Learning from Internet of Things for Improving Environmentally Responsible Behavior

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Abstract. We present two designs in the area of Internet of Things, utilizing an ontology-driven platform, namely Smart-M3, to connect domestic objects in the physical world to the information world, for coaching the behavior or raising the awareness in domestic energy consumption. The concept and architecture of Smart-M3 are introduced, in which the domestic objects are knowledge processors connected to the semantic information broker that contains the ontologies, using a blackboard design pattern and semantic web technologies, enabling the interoperability among both digital and physical entities. Two designs based on Smart-M3 are presented, as examples for coaching with and learning from the Internet of Things. Although both designs are in the area of domestic energy consumption, they can be seen as good starting points towards broader areas of ubiquitous learning with the Internet of Things.

Keywords: Internet of Things, ontology, semantic web, ubiquitous learning.

1 Introduction

The environments that people inhabit are occupied with a growing number of digital and networked devices. We have not yet succeeded in seamlessly operating among these devices. Especially when we consider the way user interaction was envisioned in paradigms like Ambient Intelligence [1], Pervasive Computing, Ubiquitous Computing [10] and the more recent notion of Internet of Things [8]. One of the key goals of these paradigms is "serendipitous interoperability", where devices which were not necessarily designed to work together (e.g. built for different purposes by different manufacturers at different times) should be able to discover each other's functionality and be able to make use of it [9].

One solution to solving the interoperability problem at the infra-structure level is a software platform developed within the SOFIA project[1]. SOFIA (Smart Objects For Intelligent Applications) is a European research project within the ARTEMIS framework that attempts to make information in the physical world available for smart services – connecting the physical world with the information world. Rather than promoting the compatibility within one specific service-level solution in terms of

[1] www.sofia-project.eu

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protocols or software stacks, it addresses information-level compatibility and the collaboration between different producers and consumers of information on a more abstract level. It does not add, nor require an additional single service-level infrastructure or middleware that all manufacturers must adopt, but builds on what is already available in the industry.

The Internet of Things is often referred to as a network of RFID tagged everyday objects. In the context of SOFIA, the Internet of Things is much more. It is a network of smart objects which each have (from very limited to extensive) computational power and connectivity. These smart objects form are from the "internet", in an environment or across environments, which makes it close to the concept of ubiquitous computing, and creates new possibilities for innovative applications.

In this paper we present two designs that utilize these new possibilities, for coaching the behavior or raising the awareness in domestic energy consumption. A study by Burgess et al [2] indicates that of all the energy that people consume, 30% is consumed in a domestic setting. Furthermore it states that, roughly 30% of domestic energy consumption which can be attributed to behavioral choices. By stimulating more Environmentally Responsible Behavior (ERB), the consumption can be reduced by up to 10%. Instead of actively and explicitly teaching and coaching, the stimuli and advices are woven into everyday objects that are connected to the energy consumption information, for people to learn from the Internet of Things to stimulate their ERB.

Next the basic structure and concept of SOFIA platform are explained, followed by two design cases. Each case is presented with the design concept and prototype, as well as the feedback collected from the user evaluations.

2 SOFIA Smart-M3

The SOFIA software platform utilizes the blackboard architectural pattern to share information between smart devices, rather than have the devices explicitly send messages to one another. When this information is also stored according to some ontological representation, it becomes possible to share information between devices that do not share the same representation model, using the semantics of that information [5].

Ontologies are used to enable the exchange of information without requiring up-front standardization. The first core component of the SOFIA platform is called Smart-M3 and an open source implementation is available online[2]. A notable feature of the SOFIA platform is the capability to subscribe to changes of data (stored as triples) in the data store, and be notified every time these triples are updated, added or removed.

Smart-M3 takes the blackboard and publish/subscribe concepts and implements them in a lightweight manner suitable for small, mobile devices. These devices (Knowledge Processors or KPs), can operate autonomously and anonymously by sharing information through an information store. The Semantic Information Broker (SIB) is the information store of the smart space, and contains the blackboard,

[2] Available from http://sourceforge.net/projects/smart-m3/

ontologies and required service interfaces for the KPs. Fig. 1 shows a simplified overview of the Smart-M3 infrastructure.

