A Profile based Energy Management System for Domestic Electrical Appliances

Kuo-Ming Chao¹, Nazaraf Shah¹, Raymond Farmer¹, Adriana Matei¹, Nazaraf Shah¹, Raymond Farmer¹, Adriana Matei¹, Nazaraf Shah¹, Raymond Farmer¹, Adriana Matei¹, Nazaraf Shah¹, Raymond Farmer¹, Adriana Matei¹, Nazaraf Shah¹, Raymond Farmer¹, Adriana Matei¹
¹Department of Computing and the Digital Environment
Coventry University
Coventry, United Kingdom
{ k.chao, nazaraf.shah, csx254, mateia}@coventry.ac.uk

Abstract—Climate change is one the driving force behind a new wave of energy management systems. Most of the currently available energy management systems in domestic environment are concerned with real-time energy consumption monitoring, and display of statistical and real time data of energy consumption. Although these systems play a crucial role in providing a detailed picture of energy consumption in home environment and contribute towards influencing the energy consumption behavior of household, but they all leave it to households to take appropriate measures to reduce their energy consumption. Some energy management systems do provide general energy saving tips but they do not consider the household profiles and energy consumption profiles of home appliances. The proposed system attempts to address this issue by taking into account household profiles and energy consumption profiles of electrical appliances. The motivation behind this approach is to provide households effective advice on their energy consumption there by enabling them to take focused and effective actions towards efficient energy use.

Keywords- Energy Management, Sensor Data, Expert System; Ontolgy, Knowledge Respresentation.

I. INTRODUCTION

Today’s world is facing unprecedented challenge in controlling increased greenhouse gases emission which is the main cause of global warming. Carbon Dioxide (CO₂) makes 72% of total emission of the greenhouse gases [1]. The burning of fossil fuel for the generation energy for domestic, commercial and industrial use is a major source of CO₂ emissions. Any attempt to deal with the issue of global warming requires the reduction in CO₂ emission which in return requires reduction in use energy generated by fossil fuel. The EU has a target to decrease the emission of greenhouse gases by 20% by 2020 [2].

In this paper our focus is on development intelligent system for efficient management of household energy consumption. Household energy consumption contributes to 27% of overall CO₂ emissions in the UK [2]. The motivation is to develop an intelligent system to influence the householder behavior through provision of detailed information regarding their energy consumption and intelligent advice on energy efficiency measures. The proposed system actively monitors energy use in a domestic environment in real time while automatically calculating household carbon footprint. The system applies a network of energy consumption reading sensors to monitor energy consumption at appliance and device level.

In this paper, we present a system for intelligent energy management for home appliances currently under development within the European project Digital Environment Home Energy Management System DEHEMS [3]. Our focus is on the role played by household profiles and appliances profiles. One of the main functions enabled by the sensor network is appliances profiling. User profiling process basically includes registration process that occurs when installer install and register sensor network with DEHEMS server.

The system connects energy consumption appliances and devices to an information system to enable better visibility and control of energy consumption appliances. The knowledge of energy consumed by each appliances connected to Zigbee network provides households the ability to fine tune their energy consumption in various situations. The main aim of this research is to provide an effective feedback and advice on appliance level electrical power consumption to household by making visible their energy consumption and the factors that contribute towards efficient energy consumption.

II. RELATED WORK

Several research efforts has been carried out in recent year to design smart home environment where various appliance forms home area network. Home automation technology and ubiquitous wireless communication protocols provide a great potential for home energy management systems to be included in smart home environment. Such an automated environment provides supporting infrastructure for home energy consumption monitoring systems. A number of initiatives has started recently in an attempt to deal with issue of energy management.

AIM [4] is a FP7 funded project for design and implementation of a system that aims to minimise energy
waste in a domestic environment. In contrast to DEHEM the focus of the AIM is to exploit the use wireless sensor monitoring network to control home appliances according to user profiles [5].

Rui et.al, proposed architecture for home energy appliances management and control [6]. Their proposed system is more focused on use of hardware components such as sensors actuators and communication network to manage energy consumption in home environment. Another strand of research focuses on providing intelligent interfaces to increase awareness of energy usage and hence influence the house holder’s behavior [7, 8].

