Creating Awareness for Efficient Energy Use in Smart Homes

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Abstract

Energy advisory services are designed to help habitants of smart homes to learn about their consumption patterns and eventually save and use energy more efficiently. In this paper we sketch some ideas for energy advisory services and present a layered software architecture that facilitates the integration of systems for power metering, home automation, and user interface technologies.

1 Introduction

Efficient use of energy is an ongoing matter of concern to everybody. Regarding the residential sector of energy end-use some progress towards reducing consumption has been made, for instance by replacing power-hungry devices such as incandescent light bulbs by fluorescent or LED light sources. Avoiding waste of energy where possible saves the user money and can generate positive net effects, such as peak demand reduction which in turn would allow power line operators to reduce maximum capacity provision. In addition many users do care about environmental issues and would like to make their own contributions – an effect that may be circumscribed as the “feel-good” factor. On the other hand, an increasing multitude of new electrical appliances and digital services are offered to the users to make their life more easy, convenient, and cozy. In the context of the IT4SE project[1] we start from the hypothesis that in a smart home environment increased comfort and reduced energy consumption are not necessarily mutual exclusive goals. Rather, smart technology may be used to increase users’ awareness of their energy consumption patterns and assist them in smart use of energy in an unobtrusive manner.

Working along this line of research we have examined a number of different technologies including equipment for power consumption metering, home automation, and a range of others that can be categorized as ambient intelligence. In the following sections we present a few example systems from each of these categories and discuss them especially with regard to their user interface issues. Afterwards, we sketch a layered architecture that allows taking advantage of existing components while enabling us to combine and exploit them for new energy monitoring and usage services in a smart home environment. In addition, we describe some scenarios to illustrate the application of our architecture.

2 Power Metering

Almost all households with a connection to the power grid have an electricity meter as the bases for electricity billing. Recently, new types of power usage monitoring (or metering) devices have been introduced to the market, including power sockets with metering/measurement displays (e.g., www.voltcraft.de), and wireless monitoring units which oversee a number of power appliances (e.g., www.elv.de, www.currentcost.com). Such monitoring equipment are, however, designed to provide users with information about the power consumption of specific appliances. This includes real-time display of consumption, as well as logging usage data over

1 IT4SE is part of the APRA initiative on the establishment of joint research structures between German universities and partners in the Asia Pacific Research Area (APRA). As all APRA projects, IT4SE is funded by the German Federal Ministry of Education and Research (BMBF).

a certain time period. For example, a user may be interested in how the power usage of their refrigerator affects their monthly electricity bill, by recording power consumption over a month.

Although low-cost power usage monitoring devices are available in the market (costing around 10-50 Euro), they have limited functionality, sparse information displays, or badly designed user interaction capabilities. Fig. 1 shows the user interface of a low-cost metering device (purchased from a German discount store). Supported functions (e.g., real-time display of power consumption, or accumulated consumption) can be selected via a toggle button. A major disadvantage of such low-cost monitoring devices is that they are “closed” systems, and therefore do not provide any mechanism for outputting usage data to an external computer program, nor is it possible to select their functions without having to operate their physical buttons manually.

Fig. 1 Low-cost power meter with a sparse display

For our research work we have been experimenting with a power-usage monitoring system called Current Cost[2] , which provides external access to measured and recorded power consumption data. The system configuration comprises three separate type of components (cf. Fig. 2):

- **power sensors:** in the form of clamps which are placed around live power cables;
- **transmitters:** each of which can process input from up to three power sensors, and use a wireless connection to transfer data to a monitoring station;
- **monitoring unit:** a PDA-style device that receives data signals from up to ten different sources (transmitters) at a refresh rate of 6 seconds. Users can inspect received data on the PDA screen, or alternatively, use a USB cable to transfer data in a special XML format (CCXML) to a PC for further processing. In addition, a so-called “Bridge” device is available that acts as a web server to enable direct access to XML data via an Internet connection. In this way, Google's PowerMeter service (Google, 2011) can be used as a user interface to recorded power consumption data.


Fig. 2 components of the Current Cost power usage monitoring system

The monitoring unit grants access to the total power consumption recorded at each of the connected transmitter stations, as well as to each of the individually attached power sensors. In addition, the monitoring station features a temperature sensor whose value is included in the system’s XML output.