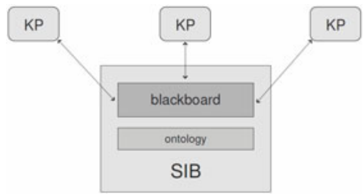

Fig. 1. SOFIA infrastructure model

For applications, a Description Logic (DL) based ontology can be created in OWL, the Web Ontology Language [9]. In the current ontology all user interaction within the system is described in terms of interaction events [4]. To enable our semantic connections interaction model (introduced in more detail after this section), the connections between the devices need to be modeled. A connectedTo relationship can be added or removed between two existing devices in the ontology. It should be noted that this relationship is both symmetric and irreflexive. A symmetric property is its own inverse, which means that if we indicate a connectedTo relationship from device A to device B, device B will also have a connectedTo relationship to device A. Another way to think of symmetric properties is that they are bidirectional relationships. An irreflexive property is a property that never relates an individual to itself. This allows us to restrict our model by not allowing a connectedTo relationship from a device to itself. In our application to energy streams, other properties such as transitivity and additivity can be added: if device A has access to energy from B and B can take energy from C then indirectly A has access to energy from C (transitivity). For a node which is neither a source nor a sink, the sum of the incoming energy flows equals the sum of the outgoing energy flow (additivity).

In this structure, to determine which other smart objects a specific device with a deviceID is connected to, a simple SPARQL query suffices:

```
select distinct ?object where {
   deviceID semcon:connectedTo ?object }
```

To get the last event belonging to a specific device, for example the event triggered by Near Field Communication (NFC) when the device comes close to the other, the SPARQL query is a little bit more complex, but still surprisingly manageable (see [4] for more details):

```
select ?position ?eventType where {
   deviceID semcon:hasRFIDTag ?tag .
   ?event semcon:hasRFIDTag ?tag .
   ?event semcon:hasPosition ?position .
   ?event a ?eventType .
   ?event semcon:inXSDDateTime ?time .
   FILTER (
      ?eventType = semcon:NFCEnterEvent ||
      ?eventType = semcon:NFCExitEvent) }
   ORDER BY DESC (?time) }
```

At a more conceptual level the term “semantic connections” is used in the SOFIA project, referring to meaningful connections and relationships between entities of the Internet of Things [6, 7]. Semantic connections exist in both the physical and the digital world. They have informative properties, i.e. they are perceivable in the physical world and have sensory qualities that inform users about their uses. However, these physical qualities might be hidden at some times, or only accessed on-demand, by a special purpose interaction device. The digital counterparts of semantic connections are modeled in an ontology. There may be very direct mappings, e.g. a connection between two real-world entities may be modeled by a connectedTo relationship between the representations of these entities in an ontology.

3 Design Cases

Based on the concepts from SOFIA and Smart-M3, two products are designed in the application area of stimulating people to improve their ERB in domestic environments, i.e, their home environments. These environments are conceptually smart spaces enabled by SOFIA smart objects. Energy consuming appliances in these environments are KP-enabled objects that are connected to the SIB hence they are interconnected, providing energy consumption status and history to the SIB and accepting and reacting on queries, events and commands from the SIB.

3.1 Doormate

Concept. The Doormate is first of all a doormat for wiping your feet, but also a coaching mate supporting lowering of electricity consumption [11]. It does the latter by communicating information through an integrated low resolution LED display (Fig. 2). The Doormate gathers data from the smart appliances in the home, such as time of use, frequency of use, intensity of the appliance during use and duration of use. By combining this data and evaluating changes, information on improving usage behavior can follow. It allows people to easily turn of devices when leaving the house as well as improving their energy consumption behavior by learning from tailored coaching when returning home.

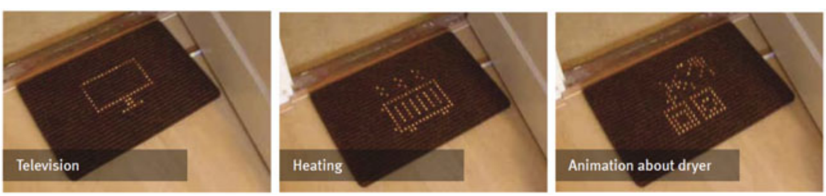

Fig. 2. Doormate integrated with a low resolution LED display

Fig. 3 illustrates the interface. To switch off the depicted device the user steps with one foot on the lit up power icon (top left) and with the other foot applies pressure on the display, as if putting out a cigarette. If more devices are available to be switched off, the arrows will light up and can be used to scroll through the icons. When entering the house the user can spend a moment to learn (or get a cue to remember) how certain behavior can be changed to be more energy efficient. As the contact time between product and user is longer, animations are used to explain the coaching tips. If the user does not understand the animation, he or she can get more information later on his/her smart phone or laptop by both pressing the lit up coaching icon (top right) as well as the display. In the case of the coaching state the user is able to 'flip' through tips if more are advised.