There are a number of freely available web based tools for providing householders advice on their energy consumption [9, 10 , 11] but these tool heavily rely on users’ manual input and provide common sense advice on efficient energy use. There are also a number of commercial ICT based energy management system available [12, 13, 14]. These tools and systems broadly focus on issues of energy consumption monitoring, displaying energy consumption data and basic statistical analysis of the data.

On the other hand the goal of the DEHEMS is to empower household in use of their energy consuming appliances by increasing visibility of energy consumption data and providing intelligent advice on their energy use based on their profiles and appliances profiles.

I. HIGH LEVEL ARCHITECTURE

Energy consumption monitoring functionality is at the heart of DEHEMS system, it provides essential energy consumption information to be used by different subsystems in DEHEMS. In this section we briefly describe the DEHEMS high level architecture as shown in figure 1. The DEHEMS is based on a sensors network of energy consumption measuring sensors. Zigbee protocol is used for networking and data exchange in DEMEMS system. The network has ability to seamlessly integrate other Zigbee compliant sensors into the system as required.

The sensors collect energy consumption data of electrical appliances every three minute and send the data to the local data collector which in turn forwards the data to the central server. In the next stage of the DEHEMS project gas consumption measuring sensors, occupancy sensors and temperature sensors will be incorporated into system in order to measure gas consumption of space heating, water heating and cooking.

The real time collection of data in DEHEMS makes it possible to understand correlation between appliances, statistical analysis, intelligent advice generation and various kind of query support. It also allows householders to see the effect of their energy consumption activities in real time. The DEHEMS consists of two main components known as monitoring and reasoning component. In this paper our focus is on reasoning component.

Our proposed advice generation system is work in progress that makes intelligent use of monitored energy consumption data collected by monitoring subsystem in order to detect abnormal patterns or behaviors in energy consumption. On detection of any abnormality the system tries to uncover the underlying cause of it by using available data on energy consumption and appliances profiles or interacting with user to get required information.

II. SYSTEM ARCHITECTURE

The overall architecture of the proposed system is shown in Figure 2. The main components of the architecture are rule based system and ontology. The system provides web services based interface to be used by other systems supporting SOAP based message exchange.

In other words, the system functionality is exposed as web services. Protégé [15] is used to for representation of the appliances profiles and energy consumption advice knowledge bases and Jess [16] expert shell is employed by the system for reasoning functionality. Jess rules basically encode
experiential knowledge about the causes of the abnormalities and appropriate recommendation to deal with such abnormalities. The energy consumption database component stores time series data of DEHEMS households. The following subsections provide brief description and role of the system sub-components.

III. APPLIANCES ENERGY CONSUMPTION AND HOUSEHOLD PROFILES

It is necessary to have appliances energy consumption profiles in order to identify in real time the abnormal situations where appliance’s energy consumption behavior is not compatible with its known energy consumption profile patterns.

The sensor network enables to monitor appliances activities in high resolution and enables to create appliances profiles by monitoring their activities. The formation of some appliances profiles requires initial input from household as well, such as information about various setting of washing machine programs.

An appliance could have one or more energy consumption profiles based on type of energy consumption activities it is capable of performing. For example a washing machine has a number of profiles for various washing programs and each profile is modeled by using, washing program name, temperature setting, load setting, cycle duration and pattern of energy consumption during the cycle. The energy consumption patterns of each washing machine cycle are constructed by using 10 second resolution.

The main purpose of constructing appliances’ energy consumption profile is to increase the accuracy of the detection of abnormal behavior and reduce false alarm thereby increasing household confidence in the advice system.

Household profiles provide an effective way of comparing a household’s appliances consumption with other household of similar profiles. Household profiles are created at the time when a household is registered with DEHEMS. Household profiles include information such as number of occupants, property type number of room etc.

IV. ENERGY CONSUMPTION ACTIVITIES DEPENDENCY

The proposed system uses the dependency relationships that exist between various energy consumption activities. Such dependency relationships are used to provide intelligent and proactive advice/suggestion on the effect of energy consumption activities on its related activities. There are various relationships exists between appliances activities in home environment and external environment. These are dependency relationship and they are formalized as a tuple.