Current Cost is devised as a measuring system only, and therefore, it does not provide any means of controlling appliances (e.g., to switch them on and off).

3 Home Automation

While it has become commonplace to monitor and maintain modern multi-story office and commercial buildings using building or facility management systems, automation in private homes is still in its infancy. However, this may change in the future for a number of reasons.

[2] Current Cost is a product of UK-based Current Cost Ltd. (www.currentcost.com)

Making private homes smarter in terms of more efficient and responsible use of energy is a societal challenge and on the political agenda in a growing number of countries. Another driving force is the manufacturers of home automation systems who view the smart home sector as an emerging market (e.g., see www.home-automation.org which lists hundreds of different systems and vendors).

From users' point of view, home automation can provide many valuable advantages:

- it can increase comfort, for instance by means of sophisticated monitoring and climate control systems,
- it can help, especially the elderly, to take care of their homes, for example by opening/closing windows and doors using remote control units,
- it can of course also help to save energy, for instance by automatically switching off appliances when they are not needed.

As an example of a commercially available home automation system we have been using in our research projects is the HomeMatic[3] system. The HomeMatic hardware configuration comprises the following types of components:

- **wireless actuators**: in the simplest case an actuator is a power socket that can be remotely switched on/off. In addition, there are dedicated actuators comprising a servomotor to open and close windows, doors, curtains, or heating radiator valves.
- **wireless sensors:** there are sensors to measure temperature and humidity, sensors that indicate whether a door or window is closed/open, and motion detector sensors. There are, however, no sensors to measure energy consumption (e.g. like the Current Cost).
- **Central Control Unit (CCU):** the CCU executes programs that can take as input data from attached sensors and output commands to control attached actuators. CCU programming is done in terms of if-then-else rules on a PC using either a web-based program composer, or a customized programming environment (such as the Homeputer Studio[4] software package). Once a program has been specified, it gets compiled and uploaded to the CCU for execution. In the execution phase no more connection to the PC is necessary. However, the CCU's built-in web server allows remote supervision of program execution, even by means of a smart-phone.

While the HomeMatic system addresses the needs of an end-user directly, its programming is not an easy task and requires technical knowledge and good familiarity with programming environments. However an XML-API has been made available which allows access to CCU via the HTTP protocol, thus making it possible to build more advanced interactive software to use the HomeMatic system.

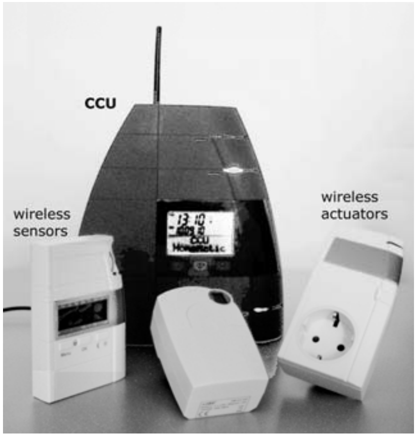

Fig. 3 components of the HomeMatic system

4 Ambient Intelligent Environments

The notion of ambient intelligent environments refers to the vision of environments that "... will react 'intelligently' upon our presence and behavior" (cf.Petersen, 2005). Interpretations of possible meanings of this vision in the context of home environments, often called smart

[3] HomeMatic (www.homeatic.com) is a product of eQ-3 AG Germany.

[4] Homeputer Studio is a softwarepackage for the HomeMatic system and is distributed by Contronics GmbH Germany (www.contronics.de).

homes, are illustrated by a number of prototype smart home installations, including the Philips *HomeLab* in Endhoven, and the *inHaus* laboratory at University of Duisburg-Essen. While home automation technologies may provide the base for any home environment with intelligent ambient services, a radically different approach to user interface design has to be followed for the development of such services. The challenge here is to meet the particular user experience goals that are of high relevance in home environments. These user experience goals include:

- release the user from the burden of administration and configuration tasks,
- provide information and advice in an unobtrusive but nevertheless effective way,
- learn from user reactions to observable events, and
- adopt automation mechanisms to observed user behavior patterns.

