SmartTecO: Context-Based Ambient Sensing and Monitoring for Optimizing Energy Consumption

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ABSTRACT

This paper presents an energy-saving concept for home/office environments, which proposes to design a multi-layered architecture for an automatic monitoring and control. Based on wireless sensor networks and a context awareness system, the acquired data will be interpreted into different energy-related contextual information. A correlation module using Hidden Markov Models could then give the actuation module a certain context, which allows managing and saving the energy consumption of home/office appliances.

Categories and Subject Descriptors

H.4 [**Information Systems Applications**]: Miscellaneous; I.5 [**Pattern Recognition**]: Miscellaneous

General Terms

Design, Management

1. INTRODUCTION

Energy saving is an important issue in times of shortages of resources and increasing energy prices. Different areas of research are investigating the relevant factors. In economic psychology, studies carried out in the last decades revealed that immediate feedback plays an important role for consumption behaviour. This aspect is neglected in most systems currently implemented in households and offices.

Domestic energy use is commonly invisible to the user. People have only a vague idea of how much energy they are using for different purposes and what sort of difference they could make by changing day-to-day behaviour or investing in efficiency measures. Key issues are for instance the lack of real time information around consumption and the influence of energy use information on energy-saving behaviour. Hence the importance of energy feedbacks consists in making energy more visible and more amenable to understand and control.

Research has shown that small changes in behaviour, such as turning off lights, reducing heat and uncovering or covering windows, can result in energy savings between 10% and 20% [5]. Pervasive and networked computing is one of the key elements to automate and enable energy saving through building smart environments. Authors in [3] presented a model-based approach for controlling dynamically lighting. They developed an intelligent occupancy sensor which can adapt to changing activity levels of user, so that about 5% more energy saving than using an ordinary sensor could be achieved. But the raw data of sensor presence (e.g.infrared sensor) can not be enough to optimize energy consumption. So another work of home energy saving [1] has employed a WSN to gather physical parameters like light and temperature, monitor the presence of users, which is aggregated and processed for user profiling. Based on the presence, temperature and light profiles as well as the real time information, a self adaptive prediction algorithm was proposed for optimizing the energy consumption of home appliances in an automatic way. In contrast to the home energy saving using intelligent and automated devices, we focus on the energy-related context awareness for optimizing the energy consumption patterns of the home or office as a whole.

ICAC'11, June 14–18, 2011, Karlsruhe, Germany.
ACM 978-1-4503-0607-2/11/06.

2. SMARTTECO ENVIRONMENT

SmartTecO is our smart laboratory environment, which employs 33 μPart sensor nodes [2] to detect movement around or of the devices, and to monitor temperature and lighting status in the rooms. Each socket is equipped with a Plugwise[1] Circle and each heater is controlled by a FHT[2] sensor.

The aim of WSNs for ambient and energy sensing is to monitor home/office environment and appliance energy consumption, in order to analyse and react to user behaviour in the environment to optimize power use. Our entire sensing network (Fig. 1) consists of three heterogeneous network components, each has three main parts: *Monitoring/Control Terminal (uBox)*, *Base Station* and *Sensor Nodes*.

μParts: are $1cm^2$ low power wireless sensor nodes with temperature, light and movement sensors. The D-Bridge [4] serves as a programmable base station for μPart, which receives μPart packets and forwards them to uBox network manager via PUT Requests.

Plugwise-Network: measures the energy consumption of connected appliances and switch them on/off with the plug. The Plugwise Stick receives data from and transmits tasks to the installed Plugwise Circles.

FHZ-Network: measures the room temperature. Based on the embedded receiver module, the FHT thermostat can communicate wirelessly with the FHZ base station.

[1] `http://www.plugwise.com`
[2] FHT is a wireless thermostat for enabling heater-control

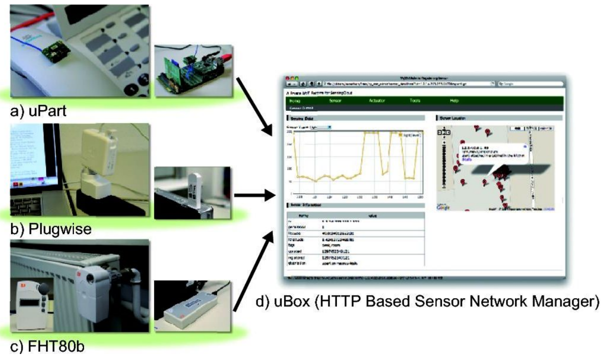

Figure 1: a) Sensor node μPart and base station "D-Bridge"; b) Sensor node Plugwise and base station "Stick"; c) Sensor node FHT and base station FHZ; d) Network manager uBox

The uBox middleware is based on an layered abstraction. Each layer can be manipulated via RESTful interface. If sensors or actuators register to this platform by POSTing themselves and the users or applications within the network can discover them and utilize them with a simple unified HTTP based interface.