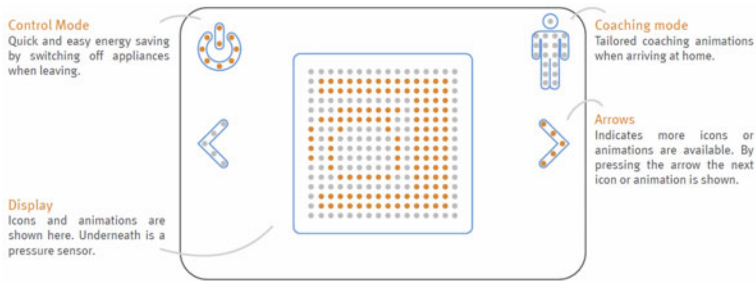

Fig. 3. Doormate Interface

Fig. 4 shows two use case scenarios. The top scenario shows how a user forgot to switch of the lights and is reminded by the Doormate. He then decides to switch them off using the Doormate. The bottom scenario shows how a person who is coming home is detected and, while he is taking off his coat, is shown an animation on how to be more electricity efficient. If he does not understand it immediately, he can press the Doormate to receive more information on his smart phone.

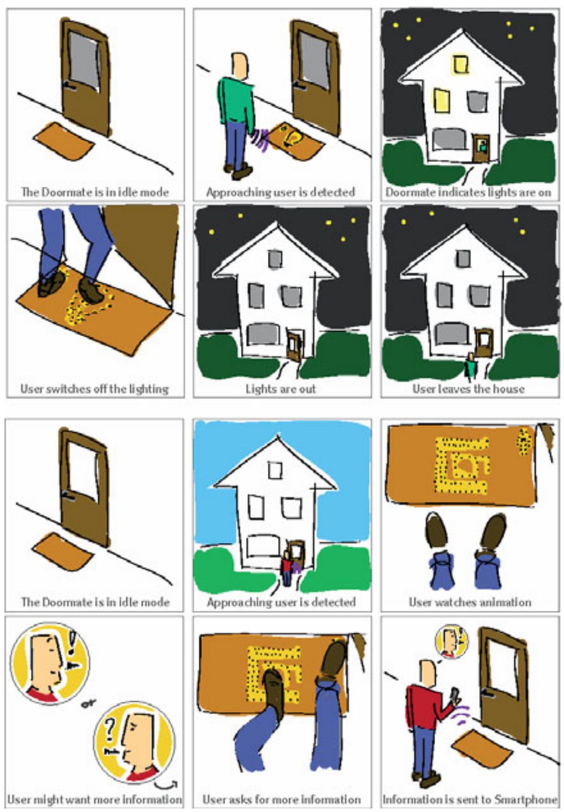

Fig. 4. Doormate scenarios

Evaluation. Preliminary tests were done with seven participants. The prototype was used to test three aspects: visibility and general understanding, animation and icon interpretation, and preference in initial coaching display. The effect of the light coming from a doormat, which is generally a very uninteresting and low value object, surprised them and gave the mat more value.

All participants were enthusiastic about the control functionality, as they all recognized the situation where they forgot to turn off appliances. The results and reactions on the Doormate are promising. People recognize the benefits and see themselves using the Doormate over a longer period of time.

3.2 Bonsai Garden

Concept. The product consists of local feedback devices and a central feedback device. The local feedback devices give direct feedback to the user on their consumption and the central feedback device gives overall feedback on ERB of the different people in a household. The overall feedback is represented by a tree and the trees are placed together in a "bonsai garden" (Fig. 5). These trees consist of building blocks and each individual user can construct their personal tree in any way they want. There are three different kinds of building blocks (straight, angled and split pieces) and they provide endless building possibilities. The amount of building blocks and thus the size of the tree represents the user's personal effort on reducing resource consumption. The user can earn building blocks with good ERB and direct feedback on ERB is given by the local feedback devices (triggers). These triggers show when the user earns points for ERB by changing shape and standing upright. These points are represented by lights in the building blocks for that person's tree. When all building blocks are lit up, the user can add a piece to it.