For instance, a standard way of making power-usage monitoring results available to the user would be a simple number display. However, if the aim is to motivate the users to influence their behavior towards a more rational use of energy, other means of presentation, might prove to be more effective. In the next section we discuss some ideas related to user experience of a smart home that facilitates energy monitoring and efficient usage.

5 Towards Energy Advisory Services in Smart Home Environments

We are currently exploring a number of different use scenarios that combine power usage monitoring and home automation technologies in order to assist the user in using energy more intelligently and efficiently.

5.1 Augmented Hall Mirror

The first use-scenario takes its inspiration from the *Interactive Mirror* developed by Philips Research (cf. www.research.philips.com). This device is a mirror augmented by an information display and a touch-sensitive surface. In our case we use a modified hall mirror and locate near the entrance door inside a home environment. Whenever someone approaches the door, the mirror displays information relevant to the current energy usage, and providing useful information and warning to assist the users with saving power. For example when the occupant of the home is about to leave the house, messages displayed on the mirror might alert the occupant that certain windows have been left open, or some electrical devices need to be switched off.

5.2 Embodied Energy Advisor

In another case example, we rely on the metaphor of an embodied character acting in the role of a personal energy advisor. Our first prototype of such a system uses the so-called Nabatzag[5] rabbit, a kind of electronic toy with Internet connection. Nabatzag rabbit can play audio clips that it receives over its Internet connection from different sources. It also features several colored LEDs and two movable ears. These components of Nabatzag rabbit can be used to draw the user's attention it, for instance by augmenting audio messages with display of non-verbal expressions.

Fig. 4 Nabatztag rabbit in the role of an energy advisor

Straightforward use cases of this system configuration include the production of voice utterances relating to individual energy consumption, e.g., “Did you forget to close the fridge door?”, or “Today it's going to be a mild day, shall I turn down the heating while you are away?”.

[5] The Nabatztag device is a product of Violet (www.violet.net)

In silent mode, the rabbit's LEDs might be used to visually communicate status information received from a home automation system. For instance, if overall energy consumption is above average, the energy advisor would get concerned and indicate this by turning on its red LEDs. However, the design of a believable and intelligent energy advisor is a complex task and requires a considerable amount of research experimentation.

5.3 Collaboration and Competition Games

A particular challenge for the design of assistive and advisory services is the fact that a smart home may be inhabited by several people, for instance by a family with children. Two questions arise in this context: (1) is it necessary to track activities related to energy consumption and saving activities of individuals and if so, what kind of tracking technologies should be used? and (2) what type of energy advisory services can be designed for groups of users? While technology exists for identification purposes (e.g., RFID tags, or camera surveillance) it is doubtful that people would accept its introduction in their own home. We therefore restrict ourselves to such group services that do not require behavior and consumption tracking of individuals. As illustrated by the following two scenarios, collaborative as well as competitive settings can contribute to increasing the awareness and smart use of energy. In both scenarios we assume that each family member has their own energy advisor in the form of a Nabatztag rabbit (cf. Sec. 5.2).

Collaborative scenario: A somewhat straightforward collaboration scenario generalizes the above presented embodied energy advisor to a group setting whose members share the goal of saving energy. Rather than commenting and providing advice on power consumption behavior of an individual, the "family advisor" now comments on aggregated consumption and observed activities of all the house occupants regardless of who was responsible for what. While this version of the advisor does not require modifications to the technically set-up, the verbal utterances of the advisor need to be adapted. For instance it might say *"Someone forgot to close the fridge"*, or *"Hey folks, it's 25 degrees in here, shall I turn down the heating a bit?"*

Competitive scenario: A comparisons of one's own behavior and performance against behavior and performance of others is central to many learning tasks. In a smart home environment family members may take part in competition games relating to energy saving. For instance, a family could try to undercut the average power consumption of a family of the same size. A similar approach was made by the BeAware/Energy Life project for smart phones (cf. BjJaEL, 2010).

