the accelerometer and gyroscope sensors.

Hybrid SVM-HMM models have been shown to significantly improve classification accuracies over the standard SVM models (Valstar & Pantic, 2007). The standard SVM is a discriminative classifier that does not provide class probabilities used by the HMM. However, simple post processing is proposed by Platt (1999) that can map the output of SVM to posterior class probabilities. The proposed method by Platt (1999) uses a sigmoid function to estimate these probabilities:

$$\hat{p}(x = m|f(\mathbf{y})) = (1 + exp(A_m f(\mathbf{y}) + B_m))^{-1} \tag{5.2}$$

where $f(\mathbf{y})$ is the output decision value of the SVM trained to separate class $m$ from all other classes.

HMM is a basic approach for modelling correlated time-series. The first order HMM is graphically shown in figure 5.1.

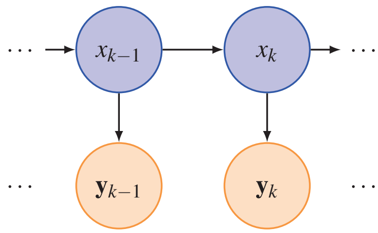


Figure 5.1 Hidden Markov Model.

It consists of a hidden state sequence $\{x_0, \cdots, x_k, \cdots\}$ and an observation sequence $\{\mathbf{y}_1, \cdots, \mathbf{y}_k, \cdots\}$. The observation vector $\mathbf{y}_k$ at time $k$ corresponds to quantities that can be directly measured by sensors or computed from sensor output deterministically. The state variable $x_k$ where $k \in \{1, \cdots, K\}$, represents the class label at time $k$ that should be inferred. Note that this formulation is only valid for our problem as it does not depict the general formulation of the HMM. Temporal dependencies between class labels can be effectively modelled using HMM by assuming that the label at time $k$ is independent of the whole history of the process given the immediate previous label at time $k-1$.

HMM is characterized with two conditional probability density functions: 1) $p(x_k|x_{k-1})$ depicted as horizontal arrows in figure 5.1, which is referred to as the state transition model and 2) $p(\mathbf{y}_k|x_k)$ represented with vertical arrows in figure 5.1, which is called the emission model. The transition model is a categorical distribution

$$p(x_k|x_{k-1} = n) = Cat(\pi_n), \tag{5.3}$$

where $\pi_n = [\pi_{1,n}, \cdots, \pi_{K,n}]$ is the parameter vector of length $K$ whose $m$th element $\pi_{m,n}$ equals the transition probability from state $n$ to state $m$ in subsequent time instances, i.e., $p(x_k = m|x_{k-1} = n)$. In total, there are $K$ parameter vectors $\{\pi_1, \cdots, \pi_K\}$, each of which corresponds to one state label. If sequences of the class labels (hidden states) are available as training data, the transition parameters can be estimated using Maximum A-Posteriori (MAP) estimation by assuming a Dirichlet distribution prior for parameter vector

$$\pi_n \sim Dir(\alpha), \tag{5.4}$$

where $\alpha$, the concentration parameter, is set to 0.05 in this experiment. With this set-up, the transition model MAP parameters can be calculated as

$$\hat{\pi}_{n,m} = \frac{\alpha + N_{n,m}}{K \times \alpha + \sum_{i=1}^{K} N_{n,i}}, \tag{5.5}$$

where $N_{n,m}$ is the number of times a transition from state $n$ to state $m$ occurs in the training sequences.

On the other hand, the emission model $p(\mathbf{y}_k|x_k)$ can be any kind of density function depending on the problem. For the HMM model, the observation vector would be the 561 feature vector but, defining a density function for such a high dimensional vector is infeasible. However, using a well trained SVM classifier, it is still possible to calculate the posterior probabilities. The filtering task in the HMM is defined as the calculation of the posterior $p(x_k|\mathbf{y}_1, \cdots, \mathbf{y}_k, \cdots)$, which is done either by calculating forward filtering $\rho_(x_k) = p(x_k|\mathbf{y}_1, \cdots, \mathbf{y}_k)$ or $T$-lag forward-backward filtering $\rho_T(x_k) = p(x_k|\mathbf{y}_1, \cdots, \mathbf{y}_k, \cdots, \mathbf{y}_{k+T})$.

These quantities can be calculated using forward $\alpha_k(m)$ and backward $\beta_k(m)$ values:

$$\rho(m) \propto \alpha_k(m), \tag{5.6}$$

$$\rho_T(m) \propto \alpha_k(m)\beta_k(m). \tag{5.7}$$

The forward value is calculated recursively as

$$\begin{aligned} \alpha_1(m) &= \gamma_1(m)/K, \\ \alpha_{k+1}(m) &= \gamma_{k+1}(m) \sum_{n=1}^{K} \alpha_k(n)\pi_{n,m}, \end{aligned} \tag{5.8}$$

and the backward value is calculated as

$$\begin{aligned} \beta_{k+T}(m) &= 1, \\ \beta_k(m) &= \sum_{n=1}^{K} \beta_{k+1}(n)\pi_{m,n}\gamma_{k+1}(n). \end{aligned} \tag{5.9}$$

where $\gamma_k(m)$ is the conditional probability of the label at time $k$ given the feature vector calculated by equation (5.2) and $m$, $n$ are hidden states $x_k$ and $x_{k+1}$, respectively. Having calculated the posterior probabilities, the activity class is found as the Maximum A Posteriori (MAP) state.

### 5.3.3 Artificial Neural Networks

Artificial Neural Networks (ANNs) is a machine learning paradigm, inspired by the way in which biological neural structures in the human brain, process information. Figure 5.2 shows the simplest model of an artificial neuron.

A single output $(y)$ of the neuron is given by

$$y = f(\sum_i w_i x_i) = f(w^T x) \tag{5.10}$$

where $x$ represents the input vector, $w$, the weight vector denotes the efficiencies of the neurons' synapses and $f$ is the activation function. An Artificial Neural Network (ANN) is a network of neurons, which consists of an input vector, propagated via weights through the hidden layer until the activation reaches the output layer (Haykin, 2007). Figure 5.3 shows a generic ANN with 5 input units, 3 neurons in the hidden layer and 1 output. In this chapter, different ANN configurations including one and two hidden layers and varying number of neurons in the hidden layers were evaluated. The configurations were trained using the scaled

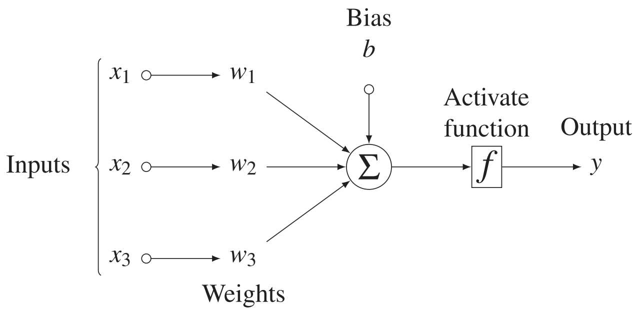


Figure 5.2 Model of a basic artificial neuron.

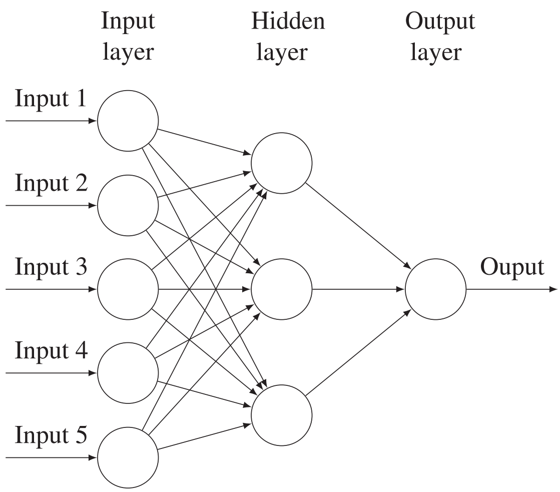


Figure 5.3 Diagram showing the topology of the multi-layered ANN.

conjugate gradient algorithm (Møller, 1993) with the number of epochs tuned to 250. In the end, the one-hidden-layer ANN with 40 neurons gave the highest accuracy for our input vector.

## 5.4 Results

As mentioned earlier, one of the primary goals of this dissertation is to achieve the best classification performance for the development of a social connectedness application within the safety critical ambient assisted living domain. To determine the classification accuracy, the prominent K-fold cross-validation (Ravi, Dandekar, Mysore & Littman, 2005) (with $k = 10$) technique was applied to each classifier. This approach to validation was preferred to the traditional holdout method as it reduced the variance of the resulting estimates. The data was randomized and partitioned into ten equal parts, where 90% was used for training and 10% for testing in the cross-validation process. Consequently, every data point was used in the test set only once. The overall average performance was then calculated.

The confusion matrices of the classifiers are shown in tables 5.3, 5.4, and 5.5, respectively. Rows of the confusion matrix represent the actual class while the columns represent the classifier output. The values in the confusion matrices are the number of instances in the test set. The last two columns of each table of the models show the classifiers' sensitivity and specificity scores for each class whilst the overall accuracies of the classifiers are provided at the bottom of the tables. Sensitivity, also known as true positive rate (TPR) or recall, defined by equation (5.11) estimates the probability of accurately identifying the class of a random data point.

$$TPR = \frac{True\, positives(T_p)}{T_p + False\, negatives(F_n)} \times 100 \tag{5.11}$$

On the other hand, the specificity or the true negative rate (TNR), defined by equation (5.12), estimates the probability that a random data point not belonging to a class will be so rightfully identified by the classifier.

$$TNR = \frac{True\, negatives(T_n)}{T_n + False\, positives(F_p)} \times 100 \tag{5.12}$$

Moreover, the overall accuracy (ACC) defined by equation (5.13) gives the fraction of data points correctly identified by the classifier.

$$ACC = \frac{T_p + T_n}{T_p + F_p + T_n + F_n} \times 100 \tag{5.13}$$

All classes predicted by the stand-alone SVM achieved over 95% true positive and true negative rates while achieving an overall accuracy of 97.6%. From table 5.3, it was observed that dynamic activities i.e., walking, ascending and descending of stairs were a few times misclassified. Also, stationary activities i.e., standing, sitting, and laying were occasionally indistinguishable by the SVM classifier .

The ANN classifier displayed the lowest detection accuracy among the classifiers with an overall accuracy of 91.4%. Like the SVM, walking, going up and downstairs, standing, and sitting were occasionally indistinguishable. However, the ANN classifier significantly displayed more misclassification when compared to the SVM. For example, the sensitivity

Table 5.3 Confusion matrix using the SVM model

| | WALK | UP | DOWN | SIT | STAND | LAY | TPR(%) | TNR(%) |
|---|---|---|---|---|---|---|---|---|
| WALK | 2703 | 11 | 20 | 0 | 0 | 0 | 98.9 | 99.7 |
| UP | 19 | 2353 | 18 | 3 | 3 | 6 | 98 | 99.7 |
| DOWN | 19 | 24 | 2289 | 0 | 2 | 2 | 98 | 99.7 |
| SIT | 1 | 0 | 0 | 2773 | 122 | 4 | 95.6 | 99 |
| STAND | 0 | 0 | 2 | 129 | 2804 | 0 | 95.5 | 99.0 |
| LAY | 0 | 5 | 0 | 0 | 0 | 2731 | 99.8 | 99.9 |

OVERALL ACCURACY 97.6%

Table 5.4 Confusion matrix using the ANN model

| | WALK | UP | DOWN | SIT | STAND | LAY | TPR(%) | TNR(%) |
|---|---|---|---|---|---|---|---|---|
| WALK | 2538 | 123 | 71 | 0 | 2 | 0 | 92.8 | 98.3 |
| UP | 111 | 2126 | 111 | 8 | 6 | 40 | 88.5 | 98.1 |
| DOWN | 108 | 104 | 2109 | 7 | 4 | 4 | 90.3 | 98.6 |
| SIT | 0 | 8 | 4 | 2540 | 304 | 44 | 87.6 | 97.7 |
| STAND | 3 | 5 | 7 | 281 | 2637 | 2 | 89.9 | 97.6 |
| LAY | 0 | 13 | 2 | 5 | 0 | 2716 | 99.3 | 99.3 |

OVERALL ACCURACY 91.4%

Table 5.5 Confusion matrix using the hybrid SVM-HMM model

| | WALK | UP | DOWN | SIT | STAND | LAY | TPR(%) | TNR(%) |
|---|---|---|---|---|---|---|---|---|
| WALK | 2722 | 0 | 12 | 0 | 0 | 0 | 99.6 | 100 |
| UP | 0 | 2399 | 3 | 0 | 0 | 0 | 99.8 | 100 |
| DOWN | 0 | 0 | 2326 | 10 | 0 | 3 | 99.6 | 99.9 |
| SIT | 0 | 0 | 0 | 2892 | 8 | 15 | 99.7 | 99.9 |
| STAND | 0 | 0 | 0 | 10 | 2925 | 0 | 99.7 | 99.9 |
| LAY | 0 | 0 | 0 | 0 | 0 | 2736 | 100 | 100 |

OVERALL ACCURACY 99.7%

(true positive rate) of sitting and standing were 87.6% and 89.9%, respectively for ANN and, 95.6% and 95.5%, respectively for SVM.

On the other hand, we noticed a very high overall accuracy of 99.7% for the SVM-HMM hybrid model outperforming the ANN and SVM models by 8.3% and 2.1%, respectively.

Notably, we observed improvements in predictions of all classes for the hybrid SVM-HMM classifier.

In sum, the hybrid SVM-HMM classification approach outperformed the other classifiers, showing an accuracy of 99.7%. Moreover, the performance of our SVM-HMM activity recognition model provides convincing evidence for its robustness and relevance in ambient assisted living environments.

## 5.5 Discussion

In this chapter, we evaluated and compared three approaches to activity recognition (i.e., SVM, ANN, and SVM-HMM) on real world data, *i. our own generated dataset* and *ii. a publicly available dataset*, using the smartphone's inertial sensors. This was done in an attempt to find the best classification accuracy for our bidirectional context-awareness system within an AAL context. Experimental results reveal the superiority of the hybrid SVM-HMM classifier for human activity recognition against the ANN and SVM classifiers within an AAL context. Moreover, we have demonstrated the successful use of the smartphone for sensing in AAL, which made the data collection process inexpensive and easy to set-up, and less obtrusive for our target users.

In total, we obtained the following recognition accuracies 91.4%, 97.6%, and 99.7% for the ANN, SVM, SVM-HMM, respectively. Albeit the SVM and ANN classifiers demonstrated good performance, the results show that SVM and ANN classifiers are less robust in dealing with the complexities and uncertainties of activity recognition data as stand alone classifiers. Through a combination of the time warping capabilities of the HMM and discriminative properties of the SVM, we obtained improved detection accuracies on all classes, demonstrating that the hybrid approach was better to overcome the HMM's weakness of discriminating between different classes.

Although smartphone based activity recognition offers great potential, it is not without limitations. For instance, within uncontrolled AAL environments, the smartphone's operational and functional challenges could impede large-scale adoption. Common challenges include limited battery life, memory capacity, and processing power, privacy concerns, and users deciding to turn off the device, or possibly forgetting to charge or carry the device as discussed by Choujaa and Dulay (2009); Eagle and Pentland (2006). Moreover, location sensitivity could be an issue as the smartphone's sensors are heavily dependent on the sensor's positioning and orientation on the participant's body as posited by Su, Tong and Ji (2014). In the future, this could be addressed with the use of the magnetometer as proposed by Ustev et al. (2013).

On the other hand, the problem of participant sensitivity, i.e., varying motion patterns among different people, makes recognition accuracy highly dependent on the participants used in the training and testing phases. By making our dataset publicly available, we contribute to the availability of diversified and reliable public mobile activity recognition datasets discussed by Choujaa and Dulay (2009) through the inclusion of people from different countries with different age groups between 22 and 79 years.

While there is room for improvement in the area of smartphone based human activity recognition, we believe the application of machine learning to activity recognition problems using smartphone sensors in AAL holds promise for data scientists, designers, and engineers to explore innovative solutions for the acquisition and presentation of activity data. To continue this work, we will exploit our proposed hybrid approach in a social connectedness setting with an AAL context in the remaining chapters of this dissertation.

## 5.6 Conclusion

This chapter describes a method for activity recognition to support context-awareness and social connectedness in assisted living scenarios. Building upon our prior work and the feedback from our participants, the proposed activity detection system could be deployed in AAL environments for distinguishing common ADLs and with its relatively high accuracy reduce false positives, a common concern in this domain. We highlight the smartphone's mobility, inexpensive cost, inbuilt sensors, and networking components as advantageous to enable activity recognition in AAL environments. Nonetheless, if battery restrictions are removed, smartphones are then a fortiori perfectly suitable for data acquisition in AAL.

As pointed out earlier, the activity recognition system presented in this chapter will be used as a basis to support data acquisition for the remaining empirical studies in this dissertation. However, prior to conducting the final study (cf. chapter 8), we must explore in further detail how light can be used to support activity awareness in addition to understanding the effects on cognition, moods, and behaviour. Building upon the users' perceptions and insights from chapter 3, in the succeeding chapter, we will conduct two exploratory studies to examine (i) how potential caregivers perceive and interpret ambient lighting configurations for presenting the elderly's activity information and (ii) the implications of activity awareness through lighting on cognitive performance, moods, and social connectedness. Thereafter, we will incorporate the current activity recognition model and ambient lighting in a real-time bidirectional activity-based system for supporting social connectedness as will be discussed in chapter 7.

# Chapter 6

# Investigating the Effects of Ambient Lighting Displays on Peripheral Activity Awareness

*"All our knowledge has its origins in our perception."*

—Leonardo da Vinci

As explained in chapter 2, by exploiting ambient intelligence and IOT technologies, ambient displays can convey activity information in the periphery of our attention. In particular, light has been used as a means to display ambient information, and there is scientific evidence that it can enhance well-being, interconnectedness, and improve productivity.

Now we have established a stable and reliable means for activity detection to propel our bidirectional peripheral display system in chapter 5. This chapter therefore focuses on expanding chapters 3 and 4, by exploring relevant ambient lighting properties to determine how they can be used to present activity information, influence moods, and cognition while evoking feelings of connectedness in AAL environments. In particular, this chapter outlines two exploratory studies that were conducted to investigate the features of light suitable for conveying subtle activity information within the periphery of the users' attention for promoting context-awareness. The second study assesses the cognitive and behavioural implications of activity awareness through lighting. Together, these studies provide additional design guidelines for representing activity information with ambient lighting and highlight potential benefits and usage possibilities for lighting displays within the AAL domain.

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This chapter is largely based on the following publications (Davis, Owusu, Marcenaro et al., 2016; Davis, Owusu, Marcenaro, Feijs et al., 2017).

## 6.1 Introduction

As we experience a new wave of AAL technologies, privacy and protection of personal information remain as considerable challenges of continuous surveillance tools (Emiliani & Stephanidis, 2005). Explicit renditions of human activities for instance, “walking”, “sleeping”, “cooking”, “toileting”, and “bathing” among others often result in privacy concerns regarding personal information. As previously examined in chapter 2, Pedersen and Sokoler (1997) were advocates for the abstraction of activity information, exploiting visual or auditory cues to enable peripheral awareness and ensure privacy protection. Inspired by the future possibilities of connected everyday devices, we envision a peripheral activity based awareness system that captures human activity information and renders this information using ambient light to enhance context-awareness and support social connectedness between the elderly and their caregivers.

Essentially, when designing ambient lighting displays the designer has to establish a context for decoding the information (Offenhuber & Seitinger, 2014). Primarily, in order to understand the information received, the viewer has to understand the significance of each lighting characteristic. In certain instances, users may understand intuitively or can be explicitly told about the significance of the encoding (Müller et al., 2012; Offenhuber & Seitinger, 2014). Occasionally, there are discrepancies between the designer’s intention of the encoding and the viewer’s interpretation of the encoding. In reality, what matters is what is understood by the viewer and not the designer’s intention (Offenhuber & Seitinger, 2014).

In this chapter, we will investigate ambient light in more detail to extend the proposal in chapters 1–4 to present activity information using subtle ambient displays to enhance context-awareness and support social connectedness between the elderly and their caregivers. Following this proposal, a smartphone activity recognition system was developed exploiting a hybrid Support Vector Machine and Hidden Markov Model (SVM-HMM) model, with an overall accuracy of 99.7% as unveiled in chapter 5, to classify six basic activity states namely, walking, walking upstairs, walking downstairs, standing, laying, and sitting. To provide abstraction and privacy protection, the explicitness of the basic activity states was reduced to activity levels (see chapter 4) i.e., “resting”, “passive”, and “active”. This abstraction of activity states into activity levels was contingent on user generated mappings where users mapped activity states to levels, based on their individual jobs and perspectives of which activity states they considered to be active, passive, or resting.

As mentioned earlier, this chapter will showcase two experiments to augment the work discussed in chapters 1–4. In the first study, we explore how ambient lighting parameters can be exploited to encode activity information. Here, we examine prospective caregiver’s preferences, perceptions, and interpretations of three ambient lighting configurations for conveying the activity information of older adults. By this, we provide consistent user-centered design guidelines for encoding activity information within an AAL context. In a second experiment, we assess the implicit and psychological effects of peripheral activity awareness through lighting on cognitive performance, moods, and social connectedness in short time periods guided by the design guidelines in the first experiment.

Our findings provide additional design guidelines for representing activity information with light and highlight potential benefits and usage possibilities for ambient lighting activity displays within AAL domains. Also, the results demonstrate a significant effect of peripheral activity awareness on cognitive performance in problem-solving tasks. However, there were no significant effects of peripheral activity awareness through lighting on implicit memory, moods, and social connectedness. Consequently, the implications of these findings for designing activity-based ambient lighting displays for AAL environments are also discussed.

In the upcoming sections, we provide an overview of the experiments conducted and describe our research goals. Subsequently, we discuss the process of evaluation and expound upon our findings. Finally, we make our concluding remarks and discuss the limitations and future work.

## 6.2 Exploring Activity-based Ambient Lighting Configurations and their Effects on Cognition and Moods

Revisiting the ambient lighting displays, i.e., the Lumitouch display (Chang et al., 2001), Casablanca Intentional Presence Lamp (IPL) (Hindus et al., 2001), and the SnowGlobe (Visser et al., 2011), which were deployed in an AAL context and reviewed in chapter 2. These studies encoded various types of information (e.g., presence and emotion) with or without physical activity information and as such, they lack a consistent framework for encoding activity information especially for AAL domains. To find more appropriate guidelines for encoding activity information to fit an AAL context, we designed two studies. Primarily, we focused on understanding how potential caregivers perceived and decoded lighting cues and examined their preferences for lighting parameters for encoding the elderly's physical activity information to provide context-awareness and elicit feelings of social connectedness. A review of published work and a user-centered approach were adopted to design three lighting configurations. Specifically, we illustrate the design and evaluation of three lighting configurations taking into consideration the following: (i) position of the light source, (ii) frequency of light changes, and (iii) lighting colour properties (hue and brightness).

Inspired by the work of Matviienko et al. (2015), we designed a study where participants had to identify light changes and state their preferences for the lighting configurations. Matviienko et al. designed a study where participants had to map lighting patterns to a set of scenarios. However, our study was centered around an AAL context with the goal of finding the best lighting parameters for encoding the elderly's activity information in order to provide context-awareness to the caregivers. Based on the aforementioned requirements we evaluated the following.

1. Noticeability and accuracy of interpretations of the lighting configurations. We assume that an ambient light that provides clear information and is perceivable at a glance would be less distracting and easily move from the foreground to the background of attention.

2. Subjective attributes such as usefulness, suitability, intuitiveness, etc. towards the system. We hypothesize that the higher the subjective positive attitudes toward the ambient lighting configuration, the more the likely it will be adopted.

3. The users' perceptions on future system adoption and their recommendations for lighting parameters to encode activity information.

As discussed in the related work, numerous experiments have shown that the properties of light can positively improve performance in cognitive tasks and improve moods. Moreover, Fitzsimons and Bargh (2003) posited that the psychological presence of relational contacts could trigger interpersonal goals, which are pursued unconsciously. On that account, we sought to understand the effects of the awareness factor (in this case, the elderly counterpart's activities) that brings about the change in the selected lighting configuration. In essence, the primary objective of study two was to investigate the effects of activity awareness through an activity-based ambient lighting display on cognition and moods. To support this evaluation, an intervention and a control condition were designed, whereby the awareness of activities was the only independent variable. The following assumptions were made.

- The implicit perception of activity states through ambient lighting can positively affect moods and improve cognitive performance in implicit memory and problem-solving tasks.

- Participants who are made aware that the lighting display renders their elderly loved one's activities would be more positively impacted than those who were not.

## 6.3 Study One

The purpose of study one was to understand how potential caregivers perceived and decoded lighting cues and examined their preferences for lighting parameters for encoding the elderly's physical activity information to provide context-awareness and elicit feelings of social connectedness. In this section, we describe the detailed procedures of our design and evaluation. In addition, the research outcomes are also discussed.

### 6.3.1 Participants

Fourteen (14) participants were recruited from the University of Genova to take part in the experiment, which lasted 50 minutes per participant. The demographics of the participants is summarized in table 6.1. The sample was predominantly male with only two female participants. Also, the sample was dominated by Italians (5 males and 1 female), followed by Pakistanis (3 males), with a few others including Tunisian, Colombian, Iranian, Indian, and Lebanese males.

Table 6.1 Table showing participants' descriptive data

| Characteristics | No. of Participants | Percentage (%) |
|---|---|---|
| Gender | | |
| Male | 12 | 85.7 |
| Female | 2 | 14.3 |
| Age | | |
| 18-24 | 3 | 21.4 |
| 25-34 | 9 | 64.3 |
| 35-44 | 2 | 14.3 |
| Marital Status | | |
| Single | 9 | 64.3 |
| Married | 5 | 35.7 |
| Nationality | | |
| Italy | 6 | 42.9 |
| Pakistan | 3 | 21.4 |
| Colombia | 1 | 7.14 |
| India | 1 | 7.14 |
| Iran | 1 | 7.14 |
| Tunisia | 1 | 7.14 |
| Lebanon | 1 | 7.14 |
| Occupation | | |
| Employed | 4 | 28.6 |
| Unemployed | 8 | 57.1 |
| Unknown | 2 | 14.3 |

All participants had normal or corrected-to-normal visual acuity and were tested for colour vision deficits using the Ishihara colour blindness test (Ishihara, 1972). Participants were informed of the required procedure and signed their consent form.

