Presenting a Real-Time Activity-Based Bidirectional Framework for Improving Social Connectedness

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Abstract. New research on ambient displays within ambient assisted living (AAL) environments, demonstrates solid potential for the application of bidirectional activity-based context aware systems for promoting social connectedness between the elderly and their caregivers. Using visual, auditory or tactile modalities, such systems can reveal subtle information concerning health and well-being and stimulate co-presence between the pair. In this paper, we present the design and development of an activity-based framework aimed at enabling the real-time viewing of bidirectional activity states between the elderly and their caregivers. This framework seeks to overcome the limitations of existing ambient displays deployed in AAL settings, which are in most cases unidirectional and confined to the homes of its users. Our bidirectional activity-based framework, is based on an extensive literature review, expert advice and user feedback, which informed the design decisions about the product features and functionality. The system exploits a highly accurate activity recognition model to facilitate real-time activity awareness and an "always connected" service through portable interactive devices for stimulating social connectedness within the AAL domain.

Keywords: Ambient assisted living · Social connectedness · Human activity recognition · Ambient displays · Internet of Things

1 Introduction

On a global scale, there has been an unprecedented rise in human life expectancy [9]. This trend towards increased longevity could have profound social, political and economic implications for ageing societies. As a result of these challenges, policy makers, not-for-profit organizations and major industry partners have

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sparked heightened interest in the development of cutting-edge interventions directed toward usability, accessibility, and safety, to provide social support, and enable older adults to maintain their independence and age in place.

To a great extent, previous ambient assisted living (AAL) technologies have explored remote monitoring, indoor positioning, and fall detection to inform caregivers and emergency services of abnormal events in the activities of daily living (ADLs) of older adults [1]. Recent AAL research corroborates the significance of the exchange of human activity information for improving social connectedness between the elderly and their caregivers [6,16]. However, the design, development, deployment and evaluation of such activity-based bidirectional systems is mostly left unexplored.

In the current era of connected devices, the combination of ubiquitous sensing technologies, the Internet and everyday objects could support older adults and their caregivers to maintain social connectivity despite separation by geographical distance. In particular, advanced human activity recognition (HAR) algorithms allow accurate detection of physical states while light's dynamic characteristics has shown potential for rendering activity information on the periphery of the users' attention to improve social connectedness [5,16].

In this paper, we present the design and development of a real-time activity-based bidirectional framework 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 future work.

2 Related Work

Social connectedness refers to the "sense of belonging" or the "feeling of being in touch" and having enough meaningful social relationships [14]. Social support is a critical component of healthy and active ageing. While loneliness is common among all age groups, the elderly are more prone to experience this social phenomenon [8]. Notably, caregivers whether family, friends, neighbours or professional helpers are key pillars of social support for older adults.

The pervasive nature of mobile devices and the Internet of Things (IOT), provide game-changing opportunities for developing smart solutions for enhancing social connectivity between older adults and their caregivers in computer-mediated environments. Moreover, 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 [11]. Inspired by the principle of calm technology [17], ambient displays beautifully illustrate awareness information in the periphery of the user's attention so one can access this information at their own convenience [10].

Formerly, most classical ambient displays such as the Digital Family Portrait [13] and the CareNet Display [3] were entirely focused on furnishing caregivers with context information to support the remote monitoring of the older adults and provide peace of mind to their family members. Conversely, a few contemporary ambient displays such as those presented in [6,16] 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 or work environments. Thus, prohibiting access to the counterpart's activity information outdoors. Moreover, the aforementioned ambient display studies [3,6,13,16] demonstrated awareness information using one decorative object namely ambient photo frames or a snowglobe lighting device.

This work presents a novel user-centered approach to the design and development of an amalgamation of 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 framework, which receives input from embedded smartphone accelerometer and gyroscope sensors and renders information through the interactive materiality of everyday artifacts such as Philips Hue light orbs, a portable LED walking cane and wallet. Consequently, enabling an "always connected" communication channel through pervasive interactive devices.