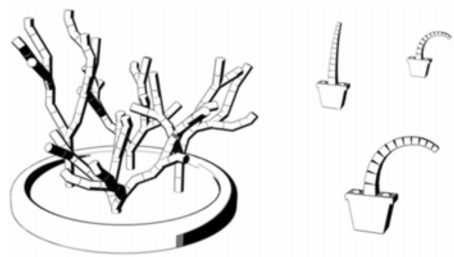

Fig. 5. Bonsai Garden

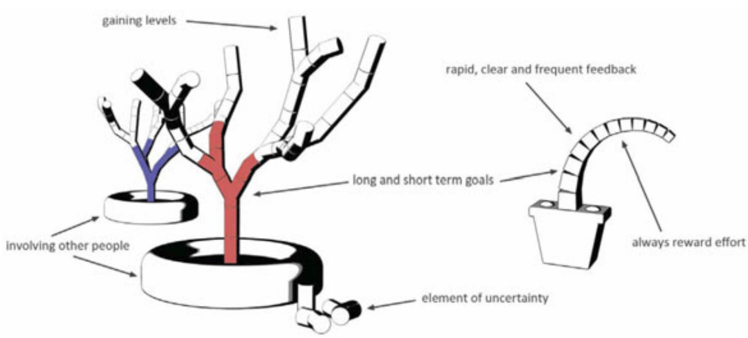

Fig. 6. Gaming elements in Bonsai Garden

The target group of this design is families with young children (8 - 12 years old). The involvement of the entire family adds to the social aspect of motivation. The design contains game elements, derived from on the work of Chatfield [3]. These elements were implemented in this project to create motivation for ERB (Fig. 6): 1) gaining levels: the size of the tree represents the level of good ERB from a person; 2) long and short term goals: The trigger is short-term, the tree represent a long-term goal; 3) always reward effort: users get rewarded for trying to behave well; 4) rapid, clear and frequent feedback: a trigger responds to each resource consuming event; 5) an element of uncertainty: users do not know what kind of building block they will get next; 6) Involving other people: users can compare their trees and compete for the best building results.

Evaluation. The prototype was used to test two aspects: motivation through competition, and motivation through personalization. The evaluation was done with five children from the target user group (Fig. 7). These children were all Dutch and either in the final years of primary or the first years of secondary school. The evaluation was performed in a home situation and the results were recorded with a camera and by taking notes of events and comments. The evaluation was performed with a prototype of the tree that allowed the participants to build a tree out of building blocks. This prototype consisted of a base unit and 30 building blocks, which allowed for complete freedom to build a unique tree.

Fig. 7. Children build their bonsai trees

The test started with an introduction to the design and how the participants could build their own tree later in the test. The competition element was evaluated by having each participant build their own tree and compare them in the final discussion. The next step was a questionnaire about ways to improve ERB. Each right answer would result in a point, and for each point a participant would get two building blocks to build a tree with. In the discussion the nicest tree would be chosen by voting.

The results show that building the trees was a fun experience for all the children. It was a social process, where they advised and commented on each other's trees. Every participant tried to make their tree unique and as different from the others as possible. The prospect of earning building blocks and building their own tree was a big motivation for the children and they were very concentrated on thinking of ways to improve ERB.

4 Concluding Remarks

The SOFIA Smart-M3 platform enables the possibility to embed intelligence into everyday objects and allows these objects to connect to each other and to information entities and services, bridging different products and services from different manufactures and providers. Two products are designed based on the concepts from this platform for improving people's ERB in energy consumption in domestic home environments, implementing different learning strategies. The Doormate provides the convenience of controlling the house appliances at the same time provide behavior coaching, while the Bonsai Garden tries to raise the awareness by employing gaming elements in the design. Although the Internet of Things is limited in one environment, the idea of providing ubiquitous learning with smart daily objects seems to be promising. In addition to smart home environments, in the SOFIA project we are also experimenting with different scenarios such as personal spaces and smart city. The technology can be applied for ubiquitous learning to a broader extent.

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