### 6.3.2 Design

The primary goal of this experiment was to empirically assess the users' perspectives regarding the use of lighting parameters to convey activity information of an elderly person to a caregiver in order to support context-awareness and promote social connectedness. Accordingly, the lighting parameters deployed must be perceived at a glance, non-distracting, and aesthetically pleasing in order to evoke a subtle sense of presence. Based on existing literature and a cognitive walk-through with six prospective users to inspect their interpretations of lighting parameters (position, rate of change, and colour properties) on encoded activity information, we had four main findings, which are listed below.

1. Ambient light must be perceived at a glance, easily controlled (e.g., turned on or off, adjust the brightness levels etc.), and should be positioned within the field of view of the users. As mentioned in chapter 3, lighting applications should be easily incorporated in users' everyday routines. One recommendation of a light source that would readily fit this criterion, was a desk lamp.

2. A pulsing light might be too distracting and fails to inconspicuously convey activity information.

3. The most obvious properties of light (hue and brightness) should be varied smoothly to subtly convey activity information.

4. Red was most favoured to represent a high activity level, green for an intermediate level, and blue for resting. Moreover, as indicated in chapter 4, red was useful for showing high activity levels while simultaneously evoking an invigorating sense of presence, while blue was convenient for showing periods of low activity levels with a lesser degree of remote presence. These findings helped to set the stage for the design choice on the colour scheme.

As discussed earlier, a user can at any point in time be in one of three activity levels: active, passive or resting. Each activity level can be represented by one distinct lighting colour property. Also, the amount of time a user stays in an activity level is another dimension that can be overtly relayed (represented by lighting colour property) or covertly relayed


Figure 6.1 Lighting configuration COL_BRI.

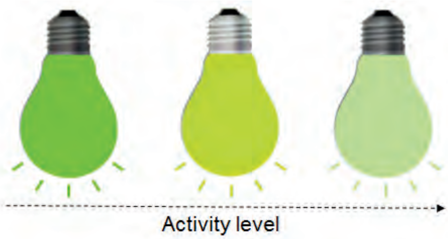


Figure 6.2 Lighting configuration BRI_ONLY.

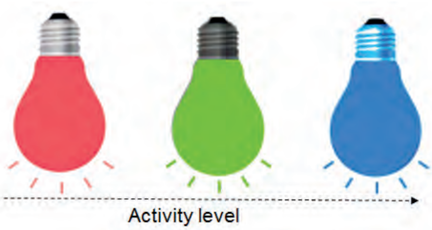


Figure 6.3 Lighting configuration COL_ONLY.

(intuitively discerned by users). Based on these findings, three lighting configurations (COL_BRI, BRI_ONLY, and COL_ONLY) were designed.

Configuration COL_BRI can convey the activity level and also the temporal duration of stay in a particular level. Figure 6.1, shows configuration COL_BRI, where red, green, and blue lights represent active, passive, and resting levels, respectively while changes in light intensity depict how long a person has stayed in a specific activity level. From chapter 5, our human activity detection model can detect a user's activity level every 1.28 seconds. Consequently, the minimum amount of time for the ambient lighting colour change is 1.28 seconds. For this experiment, the brightness for an activity level was initially set to 33.3%, while activity levels lasting for more than 10 seconds and 20 seconds were set to 66.6% and 100%, respectively.

Inspired by the Pediluma (B. Y. Lim et al., 2011), configuration BRI_ONLY exploited changes in brightness of a single default green colour to convey the change in physical activity levels. Temporal duration of activity levels was not overtly conveyed. Configuration BRI_ONLY is depicted in figure 6.2.

To convey changes in activity levels, configuration COL_ONLY employed changes in lighting colour in the same manner as configuration COL_BRI. Like configuration BRI_ONLY, the temporal duration of activity levels was not overtly represented. Figure 6.3, demonstrates lighting configuration COL_ONLY.

### 6.3.3 Experiment Set-up

The experiment was carried out in a room, located at the University of Genova, with dimensions of 10.4 x 4.3 meters. The walls and ceiling were off-white and the floor consisted of marble tiles. The ambient light source was a desk lamp exploiting the Philips Hue, a connected lighting system that enables lighting colour properties to be controlled over a network. The Philips Hue is furnished with a network bridge for connecting to the internet and provides an API for building custom applications to control the light over a network[1]. The system was operated 15 minutes before the experiment to stabilize the illumination level and also the internet connection. A hand held tally counter was used by participants to monitor the changes in lighting colour. The experiment was divided into two phases using a repeated measures design methodology (Gergle & Tan, 2014). Figure 6.4, illustrates an example of a participant performing the experiment.

[1] https://www.developers.meethue.com/documentation/how-hue-works

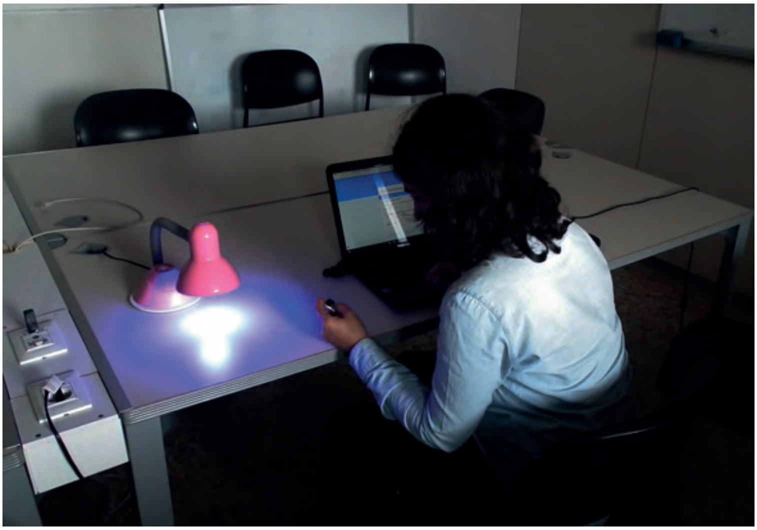

Figure 6.4 An example of a participant performing experiment.

### 6.3.4 Procedure

Phase one investigated how quickly participants processed the ambient information at a glance and examined the accuracy of recognition of the lighting changes. Notably, in this phase, participants were told that activity information was encoded through different lighting patterns without specifying the details of the mappings. A set of five practice trials were deployed to allow participants to familiarize themselves with the protocol and to clarify their misconceptions. Subsequently, they were given a total of three block trials with a randomized presentation of lighting configurations COL_BRI, BRI_ONLY, and COL_ONLY with each block comprising of ten trials. The unified length of each trial was 30 seconds with each activity lasting a minimum of 1.28 seconds (i.e., the minimum detectable activity duration of the hybrid SVM-HMM HAR model). Participants were instructed to click the counter each time they noticed a change in light. Following the display of each lighting pattern, the participant had 30 seconds to respond to the questions concerning each trial. With respect to the accuracy of change noticeability, participants were to refer to the counter and respond how many times they noticed changes in the light. The total change count was the final number seen on the hand-held tally counter. Participants then selected the correct description of the presented configuration from a list of options. Additionally, participants were asked to report the summation of the number of distinct lighting configurations observed and describe their interpretations of what each configuration tried to convey.

In phase two, the significance of the lighting parameters and their mappings to activity levels (passive, active, and resting) for each lighting configuration was explained. Subsequently, an activities of daily living (ADL) scenario of an elderly person was described to each participant, then he or she viewed the simulated activity information for lighting configurations COL_BRI, BRI_ONLY, and COL_ONLY in a randomized order. After viewing each lighting configuration, participants performed a heuristic evaluation in terms of ten desirable features (usefulness, suitable abstraction, suitability, interest, perceptibility and distinctiveness, noticeability, intuitiveness, learning ease, distraction, and aesthetics). Finally, participants ranked the lighting configurations from most to least preferred and provided their qualitative feedback.

### 6.3.5 Quantitative Results

Regarding the lighting colour property, change noticeability and accuracy of interpretations, the root mean squared errors (RMSE) of the reported change counts and interpretations were calculated per participant for each configuration. Overall, three RMSE's per participant were obtained per configuration. Figure 6.5, displays a box plot of the errors.

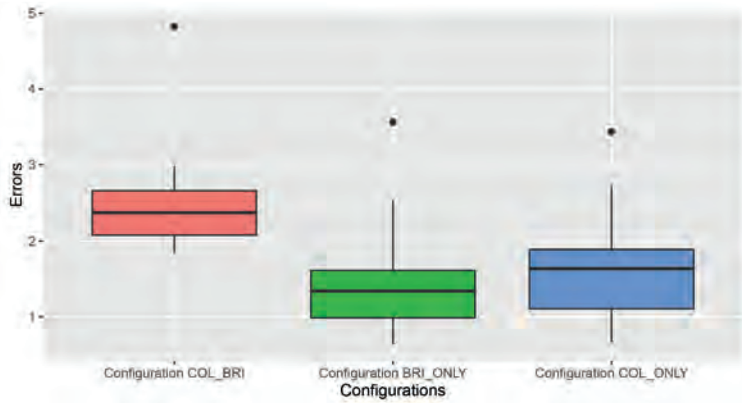


Figure 6.5 Boxplot of RMSEs of noticed changes and accuracy of interpretations.

A one-way Analysis of Variance (ANOVA) with repeated measures of the RMSEs was calculated using the R Project for Statistical Computing, where $F(2,26) = 11.91$ and $p = 0.000212$. This revealed a statistically significant reported mean error difference ($p < 0.05$) among the three configurations. A Tukey post-hoc (HSD) test was conducted to determine, which reported errors differed. Reported errors differed significantly between configurations COL_BRI and BRI_ONLY ($p = 0.002$) and between COL_BRI and COL_ONLY ($p = 0.01$).

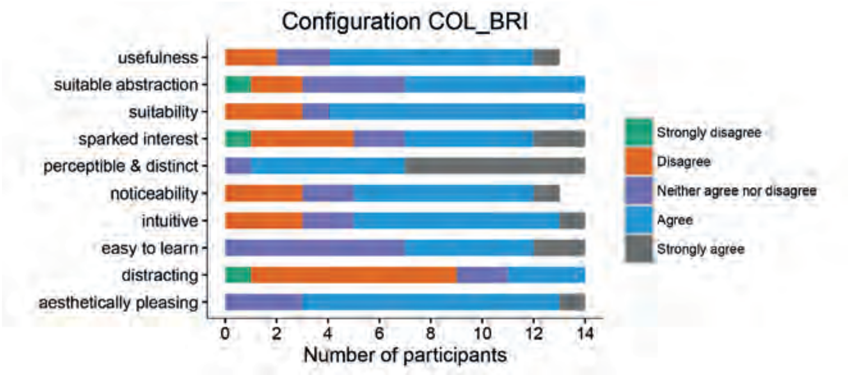


Figure 6.6 Heuristic evaluation of configuration COL_BRI.

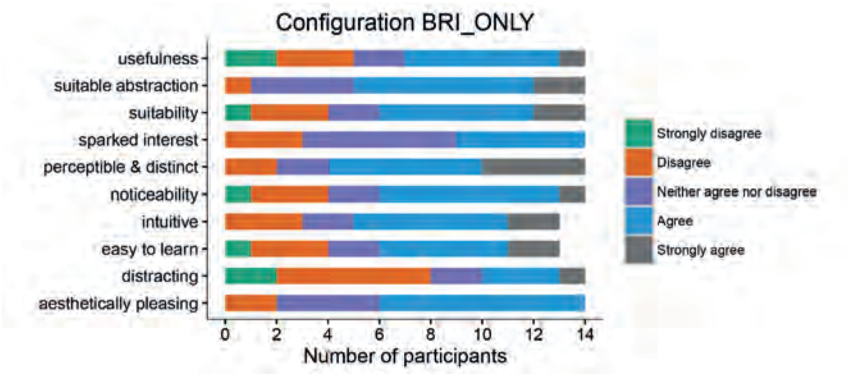


Figure 6.7 Heuristic evaluation of configuration BRI_ONLY.

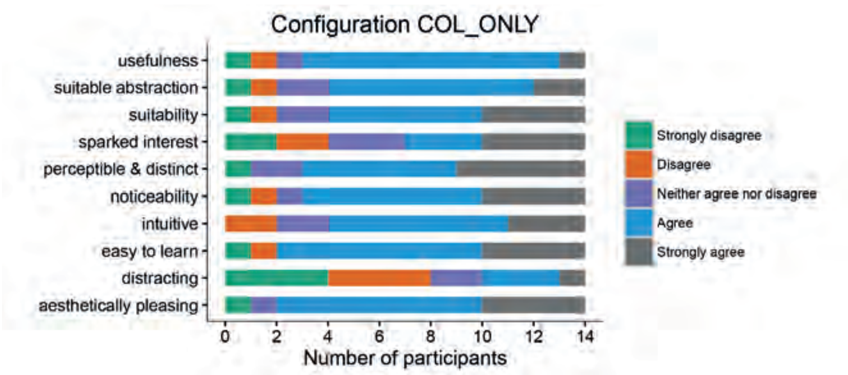


Figure 6.8 Heuristic evaluation of configuration COL_ONLY.

However, there was no significant difference in reported errors between configurations BRI_ONLY and COL_ONLY ($p = 0.78$). This suggests that configuration COL_BRI was more susceptible to misinterpretations compared to configurations BRI_ONLY and COL_ONLY.

With reference to the heuristic evaluation of the configurations, in terms of desirable features, the sum of positive and negative perceived attributes were computed for each configuration. For a desired attribute, "strongly agree" carried weight of 2, "agree" = 1, "neither agree nor agree" = 0, "disagree" = -1 and "strongly disagree" = -2 and the opposite for a non-desirable attribute. User responses are presented in figures 6.6, 6.7, and 6.8.

The configurations received a sum of 82, 56, and 105 for COL_BRI, BRI_ONLY, and COL_ONLY, respectively. A one-way ANOVA with repeated measures revealed a statistically significant difference in the mean of perceived positive attributes with $F(2,18) = 8.456$ and $p = 0.0256$. A Tukey post-hoc (HSD) test revealed a statistically significant difference between only configuration COL_ONLY and BRI_ONLY ($p = 0.022$). This shows that participants had more positive attitudes toward configuration COL_ONLY compared to BRI_ONLY.

Finally, figure 6.9 shows the ranking of preferences of the configurations with a rank of 3 being the most preferred and 1 being the least preferred. A one-way ANOVA with repeated

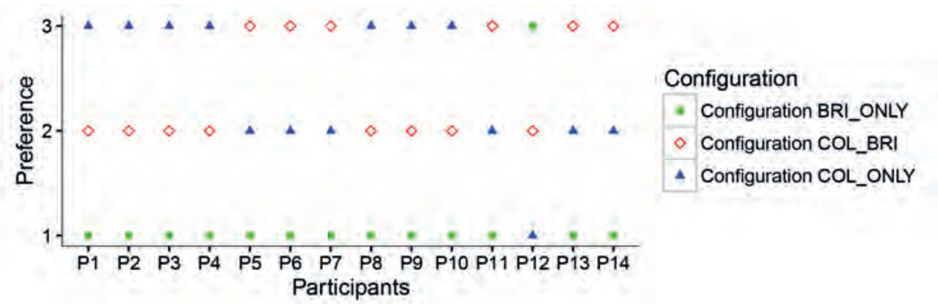


Figure 6.9 Scatter plot of user preference rank.

measures of the ranking revealed a statistically significant difference ($F(2,26) = 15.95$ and $p = 3.01e-05$) between user preferences of the configurations. A Tukey post-hoc (HSD) test showed that participants preferred configuration COL_ONLY to configuration BRI_ONLY ($p = 1.6e-06$) and configuration COL_BRI to BRI_ONLY ($p = 1.6e-06$). The preference difference between configurations COL_BRI and COL_ONLY was not statistically significant.

### 6.3.6 Qualitative Analysis

The qualitative results suggest the overarching themes that emerged following a semi-structured interview with our participants. Fifty-six statement cards were reviewed independently by two coders using a thematic analysis (Braun & Clarke, 2006) approach. The main themes and sub-themes identified are now discussed.

**Positive Perceptions of the Designs**

Participants were generally accepting of the intuitive, convenient, informative, effortless, distinctive, and simplistic nature of configuration COL_ONLY i.e., three colours at the same intensity. For example, one participant articulated,

*"I like configuration COL_ONLY because one can easily distinguish the variation in activities."* – P8

Moreover, some participants were vastly impressed by the dynamics and variety of feedback presented by configuration COL_BRI i.e., three colours with three intensity levels. For instance, one participant mentioned,

*"I prefer configuration COL_BRI because it demonstrates changes in intensities and colour, which provides more information about the state or time in an activity."* – P5

On the other hand, one person specified that configuration BRI_ONLY (one colour changing its brightness on three levels), was intuitive and discriminative in the following statement.

*"I like configuration BRI_ONLY because it shows different levels of activity, distinct levels of luminance and it is intuitive."* – P12

**Negative Perceptions of the Designs**

The participant majority alleged that configurations COL_BRI and BRI_ONLY were overwhelmingly difficult to learn and portrayed inexplicit and confusing feedback e.g., one participant described his experience as follows,

*"I was unable to memorize the meanings of colours and intensities with configurations COL_BRI and BRI_ONLY. Overall they were strange."* – P9

However, participants were most displeased with configuration BRI_ONLY as they highlighted its complexity and generally conceded that it was meaningless and inadequate for an AAL setting. An example statement is given below.

*"Configuration BRI_ONLY is not meaningful it doesn't give me information about activity changes with colours."* – P5

In addition, participants generally articulated that important notifications could be easily missed with configuration BRI_ONLY. For example, one participant mentioned the following.

*"With one colour and three intensity levels, it is more difficult to notice the changes in intensity. Also, when both colour and intensity changed in configuration COL_BRI, it was confusing."* – P8

**Reasons For and Against Adoption**

A large majority of participants recognized the potential of ambient lighting displays for enhancing context-awareness and social interaction, and also providing social support. While a few participants emphasized the therapeutic benefits of ambient displays and their ability to stimulate reflection, one participant pointed out the need for affordable LED solutions in AAL environments. These themes are reflected in the statements below.

*"My father has Parkinson's disease for* 5 *years now and my mother would greatly benefit from such a system to provide better care for him."* – P9

P14 mentioned, *"With this installation I would think about my loved-one the whole day and the colours would add therapy to my life."*

*"I am not sure because from my understanding Philips hue LEDs are extremely expensive and may not be viable for the regular consumer."* – P2

However, some participants expressed uncertainty as they considered the privacy implications of such displays and demonstrated a lack of trust in the system. Moreover, one participant highlighted that context-aware systems can be bad in excess in the following statement.

*"I am not sure because I don't want to be 100% involved in my mother's activities. It is interesting but also invasive. It is a matter of virtual reality in the sense that you don't have the person but you have to trust a device that senses and processes the information. It is bad in excess. If you are able to manage it then it can be good. But if not managed it can replace the person [...]"* – P5

### 6.3.7 Discussion

This exploratory study aimed to assess three different lighting configurations to derive the best lighting parameters for encoding activity information in an AAL context. Confirming our expectations, more errors were experienced with configuration COL_BRI (three colours and three intensity levels), when compared to configurations BRI_ONLY and COL_ONLY. Our participants confirmed in their reflection, that configuration COL_BRI had too many changes i.e., both in hue and brightness, and consequently, misidentification was a common occurrence with this configuration. Based on our observation of the participants, changes in brightness were often misclassified as changes in colour.

There was no statistical significance for change noticeability for configurations BRI_ONLY and COL_ONLY. Notably, participants in their qualitative assessment mentioned that configuration BRI_ONLY (one colour changing its brightness on three levels), was too subtle and confusing.

Moreover, with configuration BRI_ONLY, some participants mentioned that they were more engaged in thinking only about one type of activity, while configuration COL_ONLY made them think about changes in activities while intuitively discerning the concept of time. We hypothesize that configuration COL_ONLY (3 colours at the same intensity) had fewer errors due to its easily distinguishable properties such as lighting colour with constant brightness. Overall, the results suggest that a higher cognitive load was experienced with configuration COL_BRI.

In retrospect, participants generally preferred configuration COL_ONLY for encoding activity information. By configuring the lights to show red for active, green for passive and blue for resting, participants generally indicated that the intuitive meaning of these colours were effortlessly mapped to activity levels.

With respect to suitability, participants articulated that lighting configuration COL_ONLY, had specific lighting properties, which made it particularly suitable for encoding activity information. These include, it provided a suitable abstraction of personal information and a clear mapping of activity information, its aesthetic quality, noticeability, intuitiveness, minimum distraction, and ease of learning.

### Design Guidelines

Building on the previous research on ambient displays, the recommendations and experiment results, we now present nine design guidelines for the encoding of activity information for an AAL context.

1. Devise clear mappings for representing activity information with coloured lighting (Matviienko et al., 2015). Brightness might not be appropriate as it often becomes confusing. However, if brightness is used, sudden changes in intensity should be avoided.

2. Abstraction is necessary to ensure the privacy of personal information (Pedersen & Sokoler, 1997).

3. The lighting source should be aesthetically pleasing and should be smoothly integrated into the user's environment (Occhialini, van Essen & Eggen, 2011).

4. Lighting changes should be intuitive (Mankoff et al., 2003) and match the user's mental model of the other person's activities as is evident from the results in chapter 4. Moreover, the lighting parameters used should create a dynamic understanding of the changes in the other person's environment.

5. Designers should not overwhelm its users with too many changes of lighting parameters.

6. When choosing the colour, the effects of colour on emotions should be considered. Red is suitable for high periods of activity, green for periods of relaxation, and blue for resting periods. However, this can be based on personal taste, situational context, and cultural diversity. The use of one colour with varying intensities to represent different activity levels might not be acceptable as changes could be frequently indistinguishable.

7. Designers should consider the temporal nature of activity information and as such, the duration of activities should be intuitively perceived by viewers. Moreover, it might be prudent to exploit light's parameters to show the history of an elder's activities in time.

8. Activity-based ambient lighting displays should provide therapeutic benefits, which is dependent on colour choice and can be used to encourage reflection, which is useful for enhancing social connectivity in AAL domains.

9. Activity-based ambient lighting displays should augment social interaction, however, it should not replace human-to-human communication.

## 6.4 Study Two

Study two investigates the effects of activity awareness through an activity-based ambient lighting display on cognition and moods, and examines the users' willingness to adopt the ambient device. To achieve this, an intervention and a control condition with activity awareness as the only independent variable was necessary to isolate the effects of light alone from the effects of activity awareness through light. Recall that study one examined three activity-based lighting configurations, of which configuration COL_ONLY i.e., three colours at the same intensity was most preferred. Thus, in study two, configuration COL_ONLY was deployed to assess the effect of activity awareness through ambient lighting on cognition, moods, social connectedness, and the users' willingness to adopt the new technology.

### 6.4.1 Methodology

#### Participants and Stimuli

Forty-two students of an Introduction to Programming Course at the University of Genova participated in this study and received course credits in return. The major demographic characteristics of the participants are displayed in table 6.2. Participants were mostly between 18 – 24 years and were primarily male Italians.

Table 6.2 Table showing participants' descriptive data

| Characteristics | No. of Participants | Percentage (%) |
|---|---|---|
| Gender | | |
| Male | 34 | 81 |
| Female | 8 | 19 |
| Age | | |
| 18-24 | 38 | 90.5 |
| 25-34 | 4 | 9.5 |
| Marital Status | | |
| Single | 42 | 100 |
| Married | −− | −− |
| Nationality | | |
| Italy | 41 | 97.6 |
| Ecuador | 1 | 2.4 |
| Occupation | | |
| Student | 42 | 100 |

All subjects were tested individually and had normal or corrected-to-normal vision investigated with the Ishihara colour blindness test (Ishihara, 1972). Prior to their participation in the study, each participant gave their written informed consent. In addition, they described their favourite elderly relative's hobbies and activities of daily living before the experiment. The participant majority revealed their elderly relatives were generally doing various activities around the home. For instance, Italian grandmothers (nonne) were typically engaged in cooking, gardening, watching television, and reading while Italian grandfathers (nonni) were normally playing cards, taking casual walks, watching television, and repairing items. There were a few grandparents who were in most cases resting due to ill-health. Subsequently, this information was used to design different simulations tailored to suit the participants' elderly relative's basal activities of daily living, which later served as inputs to our activity-based light display, exploiting a Wizard of Oz (J. F. Kelley, 1983) design approach.

#### Experimental Design and Independent Variables

We employed a between-subjects experimental design methodology, where each participant was randomly assigned to one of two groups i.e., (test-aware and test-unaware). The test-aware participants were informed that the activity-based ambient lighting display rendered their elderly relative's activity levels in three categories, active (red), passive (green), and resting (blue) while the members of the other group were told that we were experimenting with various combinations of coloured light (red, green, and blue) – test-unaware. The experiment was conducted in Italian.

Fitzsimons and Bargh (2003) confirmed that priming the names of one's parent can non-consciously activate the motivation to achieve academic success. Thus, to stimulate more favourable goal-directed behaviour among participants, they were asked before the experiment to rank using a scale of 1 – 5 how well their closest elderly relative wanted them to succeed in school. However, only the test-aware participants were primed for 60 milliseconds (Holcomb & Grainger, 2007), prior to the cognitive tasks. This was done in an effort to solicit the effect of awareness factor (the elderly counterpart) on the non-conscious activation of interpersonal goals.

In total, the experiment lasted for approximately sixty-minutes and participants were debriefed at the end of the entire experimental period.

### Dependent Variables

Largely motivated by the non-visual effects of light demonstrated by Knez (1995), the study included memory and problem-solving cognitive tasks as well as mood, relationship closeness, and light evaluation measures.

- *Moods* – A pre- and post-test measure of self-reported moods was conducted using the self-assessment manikin (SAM) (Bradley & Lang, 1994) scale. The SAM is a nine-point non-verbal pictorial measure, based on Russel's dimensional circumplex model of emotion (J. A. Russell, 1980), evaluating the subjective levels of valence (unpleasant-pleasant), arousal (activation-deactivation), and dominance (having a strong sense of control) in a participant's response to the stimulus. This lasted for approximately five minutes in sum. Furthermore, we attempted to measure involuntary responses such as electrodermal activity otherwise known as galvanic skin response (GSR), a sympathetic indicator of arousal (Picard & Picard, 1997) and electrocardiogram (ECG), which is used to calculate heart rate variability, an additional measure of emotions (Kreibig, 2010) using Shimmer sensing[2] devices. However, participants avidly expressed discomfort alluding to an invasion of personal privacy and obtrusiveness. This was common among all female participants. Accordingly, we discontinued use of the physiological instruments in this experiment.