3 Design Rationale

Our bidirectional activity-based framework 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. However, Consolvo et al. indicates that the exchange of physical activity information can create awareness and influence social cohesion in technology-mediated environments [2]. These findings were used to drive our decision to use physical activity data for our social connectedness framework.

We were guided by the following design heuristics obtained through a thorough review of the literature [10,12,15] and our own findings from previous research [4,6,7] 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 affects their 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 and 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.

4 System Overview

The entire system is composed of 5 major subsystems as illustrated in Fig. 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 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 [5]. A custom built Android application (LED controller app.), collects the accelerometer and gyroscope readings (sensor data) at a frequency of 50 Hz (see [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 obtained are transformed into lighting property encodings and then broadcasted to the cane's led strip or the wallet's led ring via the ESP microcontroller Wi-Fi module. To 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 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

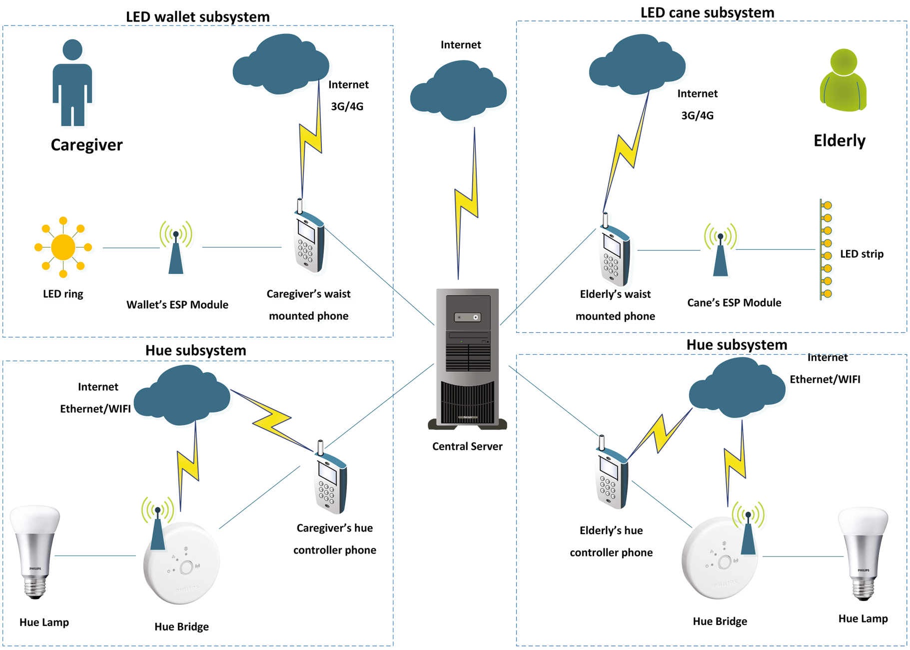

Fig. 1. Overview of the bidirectional activity-based system

homes while the LED devices are carried when users are outdoors. This enables an "always connected" system to users.

5 Central Server Subsystem

The central server subsystem is composed of a multi-threaded socket server implemented in the Python programming language, a hybrid of Support Vector Machine and a Hidden Markov Model (SVM-HMM) classifier implemented in Matlab and a RabbitMQ message queuing server. Figure 2, illustrates the 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% [5], for detecting one of six basic activities (laying, sitting, standing, walking, walking upstairs, walking downstairs) every 2.5 s. Please refer to [5] for more details on the classification model. Since the SVM-HMM model was trained with feature sets computed on fixed length windows of 2.5 s, 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

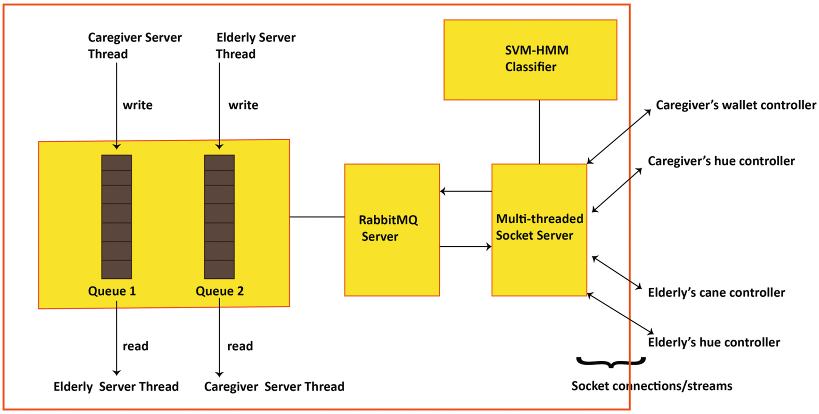

Fig. 2. Central server subsystem

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.