On the top layer, users can e.g. generate HTTP requests which dynamically aggregate temperature sensors tagged as "outside" and located within 1000m circle from coordinates (49.00, 8.38) and process the average value for each unit. Feature generation or classification of your own can be added to the uBox with posting server-side JavaScript.

3. SYSTEM DESIGN

In our work, we propose to design a multi-layered architecture consisting of four functional modules: 1) environmental and energy data acquisition through light-weight WSNs based on μPart sensor nodes and "Plugwise" power plug; 2) interpretation of the in real time acquired temperature, lighting, movement and energy data through different abstraction levels of energy-related contextual information:

- Low level contexts, e.g. window open/closed, day or night, which can be derived directly from the raw sensor data of the μParts fixed on the windows.
- High level contexts, e.g. user is working on PC, user has left the office or meeting is being held, such situational information could only be classified through combination of various low level contexts.

3) correlation of different local interpretations for a global view of the monitored situation; 4) the output of the correlation module will then give a decision-making algorithm a proper energy-saving context as input through a certain information management system to motivate the actuators. As actuators we utilize "Plugwise" for controlling on/off state of the power plug via ZigBee and "FHT" for controlling heater via wireless network. A web-based environment has been implemented, which could visualize the real-time sensor data and realize device control via RESTful interfaces.

3.1 Context-Based Monitoring and Control

A model can be built of inhabitants' patterns and device performance in home/office, which can be used to customize the environment for energy use interactions. To achieve the modeling, we propose implicit inputs which are some examples of interpreting meaning from sensed signals of human activity through recognition technologies. The implicit input defines the context of interaction between the human and the environment.

The conceptual model of the energy optimization system considers each sensor node as an input to the context awareness system. Contextual information (interpretation) is thus accumulated by the context awareness system and delivered with the raw sensor data to its correlation module. The collected sensor and context data is assumed to be temporally dynamical and has uncertain effects on an environment, so we model the correlation module as a MDP (Markov Decision Process) using HMM (Hidden Markov Models) method: ***1) Observable States:*** such as time of day, internal temperature and the status of devices; ***2) Hidden States:*** such as the performing task of the people like working on computer, holding a meeting, etc., and the health status of the individual.

The results of this correlation algorithm will ultimately be input to a decision-making algorithm that selects the energy saving actions to execute, such as turn off the heating system after the meeting or the lights and monitors according to the presence of users, etc.

4. CONCLUSION AND FUTURE WORK

We sketched an architecture for context-based monitoring and control in the home/office setting of energy consumption, based on currently deployed heterogeneous WSNs for ambient and energy sensing. The next step will be to implement the correlation module integrated in the uBox, which has the role of managing, filtering and correlating information from the local context interpretation. With a multi-layered architecture, context processing, prediction and actuation for energy saving can then be realized as collaboration strategies between local sensor nodes.

5. REFERENCES

[1] A. Barbato, L. Borsani, A. Capone, and S. Melzi. Home energy saving through a user profiling system based on wireless sensors. In *Proceedings of the First ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Buildings*, BuildSys '09, pages 49–54, New York, NY, USA, 2009. ACM.

[2] M. Beigl, A. Krohn, T. Riedel, T. Zimmer, C. Decker, and M. Isomura. The upart experience: building a wireless sensor network. In *Proceedings of The Fifth International Conference on Information Processing in Sensor Networks (IPSN '06)*, pages 366–373, 2006.

[3] V. Garg and N. K. Bansal. Smart occupancy sensors to reduce energy consumption. *Energy and Buildings*, 32(1):81–87, 2000.

[4] D. Gordon, M. Beigl, and M. A. Neumann. dinam: A wireless sensor network concept and platform for rapid development. In *Proc. of the Seventh International Conference on Networked Sensing Systems, INSS '10*, pages 57–60, June 2010.

[5] R. Woodbury, L. Bartram, R. Cole, R. Hyde, D. Macleod, and D. Marques. Buildings and climate solutions. Technical report, Pacific Institute for Climate Solutions, October 2008.