Opportunistic Sensing for Smart Heating Control in Private Households

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Abstract. This position paper provides qualitative considerations on the design and implementation of a smart heating control system for private households. We envision the system to rely on the opportunistic exploitation of information made available by existing smart devices. Since heating represents the major source of energy consumption in domestic environments, significant energy savings may be achieved. The system will opportunistically leverage smart devices, such as smart electricity meters and mobile phones, to estimate occupants' activity patterns and thus optimize the heating control strategy. By avoiding the need for installing customized sensing devices in the home, our solution may significantly lower the adoption barrier of smart heating solutions.

1 Introduction

Mobile phones, cars, household appliances, and many other devices are constantly being endowed with more powerful computation, sensing, and communication capabilities. These "smart" devices are now able to provide accurate information about their environment. In many application scenarios, however, these capabilities can only be fully exploited if cooperation between devices is enabled. For instance, fine-grained data from smart electricity meters, which are increasingly finding their way into private homes [1], may help identifying the current activities of household occupants (e.g., a flat load curve near the baseline consumption might indicate that the property is unoccupied or its occupants are sleeping). At the same time, location sensors embedded in mobile phones may be used to track users' actual mobility patterns (e.g., when are inhabitants likely to leave home or return from work) [2]. Enabling seamless cooperation among such heterogeneous devices, like electricity meters and mobile phones, will allow developing new generations of hybrid systems.

In this context, we aim to investigate how such devices can be leveraged in an opportunistic way for building a smart heating control system. Such a system has the potential to significantly reduce heating-related energy consumption in millions of households worldwide. This is particularly relevant as the energy spent on heating may reach 70% of the total residential consumption in Switzerland [3]. At the same time, recent studies have shown that almost 30% of the total energy consumed for heating could be saved just by making the system turn off when the occupants are sleeping or away [4].

As we will detail in Sect. 2.1, achieving these energy savings requires a robust heating control solution that can operate without users' intervention nor configuration. In Sect. 2.2 we present our ongoing work towards the development of such a smart heating control system.

2 Our approach

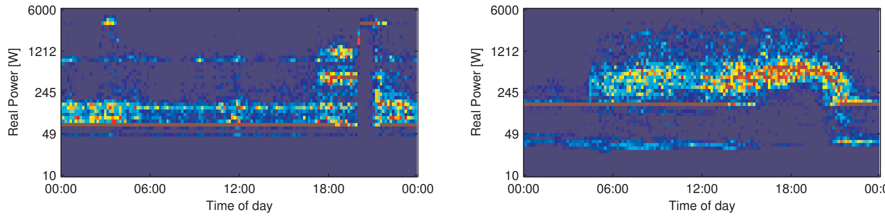
2.1 Background

Traditional heating control systems use preset time intervals to avoid heating the home when its occupants are away or asleep [4, 5]. However, since these systems use static settings, they cannot adapt to the actual occupancy pattern of the household. Requiring users to explicitly provide feedback about their behavior has proved to be a very inefficient means of performing heating control [5]. Users simply do not have enough (monetary or comfort-driven) incentives to engage with the system. Default settings are often left unchanged. As a result, systems based on explicit user feedback may even induce an increase in energy consumption [4, 5]. In contrast, recent studies have shown that systems using occupancy detection can allow for about 30% in energy savings with respect to traditional timer-based systems [4]. However, such systems require instrumenting the home with dedicated, special purpose sensors. Although the installation of such additional sensors may be simple and inexpensive [4], it still requires user intervention and commitment, and poses additional system challenges such as configuration and calibration.

2.2 Opportunistic sensing

We argue that a heating control system that adapts to household occupancy patterns can be implemented without relying on any special purpose sensors. To this end, we aim to use information gathered in an opportunistic fashion from already existing devices, like smart electricity meters and mobile phones. In this context, we focus on three major research issues: (1) Performing statistical classification from smart meter data; (2) Combining multi-modal sensor data; (3) Facilitating real-world deployment of opportunistic smart heating systems.

Classifying smart meter data. Our first goal is to develop robust statistical classification algorithms in order to infer the occupancy state of a household from electricity consumption data. We build upon previous work and analyze smart meter data sets collected in several different Swiss households [6]. Figure 1(a) shows the electricity consumption (in Watts) measured in a single-person household and aggregated over the course of 106 days. The data is depicted as a heat map and displayed on a logarithmic scale. This provides a measure of how the electrical load varies over the course of the day. Figure 1(b) shows a similar



(a) A single person's household. (b) A family's household.