Thus, a minimum delay of 5 s was introduced. Moreover, an additional delay of 1 s was spawned by the actual activity classification process and the relay of the activity information resulting in an average system delay of 6 s 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 is later read from the queue written by the elderly server thread and vice-versa, thereby facilitating the bidirectional exchange of data.

6 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 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

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

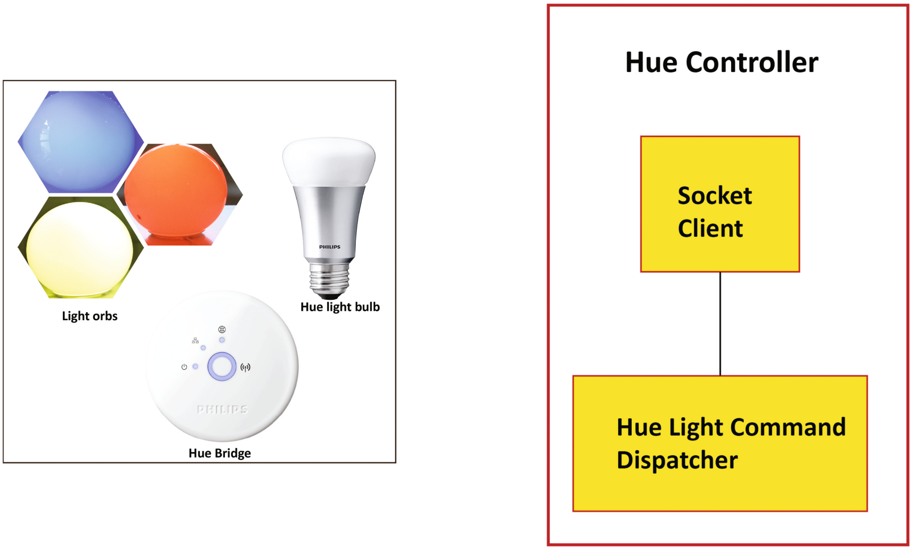

Fig. 3. Hue subsystem

of Fig. 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 is 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.

Cognizance must be taken of the fact that the mapping between the six basic activities and activity levels (active, passive, resting) and those of activity levels and lighting encodings (colour and brightness) are not arbitrary. As discussed in [7], a person walking or walking upstairs or downstairs 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 4, depicts these mappings. The mappings were generated to conceal participants actual states for privacy purposes and to

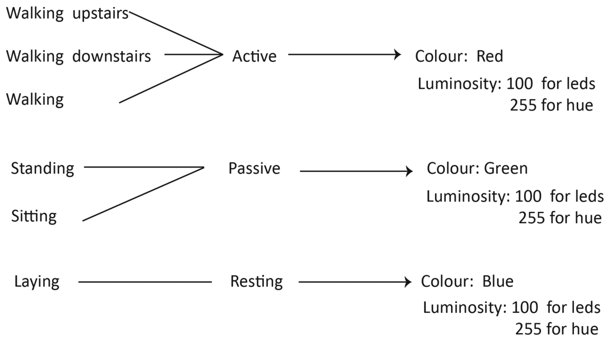

Fig. 4. Mapping between basic activities, activity levels and light configurations

mentally stimulate participants to decipher the actual activities and activity patterns as articulated in [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 an exploratory study discussed in [7].