[2]`http://www.shimmersensing.com/`

- *Social Connectedness* – In the beginning of the experiment and after 55 minutes of using the ambient light, participants ranked their subjective perception of interpersonal closeness (a measure of social connectedness) with their elderly relative using the inclusion of other in the self (IOS) (Aron et al., 1992) scale. Overall, this task was approximately five minutes long.

- *Implicit memory* – this is a form of long-term memory, whereby an individual's behaviour is changed by prior experience, which is acquired without conscious recollection (Mulligan, 1997). A word-stem completion task is a common measure of implicit memory (Mulligan, 1997). In this study, an implicit memory task (Bowers & Schacter, 1990), investigated the memory effects of studying a list comprised of 31 simple Italian nouns (Bates, Burani, D'Amico & Barca, 2001), each word comprising four to nine letters. As a manipulation tactic, participants were given 5 seconds to rate the pleasantness of each of the 31 words. For a filler task, they were given a stem completion test to complete the names of 18 major cities. Thereafter, they were asked to complete a stem completion task, which included 12 target words among 63 distractors.

- *Problem-Solving* – Inspired by the work by Knez (1995), participants completed an embedded figures assignment (Smith & Broadbent, 1980), in which they were instructed to note five solution figures positioned at the top of the page and later identify the target answers among sixteen more complex figures. Participants were given a total of twenty minutes to complete this task and their responses were scored on a scale from zero to five points.

- *Ambient lighting evaluation measure* – Following the completion of the cognitive tasks and mood measure, participants gave their perceived estimation of the lighting characteristics (e.g., adoption, aesthetically pleasing, attention-demanding etc. see figures 6.11 and 6.12) using a seven-point Likert scale along with their qualitative input. In addition, they assessed the implications of the lighting colour on productivity, concentration, and relaxation. Notably, the activity-awareness questionnaire, included four questions that probed the participant's awareness of their elderly relatives activities and its influence on problem-solving, concentration, and relaxation. Moreover, the test-aware group was cross-examined with additional questions regarding adoption such as, ("Do you prefer to receive information about the activities of elderly relatives through a voice message, a text message, or in the form of different colours of the light?"). Overall, this task was on average twenty minutes long.

**Physical Setting**

The setting was identical to that of study one. However, to avoid the glare from the computer screen all tasks were entirely paper-based as demonstrated in the set-up in figure 6.10. Also,

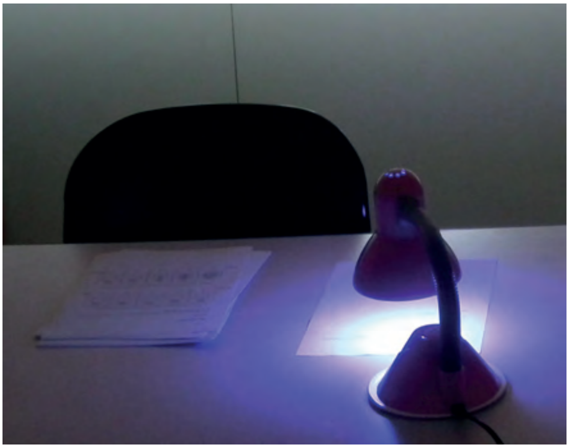

Figure 6.10 Experimental set-up for study two.

window blinds were closed to prevent the influence of day-light.

### 6.4.2 Quantitative Findings

To assess the effects of activity awareness on relationship closeness, problem-solving, implicit memory, and moods (valence, arousal, and dominance), we computed a one-way ANOVA of these measures between test-aware and test-unaware groups. We found no significant effects of activity awareness on relationship closeness, implicit memory, and moods. In the case of this experiment, the participant majority had solid relationships with their elderly relatives and therefore, it was difficult to assess changes in social connectedness over short time intervals. Also, a few participants expressed perceptions of fatigue prior to the implicit memory task, which could have possibly influenced the results.

On the other hand, the findings suggest a significant effect of activity awareness on problem-solving with $F(1,40) = 4.57$ and $p = 0.0387$. For a degree of freedom of 1 and a residual of 40, the $F$ distribution requires an upper critical value of 4.085 to reject the null hypothesis (Natrella, 2010). Moreover, using the $\eta^2$ (Eta squared) measure yielded an effect size of 0.103, which is reasonably large according to the recommendations for the magnitude of effect sizes by J. Miles and Shevlin (2001).

A multivariate analysis of variance (MANOVA) was performed to find a significant mean variance in perceived subjective attributes between the test-aware and test-unaware groups. The results demonstrated no statistical significance and yielded a p-value of 0.3987. Figures 6.11 and 6.12 illustrate the mean ratings of perceived subjective attributes of the lighting configuration for the two groups.

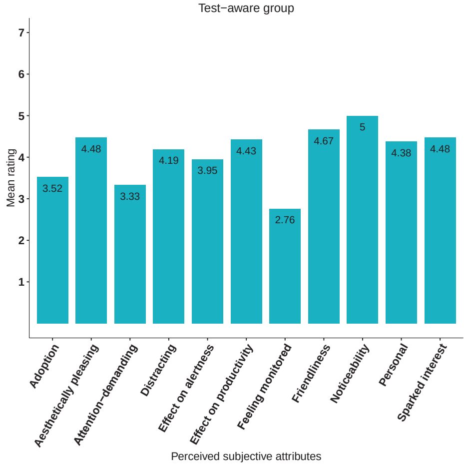


Figure 6.11 Experimental results showing the test-aware participants' perceived estimations of the lighting characteristics.

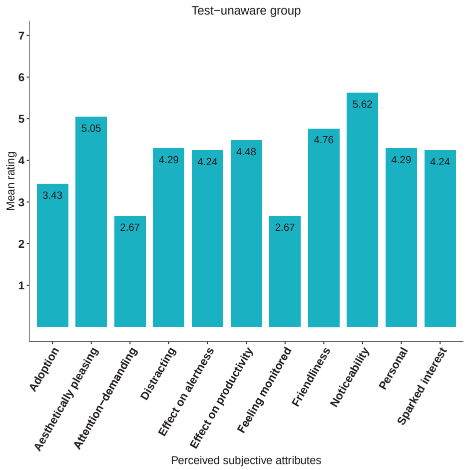


Figure 6.12 Experimental results showing the test-unaware participants' perceived estimations of the lighting characteristics.

Notwithstanding the lack of a statistically significant difference, participants in both groups generally held positive attitudes toward the ambient lighting display, with more favourable attitudes on aesthetics, noticeability, and friendliness of the installation. Regarding attention, the test-aware group of participants seemed to have utilized more attentional resources than the test-unaware group, which could be attributed to the more meaningful representation of activity information of their loved-ones and as such, prompted them to try to understand their ADL patterns. A similar trend was also observed in chapter 4, where caregiver participants were actively engaged in deciphering the activities of their elderly counterpart. This implies that activity-based lighting displays may directly or indirectly influence users to divert their attention from their primary tasks. In the next section, we discuss our qualitative findings.

### 6.4.3 Qualitative Analysis

Three hundred and ninety nine responses to a semi-structured post experiment interview were translated with the assistance of a native Italian and an upper intermediate Italian speaker. Subsequently, the statements were reviewed independently by two coders using the thematic analysis (Braun & Clarke, 2006) methodology. Overlapping concepts were then clustered to identify broad themes and categories that may play a vital role in assessing the lighting design dimensions and implications of activity awareness through ambient light on cognition, moods and perceived usefulness in AAL environments. These underlying themes and sub-themes were identified throughout the study.

#### Visible Light Patterns

All participants recognized to some degree the changes in the light patterns. The participant majority identified lighting features including the following:

- colour variation,
- colour temperature,
- rate of change,
- reflection properties, and
- brightness.

These features are encapsulated within the following statements.

*"I observed the colour of the light reflecting on the sheet. Warm light was more distinctive."* – P23 (test-aware)

*"The light changes colour, often gradually moving from shades of green to yellow to red and blue."* – P29 (test-aware)

Notably, it was observed that 24% of the participants misclassified green as yellow. Perhaps, this can be attributed to the after image effect (Shimojo, Kamitani & Nishida, 2001), where exposure to blue light produced a yellow aftermath.

**Positive Perceptions of the Design**

Participants generally displayed positive attitudes and perceptions toward the system. In particular, most interviewees reported on the ambient light's effective usability features including the following:

- aesthetic appeal,
- friendly atmosphere,
- smooth transition,
- degree of reflection,
- non-distracting, automatic, innovative, intriguing, and fun nature, and
- positive influences on vision, productivity, and psychological processes.

These example statements describe aspects of the above mentioned sub-themes.

*"The change in colours were beautiful and I guess it would be fun to have a lamp like this."* – P1 (test-unaware)

*"The changes of the light favours concentration, without being distracting as it has a smooth transition between rapid changes of the light."* – P31 (test-aware)

*"Green and blue are light colours that enhance reading and therefore it is easy to keep writing, red tones, however, are nice and friendly [...]"* – P29 (test-aware)

A few participants explicitly reported that the light seemingly had a helpful effect on problem-solving strategies. For instance, one person mentioned the following.

*"It somehow felt that the light was highlighting moments of difficulty and some moments of ease as it relates to the problem-solving tasks. It appeared as though it was helping me to find the words."* – P24 (test-aware)

### Negative Perceptions of the Design

Features such as (i) lighting position, (ii) over-illumination, and (iii) annoyance or distraction effects of warm colour temperatures (red), were reported. For example, one participant alluded to discomfort in the following claim.

*"The red light had a high intensity. Therefore, it made me a little uncomfortable while reading."* – P29 (test-aware)

Also, the lighting source, position, and reduced scattered intensities were also negatively perceived by a few participants. This is reflected in the following statement.

*"The lamp is very short, therefore the light was not well diffused."* – P11 (test-unaware)

On the other hand, one person expressed interest in being able to customize the lighting colours. This implies that the position and intensity of the lights cannot be generalized but is subject to users' preferences.

### Coloured Light on Productivity, Concentration, and Moods

The main concepts identified and the percentage of all participants responses are depicted in table 6.3.

Table 6.3 Table showing the main concepts identified from the participants' responses

| Concept | Percentage of Participants (%) |
|---|---|
| Coloured light on boosting productivity | |
| boost productivity | 24 |
| helpful influence | 7 |
| not influenced | 26 |
| distraction | 29 |
| agitation | 7 |
| time pressure | 7 |
| Coloured light on boosting concentration | |
| green | 38 |
| red | 26 |
| blue | 24 |
| not influenced | 12 |
| Coloured light on stimulating relaxation | |
| blue | 57 |
| green | 31 |
| red | 10 |
| not influenced | 2 |

Some participants noted positive effects of the ambient light on productivity alluding to sensations of major concentration and relaxation, with a handful emphasizing the light's helpful influence on cognitive tasks. However, certain participants recounted that they were not influenced by the light during the problem-solving task. On the other hand, quite a few disclosed that they were distracted mainly by the red light while some reported agitation primarily because of the red light and minimally due to the green light. A small number of participants, observed the light's influence on time pressure while performing cognitive tasks. Example recollections of the implications on problem-solving are illustrated below.

*"I was pleasantly influenced by the change from red to blue, at moments when I could not remember the words, it aided my memory."* – P22 (test-aware)

*"Sometimes the tones of the light made me relaxed and sometimes it made me concentrate more, other times I was distracted when it was too strong."* – P6 (test-unaware)

*"The red agitated me and made me feel the pressure of time."* – P35 (test-aware)

*"The light did not influence me in any way, I saw the changes every now and then but I was focused on what I was doing."* – P25 (test-aware)

In both experimental groups, the participants generally made reference to the influence of the lighting colours on concentration and moods. Specifically, a large number of participants asserted that green light was most effective for boosting concentration, while some of the interviewees emphasized that red light stimulated concentration. However, certain participants said blue light had high concentration effects while a scant amount reported no effects on concentration.

With respect to the positive influences of lighting colour on relaxation, more than half of the participants emphasized that blue light activated feelings of relaxation while performing cognitive tasks, while a considerable amount reported that they were generally relaxed with the green light. However, a few reported positive influences of the red light on relaxation while hardly any of the participants reported no influence at all.

In retrospect, more informative remarks were encountered in the test-aware group's assertions of the effect of activity awareness through coloured lighting on cognition, productivity, and moods. We will discuss these insights in the next subsection.

#### Activity Awareness through lighting on Productivity, Concentration, and Moods

The major concepts identified and the percentage of all participants responses are portrayed in table 6.4. A large majority of the test-aware group participants said that they were most productive in the passive activity level (radiates green light) while several inferred that their productivity level increased in the active activity level (emanates red light). On the other hand, the remaining few articulated that the resting activity level (displays blue light) was beneficial for boosting productivity.

Revisiting the notion of activity awareness on productivity, a few of the test-aware participants alluded to possible non-conscious motivational influences of activity awareness

Table 6.4 Table showing the main concepts identified from the test-aware participants' responses

| Concept | Percentage of Participants (%) |
|---|---|
| Activity light on boosting productivity | |
| passive | 43 |
| active | 33 |
| resting | 24 |
| Activity light on boosting concentration | |
| active | 43 |
| passive | 38 |
| resting | 19 |
| Activity light on stimulating relaxation | |
| resting | 57 |
| passive | 14 |
| active | 14 |
| all three | 5 |
| not influenced | 10 |

through lighting on social presence and performance on cognitive tasks. This is reflected in the following statements.

*"My uncle's desire for my success could have unconsciously motivated me to succeed during the test."* – P26

*"Her personal presence was felt and this stimulated me to perform well for sure."* – P35

Concerning the effect of peripheral activity awareness through lighting on concentration and reasoning, we deduce a possible relation between colour symbolism and the implicit meaning of the specific activity level e.g., an implicit link between 'active (red)' and 'fast' or 'resting (blue)' and 'quiet', which is reflected in the following statements.

*"Active, the red colour made me reason faster."* – P34

*"Resting, blue light is quiet and to concentrate I need absolute silence."* – P22

*"Passive, in the sense that the green light did not push me to make an effort to see what I am doing because it was bright and neutral in colour."* – P29

Furthermore, the active activity level was deemed as most effective for boosting concentration by the participant majority while a few regarded the passive activity level as effective for concentration boost and the others favoured the resting state for its positive influence on concentration.

Again regarding the influence of peripheral activity awareness through lighting on relaxation, we gather a possible association with the implicit meaning of the colour and the actual activity itself. For example, two participants described this effect in the following statements.

*"Resting, because blue is relaxing, in fact it has the same effect everywhere."* – P37

*"Resting tended to make me feel more relaxed, because I associated the colour blue to a state of calm and resting."* – P28

In hindsight, resting was most favoured among the participants for its positive influence on relaxation while a few participants acknowledged the benefits of the passive and active activities on relaxation. Specific benefits of the resting activity on relaxation discussed among test-aware participants are illustrated below.

- the serene nature of blue
- positive effects on sensations of calmness and peacefulness
- the feeling of time pressure gradually decreased
- a triggered a sense of security and feeling of accomplishment
- provides good readability, aids concentration, and reduces distraction

**Media Choice for Awareness Information**

Of the twenty-one test-aware participants interviewed, 76% preferred traditional information sources such as voice and text for staying connected with loved ones. However, the remaining 24% were intrigued by the possibility of peripheral displays in AAL environments owing to its 'quiet' and intuitive nature. Examples of the participant's feelings are shown below.

*"The different colours of the light indirectly stimulates attention, while written or vocal messages would be disruptive."* – P22

*"The idea of light is very interesting, but the changes tend to distract a little. Maybe not with the lamp while at work, but the light is certainly more immediate and intuitive."* – P29

*"I think I can communicate with my grandparents with voice messages. I would change my mind if other modes of communication were as easy as this."* – P38

## 6.5 General Conclusions

Activity-based ambient displays can present significant benefits and challenges to the mental, social, and emotional functioning of caregivers in AAL environments. Notably, work and study environments are uniquely challenging contexts for presenting ambient information. Exploiting a user-centered design approach, we sought to elucidate the implications of activity-based lighting displays on productivity, concentration, and moods, and based on this understanding glean compelling user insights on critical design features that will inspire innovation of such technologies.

### 6.5.1 Design Guidelines and Sensitivities

In keeping with the universal principles of accessible and inclusive design, we now articulate a set of key design sensitivities that should be observed when designing activity-based lighting displays.

- *Light sensitivity* – Over-illumination can be irritating to the eye and negatively affect performance on primary cognitive tasks (Costanza, Inverso, Pavlov, Allen & Maes, 2006). In our study, we found that a number of participants experienced negative effects induced by bright light. One plausible solution is to moderate the intensity of bold colours such as red to minimize irritation and avoid disruptive effects on primary tasks.

- *Spatial position* – the spatial position affects the perception of activity information and may cause distraction on primary cognitive tasks. Hence, designers should not position the light source directly in the field of view but more on the periphery of the user's attention. In the context of AAL, this may support the management of distraction, which is considerably greater in older adults (Connelly, Hasher & Zacks, 1991) and to avoid distraction effects for caregivers in their working environments.

- *Sensor obtrusiveness* – We found that participants were generally apprehensive regarding the notion of wearable ECG and GSR sensors, a similar pattern reported by Buenaflor and Kim (2013). This can be attributed to the position of the ECG electrodes on very sensitive parts of the body such as the chest leads and the discomfort caused by the GSR sensor. A viable solution is to explore lightweight wearable sensors that are gender neutral and minimally invasive along with additional physiological measurements reported by Kreibig (2010) for evaluating the emotional implications of the display.

Based on our qualitative results, the use of activity-based ambient displays show promise for sustaining awareness while simultaneously depicting positive influences on concentration, relaxation, and positive moods in work environments. This is mainly attributed to coloured lighting, which was enjoyed by our participant majority. Additionally, participants were more accepting towards the intriguing, intuitive, and creative characteristics of the display, while asserting its influence on positive moods (Kreibig, 2010) such as contentment (serenity, calmness, peacefulness, and relaxation) and relief (safety).

Moreover, the results show positive implications of coloured lights on concentration and productivity, which are consistent with previous research insinuating unconscious influences of colour on cognition and behaviour through learned associations (Olsen, 2010).

Traditionally, red is activating, stimulating, and exciting (Mikellides, 1990), while other studies have suggested negative implications of red on performance due to its association with psychological danger or failure in achievement scenarios (Maier, Elliot & Lichtenfeld, 2008). Conversely, in our study, we found that the test-aware participants had perceptions of higher concentration boost with the active activity level, which emanated red light. We posit that this can be attributed to an implicit link between the stereotype associated with the word or activity itself as demonstrated by Bargh, Chen and Burrows (1996) coupled with the psychophysical influence of the coloured lighting exposure on the participant. Also, the subjective experience of increased time pressure with the red activity light is consistent with the work by Delay and Richardson (1981), whereby subjective estimates of time runs faster with higher light intensities. From the qualitative findings, we can infer that activity-based ambient lighting displays can serve a dual function as a source of activity information of the elderly counterpart while simultaneously creating a relaxing and pleasant atmosphere, together with a positive modulation of cognition and moods.

Although traditional media was by far the most preferred information source for activity information, the qualitative results show promise for activity-based ambient displays to sustain social connections and stimulate productivity while working through induced social presence, with potential offerings of immediate and intuitive awareness of ADLs in AAL contexts. Arguably, subjective feelings of social connectedness in long-term interpersonal relationships tends to be relatively stable over time (Insel & Young, 2001; H. H. Kelley et al., 1983).

Notwithstanding these benefits, we identified certain areas for improvement of activity-based ambient displays from the participants' responses. We observed the need for customization of properties (such as colour, intensity, and position) of the lighting system in order to infuse flexibility in our design.

In summary, this research provided insights into the perceptions of the lighting parameters to inform the design of an ambient lighting display to portray activity information for an AAL context and explored the implications and practicality of such awareness technologies in AAL environments. The research outcomes indicate an overall positive attitude towards the technology, as well as the potential influence of activity-awareness through lighting on mood enhancement, concentration, and productivity in work-related environments. From the experimental results, we posit that caregivers in their work environments could potentially benefit from a mediated connection with their elderly counterparts.

In addition, the results indicate the relevance of lighting parameters such as colour to encode activity information for easy interpretation, minimal distraction and reduced mental effort to facilitate information access, and create an aesthetically pleasing and meaningful interaction.

Notably, constraints regarding distractions, privacy, and trust in working environments can create a challenge for designers in the AAL field. However, to accommodate perceptual deficiencies, building on previous research, this chapter culminates with in a series of design guidelines and sensitivities to be observed when designing activity-based ambient lighting displays for AAL settings. Accordingly, these insights could have positive implications for the design of future ambient lighting displays within an AAL context because of its great potential for increasing awareness, engagement, and positive emotional responses.

### 6.5.2 Limitations and Future Work

The work conducted in this chapter is not without limitations. First, we capitalized on opportunistic sampling, therefore the participants recruited in both studies were not necessarily representative of all stakeholders within the AAL domain. Considering only a specific target group (caregivers) were examined in this work, findings should not be generalizable to the elderly on a whole as older adults are usually challenged with changes in their colour perception and pupillary excursion capability (i.e., older eyes are less sensitive to short wavelengths (e.g., blue) and less light reaches the retina, particularly under low light conditions) (Schieber, 2006). Therefore, an additional study with more variability in age would be useful for evaluating the perceptions of older adults on lighting features and assessing the implications of activity awareness through coloured lighting on cognition and behaviour.

Second, the quantitative findings exhibited a change in neither implicit memory nor moods. Rather, the qualitative findings provided insights into how the activity-based ambient lighting displays affected memory, mood enhancement, and behaviour in response to the stimulus. To achieve a more informed and extensive evaluation of the changes in psychophysical behaviour, a long-term study is required with a sufficiently larger sample size, accompanied by the use of wearable unobtrusive physiological measurements.

Third, in a real AAL scenario, we acknowledge that it might be prudent to combine different types of effectors (ambient displays) depending on the specific activity performed and the physical location of the users. The hue lamp in its current state lacks portability and is limited to the homes or work environment of potential users. Therefore, it is reasonable to consider how to exploit everyday objects to enable design flexibility and real-time and ubiquitous access to activity information for both user groups. This will be implemented in the subsequent chapter.

Furthermore, in chapters 7 and 8, we combine most of the design guidelines obtained from prior studies and our own study results to implement a real-time, portable, and bidirectional activity based system deployed in a semi-controlled AAL environment. In this study, we present the implementation challenges and ascertain further insights into how the system influences activity awareness and fosters the maintenance and strengthening of social connectedness over time.

# Chapter 7

# Seamless Connectivity for AAL: Implementing a Real-time Activity-Based Bidirectional Display System

*"Beauty and brains, pleasure and usability — they should go hand in hand."*

—Donald A. Norman

In this chapter, we present the design and development of an activity-based implementation aimed at enabling the real-time viewing of bidirectional activity states between the elderly and their caregivers. This implementation seeks to overcome the limitations of earlier ambient displays deployed in AAL settings, and our own ambient lighting display employed in chapter 6, which altogether were unidirectional and confined to stationary locations in the users' home, work, or school environments. Our bidirectional activity-based application is based on an extensive literature review (see chapters 2 and 5), expert advice and user feedback, which informed the design decisions about the product features and functionality. In addition, we extended the activity recognition model in chapter 5, such that it facilitates real-time activity awareness and an "always connected" service through portable interactive devices for stimulating social connectedness within the AAL domain.

This chapter is largely based on the following publication (Davis, Owusu, van den Boomen et al., 2017).

## 7.1 Introduction

Recent AAL research corroborates the significance of the exchange of human activity information for improving social connectedness between the elderly and their caregivers as confirmed by Visser et al. (2011) and our results in chapter 4. However, the design, development, deployment, and evaluation of such activity-based bidirectional systems is mostly left unexplored.

Formerly, most classical ambient displays such as the Digital Family Portrait (Mynatt et al., 2001; Rowan & Mynatt, 2005) and the CareNet Display (Consolvo et al., 2004) were entirely focused on furnishing caregivers with context information to support the remote monitoring of older adults and provide peace of mind to their family members. Conversely, a few contemporary ambient displays such as those presented in chapters 4 and 6 and (Visser et al., 2011) are geared toward interpersonal awareness using physical activity information in mediated environments. However, in both cases, the ambient displays are positioned as decorative objects in a fixed location inside the users' home (Visser et al., 2011) or work or study environments (in the case of chapter 4 and 6, respectively). Thus, prohibiting access to the counterpart's activity information outdoors. Moreover, the aforementioned ambient display studies (Consolvo et al., 2004; Mynatt et al., 2001; Rowan & Mynatt, 2005; Visser et al., 2011) and those in chapters 4 and 6 demonstrated awareness information using one decorative object namely ambient photo frames, a desk lamp, or a snowglobe lighting device.

In this dissertation, it has been repeatedly pointed out that the pervasive nature of mobile devices and IoT, provide game-changing opportunities for developing smart solutions for enhancing social connectivity between older adults and their caregivers in computer-mediated environments. Inspired by the principle of calm technology (Weiser & Brown, 1997), this chapter presents a novel user-centered approach to the design and development of an amalgamation of ambient interactive tools to enhance social connectedness between the elderly and their caregivers. To address the limitations of the previous research, we have developed a bidirectional implementation, which receives input from embedded smartphone accelerometer and gyroscope sensors and renders information through the interactive materiality of everyday artefacts such as Philips Hue light orbs, a portable LED walking cane and wallet. Consequently, enabling an "always connected" communication channel through pervasive interactive devices.

In this chapter, we present the design and development of our real-time activity-based bidirectional implementation for improving social connectedness between the elderly and their caregivers. In subsequent sections, we give an overview of the related work, discuss our design rationale and provide a detailed description of the system's architecture. Finally, we discuss the limitations of the system and our plans for deployment in the succeeding chapter.

## 7.2 Design Rationale

As displayed in figure 1.1 – chapter 1, our bidirectional activity-based implementation is an ambient lighting system that detects human activities and provides visual feedback through a LED cane, LED wallet, and Philips hue light orbs to create a sense of awareness and social connectedness between older adults and their caregivers. In general, physical activity data has been studied about health issues, e.g., for motivating people to exercise.

We were guided by the following design heuristics obtained through a thorough review of the literature in chapter 2, (Mankoff et al., 2003; Matthews, Rattenbury & Carter, 2007; Vastenburg et al., 2008) and our own findings from earlier chapters 3, 4, and 6 using ambient displays.

- The system should be practical, not distracting, portable, perceptible, comfortable, meaningful, reliable, subtle, discrete, aesthetically pleasing, accessible, and safe.
- The system should accommodate the vision and motor impairments of the elderly population and should appeal to the intrinsic motivation to share knowledge.
- The system should support ease of use, affordance, and learnability bearing in mind that the elderly are susceptible to cognitive impairments, which affect cognitive abilities such as attention and memory.
- The system should support the elderly's autonomy and should seamlessly fit into their existing lifestyle patterns.