Fig. 1. Heat maps showing daily electricity consumption, averaged at 20 min intervals and aggregated over 106 days.

heat map but for a family of 4. The two figures highlight how energy can be saved in private households. The single-person household exhibits a peak in the morning. This is due to the electric water heater and coincides with the person getting up and ready to leave the house. Likewise, the event of returning home is clearly visible in the cloud on the right hand side of the graph. During the day there is limited activity. This shows how consumption data gathered by a smart meter can help gaining occupancy information and thus be used for accordingly controlling the thermostat. For the family household, the picture is a little less clear. There is a lot of electrical activity going on during the day. This makes the decision about how to control the thermostat more complex. However, this is a limitation of any automatic heating control system. If the property is occupied around the clock, there is not much room for energy savings.

We are currently investigating how classical Bayesian inference methods allow to calculate the probability of a person currently staying at home. A naive Bayesian classifier is used in conjunction with live training data from a mobile phone to create a reliable system for occupancy detection. The Bayesian approach allows to associate a measure of certainty with the inferred occupancy data. The system can use this information to take decisions with a measure of confidence. A threshold value determining the trade-off between comfort and energy savings must be set by the user or learned automatically from user behavior. If the current certainty level is below the desired threshold, the system is not permitted to switch the heating off. Instead, it must step back to a simple (e.g., timer-based) control strategy. We believe such an adaptive behavior is crucial for the acceptance and efficiency of a smart heating control system.

Combining smart meter data with multi-modal sensor data. In order to minimize the need for a timer-based fall-back strategy, further sensors must be taken into account to increase the accuracy of our classification algorithm. As mentioned above, we are planning to make use of existing ubiquitous sensors, such as mobile phones, for this purpose. When a user's mobile phone registers itself at a router in the vicinity of her household, one can assume there is a high probability that she is about to return home [2]. This information can clearly help improving the performance of the smart heating system. Nonetheless, it also poses additional challenges. In particular, it is necessary to understand how to model the information gain achieved by combining data from different devices and how to cope with the heterogeneity of the various sensors (i.e., accuracy, reliability, and data ontology). We believe that the adaptive strategy outlined above, which allows the system to autonomously assess and improve its performance, will also ease its adoption, since it can adapt to available sensors and users' preferences.

Real world deployment. We have currently deployed Web-enabled electricity meters in four Swiss households with more to come in the future [6, 7]. We use the data gathered in these deployments to validate our occupancy recognition algorithm.

3 Conclusions

In this position paper we described a novel approach to heating control in households that makes use of existing sensors, like smart electricity meters and mobile phones. With the help of Bayesian learning techniques and additional input from other readily available sensors such as mobile phones, we are currently developing a smart heating control system that has the potential to enable significant reduction of domestic energy consumption.

References

1. Mattern, F., Staake, T., Weiss, M.: ICT for Green – How Computers Can Help Us to Conserve Energy. In: Proceedings of the ACM e-Energy Conference. (2010)
2. Gupta, M., Intille, S.S., Larson, K.: Adding GPS-Control to Traditional Thermostats: An Exploration of Potential Energy Savings and Design Challenges. In: Proceedings of the 7th Int. Conf. on Pervasive Computing (Pervasive 2009). (2009)
3. Kirchner, A., Kemmler, A., Hofer, P., Keller, M., Jakob, M., Catenazzi, G.: Analysis of Energy Consumption in Switzerland 2000–2009. Swiss Federal Office of Energy, Bern, Switzerland (2010) [Original publication in German].
4. Lu, J., Sookoor, T., Srinivasan, V., Gao, G., Holben, B., Stankovic, J., Field, E., Whitehouse, K.: The Smart Thermostat: Using Occupancy Sensors to Save Energy in Homes. In: Proceedings of the 8th ACM Conference on Embedded Networked Sensor Systems (SenSys 2010). (2010)
5. Environmental Protection Agency: Summary of Research Findings from the Programmable Thermostat Market. Washington, DC: Office of Headquarters (2004)
6. Weiss, M., Mattern, F., Graml, T., Staake, T., Fleisch, E.: Handy feedback: connecting smart meters with mobile phones. In: Proceedings of the 8th International Conference on Mobile and Ubiquitous Multimedia (MUM 2009). (2009)
7. Guinard, D., Trifa, V., Mattern, F., Wilde, E.: From the Internet of Things to the Web of Things: Resource Oriented Architecture and Best Practices. In Uckelmann, D., Harrison, M., Michahelles, F., eds.: Architecting the Internet of Things. Springer (2010)