7 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 Fig. 5. 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 3.7 V Samsung 18650 Lithium-ion battery of 2600 mAh capacity was used. Batteries are charged via the inbuilt micro USB connection. Embedded software is uploaded to the microcontroller via the serial port, using

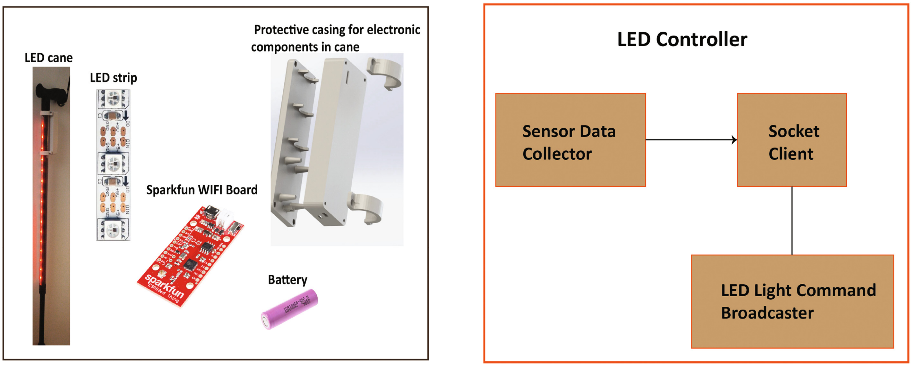

Fig. 5. LED cane subsystem

a so-called FTDI board (a USB-to-serial adapter). Also, development of the embedded software was done within the popular Arduino environment.

Recall that the waist-mounted smartphone has two main responsibilities with respect to the LED subsystems; i.e. (1) sending collected sensor (accelerometer and gyroscope) data to the remote server for activity classification, and (2) 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 Fig. 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 3.3 V power supply. When all LEDs are at full brightness, and only one colour is "active" the total current consumption is almost 200 mA with 16 LEDs and when all LEDs were off the current consumption was no more than 88 mA.

According to the datasheet[2], the battery has a capacity of 2600 mAh when discharging with a constant current of 520 mA down to a voltage of 2.75 V (cut-off voltage) after the cell is charged up to 4.2 V. Also, the Wi-Fi module is expected to have at least a supply voltage of 3.0 V. With the voltage regulator in between the battery and the Wi-Fi module, having a dropout voltage of 125 mV, the minimal battery voltage needed is 3.125 V. That means that we cannot use the full capacity of the cell since we cannot drain it down to 2.75 V. With a discharge current of 0.2 A the available operating time is 12.5 h. However, the rate of discharge of the battery does not only depend on the consumption of

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

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 h in a full outdoor deployment.

8 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 Fig. 6. Basically, the communication 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 3.7 V rechargeable lithium battery of 2000 mAh capacity was installed. With a lower battery capacity, we recorded an average operating battery life of 3 h in a full outdoor deployment.

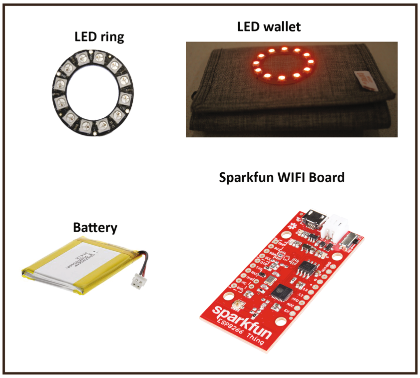

Fig. 6. LED wallet subsystem

9 Discussions and Conclusions

In this paper, we present the design and development of a real-time activity-based bidirectional framework aimed at improving social connectedness between the elderly and their caregivers. Leveraging the internet of things (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 [13], CareNet Display [3] and the Snowglobe [16], 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 and expectations, their context of use and feedback in the design loop. The process culminated with the realization of intelligent interactive product 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, introducing a sleep mode based on a pre-defined stimulus will also aid in reducing battery consumption. Secondly, the average delay of 6 s 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. Finally, although the system has been implemented, deployed and tested, an experimental study has not been conducted to evaluate general user acceptance and its implications on social connectedness in AAL. Hereafter, we plan to implement the system on a larger scale and perform an experimental study in order to analyse in depth the objective, behavioural and social connectedness implications of the system and its acceptance.

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