Motivated by the central goal of designing usable, acceptable, and accessible products for the elderly and their caregiver counterparts we sought to determine appropriate everyday objects for conveying activity information that would meet our design criteria. This was done over the course of several brainstorming sessions. Notably, to provide an "always connected" service, we were interested in complementing our already existing Hue lighting system with portable ambient lighting devices. As such, we consulted the following prospective users: one biomedical engineer, two industrial designers, two gerontechnology researchers, two electrical engineers, one embedded software engineer, a retired professor, an elderly professional in the medical industry, one retired engineer, and two professors to capture their likes and preferences for interactive products to convey activity information. We encountered various suggestions including the following LED objects: a walking cane, wallet, bracelet, wrist-watch, ball, portable speakers, and other wearables such as clothing and shoes. After much deliberation, we decided that the LED cane and wallet were most suited for conveying activity information while simultaneously adhering to the design heuristics.

Notably, our attempts to find similar studies exploiting a LED cane and a wallet for transmitting activity information and enabling social connectedness in AAL environments were futile. However, we discovered the Smart Cane System designed by S. Lim, Yu, Kang and Kim (2016), which includes the following features to provide direction guidance for the blind.

- *Smart cane* – Accesses RFID information using a RFID reader and delivers this information to the mobile application using Bluetooth. In addition, the Smart Cane is comprised of the following components (i) a $9V$ battery, (ii) Bluetooth module, (iii) RFID modules, (iv) an Arduino Uno, and (v) an RFID integrated circuit.

- *Mobile Application* – Delivers the RFID information from the smart cane to the server. Also, retrieves valid data from the server.

- *Web Server Server* – Serves as a repository for direction information, which is globally accessible irrespective of the country.

Despite the fact that the Smart Cane is targeted for blind users, there are similarities in the system design and the electronic components of the system. However, system differences such as the use of WiFi technology is discussed in the subsequent section.

## 7.3 System Overview

The entire system is composed of 5 major subsystems as illustrated in figure 7.1. A remote server subsystem resides in the central part of the system and is responsible for classifying human activities and relaying detected activities to other subsystems. A LED and Hue subsystem are located on each side of the remote server subsystem, respectively. Each LED subsystem consists of a waist-mounted smartphone, an Espressif (ESP) microcontroller with Wi-Fi capability, and an LED ring or strip. The waist-mounted phone is equipped with an accelerometer and a gyroscope for measuring the proper acceleration and orientation of the body, respectively (cf. chapter 4). A custom built Android application i.e., the LED controller application (app.), collects the accelerometer and gyroscope readings (sensor data) at a frequency of 50Hz (cf. chapter 5) and sends it to the remote server subsystem for classification. The Android application maintains two socket connections to the central remote server, one for sending sensor data to the server for classification and the other for receiving the classified activities of the counterpart. Subsequently, the classified activities received are mapped to activity levels and then transformed to lighting property encodings, which is later broadcast to the led strip/ring via the ESP microcontroller Wi-Fi module. To

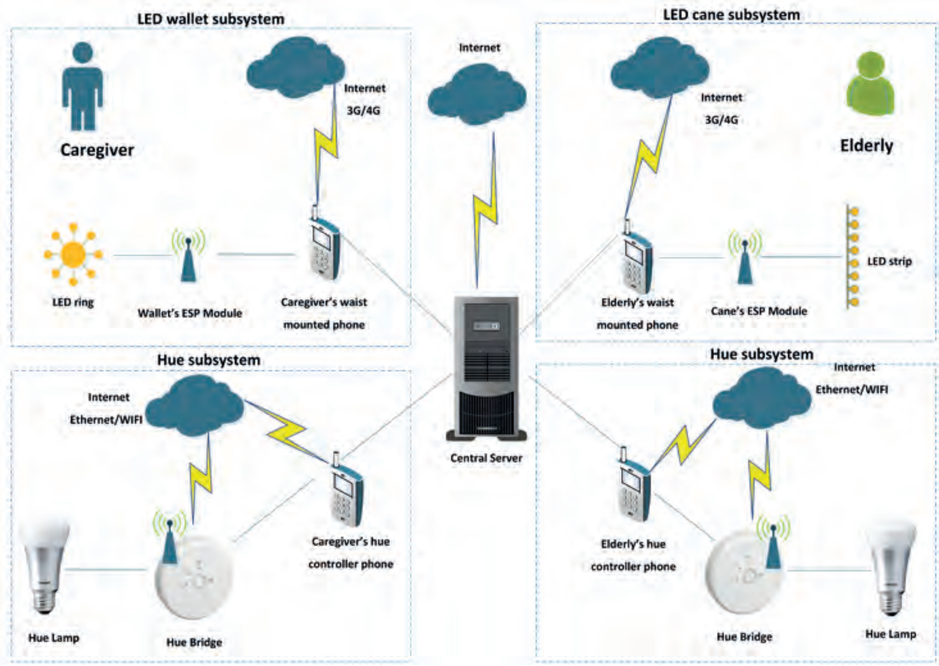


Figure 7.1 An overview of the bidirectional activity-based system.

achieve this, the waist mounted phone requires a 3G/4G internet connection by which data is streamed to the remote server and a portable Wi-Fi hotspot to provide an internet connection to the ESP Wi-Fi module.

Besides, the Hue subsystem consists of a mobile phone with Wi-Fi internet connection and a Philips Hue bridge and bulb. Another custom-built Android application (i.e., the Hue controller), maintains a single socket connection to the central server subsystem for receiving the classified activities of the partner. The Hue controller then relays this information to the hue bulbs as light property encodings via the hue bridge. The Hue subsystems are deployed indoors to convey bidirectional activity information while users are situated in the comfort of their homes while the LED devices are carried when users are outdoors. This enables an "always connected" system to users.

## 7.4 Central Server Subsystem

The central server subsystem is composed of a multi-threaded socket server implemented in the Python programming language, a hybrid Support Vector Machine and Hidden Markov

Model (SVM-HMM) classifier implemented in Matlab, and a RabbitMQ message queuing server. Figure 7.2, illustrates the server subsystem.

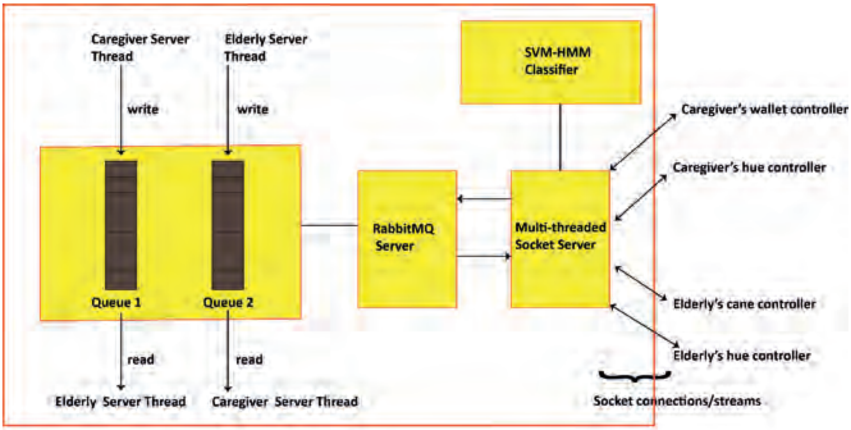


Figure 7.2 The Central Server subsystem.

The multi-threaded server allows concurrent requests to be handled in parallel to reduce response delays. It receives continuous streams of raw sensor data from the waist-mounted mobile phones from the LED subsystems, which is passed to the SVM-HMM classifier for cleaning, feature extraction and selection, and classification. It uses a trained hybrid SVM-HMM activity classification model with an accuracy of 99.7%, for detecting one of six basic activities (laying, sitting, standing, walking, walking upstairs, and walking downstairs) every 2.5 seconds. The reader may revisit chapter 5, to refresh his/her knowledge on our classification model. Since the SVM-HMM model was trained with feature sets computed on fixed length windows of 2.5 seconds, a maximum of one activity can be determined in a window. In the server's implementation, however, sensor data is passed to the classifier, every two windows instead of one. This decision was based on the fact that the classifier requires a minimum amount of sensor data within a window to correctly extract and select features. In rare cases, the data received in a window was not sufficient for classification. Therefore, passing two windows of data to the classifier allowed a minimum of one activity to be detected without errors. Furthermore, to keep the implementation of the server simple, we did not use the sliding window of 50%.

Thus, a minimum delay of 5 seconds was introduced. Moreover, an additional delay of 1 second was spawned by the actual activity classification process and the relay of the activity information resulting in an average system delay of 6 seconds between the time a participant changes an activity state and the time their partner sees this change in the peripheral displays (LED and Hue client subsystems).

To achieve bidirectional exchange of activity information, client subsystems must uniquely identify themselves and their partners. With this information, the RabbitMQ server, a robust and high-performance implementation of the Advanced Message Queuing Protocol (AMQP), creates two queues for each elderly-caregiver pair. The caregiver server thread then writes to one of the queues, which is read by the elderly server thread and later reads from the queue written by the elderly server thread and vice-versa, thereby facilitating the bidirectional exchange of data.

## 7.5 The Hue Subsystem

The Hue subsystem consists of a mobile phone with Wi-Fi internet connection, a Philips Hue bridge and two Hue bulbs infixed in orbs. The Philips Hue is a connected lighting system that enables lighting properties such intensity, colour, and brightness to be manipulated over a network. It is furnished with a network bridge for establishing an internet connection and

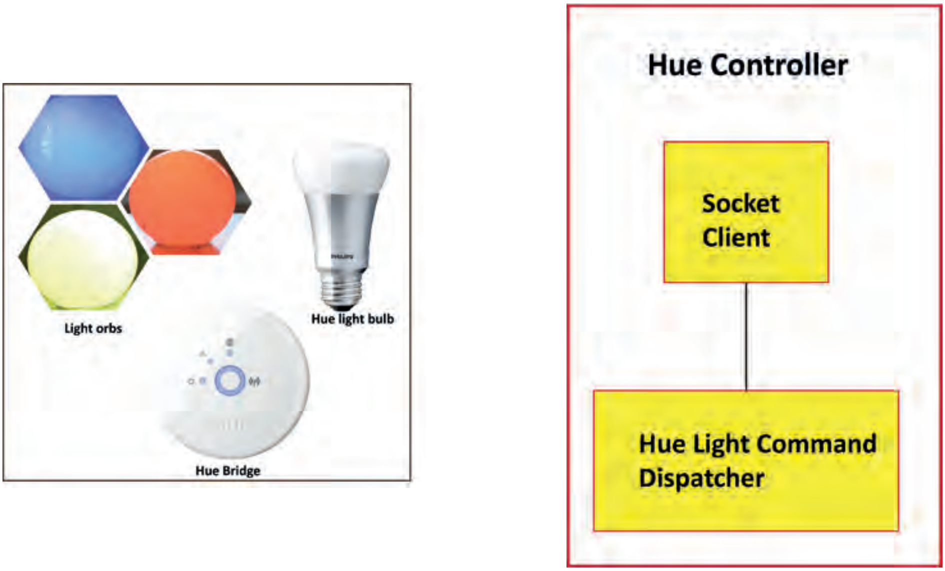


Figure 7.3 The Hue subsystem.

provides an API for building custom applications to control the light over a network. The bulbs connect to the bridge via the ZigBee Light Link open standards protocol[1]. On the left side of figure 7.3, the components of the Philips lighting system are illustrated, which includes a Hue bridge, a Hue bulb, and three example light orbs in different colours. The major software constituents of the Hue controller Android application are displayed on the right of the diagram.

The Hue bridge connects to the internet via an Ethernet cable and each Hue bulb connected to the hue bridge is identifiable by a unique ID and name on the network. However, the accompanying API is local to the bridge, i.e., it is only accessible on a local Wi-Fi network and is therefore unreachable outside this network. Accordingly, all applications or interfaces that send commands to the bridge should be on the same network as the bridge. This is a security requirement implemented by Philips to prevent Hue lights from being controlled from outside a user's home network. In consequence, we built a Hue controller Android application on a dedicated phone, which connects to the same Wi-Fi network as the Hue bridge. The Hue controller application makes a socket connection to the central remote server and waits for streams of detected activities from the counterpart. Each received activity value is mapped to a set lighting colour properties and relayed to the bridge, which then forwards these commands to the connected light bulb.

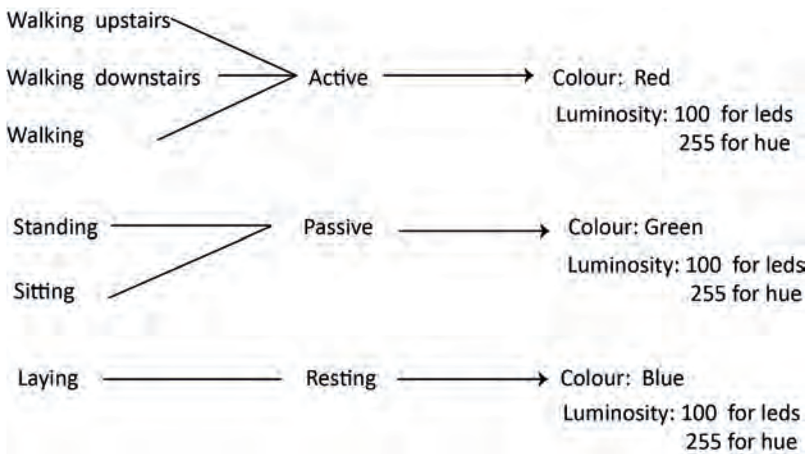


Figure 7.4 Mapping between basic activities, activity levels and light configurations.

Note that the mapping between the six basic activities and activity levels (active, passive, and resting) and those of activity levels and lighting encodings (colour and brightness) are not arbitrary. As discussed in chapter 6, a person walking or walking upstairs or downstairs

[1]`https://www.developers.meethue.com/documentation/how-hue-works`

is said to be in an ‘active state’, one sitting or standing is in a ‘passive state’ while another who is laying is in a ‘resting state’. Figure 7.4, depicts these mappings. The mappings were generated to conceal participants actual states for privacy purposes and to mentally stimulate participants to decipher the actual activities and activity patterns as articulated in chapters 4 and 6. Furthermore, the choice of red, green, and blue lighting colours with moderate brightness to represent active, passive, and resting states respectively, is by virtue of the exploratory studies discussed in chapter 6.

## 7.6 The LED Cane Subsystem

To enable elderly-caregiver pairs to have continuous receipt of activity information outdoors, in a similar mode (i.e., display via lights), we envisioned using portable everyday objects as forms of display. After careful consultation with design experts and potential users, we agreed upon a cane adorned with the Adafruit NeoPixel Digital RGB LED strip for the elderly. The Adafruit NeoPixel Digital RGB LED Strip is a set of individually addressable RGB LEDs encased in a strip as shown in the left of figure 7.5.

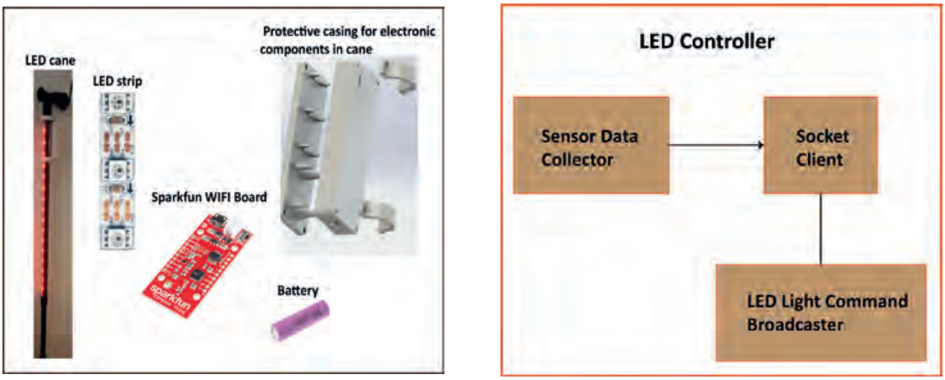


Figure 7.5 The LED cane subsystem.

To improve the look and feel of the cane, the Adafruit led strip was fitted with a transparent PVC pipe. The LED subsystem controls the NeoPixel LEDs based on the sequence of detected activity information received from the remote server subsystem, which is later transformed into lighting colour properties. To achieve this, the LED strip’s microcontroller requires a communication module to receive input from the LED controller Android application on the waist-mounted smartphone. Since the LED Cane subsystem is designed for outdoor use, a wireless connection between the mobile phone and the cane’s microcontroller module was the most feasible approach. In retrospect, we basically had two options available: a Wi-Fi or Bluetooth connection. For connection reliability and speed, the Wi-Fi option was chosen.

We selected the ESP8266 based Wi-Fi board, a low-cost Wi-Fi chip with TCP/IP stack and a microcontroller from a Chinese manufacturer, Espressif Systems. The board not only enables Wi-Fi but also comes with an on board Li-ion battery charger and a voltage regulator circuit. To power the microcontroller and the LED strip, a 3.7V Samsung 18650 Lithium-ion battery of 2600mAh capacity was used. Batteries are charged via the inbuilt micro USB connection. Embedded software is uploaded to the microcontroller via the serial port, using a so-called FTDI board (a USB-to-serial adapter). Also, development of the embedded software was done within the popular Arduino environment. A three dimensional (3D) model of the protective casing was designed to house the electric components of the cane using the Solidworks Computer Aided Design software, which was later printed using 3D printing technology.

Recall that the waist-mounted smartphone has two main responsibilities with respect to the LED subsystems; i.e., (i) sending collected sensor (accelerometer and gyroscope) data to the remote server for activity classification, and (ii) relaying the received partner's activity data to the cane's microcontroller so as to change the LEDs' colour and brightness. To enable this functionality, the LED controller application running on the waist-mounted phone requires a cellular internet connection (3G/4G) to communicate with the remote server and a portable Wi-Fi network to communicate with the Sparkfun microcontroller. The main software components of the LED controller application is illustrated on the right of Figure 7.5.

The power consumption of the Wi-Fi board, with the LEDs connected, is a limitation to the maximum amount of time the system can be deployed outdoors. We determined the current consumption of the Wi-Fi board, with the LEDs connected using a stable 3.3V power supply. When all LEDs are at full brightness, and only one colour is "active" the total current consumption is almost 200mA with 16 LEDs and when all LEDs were off the current consumption was no more than 88mA.

According to the datasheet[2], the battery has a capacity of 2600mAh when discharging with a constant current of 520mA down to a voltage of 2.75V (cut-off voltage) after the cell is charged up to 4.2V. Also, the Wi-Fi module is expected to have at least a supply voltage of 3.0V. With the voltage regulator in between the battery and the Wi-Fi module, having a dropout voltage of 125mV, the minimal battery voltage needed is 3.125V. That means that

[2] `http://www.batteryspace.com/samsung-lithium-18650-rechargeable-cell-3-7v-2600mah-9-62wh---icr18650-26f---un38-3-passed.aspx`

we cannot use the full capacity of the cell since we cannot drain it down to 2.75V. With a discharge current of 0.2A the available operating time is 12.5 hours. However, the rate of discharge of the battery does not only depend on the consumption of the LEDs but also on the speed of communication between the microcontroller's Wi-Fi module, the LED controller app. and the LED strip. Overall, we recorded an average operating battery life of 4 hours in a full outdoor deployment.

## 7.7 The LED Wallet Subsystem

The components of the wallet subsystem are similar to the LED cane subsystem excluding the shape of the led strip (ring-shaped LEDs) and the rechargeable lithium battery utilized. The wallet subsystem components are portrayed in Figure 7.6. Basically, the communication

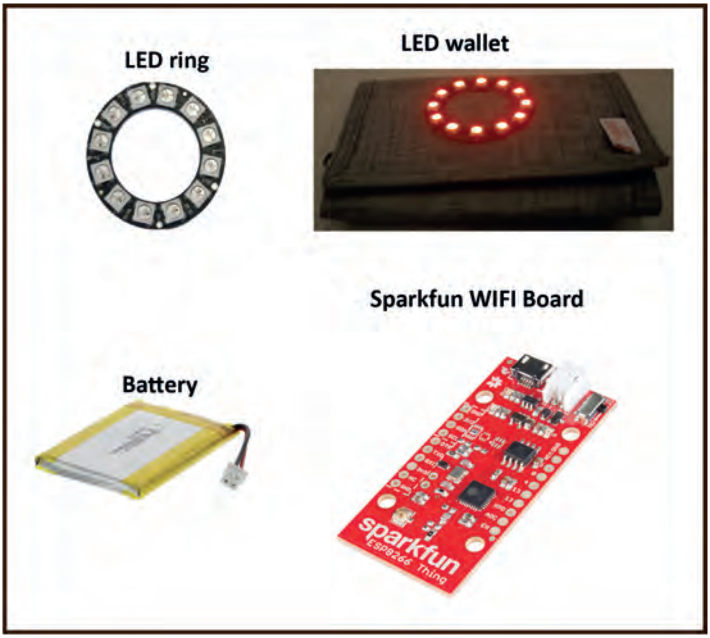


Figure 7.6 The LED wallet subsystem.

protocol between the wallet's Wi-Fi microcontroller, LED controller app and LED ring is identical to that of the cane subsystem. However, we chose a different form factor for the wallet subsystem, as the battery needed to be as flat as possible to not show any protrusions. Thus, a MikroElektronika 3.7V rechargeable lithium battery of 2000mAh capacity was installed. With a lower battery capacity, we recorded an average operating battery life of 3 hours in a full outdoor deployment.

## 7.8 Discussions and Conclusions

In this chapter, we have presented the design and development of a real-time activity-based bidirectional implementation aimed at improving social connectedness between the elderly and their caregivers. Leveraging IoT this system can be easily deployed and promises to transform the way the elderly and their caregivers communicate and maintain awareness of each other's activities in daily life. Unlike its predecessors e.g., the Digital Family Portrait (Mynatt et al., 2001; Rowan & Mynatt, 2005), CareNet Display (Consolvo et al., 2004) and the Snowglobe (Visser et al., 2011), we strive to present an accessible form of technology designed for use in and outside the home environment. By adopting a user-centric approach, we assessed the users' needs, expectations, and their context of use. The process culminated with the realization of intelligent interactive products suited for use in the ambient assisted living domain. In particular, the Hue lighting system, LED wallet, and LED cane may have considerable added value or complement traditional approaches to maintain awareness and stimulate social connectedness. Through an in-depth description of the technical processes and system components, we aspire to encourage researchers to design innovative and usable systems that enhance social relationships in AAL environments.

Despite the considerable potential of our system, we acknowledge some limitations and challenges we have encountered during the design, implementation, and test deployment. Firstly, efficient battery power is the prime limitation of our system's deployment outdoors. In future work, we will consider optimizing computation and communication within the system and also use LEDs of higher resistance to help reduce power consumption. Moreover, by increasing the LED's resistors and making the system enter into a "Sleep" state, awakening it after an event interrupt could increase the system's autonomy. Also, using devices that work at 1.8V would open the possibility to use the whole battery capacity. Secondly, the average delay of 6 seconds through the exchange of activity cues might be unacceptable in situations where feedback is safety-critical. Even though the bidirectional activity-based system is not intended as a safety monitoring system; we will investigate methods of reducing the classification window size of our SVM-HMM model in order to reduce the overall response time. In the next chapter, we have the deployment results of an experimental study investigating the behavioural and social connectedness implications of the system and its acceptance.

# Chapter 8

# Towards a Deeper Understanding of the Behavioural Implications of Bidirectional Activity-Based Ambient Displays

*"Nonverbal communication forms a social language that is in many ways richer and more fundamental than our words."*

—Leonard Mlodinow

As far as we know, a real-time bidirectional platform exploiting both indoor and portable activity-based ambient displays in an AAL context has not been evaluated. Moreover, there is little or no scientific evidence to determine the extent to which the exchange of activity information can influence interpersonal synchrony in AAL.

Consequently, this chapter examines the effects of the bidirectional activity-based ambient display platform on context-awareness, social presence, social connectedness, and importantly interpersonal activity synchrony. Also, we present the evaluation of the final iteration of our platform aimed at supporting context-awareness and social connectedness in AAL.

This chapter is largely based on the following publication (Davis et al., 2018).

## 8.1 Background and Introduction

For many years, coordinated actions have been considered to enhance relationships and are deemed as an essential component of social behaviour and interactions (Bargh et al., 1996; Bernieri, 1988; Chartrand & Bargh, 1999; Chartrand, Maddux & Lakin, 2005; Cirelli et al., 2014; Lakin & Chartrand, 2003; L. K. Miles, Nind & Macrae, 2009a; R. Schmidt & O'Brien, 1997; R. C. Schmidt & Richardson, 2008). In addition, scholars such as Bargh et al. (1996); Chartrand and Bargh (1999) suggest a possible link between perception and behaviour such that automatic mimicry can be evoked by the mere perception of an interaction partner's behaviour. In this dissertation, interpersonal synchrony is investigated through a set of analogous and sometimes overlapping terms namely (i) behavioural coordination, (ii) coordinated action, (iii) motor coordination/synchrony, and (iv) emotion contagion.

Coordinated behaviour has been shown in a variety of contexts such as parent-infant bonding (Cirelli et al., 2014), teacher-student interactions (Bernieri, 1988), and intimate relationships (Julien, Brault, Chartrand & Bégin, 2000), such that coordinated action, i.e., interpersonal activity synchrony is regarded as indicators of social interaction. In particular, previous studies have examined this construct with reference to the synchronization of bodily actions such as oscillations of rhythmic limb (Scott Kelso, Holt, Rubin & Kugler, 1981) and lower leg (R. C. Schmidt, Carello & Turvey, 1990) movements. Likewise, some scholars have found evidence of interpersonal motor coordination while two people either (i) walked side-by-side (Ulzen, Lamoth, Daffertshofer, Semin & Beek, 2008; Zivotofsky & Hausdorff, 2007) or (ii) swayed side-by-side in rocking chairs (Richardson, Marsh, Isenhower, Goodman & Schmidt, 2007). Added to motor synchrony, other studies have investigated coordinated behavioural markers in terms of the mimicry of conversations, collective musical behaviour, dancing, laughter, facial expression, and emotions (Chartrand et al., 2005; Gill, 2012). Altogether, these indicators can be combined under one umbrella term, i.e., emotion contagion, which is defined as follows.

*"The tendency to automatically mimic and synchronize facial expressions, vocalizations, postures, and movements with those of another person's and, consequently, to converge emotionally"* (Hatfield, Cacioppo & Rapson, 1994, p. 5).