6 Implementation Framework

As a basis for the implementation of the scenarios sketched above we have designed a layered architecture, drawing on inspirations from other projects (www.intube.eu, www.ip-symcon.de) and initiatives (OpenAPC, www.openapc.com) with related aims. The bottom layer of our architecture is formed by APIs and wrappers which allow us to include hardware components of different manufactures, such as the Current Cost metering devices, HomeMatic automation sensors and actuators, and other micro-controllers (e.g., ARDUINO) for additional sensing and control tasks. The middle layer is to provide network services as well as a unified application programming interface (API). Sensors and actuators are specified in XML, abstracting away from the peculiarities of manufacturer-specific communication protocols, and thus increasing the interoperability between different hardware components. The architecture forms the basis for the development of our energy advisory applications.

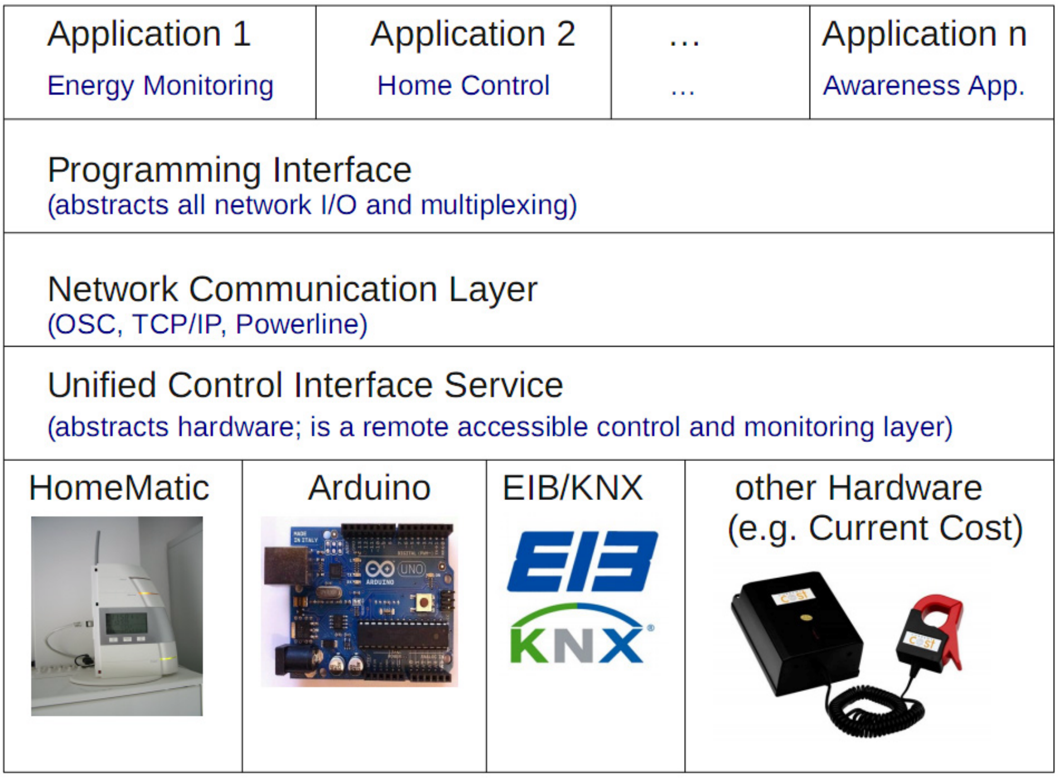

Fig. 5 layered architecture for the development of energy advisory services in the smart home.

7 Conclusion and Future Work

In this paper we presented several design concepts for the development of energy usage monitoring and advisory services for smart homes. We have argued that these systems can be developed using commercially available hardware components such as power usage measurement/metering devices, home automation technologies, and even interactive electronic toys (e.g. for providing ambient user interfaces to such systems). As component integration is a technical challenge, we have developed a layered architecture that facilitates integration of components from a range of manufacturers.

However, there is still a considerable amount of research work to be carried out. Firstly, longitudinal trials should be conducted in order to evaluate acceptance and effectiveness of the advisory services. For example, in a study with elderly people (Klamer and Allouch, 2010) identified a number of factors that influence the acceptance of Nabatztag companions. Secondly, there are many technical issues to be addressed further, such as making IT services for the smart home secure against attacks and unauthorized access.

8 References

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