A key problem with much of the literature examining behavioural coordination is that they tend to focus on face-to-face interactions with very little studies conducted in mediated environments. While we wholeheartedly agree that face-to-face interaction is perhaps one of the most active forms of interpersonal interaction (Newberry, 2001; Short et al., 1976), given its offerings of immediate feedback, engagement, and interpretation of non-verbal communication cues among others, we also believe that there is a need to explore other types of interaction, especially for enabling peripheral interaction in AAL. As mentioned previously in chapter 2, Biocca and Harms (2002) highlighted interdependent actions as a critical determinant of social presence in mediated environments. Thus, in an attempt to facilitate coordinated behaviour in mediated AAL environments, this chapter evaluates the behavioural implications of a real-time bidirectional activity-based ambient display platform on users within an AAL context. Furthermore, we evaluate the extent to which the system can trigger or influence interpersonal activity synchrony.

In the remaining sections of this chapter, we will discuss the following. First, we will explore the approaches to quantifying interpersonal activity synchrony in more detail. After that, we present a user study describing our evaluation process, and later we expound upon our findings. Ultimately, we make our conclusions and discuss our plans for future work.

## 8.2 Synchrony – Computational Methods in the Field

Very few studies (Ekman et al., 2012; Gill, 2012; Järvelä et al., 2016) address the issue of interpersonal synchrony in mediated environments. Thus, to gain a deeper understanding of this social phenomenon we had to review studies demonstrating synchrony in both real life and mediated contexts. From the literature reviewed, e.g., (Ekman et al., 2012; Järvelä et al., 2016; Richardson et al., 2007; Ulzen et al., 2008) we can infer the following indicators of synchrony.

- co-action
- coordination
- mimicry
- emotion contagion

So, how do we compute interpersonal activity synchrony in mediated AAL environments? Findings from different studies suggest that activity synchrony is determined by calculating the autocorrelation (Thomas, Burr, Spieker, Lee & Chen, 2014) or Pearson correlation (Tsai, Barnard, Lentz & Thomas, 2011) of the linear coupling of activity patterns. Also, researchers such as Haken, Kelso and Bunz (1985) have considered an in-phase approach to synchrony such that motor signals are homologous and in synchrony. Concerning mediated environments, scholars such as Ekman et al. (2012); Järvelä et al. (2016) suggest cross-correlation measures for computing physiological linkage – a related measure of emotion contagion. Moreover, Biocca and Harms (2002) conferred in their model of social presence that the degree of symmetry or correlation is a measure of social presence.

Although correlation measures are critical for calculating interpersonal synchrony, there are other mathematical constructs to consider. For example, Hove and Risen (2009) discuss the necessity of imposing a temporal lag (lasting a couple of seconds) following the reference behaviour in the cross-correlation calculation so that mimicry and by extension synchrony can be determined.

Considering the previously explored computational methods for evaluating interpersonal activity synchrony, we will employ cross-correlation measures for assessing this phenomenon in this dissertation. Furthermore, we will impose a lag to compute this cross-correlation. More details on our evaluation and data analytical methods will be described later in this chapter. We will now discuss our methodological approach.

## 8.3 Methodology

In a semi-controlled study, we evaluated a conglomerate of activity-based lighting displays from chapters 6 and 7, to determine the effects of bidirectional deployment on behaviour and social connectedness. Our experimental approach can be described in three main stages, which are listed below.

1. *The Pre-trial* – Following the design and development of our real-time bidirectional activity-based implementation in chapter 7, we conducted two practice sessions with the prospective caregiver and elderly stakeholders to identify system glitches and obtain technical insights and practical recommendations for system deployment and improvement.

2. *The Real Deployment* – Following system adjustments, our bidirectional activity-based system was deployed in semi-controlled mediated environments to evaluate the effects on synchronized activities, context-awareness, social connectedness and social presence, information clarity, attentional engagement, and the users' willingness to adopt the system.

3. *Post Deployment Interview* – We conducted a series of in-depth interviews to determine the participants' experiences and acceptance of our activity-based system and how it affected their behaviour.

Ekman et al. (2012) maintains that synchrony is inherently activated by the degree to which people are exposed to the same stimulus. He further highlights a study by Hasson, Nir, Levy, Fuhrmann and Malach (2004) whereby participants were exposed to an identical visual stimulus (i.e., a movie scene) to incite synchronized cortical activity. Accordingly, influencing our study design decision to expose half of our participants to the same stimulus (i.e., scripted activities of an actor) to induce interpersonal activity synchrony. Inspired by the previous studies on interpersonal synchrony (Cirelli et al., 2014; L. K. Miles, Nind & Macrae, 2009b) and physiological linkage (Ekman et al., 2012; Järvelä et al., 2016) to enhance interpersonal connectedness we assume the relevance of these constructs to provide social support in AAL environments. As such, we defined the following research questions.

- To what extent does activity awareness through a bidirectional activity-based system impact the synchronization of the counterpart's activity level with that of the caregiver?
- How does the activity level of an actor (caregiver) modulate the activity levels of their counterpart?
- What are the implications of the bidirectional activity-based system on
  - social connectedness,
  - social presence,
  - context-awareness,
  - information clarity,
  - attentional engagement and,
  - the users' willingness to adopt the system?

### 8.3.1 Participants

Participants were recruited through personal networks and referrals from a retired professor, and engineer in the Netherlands. Notably, both the retired professor and the engineer acted as proxies to represent prospective elderly recruits. Thus, before experimentation all system requirements, designs, prototypes, and the study design were repeatedly cross-validated with these proxies. This was done as a measure to guarantee system functionality, user comfort, and privacy so that they could proceed with the recruitment. Overall, twenty-four persons (twelve pairs) participated in the study. The following are criteria for the inclusion and exclusion of participants in this study.

- Equal numbers of younger adults and elderly participations are essential for this study.
- Prospective younger adults should be over 18 years while prospective older adults had to be over 65 years of age.

- All prospective older adults should be relatively healthy with no history of chronic, motor, or mental diseases.
- All prospective older adults should live independently and demonstrate the ability to execute their ADLs on their own.
- Equal numbers of male and female participations are valuable for this study.

Table 8.1 Demographic characteristics of participants

| Role | Name | Age | Gender | Nationality | Marital Status | Education Level |
|---|---|---|---|---|---|---|
| Caregiver | A | 31 | M | Ghanaian | Married | MSc |
| | B | 26 | F | Chinese | Single | MSc |
| | C | 26 | F | Chinese | Married | MSc |
| | D | 75 | M | Dutch | Married | PhD |
| | E | 31 | F | Malaysian | Married | MSc |
| | F | 27 | F | Chinese | Single | MSc |
| | G | 21 | F | Dutch | Single | WO |
| | H | 65 | F | Dutch | Married | HBO |
| | I | 35 | F | Iranian | Married | MSc |
| | J | 67 | F | Dutch | Married | HBO |
| | K | 73 | M | Dutch | Married | PhD |
| | L | 61 | F | Dutch | Married | MBO |
| Counterpart | M | 32 | M | Tanzanian | Married | MSc |
| | N | 28 | F | Chinese | Single | MSc |
| | O | 31 | F | Malaysian | Single | MSc |
| | P | 69 | M | Dutch | Married | PhD |
| | Q | 33 | M | Malaysian | Married | MSc |
| | R | 40 | M | Dutch | Married | PDEng |
| | S | 24 | M | Dutch | Single | WO |
| | T | 71 | F | Dutch | Married | MBO |
| | U | 67 | M | Dutch | Married | MBO |
| | V | 68 | M | Dutch | Married | WO |
| | W | 74 | M | Dutch | Married | HBO |
| | X | 73 | M | Dutch | Married | MBO |

Each participant was assigned to one of two distinct user groups: (i) caregiver – who is expected to execute a series of scripted activities while simultaneously maintaining awareness of their counterpart through the proposed bidirectional activity-based system and (ii) the counterpart – who upon receiving the caregivers' activities via the ambient display is expected to carry out their activities at their own free will. In this study, an elderly participant could serve as a caregiver, which was determined by the preliminary results in chapter 3, showing evidence of elderly persons caring for their fellow elderly loved ones. The participant demographics are presented in table 8.1. To preserve anonymity, caregivers are indicated by letters A-L and their respective counterparts are disguised using letters M-X, and not names.

Participants ranged in age from $21 - 75$ (mean age = 47.8 and standard deviation = 20.8). In addition, we noticed that our sample size was comprised of the relatively 'young elderly'. The sample was dominated by the Dutch (58%), followed by the Chinese (17%), the Malaysians 13%, and a few (4% each) Ghanaian, Iranian, and Tanzanian participants. All participants except one pair were somewhat familiar with each other. For example, most elderly participants were members of clubs and societies for retired professionals in the Netherlands, while others were neighbours, friends, colleagues, or relatives. In addition, all participants were educated having attained either secondary diplomas, bachelor, master, or doctoral degrees. No participant reported ill health. The experiment was conducted in English and Dutch to facilitate the Dutch speaking participants. Participants received information of the protocol and provided their written, informed consent according to the Central Committee on Research Involving Human Subjects[1].

### 8.3.2 Experiment Set-up

The experiment was conducted in two separate living labs at the Eindhoven University of Technology (Tu/e). These rooms were each equipped with the following items: a sofa, dining table and chairs, books, map of the building, notebook and pen, music for relaxing, coffee table, computers with WiFi connection, dumbbells and exercise videos, refreshments, newspapers, games (puzzles, bowling, and diabolo), Philips Hue light Orbs, which formed part of the room design, Philips Hue bridge, smartphone (with the custom-built Hue controller app cf. chapter 7), and a portable LED ambient display (cane for the counterpart and wallet for the caregiver). Figure 8.1 demonstrates the set-up of the rooms before and after the ambient displays were deployed while figure 8.2 depicts sample game and exercise items in the rooms.

Adhering to the protocol for activity detection described in chapters 4, 5, and 7, our hybrid SVM-HMM HAR model deployed in a central server subsystem, was used to detect six basic activities (standing, sitting, walking, walking upstairs and downstairs, and laying) from data received via a waist-mounted smartphone equipped with accelerometer and gyroscope

[1] http://www.ccmo.nl/en/

Figure 8.1 Snapshots of the experiment set-up pre- and post deployment of the ambient displays.

sensors and an internet connection. Activities classified are saved on the server before they are sent to the Hue and LED controller subsystems. These controller subsystems are responsible for abstracting the detected activities into activity levels and mapping them to coloured lighting encodings and finally transmitting them to the ambient display components of the bidirectional system. The ambient display components of the system are the Hue light orbs, NeoPixel LEDs fitted on a wallet and a cane as illustrated in figure 8.3. The displays render red coloured lighting for high activity levels (walking, walking upstairs and downstairs), green for passive activity levels (standing and walking), and blue coloured lighting for resting activity level (laying).

Figure 8.2 An illustration of the sample games and exercises available in the rooms.

### 8.3.3 Evaluation Measures

- *Social Connectedness* – Participants rated their perceptions of their feelings of relational closeness toward their counterpart using the IOS scale (Aron et al., 1992).
- *Social Presence* – Participants evaluated their sense of co-presence, perceived attentional engagement, and their perception of behavioural interdependence using an adapted version of the Networked Minds Social Presence Inventory developed by Harms and Biocca (2004).

Figure 8.3 A pictographic representation of the activity-based ambient display components captured during experimentation.

- *Willingness to Adopt* – Using a scale of 1 – 10 with 10 being the most willing, participants were asked to describe their willingness to adopt bidirectional activity-based ambient displays in their own homes.

- *Post-test Interview Questions* – Participants gave their qualitative input on context-awareness, system relevance and usability, aesthetics, adoption, and evaluated their experience with and without the ambient displays.

### 8.3.4 Experiment Protocol

We employed a repeated measures design (Gergle & Tan, 2014), with one independent variable namely the interaction style (with activity-based ambient light and with white light). There were two experimental conditions having two interaction styles each lasting for 30 minutes each.

- *With activity-based ambient light* – such that there is a bidirectional exchange of activity level information between the caregiver–counterpart pair using smart objects such as the Philips Hue, a LED cane, and wallet. This is the intervention condition.
- *With white light* – such that there is no exchange of activity information between caregiver and their counterpart. This is the control condition.

In both conditions, the caregiver followed a script and performed a similar sequence of activities. To minimize carry-over and order effects, we counterbalanced interaction styles using an AB-BA format (Gergle & Tan, 2014). There were two experimenters to facilitate this study. The dependent variables examined include (i) the synchrony of activity levels – interpersonal activity synchrony (on the part of the counterpart), (ii) context-awareness, (iii) social connectedness, (iv) social presence (behavioural interdependence i.e., the counterpart's synchronized actions with the caregiver), (v) information clarity, (vi) attentional engagement, and (vii) system adoption.

Prior to the experiment, the experimenters ensured that the server was properly communicating with all subsystems. Thereafter, a meet and greet session was held with each caregiver–counterpart pair. The experimenters elaborated on the experimental details such as the significance of the light encodings, experimental conditions, measurement instruments, ambient displays, and moderated the signing of the informed consent forms. Each caregiver–counterpart pair was then fitted with the waist-mounted smartphone.

Subsequently, both the caregiver and their counterpart were placed in two separated living labs. Note that upon arrival, participants were orientated with their environment and told that they were not limited to remain indoors during each condition. In particular, caregivers were encouraged to follow a script comprising of five activities each lasting six minutes. Caregivers were also advised to execute the activities in sequential order. An example of the scripted sequence of activities is given below.

1. Read book or the newspaper or browse the internet
2. Do some physical exercise
3. Do some mental activity e.g., puzzle

4. Take a stroll

5. Lie on the couch

In contrast, the counterparts were not expected to follow a script. Instead, they were given a deck of activity cards (see figure 8.4 indicating the types of activities they could perform within the experiment), bearing in mind that there were no restrictions in the order or time spent in a particular activity. Additionally, counterparts were instructed to record the sequence of activities performed and the time spent in each activity in the notebook provided. This was done to establish the ground truth in a minimally invasive way.

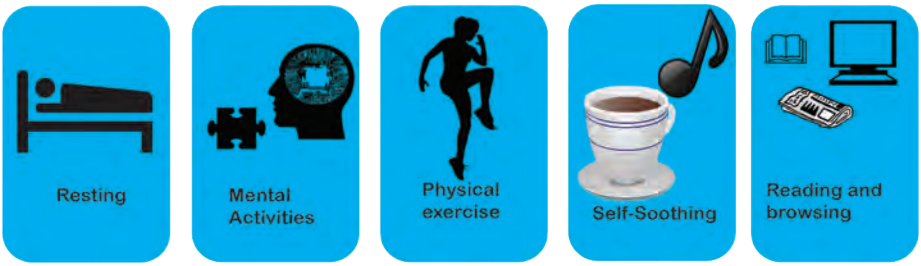


Figure 8.4 A snapshot describing the possible activities, which could be performed in the experiment.

After the experiment preliminaries were completed, in a pre-test participants ranked their assessment of relationship closeness with their counterpart. Each experimental condition lasted for 30 minutes. Also, at the end of each experimental condition all participants completed a post-test ranking their interpersonal closeness with the IOS scale. Following the completion of both experimental conditions, participants ranked their experience of social presence using an adapted version of the social presence questionnaire (Harms & Biocca, 2004) and thereafter participated in a post-evaluation interview, which was audio-taped. Interviews conducted in Dutch were facilitated and translated with the assistance a native Dutch speaker.

## 8.4 Quantitative Results

The results from both interactions styles, i.e., (i) with activity-based ambient light and (ii) with white light were analysed using the R Project for Statistical Computing. The analytical methods and research outcomes are presented and discussed below.

### 8.4.1 Clarity of Perceived Bidirectional Activity Levels

From the shorthand definition of social presence (cf. chapter 2) (Biocca & Harms, 2002), it can be inferred that an understanding of a mediated body's intentional states is an important pre-requisite for promulgating social presence in mediated environments. Figure 8.5 shows a scatter plot of the clarity of the information perceived in both interaction styles. Noteworthy

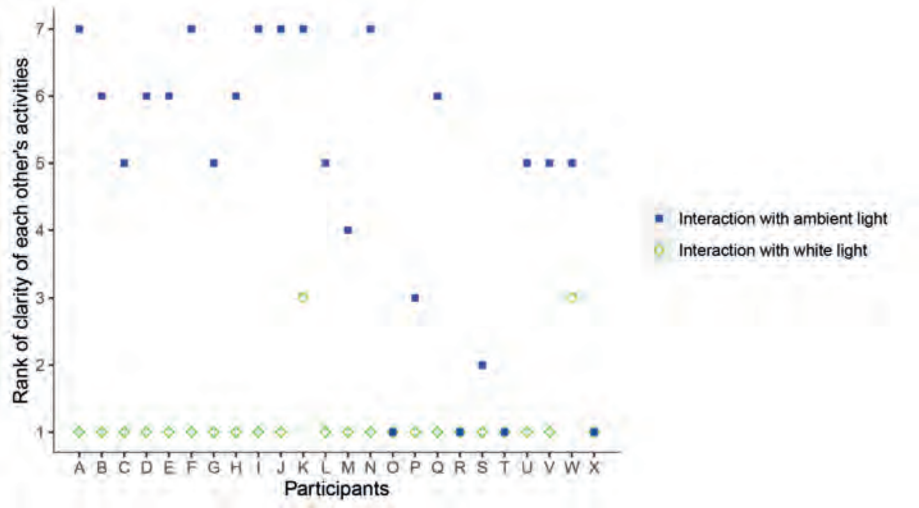


Figure 8.5 Scatter plot portraying the clarity of perceived bidirectional activity levels.

differences were found in the reports of information clarity with respect to the perception of activity levels in the activity-based ambient light interaction and that of white light. Statistically, a one-way ANOVA with repeated measures gave $F(1,23) = 70$ and $p = 1.97e{-}08$. Furthermore, by computing the $\eta_p^2$ (partial eta squared) measure, we obtained an effect size of 0.75, which is substantial according to the recommendations for the magnitude of effect sizes by J. Miles and Shevlin (2001). From the results, we can infer that the information portrayed in the "activity-based ambient light" interaction was clear and meaningful. However, this will be confirmed later by the qualitative results.

### 8.4.2 Perceived Attentional Engagement

Recall from the study findings in chapters 4 and 6 that the overuse of attentional resources was a marked limitation in both studies. A remarkable result to emerge from the data is that there were fewer accounts of attentional burden during system deployment. Figure 8.6 provides an overview of the subjective estimates of attentional resources utilized in both interaction styles. The scatter plots illustrate almost similar distributions between the "with

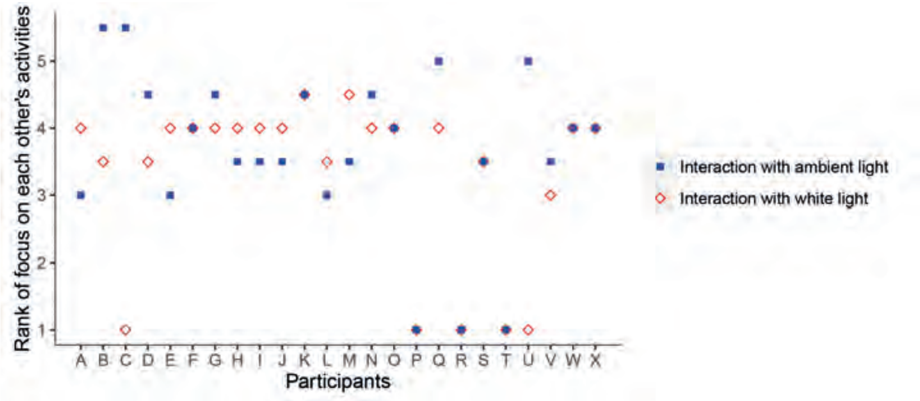


Figure 8.6 Scatter plot of the estimated attentional resources utilized per interaction style.

white light" and the "with activity-based ambient light" interaction styles with no statistically significant difference ($p = 0.195$) between them. Our findings appear to be well supported by the participants' qualitative accounts of multi-tasking only taking occasional glances at their partner's activities to avoid distraction and concentrate on their primary tasks.

### 8.4.3 Relationship Closeness Pre- and Post Interaction Styles

As discussed in chapter 2, Van Bel et al. (2009) highlighted the feeling of closeness as a dimension of social connectedness. Consequently, this measure was computed to determine the implications on interpersonal closeness with and without the activity-based ambient display.

A one-way analysis of variance (ANOVA) with repeated measures was calculated, which revealed a statistically significant difference between the self-reported IOS pre- and post-experiments with $F(2,46) = 16.25$ and $p = 4.58e-06$. In addition, by computing the $\eta_p^2$ measure yielded an effect size of 0.41, which is reasonably large according to the recommendations for the magnitude of effect sizes by J. Miles and Shevlin (2001). Figure 8.7 portrays a box plot of the perceived relationship closeness pre- and post- interaction styles. From figure 8.7, it is apparent that the mean IOS depreciates during the white light interaction in which there was no exchange of activity information between interaction partners. A pairwise comparison revealed a statistically significant difference in relationship closeness before stimulus exposure and following the interaction with activity-based ambient light

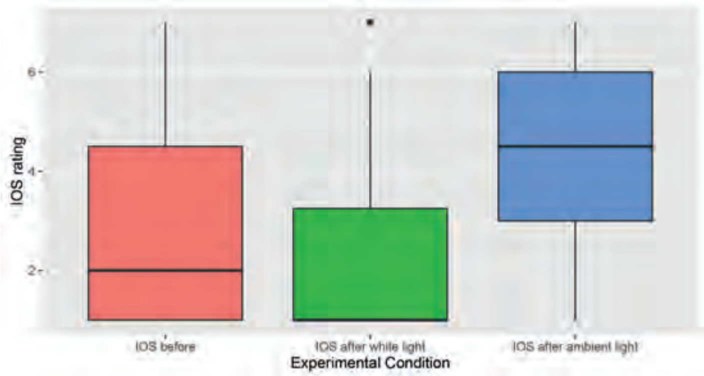


Figure 8.7 Box plot showing IOS estimation pre- and post- interaction styles.

resulting in a p-value of 0.00251. Comparing the IOS ratings before exposure and post the interaction with white light did not reveal a statistical difference ($p = 0.0568$).

### 8.4.4 Estimation of Co-presence

The findings from the study in chapter 4, point to the likelihood of experienced social presence – the feeling of being with mediated the other (Biocca & Harms, 2002). As we sought to validate this finding, participants gave their estimations of perceived co-presence in each interaction style. By deploying a one-way ANOVA with repeated measures we obtained a statistically significant result with $F(1,23) = 26.74$ and $p = 3.05e-05$.

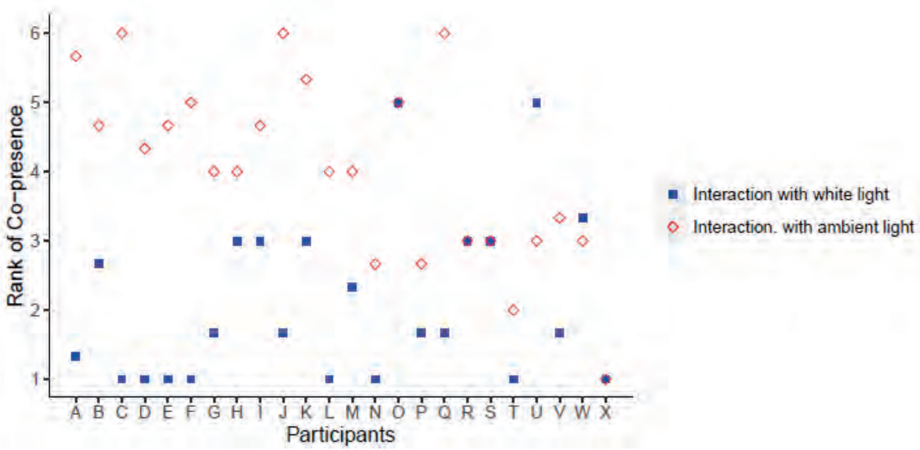


Figure 8.8 Scatter plot illustrating the extent of co-presence between participant pairs.

Moreover, using $\eta_p^2$ we obtained an effect size of 0.54, which is relatively large according to the rules of thumb on the magnitude of effect sizes by J. Miles and Shevlin (2001). From figure 8.8, it is apparent that there were more reports of experienced co-presence in the "activity-based ambient light" interaction when compared to the interaction "with white light". This finding reinforces the usefulness of bidirectional activity-based displays for stimulating social presence.

### 8.4.5 The Extent of the Caregivers' Influence on the Counterparts' Activity Levels

Behavioural interdependence is underlined as an important dimension of social presence (Biocca & Harms, 2002). Thus, self-reports of interdependent actions could complement the cross-correlation analysis on sensed activity data. Recall that this measure was only ranked by the counterparts as caregivers were expected to strictly follow the activity script. A one-way ANOVA with repeated measures revealed a statistically significant difference between the reported influence with $F(1,11) = 10.24$ and $p = 0.00845$. Also, by calculating $\eta_p^2$ the results show an effect size of 0.48, which is large enough according to the rules of thumb on the magnitude of effect sizes by J. Miles and Shevlin (2001). Figure 8.9 demonstrates the degree of symmetry of the counterparts' activity levels with that of the caregiver.

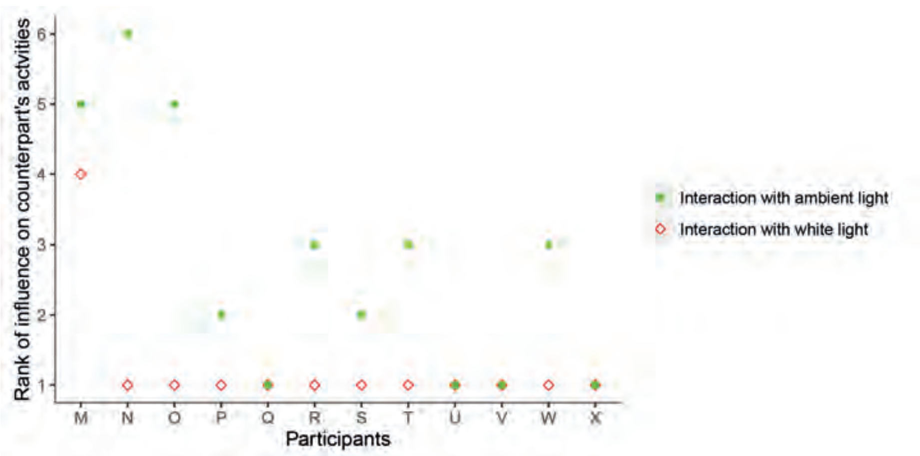


Figure 8.9 Scatter plot showing the extent of the caregivers' influence on the counterparts' activity levels.

Overall, counterparts reported that they were more motivated to coordinate their activity levels with that of their caregivers while interacting with the activity-based ambient light in comparison to their interaction with white light. This confirms our assumption that a stimulus is necessary to create awareness and prompt a behavioural change to act upon the information received in mediated environments. In the case of the "with white light" interaction, the activity information was unknown, and hence there was no interaction.

### 8.4.6 System Adoption

Following system deployment, we wanted to determine the number of participants who were interested in adopting the system in the long-term. Logically, system adoption was only computed for the "with activity-based ambient light" interaction style. In this case, both the caregivers and their counterparts stated their perceptions on future system adoption. Their subjective attitudes toward adoption are depicted in figure 8.10. The findings suggest that

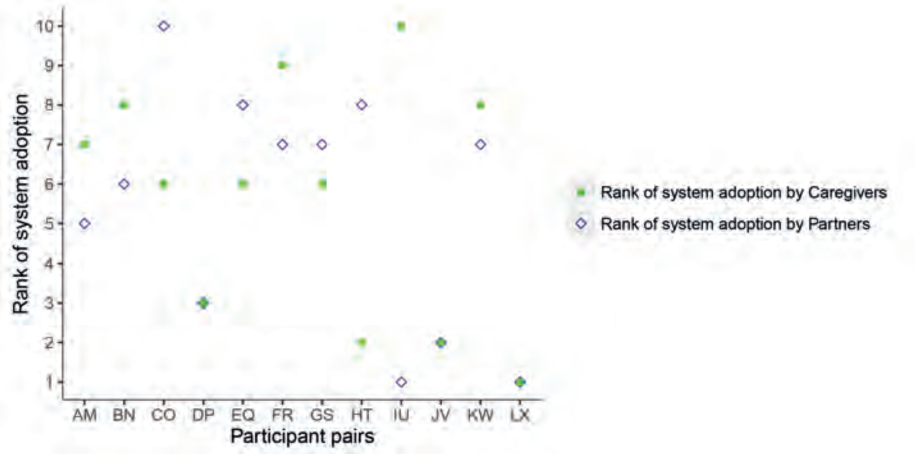


Figure 8.10 Scatter plot representing the subjective ratings on system adoption.

participants were moderately inclined toward system adoption in the long-run. Additional insights are further implied in the qualitative analysis.

### 8.4.7 Towards Interpersonal Activity Synchrony – the Caregiver's Influence on their Counterpart's Activity Levels

To analyse interpersonal activity synchrony, we calculated the sample cross-correlation coefficient (CCF) (Shumway & Stoffer, 2010) between activity levels of caregivers and their counterparts for every $6 - minute$ interval that the caregivers remained in an activity level specified by the script. Due to time constraints, the script specified 5 activities to be performed within a $30-minute$ interval. Therefore, activity levels were distributed equally in $6-minute$ intervals. Note that resting, passive, and active activity levels were assigned the following values 0, 1, and 2, respectively.

As described in the system architecture of the bidirectional ambient display platform (cf. chapter 7), the server detected a maximum of two activities for every 5 *seconds* worth of data from the waist-mounted smartphone. This implies that a minimum of 2.5 *seconds* of sensor data was required in order to detect an activity. This introduced a minimum lag of 2.5 *seconds* (1 *lag unit*) and a maximum lag between 5 *seconds* (2 *lag units*) and 7.5 *seconds* (3 *lag units*) for an activity to be collected, detected, and transmitted to a participant. The sample CCF of time-series variables $x$ and $y$, representing both the caregiver's and their counterpart's activity levels respectively, at time $t$, given a lag $\tau$ was calculated as follows: Given a sample cross-covariance,

$$\sigma_{xy}(\tau) = \frac{\sum_{t=1}^{n-\tau}(x_{t+\tau}-\bar{x})(y_t-\bar{y})}{n}$$

the sample cross-correlation (CCF) is given by:

$$\rho_{xy}(\tau) = \frac{\sigma_{xy}(\tau)}{\sqrt{\sigma_x(0)\sigma_y(0)}}$$

where $n$ is number of activity levels detected within a $6-minute$ interval and $\bar{x}$ and $\bar{y}$ are the means of the activity levels of a participant pair (i.e., elderly – caregiver) within a $6-minute$ interval. With negative lags, the caregiver is made to lead their counterpart to serve as a reference for analysing activity synchrony of the counterpart. The sample (CCF) was calculated for each $6-minute$ interval. Thereafter, the mean of the sample CCFs with lags

$$-1 \leq \tau \leq -3$$

were estimated for each interval.

From the analysis shown in figure 8.11, we found no statistically significant pattern of activity synchrony between caregiver and their counterparts in the "with activity-based ambient light" interaction style. In some instances, we observed a significant positive correlation (indicating interpersonal activity synchrony) as in the case of the participant pair KW, but there was no other significant positive or negative correlations among the remaining cases. Consequently, these findings need to be interpreted with caution as we are unable to make any significant assertions regarding interpersonal activity synchrony on the basis that there was also no consistent sample CCFs within and between interaction styles.

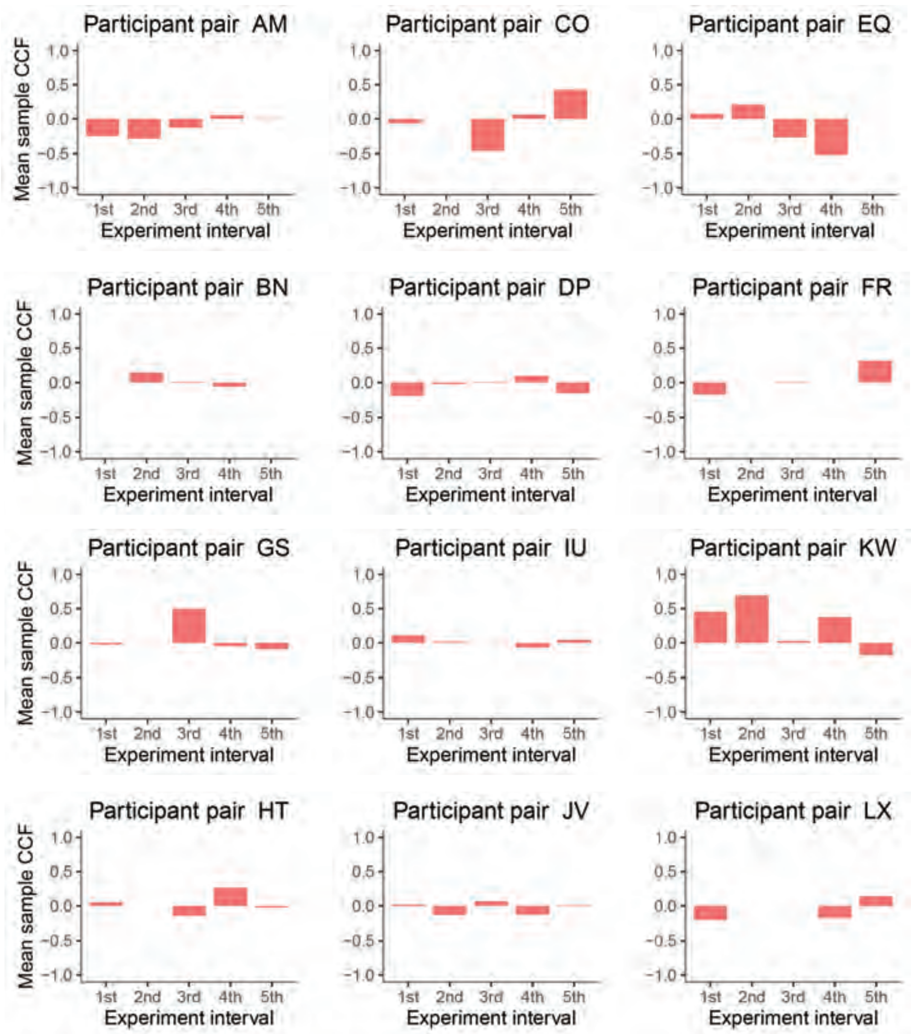


Figure 8.11 Mean sample CCF for the activity-based interaction.

Table 8.2 Percentage of time spent in activity levels

| | Resting (%) | Passive (%) | Active (%) |
|---|---|---|---|
| **Ambient Light** | 17.06 | 68.1 | 14.8 |
| **White light** | 26.4 | 60.9 | 12.8 |

Notwithstanding the lack of synchrony, we observed that in the activity-based ambient light interaction, counterparts were in most cases as equally or more active than their caregivers whilst counterparts were frequently observed to be less active than their caregivers during the interaction with white light. Table 8.2 portrays the percentages of time partners spent in each activity level per interaction style. While figures 8.12 and 8.13 demonstrate the mean activity levels with white light and with activity-based ambient light.

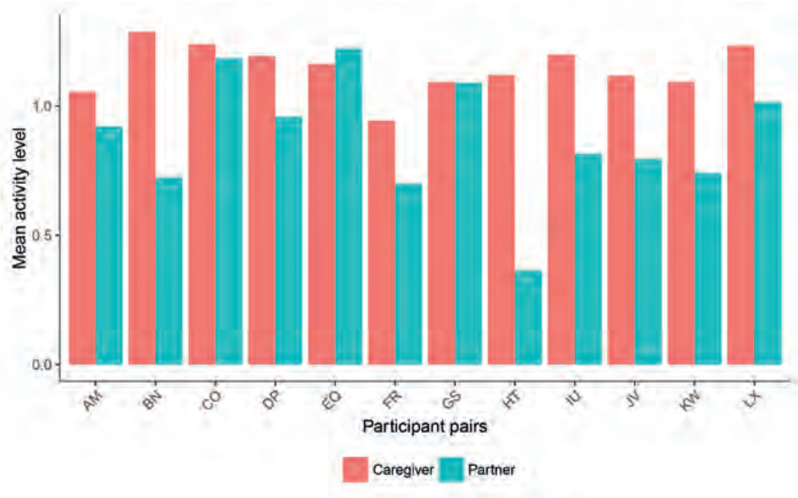


Figure 8.12 Mean activity levels in the interaction with white light.

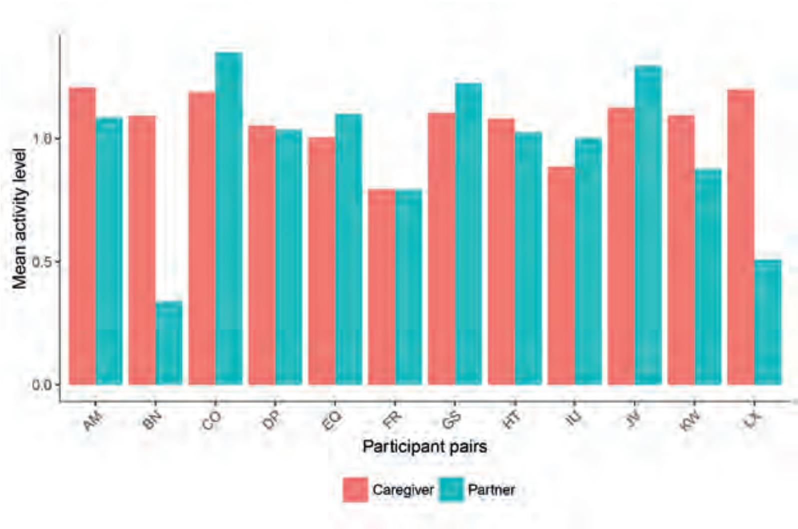


Figure 8.13 Mean activity levels in the interaction with activity-based ambient light.

This finding together with estimations of the influence of the receipt of caregivers' activity information on their counterparts points to the possibility of interpersonal activity synchrony in long-term deployments of the system.

### 8.4.8 Discussion

In this experiment, we aspired to investigate how the exchange of activity information between two user groups (caregivers and their counterparts) would affect the following: interpersonal synchrony on the part of the counterpart, interpersonal relationship closeness, co-presence, behavioural interdependence, information clarity, attentional engagement, system adoption, and interpersonal activity synchrony. The results have further strengthened our confidence that the "with activity-based ambient light" interaction style was clearly more effective for affecting the social connectedness experience in the case of our experiment. The subjects reported increased sensations of relational closeness, co-presence, co-action with their caregiver partner in the case of the elderly, and information clarity during their interactions with the activity-based ambient display. Moreover, the idea of usable everyday objects for the bidirectional exchange of activity information was supported by a large number of participants. In addition, the findings on attentional allocation are in accordance with our intended goal to facilitate perception at a glance thereby facilitating divided attention (Kahneman, 1973) as elaborated in chapter 2. Regrettably, evidence of interpersonal activity synchrony was significantly weaker than anticipated in this short-term deployment. However, it is worthwhile to note that the assessment of interpersonal activity synchrony in mediated environments is not trivial. In fact, recall from chapter 5 that Rashidi et al. (2011) reminded us of the difficulty in measuring ADLs based on the assertion that the sequence and the way in which activities are performed may vary across individuals. From this claim, it is clear that this assumption not only holds true for the recognition of ADLs in general, but also for computing interpersonal activity synchrony using peripheral displays in AAL environments. Likewise, Ekman et al. (2012) also articulated their uncertainties regarding the extent to which synchrony can occur in mediated environments. Although there were spontaneous instances of interpersonal activity synchrony as clarified in our qualitative analysis, we believe that 30 minutes was not enough to significantly affect interpersonal activity synchrony in mediated domains. Further work will focus on longer deployments to estimate the effects on interpersonal activity synchrony in mediated AAL environments. We will now present the qualitative findings.

## 8.5 Qualitative Results

Our analytical approach bears close resemblance to the procedure proposed by Steele et al. (2009) such that interview transcripts were analysed and the findings were discussed and validated with a professional care support worker. Important ideas and suggestions provided by the domain expert were taken into account during the discussions. Exploiting the thematic analysis (Braun & Clarke, 2006) approach, two hundred and ninety-four statements were examined to identify major themes and sub-themes related to the users' impressions on perception, usability, system adoption, interpersonal activity synchrony, and envisioned system benefits among others. These themes and sub-themes are now discussed.

### 8.5.1 Perceived Usefulness of Bidirectional Activity-Based Displays for Promoting Context-Awareness

The participant majority praised the system for its ability to raise context-awareness. In particular, most interviewees reported on the system's ability to trigger context-awareness owing to the following properties.

- peripheral features enabling divided attention
- information clarity
- respects privacy and dignity rights
- simplicity and effortlessness
- portability and multifunctional everyday objects
- implicit communication channel

From the quotations below, further insight can be gleaned on the implications of bidirectional for promoting social connectedness.

*"I only looked at the light for a few minutes, and then I just started focusing on what I was doing while taking occasional glances."* – Q

*"It is rather clear what he is doing."* – D

*"I don't feel like someone is looking around for me. It is simple."* – W

*"The ability to carry the wallet around is good so you can see the activities of your partner whilst you are outside and when you in the house you can see the lamp."* – A

*"The cane is so cool, I can carry it around, and it serves two purposes one as a light and the other to access information anywhere. "* – M

*"We sit in the same office and to know what he is doing I would have to look at him, and then I can see that he is working on his computer. Now, the lamp is a bit more discrete and is a good indicator of his activities."* – F

*"It would be nice to see what they are doing without FaceTime or taking too much time to feel their existence."* – C

### 8.5.2 Uncertainty

Although a large number of participants acknowledged the potential benefits of the system, yet, there were a few elderly participants who consistently expressed uncertainty regarding ambient technologies for social connectedness. During the investigation, it was apparent that one participant appeared to be technology-illiterate (e.g., he expressed his disdain for assistive devices due to technical inexperience). In addition, the significance of culture on adoption played an important role in the level of uncertainty and ultimately another participant's disapproval of peripheral technologies.

*"I never use a computer, in fact, I don't know how to use it. I don't even have a smartphone. I know there are technologies to call the doctor if you need help but I would never use them, I would rather use the telephone."* – X

It is also evident that culture played a significant role in the adoption of peripheral technologies. In fact, some Dutch participants reflected response patterns that were highly individualistic[2] in nature.

*"I don't need to know what another person is doing every moment of the day."* – X

*"Okay, I see different lights showing me my partner's activities. Then, I didn't know what to do with it. What are the implications? Why do I need it? If my mother were alive then maybe when she was ill it would have been useful, but I don't need it now to keep in touch with my friend."* – W

*"It is not so important for me maybe there are positive effects but not for me. Most of the time, my wife and I we leave each other free, so I don't need it."* – V

Moreover, another respondent perceived that the system could easily disappear in the background, which he thought to be negative especially for both context-awareness and social connectedness.

*"I saw different lights, but it could be the same as having the television on and it fades in the background. If there are changes, then I wouldn't notice them and I wouldn't feel anything."* – U

[2] `https://geert-hofstede.com/netherlands.html`

### 8.5.3 Role of Perceptual Processes on the Experience of Social Connectedness and Context-Awareness

Based on the responses we can infer a possible link between context-awareness and social connectedness, which is exemplified by Mr. A's comment.

*"Perceiving your partner's activity information makes you feel like you know their daily routines so you can form a mental pattern of what they do overtime and that can make you feel connected."* – A

Also, from Mr. A's statement, we can deduce the relevance of cognitive processes discussed in chapter 2 (e.g., attention, perception, pattern recognition, and memory) as key concepts essential for facilitating context-awareness and social connectedness. Furthermore, it is imperative that the activity information received from the display is aligned with the user's mental model of their counterpart's activities. This is reflective of top-down processing as discussed by Engel et al. (2001).

Moreover, from Mr. M's comment, we reckon the significance of habituation (cf. chapter 2) for social interaction in mediated environments. This is reflected in the following quotation.

*"I think if I get accustomed to observing someone else's activity then over time I would feel even more connected."* – M

### 8.5.4 Interactivity and Social Influence

The opportunity to exchange activity information without communication media such as Skype, FaceTime, or text messaging was highly valued among younger participants. A possible explanation for their acceptance can be attributed to multiple references to separation by geographical distance from their parents. In general, a great deal of social presence was experienced between younger interaction partners coupled with sporadic occurrences of interpersonal activity synchrony between them. Furthermore, respondents elaborated on the potential social influences of bidirectional activity-based ambient systems and highlighted the effects on engagement by virtue of the cryptic nature of the display.

#### Social Presence

Like the respondents in chapter 4, most younger participants were very passionate about the system's indirect influence on social presence and by extension social connectedness. Example statements are given below.

*"I liked the fact that although we were in different places, I still felt like she was quite close to me. I knew what she was doing and I was wondering what she thought about my activities. I am quite anxious for us to discuss our activities later."* – B

*"I feel like she is somehow with me indirectly."* – O

*"With ambient light even though I was alone, I didn't feel alone. I think this will be useful for lonely people."* – I

**Interpersonal Activity Synchrony**

Figure 8.14 Pictorial representation of interpersonal activity synchrony, the counterpart is observed in a resting state while is his caregiver is also in a resting state as depicted by the blue light. This snapshot was captured during the experiment.

Most of the younger participants were captivated by the possibility of synchronizing their activities with their partner. Furthermore, the participant majority suggested that the exchange of activity levels could create intimacy and increase social interaction. This is encapsulated in the statement below.

*"It is nice to see what the other person is doing and that perhaps you can do the same things together to form some kind of bond."* – R

An interesting observation reflecting interpersonal activity synchrony of two interacting partners is demonstrated below.

In one instance, the caregiver stated the following. *"There were times I had the feeling that he was doing what I was doing because when I was doing physical exercise, his light was also red."* – G

While her counterpart mentioned,

*"I had the impression that she was mirroring me especially when I was resting she was resting."* – S

This interaction is evidenced in figure 8.14.

### Social Influence: Persuasion versus Peer Pressure

Although synchrony appears to be intriguing, some participants argued that it could potentially have positive and negative effects on social interaction. Positive influences include the system's functional role in persuading its users to engage in the same activities. An example statement is given below.

*"When I saw that my partner was active it made me feel like I should have been active as well. Also, while I was exercising and she was relaxing I felt like I wanted to relax as well."* – C

On the other hand, a few participants stated that the system appeared to have adverse consequences resulting in social pressure to prevent embarrassment. In one instance, a participant mentioned that she was uncertain as to whether or not she should coordinate her activities with her partner. This is shown below.

*"There was a moment when I was sitting because I already finished exercising and I was going to read, but then she was engaged in a physical activity maybe exercising. I didn't want her to feel like I wasn't doing anything. I felt a bit embarrassed. She was doing something productive, and I was just there sitting. That's not good for my reputation."* – O

While another respondent was bothered by the system's persuasive effects as an implicit trigger point for stress.

*"For me, my mom always wants me to exercise and also my dad is trying to lose weight. So, if we are both home and my dad is exercising, then it could influence me to exercise also. But this could be silently stressful because I can see my father is exercising and I am either sleeping or eating a hamburger or watching TV. Then, I could feel a bit stressed."* – N

### Mysterious Engagements

As highlighted in chapter 4, some participants expressed a liking for the system's mysterious effects, which prompted them to mentally decrypt the exact nature of their partner's activities. This is reflected in the following statement.

*"Sometimes, I was guessing what my partner was doing. In some instances, I knew she was doing some kind of mental activity but I didn't know exactly what she was doing. I would say it was a bit mysterious."* – Q

The respondent further argued that the system's mysterious effects could stimulate communication through other communication media.

*"For example, if I am alone at home and I am trying to figure out what my partner is doing based on the information received. Then, I may initiate further communication by calling her on Skype to determine what exactly she is doing."* – Q

### 8.5.5 Relevance to the Frail Elderly – I'm Still Young I Don't Need It Now

Like the elderly respondents in chapter 3, most elderly participants in this study commented on the relevance of the context-awareness systems for the frail elderly. These comments illustrate the tendency among our older participants to still feel young inside (Andrews, 1999) by articulating their independence and stating how they demystified ageist stereotypes, e.g., ill-health, cognitive decline, feeling sad or lonely, and the lack of vigour or vitality discussed by Thornton (2002). Example statements are presented below.

*"My wife and I are very active, so we don't need it now maybe when we are older."* – D

*"I am alright, I am very capable of taking care of myself at home."* – H

### 8.5.6 Risks and Emergency Management

As pointed out earlier, the majority of our younger participants were excited about the social connectedness benefits of the system. However, some participants were more focussed on the context-awareness features mainly for its potential in supporting the safety and monitoring of their elderly loved ones. One elderly participant was readily accepting of such systems because of her husband's current battle with dementia. As Mrs. T reflected on her husband's dementia, she stated the following.

*"With lighting colour changes, I can easily observe my husband's activities while he is in another room without being present with him all the time."* – T

Also, others mentioned the need for such systems for anomaly detection to identify irregular movement patterns of their elderly loved ones. These accounts are discussed below.

*"If my relative is sick then is important to know if she is not moving at all."* – I

*"I want to know if something goes wrong"* – N

Although the bidirectional activity-based ambient displays were designed to provide context-awareness and enhance social connectedness, some participants suggested that it is still necessary to provide emergency detection capabilities to complement the existing system. Additionally, a few participants suggested the need for an alarm feature for notifying caregivers in the event of an emergency.

*"How can you distinguish between a person sleeping or an accident where someone has fallen on the floor? I think there is need of an extra indication for falling."* – D

Also, Mr. K suggested that by introducing additional physiological measurements such as heart rate along with an alarm system could assist professional care workers.

*"A supervision system for a nurse monitoring several people could detect heart rhythm and send an alarm if something is wrong."* – K

Furthermore, Mrs. T pointed out that an alarm system could assist with the monitoring of her husband with dementia who tends to wander off outdoors.

*"What if my husband wakes up from his sleep and starts moving? What if he wanders off outdoors? Maybe the system could signal an alarm once the front door is opened or illuminate all the colours at once to indicate some form of danger."* – T

### 8.5.7 Design Suggestions

Overall, the design suggestions include ideas to offer more subtlety, humanize the display, improve aesthetics, battery life and sensor comfort, the addition of ancillary features such as vibration and sound, reduced sensitivity, and an extension of the system's scope.

#### Support Invisible Design

Going back to Weiser's vision of calm technology (Weiser, 1991) ("those that disappear [...] They weave themselves into the fabric of everyday life until they are indistinguishable from it" (p. 1). A few participants made recommendations to improve the subtlety of the design. The following comments suggest how this can be achieved through simplicity, smaller LEDs, and reduced brightness for portable displays.

*"Although the wallet is useful and attractive the light is quite obvious. Let's say you have to pay with the wallet then everyone says hey it's Christmas time! Therefore, a much simpler LED would be sufficient."* – K

*"Is it necessary to have such a long stick to receive information? Is it possible to have something smaller? I think that would be better."* – W

*"The cane's LED could become irritating. Maybe, it's because I really don't like LED strips it's a personal thing."* – P

*"The light on the wallet is very strong maybe something less bright and smaller."* – D

### More Explicit Communication Features

Although most participants were enthralled by the implicit communication characteristics of the light, there were two exceptions. In fact, these participants expressed interest in more explicit interpersonal communication features. This is apparent in the quotations below.

*"When you are in the same room with a person, and you feel like you want to talk you can just talk to them. But in two different rooms, you cannot talk to the lights."* – G

*"Maybe, we can interact not only by changing activity states with the lights but also exchanging messages saying now let's get active.* – C

### Improve the Battery Life

Interestingly, one participant observed the battery limitations of the LED wallet. This is depicted below.

*"I think it's a good system however the lifespan of the LED battery is short.* – A

Recommendations for maximizing the performance of the battery life (e.g., exploiting devices that work at 1.8V ) were discussed in chapter 7 of this dissertation.

### Colour

Like the experimental results in chapters 3, 4, and 6, various participants desired the freedom of colour choice based on personal preference. Moreover, a few respondents were more in favour of exploiting green for resting and blue for passive. While other younger participants were cognizant of the implicit association of red with danger and a few expressed disturbance and restlessness with the colour red. As such, warmer colours such as orange were proposed as a replacement for red. Example statements are highlighted below.

*"Intuitively, I would use green for a state of calmness and blue for mental activity."* – R

*"For physical activity, I would use orange or yellow, something warm."* – C

### Position of the Smartphone

Even though all older participants expressed their satisfaction with the waist-mounted smartphone, there were a few younger participants who expressed their discomfort. In hindsight, these participants expressed discomfort during physical activities and one participant described her overall experience with the smartphone sensor as "burdensome". To rid themselves of the excess baggage, they proposed the following.

*"The smartphone was a bit heavy. If it's on my personal smartphone it's okay, but if I have to carry an extra smartphone it might be too much.* – F

*"The smartphone could be in the pocket to prevent discomfort during exercise."* – B

### Vibration / Sound Effects

Although most participants were pleased with the peripheral nature of the system, a few were critical on the system's ability to sustain awareness during high periods of concentration. Accordingly, they prescribed additional sound or vibration effects to alert the user's attention and in some cases minimize the cognitive load. These recommendations are illustrated below.

*"Maybe, add some vibration because when we are doing a mental activity we tend to focus and vibration could make us more alert."* – E

*"Maybe, I would add sound effects so that I wouldn't have to always look at the light."* – L

### Exploitation of Additional Everyday Objects

Although almost all the informants were positive toward our design choice of exploiting a cane and wallet, there were two respondents who suggested other everyday objects such as an ambient smartphone or an ambient id/key card. Their propositions are encapsulated within the following comments.

*"You can use something that's more portable something like a mobile phone. Maybe you can use the Philips Ambilight TV as a reference."* – R

*"In the context of a caregiver, I wouldn't check my wallet all the time. They always carry an ID or a key card so some indication on those objects could be better."* – C

### Expanding the System Scope

A few participants were desirous of knowing the strength of the activity level, which could be illustrated with additional colours or changes in light intensity.

*"I would increase the brightness based on the intensity of the activity."* – W

However, one participant articulated her preference for only two activity levels namely (i) active or (ii) inactive to reduce any misconceptions of an intermediate activity level. Recall that a similar abstraction is implemented in chapter 4. Her citation is recorded below.

*"Sometimes I forgot the meaning of the green and wondered whether they were engaged in mental activities or not. I think it would be better to have active or inactive states."* – C

Remarkably, the temporal nature of activity information (cf. chapter 6) was reiterated by a young male informant when he voiced the following.

*"It would be nice if I could see a summary of the data so I can see what happened in the past."* – S

Moreover, one responded urged for an expansion of the system to support self-tracking.

*"It's an interesting concept. However, I am more interested in knowing how I react when I am reading or sleeping or exercising. This would give me personal biofeedback."* – B

### 8.5.8 Design Considerations for Bidirectional Ambient Displays for AAL

There were some key factors that emerged during the discussions with our participants, which include the following.

- Privacy and Ethics
- Context of Use
- Spatial Position
- Aesthetics

**Privacy and Ethics**

Generally participants were satisfied with the level of privacy offered by the system. Example accounts are given below.

*"You have a feeling of connectivity indicating what the partner is doing without disturbing him with camera supervision. So, everyone is free to do what he or she wants while there is still a feeling that there is life, to say the least."* – K

*"It gives a good indication of what the other is doing. It is simple, and there is a certain privacy it provides. You don't feel observed."* – P

Still, a few participants were fundamentally concerned with the potential privacy risks of ambient technologies. For example, Mrs. H remarked on the 'big brother is watching you' effect of the deployment of context-aware technologies in AAL environments.

*I won't like it if I lost my independence and someone can see if I feel okay or not. I would like to maintain my privacy as it's my right not to be okay. Someone else doesn't need to know. For me, it would feel like a 'big brother is watching me'. No, I wouldn't want to be constantly monitored so that someone can see how I feel. No, I don't like that."* – H

Moreover, even though some participants were well aware of the privacy risks they were more willing to trade privacy for security. For example, Ms. O argued in the following statement.

*"It's kind of uncomfortable for me to know that my mother always knows what I am doing right now, but for both of us to determine if we are in a 'safe' state then this system is very good. We are two far away [...] I want to her to know that I am okay."* – O

### Context and Purpose

From the commentaries, we observed that a few younger adults highlighted that the context and purpose of the system could affect adoption. Importantly, one young person stated that the system was only relevant for context-awareness only if her elderly relative was ill. Otherwise, it could be distracting.

*"It depends on the situation if my relative is sick, then I will use it. But if I don't need to know what she is doing then it would be disturbing for my own life. So, the purpose is important."* – I

With reference to situational context, another young person mentioned its relevance only in the home.

*"Also, context is important if I am at home and they are at home then possibly it is okay. If I am at work and they are at work, then I don't need to know what they are doing. What's important is that they are okay."* – N

However, in the home context, the user further expressed privacy concerns in the following statement.

*"The thing is sometimes I sleep late and I wouldn't want them to know that. In truth, there are some things that I need to hide. I wouldn't want them to call and say why are you sleeping so late?"* – N

To address privacy and situational context concerns, one participant suggested a service upon request functionality to maintain the right to control, access, and disseminate activity information at his convenience.

*"I would use the lamp when it's a service on request so I should be able to control the functionality. It's a personal system so it should be visible to others only if I want to show them."* – S

Reverting to N's reference on the importance of situational context, she also mentioned that consideration should be given to the time zones of two interacting partners for successful adoption.

*"For me, I need to consider the time zones because sometimes when they are sleeping I am active and vice versa. Sometimes it would be disturbing for them."* – N

Thus, by extension, we believe that the time-zones can affect the degree of synchrony between two interaction partners.

### Spatial Position and the Stability of Social Bonds

From the remarks, we see that spatial position can change how the information is perceived and the degree of experienced social connectedness.

*"In a real life situation, the positioning of the light in the room would be extremely important."* – P

*"I didn't really feel the connection with the light maybe because of the location of the lamp."* – E

Besides, both P and E shared similar perspectives that perception and social connectedness are not only determined by the spatial position but also the stability of the emotional connection, which serves as a motive for observing the display consequently affecting how deeply the information is processed.

*"In fact, I think the real connection outside the experiment will influence the results. If I don't have a good relationship with the partner, then I won't feel anything."* – E

*"If there is an emotional connection between the person in the other room or the person that you are taking care of. Then, there is a positive motivation to look at the lights."* – P

**Aesthetics**

In a general sense, aesthetics was a major perceived benefit of the installation of the ambient displays. Thus, in designing bidirectional ambient technologies consideration must be given to the aesthetic needs of the participants. In retrospect, the participants postulated that the light's aesthetic properties created a pleasant atmosphere, fostered creative thinking through its mysterious effects, and led to elements of surprise, and more fun and playful interactions. Example remarks are demonstrated below. Figure 8.15 demonstrates a participant's interaction with the cane.

*"I think the cane is an eye-catcher for the elderly. I think it's is nice and I like the fact that it surprises me."* – S

*"It was very fun and playful! You can use it for special activities in the home.* – T

Also, C contends the prescriptive interpretation of Sullivan's notion of 'form follows function' (Sullivan, 1896) as she suggests that form is attuned to function in the statement below.

*"It indicates the partner's activities and these colours add a certain ambiance to the room."* – C

However, Lidwell, Holden and Butler (2010) assert that the prescriptive interpretation of 'form follows function' "aesthetic considerations in design should be secondary to functional considerations " (p. 106).

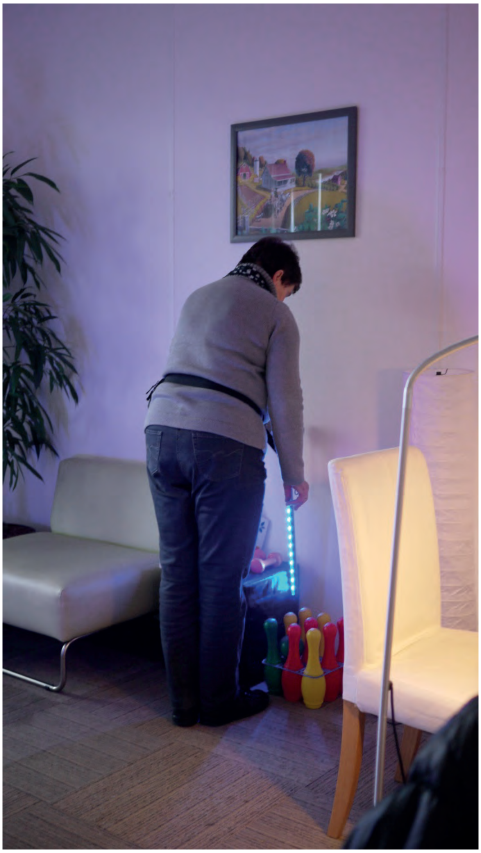

Figure 8.15 Photo demonstrating a participant's interaction with the cane.

## 8.6 General Discussion

Overall, our participants identified several aspects that they found positive about the bidirectional activity-based ambient displays. Most participants could multi-task, feel a sense of their partner's presence, access the activity information any and everywhere, understand the information received, enjoy an implicitly shared interaction, coordinate their activities to some extent, and maintain their privacy. Altogether, we can deduce from our findings that the process of experienced context-awareness and social connectedness among our participants included five phases: (i) visual perception, (ii) attention, (iii) memory, (iv) curiosity, and (v) habituation. Subsequently, the bidirectional exchange of activity information may consciously or unconsciously affect behavioural responses as depicted by the periodic accounts of interpersonal activity synchrony within this study. These irregular instances of coordinated actions could spark interest for further inquiry on the possibility of interpersonal activity synchrony in mediated AAL environments.

On the negative side, a few persons desired increased sensor comfort, more discreet portable displays while some felt that ambient technologies were an invasion of their personal privacy. To address privacy concerns, one informant suggested the addition of a “service upon request feature.” Likewise, Hoof, de Kort, Markopoulos and Soede (2007) recommended that the user has complete control over his information collected and distributed in smart home environments.

### 8.6.1 Design Challenges

The most striking result to emerge from the discussion was the consistent reference to safety and monitoring systems. In fact, this was not surprising as the sense of safety and security in AAL environments has been a recurring theme throughout this dissertation. A possible interpretation for this recurrence can be found in Maslow’s hierarchy of needs (cf. figure 2.1, chapter 2), such that safety and family security needs precede the need for love and belonging (Maslow, 1954). Accordingly, we can infer that once our participants can guarantee the safety of their loved ones, then they can proceed to other forms of interaction to create a sense of belongingness in mediated AAL environments. As such, our design challenge has now become greater given the system scope has stretched beyond the main goal of promoting social connectedness through bidirectional ambient displays. Based on the lessons learned throughout this research, we have devised a set of heuristics, which could be useful to narrow the design scope of peripheral technologies for AAL environments.

- What is the scope of the system?
  - What is the purpose of the peripheral technology that will be designed?
  - Is it a context-aware system for emergency management? Or will it promote social connectedness or both?
  - The system’s scope should be decided in the early phase of the research process based on the available man-power, cost, technical resources, and experts, etc. Note that research in AAL environments especially for emergency management could require extensive bureaucratic processes for conducting experiments with prospective elderly users. Therefore, a designer needs to consider the intended audience. Is the target the ‘young old’, the ‘middle old’, or the ‘frail elderly’?
- Once the decision is made then one should pay keen attention to the following.

  - What kind of information will be portrayed?
  - What type of content will be used to convey information? – In essence, the right data is dependent on the overall purpose of the system.
  - How will this information be collected? How will it be analysed? How will it be portrayed with minimum effort?
  - Are there similar peripheral technologies within AAL? If so, what is the added value the proposed design?

- How is the proposed design relevant to the AAL community?
- How is it expected to change behaviour?
- Explore the available design guidelines, considerations, and sensitivities for AAL, and explore the needs and expectations of the target users.

Going back to Mr. A's statement regarding a mental pattern of the partner's routine activities, it is clear that participants refer to their mental model as a reference for understanding their partner's activities. Consequently, this raises the challenge of designing peripheral technologies, which are coherent with the user's mental model. Norman (2013) suggests that misfortune could arise if the 'system image' is incoherent with the user's conceptual model. Thus, the information portrayed should match with the user's ideology of their partner's activities. To address this, one could deploy highly accurate machine learning classification algorithms. However, system trust is critical for determining the match between the information presented and the user's conceptual model. Also, if there is no system trust then challenges with learnability and usability could emerge.

From our findings, technical literacy and cultural values can shape the users' experience of interacting with the system. Recall that our bidirectional activity-based system exploits ambient technologies and IoT to create awareness and maintain social connectedness between two interaction partners in AAL. Thus, Demiris and Hensel (2009) highlight that inadequate technical literacy could impede the process "because the discussion of security and privacy concerns or issues of accuracy and reliability of sensor systems or other computing applications often require basic understanding of networking and data transfer" (p. 110). Thus, driving the need for technological literacy interventions in AAL. The implications of culture on adoption will be addressed in the succeeding chapter.

### 8.6.2 New Design Opportunities

As is evidenced by the findings, maintaining independence, safety, and quality of life are integral to the ageing process. Moreover, as part of their integration in society and quest to maintain a healthy and balanced lifestyle, the elderly desire to be active, to participate in social life, and venture outdoors. However, challenges such as frailty, mobility, and (mild) cognitive impairment (dementia in the case of Mrs. T's husband) could limit the elderly's ability to go outdoors and manage to return home safely. Nonetheless, these challenges are sheer obstacles, which can be circumvented with peripheral ambient technologies. In fact, from our empirical findings, the ubiquitous nature of sensing infrastructure and the IoT provide unique opportunities for developing smart solutions for creating safer environments for older adults. Through the application of human-centered approaches, impending researchers could develop interactive solutions using everyday objects, which go beyond normal functions to improve the safety, security, and the overall well-being of older adults.

In addition, the notion of the quantified self – self tracking[3] emerged during the discussions as one participant stated her interest in personalized activity tracking via coloured lighting for behavioural introspection. This presents a new design opportunity for prospective researchers to explore personalized tracking of activity information, which could be rendered using ambient displays.

## 8.7 Conclusion and Limitations

To strengthen our assessment of the behavioural implications of bidirectional activity-based displays, this chapter provides a background on interpersonal activity synchrony. Based on the knowledge acquired from prior works, it was possible to evaluate interpersonal activity synchrony by computing the cross-correlation coefficient of the counterpart's activity levels with that of their caregiver's. The results of a semi-controlled study suggest higher incidents of subjective interpersonal relationship closeness, experienced social presence, behavioural interdependence (for the counterpart only), information clarity, and the participants' willingness to adopt the technology, while utilizing minimum attentional resources with the activity-based ambient light interaction style. However, there was hardly any occurrence of interpersonal activity synchrony by using the cross-correlation approach. Nonetheless, during the post-trial interview, a few participants reported sporadic moments of synchrony during their interaction with the activity-based ambient light. Furthermore, in the said interaction

[3] `http://quantifiedself.com/`

style counterparts demonstrated increased tendencies to remain active in contrast to their interaction with white light.

It is plausible that some limitations could have influenced the results of this study. To begin with, we acknowledge convenience sampling as a constraint of this work. Accordingly, the findings are not entirely representative of all users within AAL community. To heighten the interest in our system, one option for future work is to specify the inclusion criteria only for the frail elderly, e.g., those with (Parkinson's disease, Alzheimer's disease, or even users with epilepsy). This we know would reduce the population of our study. On the other hand, it could increase the interest in our system.

We are aware that a larger data stream of activity data is necessary to better estimate interpersonal activity synchrony in mediated environments. This can be achieved by increasing the number of participants and deploying a significantly longer experiment in the users' natural environments.

Unfortunately, the self-awareness of the wearable smart-phone sensor from chapter 4, is still an open problem that will be addressed in future work. Notably, if our algorithms were independent to orientation and location, it could be one of the best contributions in the field of activity recognition for AAL. There are some attempts, but are very limited.

Despite the limitations discussed, the study concludes with a series of design suggestions, considerations, heuristics, challenges, and opportunities for future designers and researchers of peripheral technologies for AAL environments. In the subsequent chapter, we discuss the research conclusions, limitations, and plans for future work.

# Chapter 9

# Conclusions, Limitations, and Future Work

*"Reasoning draws a conclusion and makes us grant the conclusion, but does not make the conclusion certain, nor does it remove doubt so that the mind may rest on the intuition of truth, unless the mind discovers it by the path of experience."*

—Roger Bacon

In this dissertation, we realized a system to support real-time activity awareness and social connectedness through an accessible form of technology designed for use in and outside of the home. The practical relevance of this dissertation is to develop a better understanding of the users' context to support the design and development of a peripheral bidirectional activity-based system to augment context-awareness and alleviate the sense of loneliness commonly experienced in old age.

In this chapter, we first respond to the research questions formulated in chapter 1. Then, we discuss the limitations and our plans for future research.

## 9.1 Answers to Research Questions

**Research Question 1 – *How a better understanding of the users' context can better support the design of connectedness oriented solutions in AAL?***

As previously mentioned (cf. chapter 3), Norman (2013) emphasized the relevance of understanding the user to avoid negative implications on the design of technical interventions. To achieve this goal, we conducted four studies (cf. chapters 3, 4, 6, and 8) to gain a closer look into the users' social context, daily routines, and the elderly's functional ability and independent living skills. More specifically, we employed a participatory design approach (O'reilly, 2012; Schuler & Namioka, 1993) adapting on-site observations, co-constructing stories (Buskermolen & Terken, 2012), in-depth interviews, and questionnaires. As argued in chapter 3, the sensitizing phase of the co-constructing stories methodology was helpful to introduce stakeholders to the risk factors of ageing and encourage users to determine how they could identify with the characters in the story. In hindsight, the participants gave detailed accounts of their social networks, methods of social cohesion, barriers to communication and expressed their perspectives on the relevance of connectedness oriented solutions in AAL.

The results of the studies conducted in chapters 3, 4, 6, and 8 suggest that our participants were relatively well connected, caregivers maintained busy lifestyles, and that the elderly were mostly active in their communities (religious, sports, and volunteer societies, etc.). Also, most elderly participants lived independently and were able to execute their ADLs on their own. On the other hand, sickness, loss of loved ones, and denial were some factors contributing to loneliness among some respondents especially those in chapter 3. Interestingly, our findings showed that some older adults assumed the role of caregiver by taking care of their fellow elderly family members, neighbours, and friends.

As expected, most participants mentioned face-to-face communication as their preferred mode of contact with their relational counterparts. However, distance and job demands prevailed as barriers to communication for the elderly and their caregivers (cf. chapters 3, 4, 6, and 8). Thus, as demonstrated in chapter 8, the caregiver majority had a high reliance on pervasive and ubiquitous technologies (mobile phones, social media, and Skype) to keep in touch and maintain awareness of their elderly relative's well-being. However, due to busy lifestyles and privacy preferences, our findings show that most participants were more in favour of subtle, inconspicuous, bidirectional, and portable devices to support peripheral awareness and their mutual social connectedness (cf. chapters 3, 4, 6, and 8). In fact, both older adults and younger caregiver participants who lived remotely desired to share mutual awareness of each other's activity and well-being information. To address this need, we designed and developed a bidirectional activity-based ambient display system to create peripheral awareness and promote social connectedness in AAL. The results demonstrate that direct communication channels can be complemented with bidirectional peripheral technologies to create indirect awareness and stimulate a sense of social presence for our users. Also, the findings illustrate that by considering the users' needs and context and engaging them throughout the design process, can inform the design decisions about the product functionality and acceptance.

**Research Question 2 –** ***What are the general attitudes, preferences, expectations, and concerns regarding the potential use of AmI technologies for context sensing and increasing social connectedness in AAL environments?***

The studies conducted in chapters 3, 4, 6, and 8 suggest a range of attitudes, preferences, concerns, and perceptions of the elderly and their caregivers regarding AMI technologies supporting context sensing and social connectedness in the AAL domain. Findings from the studies unveiled that culture is a predominant factor determining the acceptance of connectedness oriented solutions in AAL. In fact, scepticism was more prevalent among participants from individualistic Western European societies while participants from collectivist cultures were more accepting of the system (cf. chapters 3, 4, and 8). A prevailing theme was that the participant majority viewed the activity-based bidirectional ambient system as a viable resource for older adults (especially the frail elderly) to provide mutual context-awareness, offer a sense of reassurance to those involved in their care, and provide emergency alerts. Thus, accuracy and reliability to prevent false alarms were common concerns among the respondents. Additionally, some participants identified circumstances and factors that could influence the usefulness and adoption of AmI technologies. Examples include (i) the system's ability to provide meaningful ambient information, (ii) the system's ability to ameliorate the constraints of distance in communication, (iii) the system's ability to support playful interactions in mediated environments, and (iv) the system's influence on moods, well-being, and productivity.

It was evident from the findings that privacy, selective content control, and the provision of an on-demand service should be made readily available to AAL users. Otherwise, a perceived lack of privacy and control over contextual information could lead to uncertainty, a lack of system trust or outright rejection of the system (cf. chapters 3 and 8). Concerning sensing devices, there were clear indications that participants would be more willing to accept subtle and comfortable wearable sensing devices to avoid obtrusion. Similarly, participants generally preferred more discreet ambient displays for conveying information that would quickly fade into the background of their attention.

**Research Question 3 –** ***How to design and develop bidirectional activity-based displays for promoting social connectedness and context-awareness in AAL?***

The work conducted throughout this dissertation exploited visual features namely form, i.e., length of lines (cf. chapter 4), motion (cf. chapter 4), colour (cf. chapters 3, 4, 6, and 8), and light (cf. chapters 3, 6, and 8). In chapter 4, we used animated curve stitching patterns in a real-life study, to examine the effects of a bidirectional activity-based display on context-awareness and social connectedness in mediated environments. Generally, colour and speed were cited as factors that influenced the degree to which social presence was felt over a distance. For instance, red fast curve stitching patterns incited sensations of energy and presence among some respondents. While blue slow curve stitching patterns evoked feelings of calmness, peace, and relaxation. Also, some participants acknowledged the artistic value of the displays, adding to the beauty of their surroundings and promoting introspection. Building on the work conducted by Mankoff et al. (2003); Matviienko et al. (2015); Müller et al. (2012); Tomitsch et al. (2007) we studied how the features of light and colour can be exploited to support activity awareness and social connectedness in AAL. More specifically, we evaluated three lighting configurations that demonstrate changes in activity levels through (i) lighting colour only – (COL_ONLY), (ii) both colour and brightness – (COL_BRI), and (iii) brightness only – (BRI_ONLY), to determine how participants perceived and decoded lighting cues. Also, we evaluated their preferences for lighting features encoding activity information. The results show that the BRI_ONLY configuration was least preferred among participants while the participant majority supported the idea of exploiting the COL_ONLY configuration for easy interpretation, minimal distraction, and reduced mental effort to facilitate information access and meaningful interactions in AAL.

A set of sensitivities and guidelines were produced to inform the design of ambient lighting displays for AAL environments. Building on these findings, we aimed to create aesthetically pleasing visual displays that were simple and intuitive, maintained clear mappings for conveying activity information, and minimized distraction. Although participants perceived the visual modality as suitable for an AAL context, a few participants expressed a genuine interest in an extension of the system to support vibration and sound effects. In addition, a few caregivers requested the inclusion of aggregation features to determine current trends and monitor long term activity patterns of their elderly relatives.

As suggested in response to research question 2, some participants in chapters 3 and 4 were more concerned with the system's ability to provide accuracy and reliability, to avoid false positives in AAL environments. Accordingly, to satisfy user needs, in chapter 5, we developed a hybrid SVM-HMM model to support activity detection with a small margin of error. This hybrid model was evaluated against standalone classical multi-class SVM and ANN classifiers. These three models were trained with public data and data collected from an additional 31 healthy elderly and caregiver volunteers from 14 different countries, ranging from 22 – 79 years. The hybrid SVM-HMM model demonstrated the best classification performance. To assess the feasibility and reliability of the model in a real environment, a real-time bidirectional system was developed (cf. chapter 7) and tested (cf. chapter 8).

More detailed accounts of the participants' daily routines revealed that our caregivers were often busy with their work and family lives while the elderly were relatively active outdoors (e.g., shopping, taking morning walks, etc.). Therefore, we envisioned that prospective users could utilize portable and discreet everyday objects that could seamlessly blend into their environments. To this end, we developed a Philips hue lighting system to support connectivity at home and portable LED ambient displays using a wallet and cane to enable context-awareness when outside. The results indicate that the participant majority were appreciative of the system's ability to support portability. Therefore, designers should consider the importance of form factor, i.e., the shape and size of electrical and non electrical components to meet this need.

Overall, it can be inferred from the respondents in chapters 3 and 8, that many older adults do not consider themselves as old. In practice and from the qualitative portion of this dissertation, it is over simplistic to assume that the elderly are a homogeneous group of people and the application of the 'one size fits all' design approach runs the risk of excluding some older adults. This is particularly challenging especially when working in a culturally diverse environment. Thus, it is imperative to understand the user's context in order to develop useful and acceptable technologies for improving the elderly care experience. Thus, particular attention should be paid to designing technologies that do not allow the elderly to feel helpless or even older than they already are.

**Research Question 4 –*What are the implications of the deployment of bidirectional activity-based displays within AAL?***

The research findings point to a number of social and behavioural implications in mediated AAL environments. From the results, we can infer that the system's ability to support bidirectionality and peripheral awareness was in most cases useful to facilitate the experience of mutual awareness and connectedness between our elderly and caregiver participants. A potential benefit for both the elderly and their caregivers included the ability to implicitly observe their counterpart's activity trends from a distance. In the case of our real-life deployment, the system was useful to provide a sense of comfort and reassurance to our participants.

Also, the research findings show that the bidirectional exchange of activity information can facilitate implicit interactions (e.g., the sense of experienced social presence and connectedness in mediated environments) and evoke more positive social behaviours between the elderly and their caregivers (cf. chapters 4 and 8). However, due to the short duration of the study in chapter 8, we are unable to make conclusive remarks regarding the implications of bidirectional activity displays on interpersonal activity synchrony in AAL environments.

Although the studies conducted in chapter 6 were not representative of our entire population, we were still able to assess the effects of the bidirectional activity-based display on moods and cognitive function in the caregiver's work environment. The findings show positive influences of coloured lighting on perception, concentration and productivity, relaxation and positive moods. However, participants occasionally experienced distraction from the lighting source. Thus, in the subsequent study (cf. chapter 8), we paid close attention to the design sensitivities, e.g., spatial position, light sensitivity, etc. to aid perception and reduce distraction among participants. The research findings suggest that participants experienced minimal distraction with the system (cf. chapter 8). Therefore, multi-tasking (Kahneman, 1973) was highly valued by the participant majority as they were able to execute their primary activities while simultaneously receiving activity information in the background of their attention.

Through the use of abstraction (i.e., the hiding of actual activities and grouping them into levels), the bidirectional activity-based system was cited as potentially useful for enhancing mental performance for older adults (cf. chapter 3). Furthermore, the system was viewed as a potential resource to encourage reflection, i.e., drawing from episodic memory of past interactions with one's counterpart.

Overall, most participants were moderately inclined toward system adoption in the long-run. As mentioned earlier, factors such as relevance based on the older adult's level of frailty, culture, technical abilities, sensor comfort, ease of use, their level of social connectedness, and the system cost could affect the users' attitudes toward the system and by extension adoption.

## 9.2 Limitations and Future Work

The work conducted in this dissertation is not without limitations. These limitations and our future research directions are discussed below.

### Power Consumption

We acknowledge the use of WiFi may not have been a suitable mechanism to support data transfer for our activity recognition system (cf. chapters 7 and 8). Therefore, we hope to explore other options such as Bluetooth to preserve battery life. In fact, the overall consumption is high, and that is the main drawback of the system. In the future, we hope to increase the LED's resistors and introduce sleep modes. We believe that awakening the system after an event interrupt could increase the system's autonomy. Also, using devices that work at 1.8 V would open the possibility to use the whole battery capacity.

### Ambient Modalities Explored

We reckon that we could have explored other modalities to determine the effects of activity awareness on social connectedness and context-awareness. Thus, in the next steps, we hope to integrate audio and vibration effects to offer flexibility in the design and to enable prospective users to select their preferred mode for receiving activity information.

### Length of Studies

We acknowledge that the studies conducted within this dissertation were relatively short and were often carried out in a controlled or semi-controlled environments. As such, in future studies, we hope to deploy longer studies in the users' natural environments.

### Sampling Methods

The studies employed opportunistic sampling thus, most participants were of a higher socio-economic status and educational background, which is not representative of all stakeholders within the AAL community. Furthermore, considering that the elderly are not a homogeneous group, the findings should not be generalizable to the elderly on a whole as older adults differ in their abilities, values, behaviour, needs, experiences, and expectations. In future studies, participants having different educational backgrounds, socio-economic status, value systems, levels in social connectedness and frailty, and technical abilities, etc. should be recruited. In addition, considering the notion of system adoption discussed in chapters 3, 4, 6, and 8, in future work, these experiments could be deployed using a specific set of patients with a determined disease, e.g., (Parkinson's disease, Alzheimer's disease, dementia, or even patients with epilepsy) in order to see the effects on social connectedness and context-awareness.

### Objective Measures

We envisage that the addition of physiological sensors, e.g., heart rate or skin conductance could lead to an improved understanding of the psycho-physiological implications of bid-irectional displays. We suggest this psychophysical approach could be worthwhile for future investigators.

In the subsequent chapter, I provide a personal account of my experiences and observations while designing technologies for social interaction. Also, I discuss some of the challenges experienced during this research.

# Chapter 10

# Reflections

*"Reflect upon your present blessings – of which every man has many – not on your past misfortunes, of which all men have some."*

—Charles Dickens

## 10.1 Introduction

Over the last three and a half years, as part of my doctoral program, I have had the opportunity to live and study in the Netherlands and Italy, while visiting Canada, China, and Japan to fulfil my research obligations. In retrospect, I was very fortunate to be situated in a diverse landscape fashioned by a melting pot of cultures, all struggling to cope with a rapidly ageing population. In hindsight, the trends of population ageing were quite visible in these countries. To my surprise, many naive ageist assumptions were confounded by a platoon of strong, healthy, active, and well-functioning older adults. Nonetheless, some exceptions faced physical disabilities, cognitive, and cardiovascular diseases as well as vulnerabilities to social isolation and loneliness. Despite these challenges, many older adults were insistent on striving to maintain their autonomy and quality of life. Thus, providing a rich opportunity space for designing technologies to promote 'healthy and active' ageing.

In this chapter, I present some of my research observations and later reflect on my experiences with a particular focus on issues that influenced our ability to recruit potential elderly participants.

## 10.2 Understanding the Context At Hand

The doctrine of understanding the user's context has been repeatedly asserted throughout this dissertation. In fact, to analyse the user's context, I kept a watchful eye on the methods of social cohesion, routine tasks, mobile and cognitive vulnerabilities, and technical constraints for prospective users. First, I will recount my observations of older adults in the western hemisphere (Canada, Italy, and The Netherlands) and later briefly reminisce on my encounters with the elderly from the Asia-Pacific region (Japan and China).

### 10.2.1 Independence, Mobility Aids, and Technology Use

For a short while, I was fortunate to live at an independent living facility in Canada. This was a remarkable experience as I had the opportunity to consult with a number of naturalized Canadian senior citizens mostly between 70 and 93 years. Frailty was observed among a few older adults residing at the facility. These adults received assistance from formal care workers at least two to three times weekly or relied on mobility aids (e.g., walkers and wheel chairs) to move around. On the contrary, I was greatly surprised by the vast number of 80+ older adults who were still able to execute their ADLs on their own. However, in an era where technology is accelerating, I observed a few barriers to technology access among some elderly residents. Conversations revealed that most older adults in that facility were reliant on their house phones to maintain contact with their family and friends. Moreover, those who were equipped with smartphones expressed difficulties in learning to use the phone features, and other social technologies such as WhatsApp or Skype. Also, some older adults mentioned that they were unfamiliar with how the Internet worked. Moreover, it was viewed as expensive or an unnecessary cost by some elderly residents. Thus, there is a need to promote technical literacy along with the provision of stable, reliable, and affordable internet connectivity to facilitate networked smart objects in AAL.

In Italy, on my daily commute, it was interesting to note that the Genovese elderly thrived in executing their ADLs (shopping, walks, bill-payments, etc.) in the mornings. Moreover, like the frail older adults observed in Canada, the Genovese frail elders had a strong reliance on manual mobility aids (walkers and canes) to execute their ADLs. In some instances, there were signs of vulnerability and discomfort, and my efforts to assist were often futile as I was challenged by a set of older adults resolute on maintaining their independence. In hindsight, from my perspective, I observed a minimum dependence on AAL solutions to support mobility in Genova.

In contrast, when I reflect on my experience in Eindhoven, The Netherlands, I noticed a higher reliance on electronic mobility aids (e.g., scooters and stair lifts) to support the execution of ADLs among the dependent elderly population in Eindhoven when compared to the Canadian and Italian senior citizens. Affordability of the scooter was a factor mentioned by a care worker at the independent living facility in Canada. Nonetheless, like the Canadian and Genovese elderly, I perceived that the Dutch elderly maintained a strong sense of independence on the whole. Regarding technology use, I noticed that the majority of our elderly Dutch participants were well equipped with smart devices, e.g., (mobile, phones, and tablets) and were also adept at using technology. Yet, there was still a measure of uncertainty among some elderly Dutch participants (cf. chapters 3 and 8) regarding the acceptance of technical assistive devices.

Looking back at my experience in two Japanese cities (Kochi and Tokyo), I observed a large number of working people in the post-retirement age. Notably, the Japanese older adults appeared to be strong and often worked as taxi-drivers, farmers, and traders in Kochi. I had the most remarkable encounter at the Kochi market, where I saw an incredibly elderly lady, as she bustled through the crowded venue appearing to carry all her produce on her back. Signs of her pigmented skin, deep wrinkles, and faded youth were some of the indicators of her frailty, yet she vigorously braced through the crowd on a quest to independently complete her grocery shopping. Her resilience was applauded by the crowd who treated her with much honour and respect. Notably during my short stay, I hardly ever noticed a mobility scooter in either of these Japanese cities.

### 10.2.2 The Social Context

Sociality and a strong sense of family appeared to be ingrained in the Italian culture. In addition, my observations and discussions with the Italian caregivers from chapter 6, revealed that mealtime is a means of maintaining social connectivity in Italy. This observation is also supported by the work done by Ochs and Shohet (2006). In hindsight, the Italian grandmothers (nonne) were often seen as the matriarchs of the family. Their cooking skills, recipes, and profound wisdom were sometimes used as a reference for initiating contact on the part of the younger adults. An additional factor supporting the profound sense of belongingness in Italy was its strong group culture. As such, older adults were frequently observed to engage in family outings, dinner parties, Sunday brunches, attendance to the cinema or orchestra with their elderly peers, and early morning coffee breaks among others.

Similarly, a strong in group culture was observed in the Eastern Hemisphere. Specifically, square dancing was commonly seen among retirees in the parks of these Chinese cities (Hangzhou, Wuxi, and Shanghai). While to my surprise in Tokyo, a communal hot spring (onsen) was mainly occupied by a group of elderly women. I was intrigued by the sense of social cohesion among these ladies and given my current interest in ageing societies; I proceeded to enquire more about their social practices. These older women highlighted that being naked in the onsen was a tradition since childhood and was a means to bring them closer, release their stress, and embrace their youthfulness despite the challenges of ageing. Further discussions with a home room teacher (Ms. Leng – for the purposes of anonymity), who has resided in Japan for over six years provided additional insight into Japan's in group culture (uchi). Ms. Leng emphasized that the uchi is entrenched in the entire Japanese society as they strive toward a spirit of harmony, where one is encouraged to think of the group over himself. Moreover, she highlighted that the in group culture encourages conformity as suggested by the following Japanese proverb. *"The nail that sticks out gets hammered down."* In essence, an individualistic mentality is perceived as negative within the Japanese culture, and there are many instances of self-sacrifice to ensure another person's happiness. This proverb confirmed the impassioned sense of loyalty that I felt during my stay in Kochi, as some store owners even left their expensive jewellery shops unattended to ensure my safety.

Although the Dutch elderly had their mechanisms for social cohesion (e.g., interdependence among neighbours, sports, knitting, and health groups, retired professional associations, volunteer societies, and Sunday family brunches). Seemingly, there is a tendency towards individualism in the Dutch culture as is evidenced by the results of chapters 3 and 8. In hindsight, from my interactions with our Dutch participants, a higher value is placed on their personal and immediate family needs when compared to the Italian and Japanese elderly. Moreover, personal freedom and the right to privacy were recurring traits of Dutch older adults. Nevertheless, I had the opportunity to get to know some of my elderly Dutch participants who are good natured and extremely helpful, encouraging, and friendly. To date, they remain as some of my most treasured friends in Eindhoven.

Interestingly, the Canadian independent living facility was multicultural as most occupants were naturalized Canadian citizens, having roots in the Caribbean, Africa, Asia, and some European countries. Evidently, the sense of community was promoted at the facility, which boasted a game room and a number of support groups including (health and fitness clubs) to ensure their social integration. Older adults at the facility were usually seen in pairs and interdependence among neighbours was quite common among residents. For instance, one frail female resident (aged 80+) expressed that her children were too far away and her neighbour (aged 70+) was her only source of help and care. On a different note, the experience of loneliness and social isolation was quite uncommon among our elderly participants (cf. chapter 4). One female resident (90+), never married and has limited contact with surviving friends and family, expressed peace and content with her situation. In an interview, she mentioned that she enjoyed her own company and found a myriad of things to do to occupy her time (reading, prayer groups, television, church attendance, exercise, and chores, among others). This encounter was a pleasant reminder of the need to avoid clichés and stereotypes when working with older adults.

In sum, by describing my observations and experiences, I have provided a glimpse into the methods of social cohesion, use of technology, challenges, and cultural situation of a small fraction of seniors from eastern and western societies. From a design perspective, it is imperative to get closer to your elderly users and give them a voice throughout the stages of the design process. In fact, their knowledge, experience, and skills could be useful to design interactive assistive solutions to improve their overall quality of life. In the next section, I will provide a synopsis of the experimental challenges experienced during the tenure of this research.

## 10.3 Reflection – Experimentation Challenges

Our experimentation challenges are listed below.

1. *Participant Recruitment* – As described in chapter 3, participant recruitment proved difficult. Moreover, there was a long process to find participants to complete the studies in chapters 4, 5, and 8. To address this challenge, we relied on personal networks and the assistance of two older adults who were connected with a number of ageing clubs and societies. These two Dutch senior citizens (cf. chapter 8) acted as proxies for potential elderly recruits. Following two separate interviews, both proxies unveiled the reasons behind the potential Dutch recruits' unwillingness to participate in experiments, which are shown below.
    - *Busy lifestyles* – Some older adults are extremely active in their communities through volunteering work, gardening, taking care of their grandchildren, sports, and religious activities among others.
    - *Inconvenience* – The invasive nature of conducting experiments in their own homes is somewhat inconvenient. Likewise, it could be difficult to travel to the university.
    - *Privacy risks involved* – Despite the ethical obligations of signed informed consents, some participants might still worry about the experimenter's data practices (e.g., how he/she stores and disseminates of the participant's data).
2. *Language barriers* – Although we were surrounded by a plethora of adults in both The Netherlands and Italy, the language barriers remained as a consistent challenge. Discussions with the elderly proxies revealed that older adults want to feel comfortable

when participating in experiments and it is only natural for them to express their feelings and experiences in their native language. In fact, if they are unable to converse in English this could lead to embarrassed feelings.

Despite the challenges encountered, we managed to successfully deploy our proposed bidirectional activity-based ambient display within an AAL context. In hindsight, it was a rewarding experience as I was thrilled to see the evidence of increased social connectedness between participant pairs (especially those in Canada). This achievement brought a deep sense of personal satisfaction.

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# Appendix A

# Smartphone Dataset for Human Activity Recognition (HAR) in Ambient Assisted Living (AAL)

## Dataset Description

This dataset is an extension of the dataset created by (Anguita et al., 2013), which was collected in a similar manner and at the same frequency. We collected additional data to improve the accuracy of our HAR algorithm in chapter 4. Data was collected using a waist-mounted smartphone exploiting inbuilt accelerometer and gyroscope sensors (cf. figure 4.2). We received 5744 samples from 31 healthy volunteers, ranging from 22 to 79 years from 14 different countries. Each activity (standing, sitting, laying, walking, walking upstairs, walking downstairs) was performed for 60 seconds and the 3-axial linear acceleration and 3-axial angular velocity were collected at a constant rate of 50Hz.

## Attribute Information

The following are provided for each record in the dataset:

- Triaxial acceleration from the accelerometer (total acceleration).
  Filenames: `final_acc_train.txt`, `final_acc_test.txt`
- Triaxial Angular velocity from the gyroscope.
  Filenames: `final_gyro_train.txt`, `final_gyro_test.txt`

- A 561-feature vector with time and frequency domain variables (extracted from the triaxial data)
- Filenames: `final_X_train.txt, final_X_test.txt`
  For more information about the features extracted see (features.txt and features_info.txt)
- The corresponding activity labels.
  Filenames: `final_y_train.txt and final_y_test.txt`

## Feature Selection

Adapting the methodology outlined by Anguita et al. (2013) we describe the feature selection process below. The features selected for this dataset were obtained from the accelerometer and gyroscope 3-axial raw signals `tAcc-XYZ` and `tGyro-XYZ`. As mentioned earlier, these time domain signals (prefix 't' to denote time) were captured at a constant rate of 50Hz. Then, they were filtered using a median filter and a 3rd order low pass Butterworth filter with a corner frequency of 20Hz to remove noise. Similarly, the acceleration signal was then separated into body and gravity acceleration signals (`tBodyAcc-XYZ` and `tGravityAcc-XYZ`) using another low pass Butterworth filter with a corner frequency of 0.3Hz.

Subsequently, the body linear acceleration and angular velocity were derived in time to obtain Jerk signals (`tBodyAccJerk-XYZ` and `tBodyGyroJerk-XYZ`). Also, the magnitude of these three-dimensional signals were calculated using the Euclidean norm (`tBodyAccMag`, `tGravityAccMag`, `tBodyAccJerkMag`, `tBodyGyroMag`, `tBodyGyroJerkMag`).

Finally, a Fast Fourier Transform (FFT) was applied to some of these signals producing `fBodyAcc-XYZ`, `fBodyAccJerk-XYZ`, `fBodyGyro-XYZ`, `fBodyAccJerkMag`, `fBodyGyroMag`, `fBodyGyroJerkMag`. (Note the 'f' to indicate frequency domain signals).

These signals were used to estimate variables of the feature vector for each pattern: '-XYZ' is used to denote 3-axial signals in the X, Y, and Z directions.

- `tBodyAcc-XYZ`
- `tGravityAcc-XYZ`
- `tBodyAccJerk-XYZ`

This dataset can be retrieved from the UCI machine learning repository at `https://archive.ics.uci.edu/ml/datasets/Smartphone+Dataset+for+Human+Activity+Recognition+(HAR)+in+Ambient+Assisted+Living+(AAL)`

- `tBodyGyro-XYZ`
- `tBodyGyroJerk-XYZ`
- `tBodyAccMag`
- `tGravityAccMag`
- `tBodyAccJerkMag`
- `tBodyGyroMag`
- `tBodyGyroJerkMag`
- `fBodyAcc-XYZ`
- `fBodyAccJerk-XYZ`
- `fBodyGyro-XYZ`
- `fBodyAccMag`
- `fBodyAccJerkMag`
- `fBodyGyroMag`
- `fBodyGyroJerkMag`

The set of variables that were estimated from these signals are:

- `mean()`: Mean value
- `std()`: Standard deviation
- `mad()`: Median absolute deviation
- `max()`: Largest value in array
- `min()`: Smallest value in array
- `sma()`: Signal magnitude area
- `energy()`: Energy measure. Sum of the squares divided by the number of values.
- `iqr()`: Interquartile range

- `entropy()`: Signal entropy
- `arCoeff()`: Auto regression coefficients with Burg order equal to 4
- `correlation()`: correlation coefficient between two signals
- `maxInds()`: index of the frequency component with largest magnitude
- `meanFreq()`: Weighted average of the frequency components to obtain a mean frequency
- `skewness()`: skewness of the frequency domain signal
- `kurtosis()`: kurtosis of the frequency domain signal
- `bandsEnergy()`: Energy of a frequency interval within the 64 bins of the FFT of each window.
- `angle()`: Angle between to vectors.

Additional vectors obtained by averaging the signals in a signal window sample. These are used on the `angle()` variable:

- `gravityMean`
- `tBodyAccMean`
- `tBodyAccJerkMean`
- `tBodyGyroMean`
- `tBodyGyroJerkMean`

The complete list of variables of each feature vector is available in ‘features.txt’

# Appendix B

# List of Publications

## Book Chapters

1. Davis, K., Owusu, E., Hu, J., Marcenaro, L., Regazzoni, C., & Feijs, L. (2017, October). Pervasive Sensing for Social Connectedness. In R. I. Goleva, I. Ganchev, C. Dobre, N. Garcia & C. Valderrama (Eds.), Enhanced living environments: From models to technologies. Michael Faraday House, Stevenage: Institution of Engineering and Technology, accepted for publication.
2. Davis, K., Owusu, E., Marcenaro, L., Regazzoni, C., Feijs, L. & Hu, J. (2018). Towards a deeper understanding of the behavioural implications of real-time, always connected, bidirectional activity-based ambient displays in ambient assisted living environments. In I. Ganchev, N. Garcia, C. Dobre, C. X. Mavromoustakis & R. Goleva (Eds.), Algorithms, architectures and platforms for enhanced living environments. Cham: Springer International Publishing, chapter proposal under review.

## Journal Paper

1. Davis, K., Owusu, E. B., Marcenaro, L., Feijs, L., Regazzoni, C. & Hu, J. (2017). Effects of ambient lighting displays on peripheral activity awareness. IEEE Access, 5, 9318-9335. doi: 10.1109/ACCESS.2017.2703866

## Conference Papers

1. Davis, K., Hu, J., Feijs, L. & Owusu, E. (2015, March). Social hue: A subtle awareness system for connecting the elderly and their caregivers. In 2015 ieee international con-

ference on pervasive computing and communication workshops (percom workshops) (pp. 178–183). IEEE.
doi:10.1109PERCOMW2015.7134015

2. Davis, K., Owusu, E., Regazzoni, C., Marcenaro, L., Feijs, L. & Hu, J. (2015). Perception of human activities a means to support connectedness between the elderly and their caregivers. In Proceedings of the 1st international conference on information and communication technologies for ageing well and e-health (pp. 194–199). SCITEPRESS.

3. Davis, K., Owusu, E., Bastani, V., Marcenaro, L., Hu, J., Regazzoni, C. & Feijs, L. (2016, July). Activity recognition based on inertial sensors for ambient assisted living. In 2016 19th international conference on information fusion (fusion) (p. 371-378). IEEE

4. Davis, K., Owusu, E., Hu, J., Marcenaro, L., Regazzoni, C. & Feijs, L. (2016). Promoting social connectedness through human activity-based ambient displays. In Proceedings of the international symposium on interactive technology and ageing populations (pp. 64–76). New York, NY, USA: ACM.

5. Davis, K., Feijs, L., Hu, J., Marcenaro, L. & Regazzoni, C. (2016). Improving awareness and social connectedness through the social hue: Insights and perspectives. In Proceedings of the international symposium on interactive technology and ageing populations (pp. 12–23). New York, NY, USA: ACM.

6. Davis, K., Owusu, E., Marcenaro, L., Feijs, L., Regazzoni, C. & Hu, J. (2016). Evaluating human activity-based ambient lighting displays for effective peripheral communication. In Proceedings of the 11th eai international conference on body area networks (pp. 148–154). ICST, Brussels, Belgium, Belgium: ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering). Retrieved from `http://dl.acm.org/citation.cfm?id=3068615.3068648`

7. Davis, K., Owusu, E., van den Boomen, G., Apeldoorn, H., Marcenaro, L., Regazzoni, C., Feijs, L., & Hu, J. (2017). Presenting a real-time activity-based bidirectional framework for improving social connectedness. In I. Rojas, G. Joya & A. Catala (Eds.), Advances in computational intelligence: 14th international work-conference on artificial neural networks, iwann 2017, cadiz, spain, june 14-16, 2017, proceedings, part ii (pp. 356– 367). Cham, Switzerland: Springer International Publishing. Retrieved from

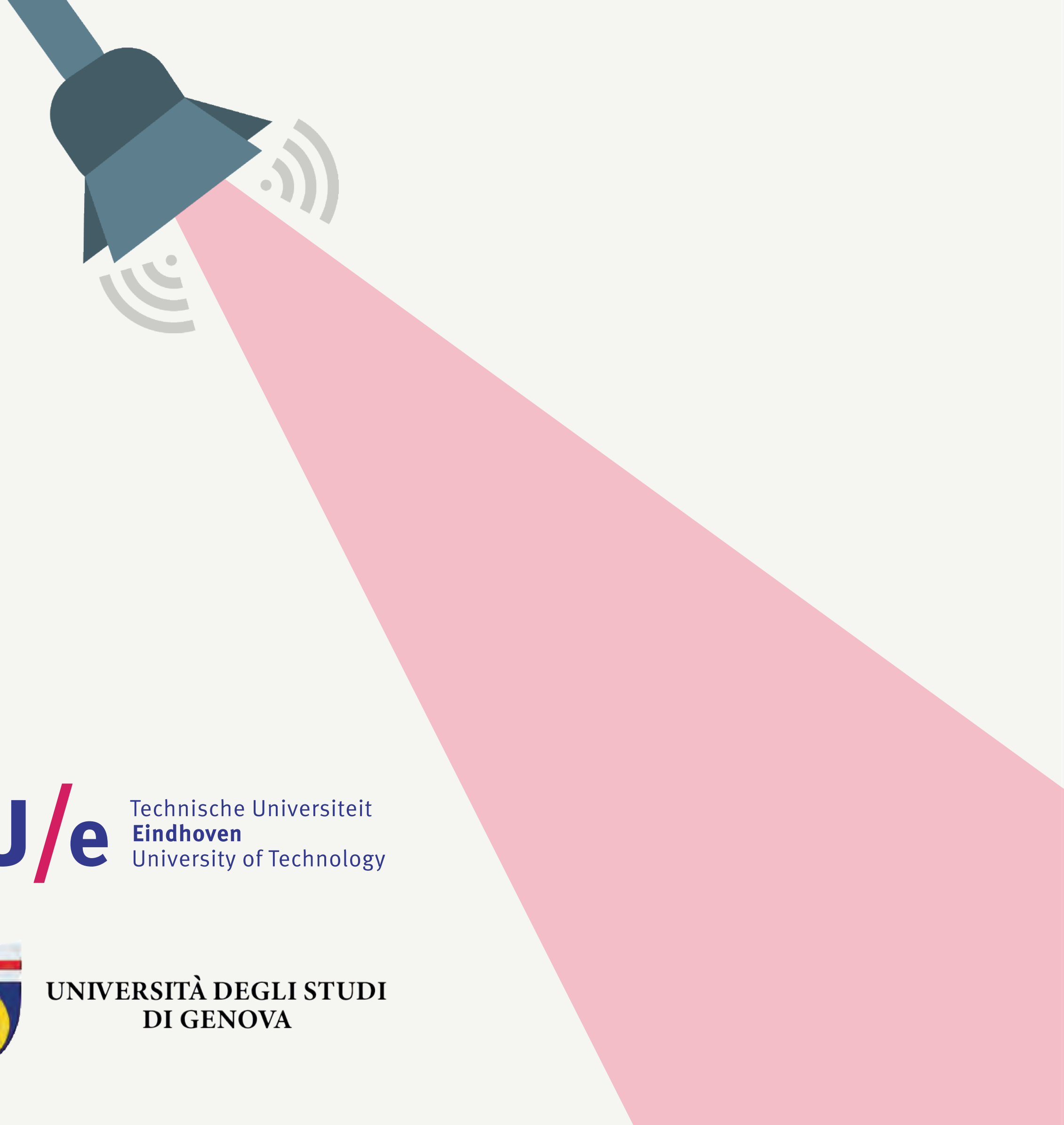
https://doi.org/10.1007/978-3-319-59147-6_31 doi: 10.1007/978-3-319-59147-6_31

# Data Set

1. Davis K and Owusu E. Smartphone Dataset for Human Activity Recognition (HAR) in Ambient Assisted Living (AAL). UCI Machine Learning 2016. Available from: https://archive.ics.uci.edu/ml/datasets/Smartphone+Dataset+for+Human+Activity+Recognition+(HAR)+in+Ambient+Assisted+Living+(AAL)

# Biography

Kadian Davis hails from the lush green island of Jamaica and was born on February 14th, 1985. In 2003, she pursued a Bachelor of Science (BSc) degree in Computer Science at the University of the West Indies (UWI), and upon completion in 2006, she started a Master of Philosophy (MPhil) in Computer Science with a specialization in User Centered Design for Computer Science Education at the said university. Davis worked as a teaching assistant in the Department of Computing, UWI, for over four years and was involved in several extra-curricular activities during her tenure. Following her MPhil degree, in 2011 she worked for two years as the Head of the Information Technology (IT) Department at the University College of the Caribbean (UCC), where she reformed the IT course curriculum, lectured IT courses and led several initiatives for technology access and awareness for the general public. Davis has also offered recommendations regarding the changes of Jamaica's Cyber Security Act and was the UCC representative to the Cyber Emergency Response Unit of the Ministry of Science, Technology, Energy and Mining in Jamaica. In 2013, Davis commenced her Ph.D. project in the Erasmus Mundus Joint Doctorate Programme in Interactive and Cognitive Environments (ICE), primarily based at the Eindhoven University and secondarily at the University of Genova. During her tenure as a Ph.D. student, she served as the Ph.D. representative for ICE students and has conducted research in the area of Design for Social Interaction for Ambient Assisted Living Environments (AAL), of which the findings are presented in this dissertation.



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"The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it."

— Mark Weiser, 1991