\(<\text{app}_a, \text{act}_a, \text{app}_b, \text{act}_b>\)

Where \(\text{app}_a\) and \(\text{app}_b\) represent appliances \(a\) and \(b\) act, and \(\text{act}_a\) and \(\text{act}_b\) represent activities of the appliances respectively. For example clothes not spun properly by washing machine will have effect on drying activity of the tumble dryer or over dried clothes will cause ironing activity to consume more energy.

There are some internal relationships that exist between internal environment and appliances, for example relationship between fridge energy consumption and ambient temperature and also between fridge energy consumption and cooking activity if fridge and cooker are in same kitchen.

The dependencies between appliances and internal home environments are internal dependencies and the dependencies that exist between appliances and external environment are known as external dependencies. Such dependencies include relationship between weather conditions and activities of appliances such as heating appliances activities and washing activities etc.

The context sensitivity information enabled by such dependency relationships allows the system to take various relationships into account that may exist between energy consumption activities and provide intelligent advice to household.

V. LARGE VOLUME OF DATA

The amount of the data generated by the sensors is growing rapidly. To extract meaningful information from the database is a very resource consuming task. In order to reduce response time and satisfy the users’ queries, the raw data need to be pre-processed and analyzed, so the system needs to convert these data into meaningful information and store them in a collection of analytic databases. These databases can be interrogated from different dimensions such as time, household, appliance peak energy usage, the duration, the frequency and etc. We can compare an appliance in a household, for example, average usage over a period of time with another period of time to determine if there is any change or improvement. We can compare an appliance in one household with another household which has the same appliance to examine if there is any difference in their performance or usage.

The analytic data can be aggregated into high or abstract level information about energy usage such as type of appliances, region of households, period of time and etc. The information can be drilled down to high resolution energy usage data.

This can be used to alert the households if there is any abnormal activity taking place. For example, a kettle normally takes about 2-3 minutes to boil water, but after 4 minutes the kettle is still on duty and according to readings it continuously consumes a lot of electricity. It could mean the lid is not placed well, so the kettle cannot produce sufficient pressure to trigger the sensor to switch off. In order to support this function and give timely alert or recommendation, another dimension needs to include is appliance duty starting time.

VI. USER RATING ON RECOMMENDATIONS AND THE CONSENSUS

The knowledge base system contains numerous tips or recommendations for energy saving. Most of the knowledge is only applicable to specific conditions, but some of them are fairly generic. In addition, the appliance conditions or other factors which influence the appliance performance sometimes
cannot be determined, so all the possible recommendations will be given. In order to improve the system effectiveness, we ask users to give their feedbacks on these recommendations in terms of effectiveness, timely, and convenience. So, these feedbacks or comments can be fed back into the system for improvement. Since different users have their subjective opinions and preferences and the process also involves multiple evaluation criteria, we adopt the TOPSIS method to identify their consensus in order to rank the recommendations. Normally, the top three highest ranked recommendations are shown to the users.

There are two main data tables are used by TOPSISO. One table is to record the ratings on the recommendations and the criteria related to their importance given by the users. The other table is to maintain the outcomes derived by the TOPSIS reasoning over the users’ preferences to conclude their consensus on the recommendation ratings. The overall approach includes the following steps.

**Step 1:** All the recommendations or tips are set to a neutral value. So, the user can rate the recommendations and give their preferences on the criteria such as effectiveness, timely, and convenience.

**Step 2:** The system gathers the users’ preferences from the GUI, transforms them into RDFs, and store them into a database.

**Step 3:** The system makes the data available to the TOPSIS evaluation service to reason. The importance weight of each criterion is represented as a graded mean integration. The TOPSIS is able to reason over the values related to these criteria and recommendations (tips) to identify the possible consensus.

**Step 5:** These feedbacks can be included in the system as inputs to recalculate the next round of users’ consensus.

The approach allows different opinions to be considered. The recommendations can be made systematically.

![TOPSIS Architecture](image)

**Figure 3: TOPSIS Architecture**

![User Interface for Feedback and Suggestion](image)

**Figure 4: User Interface for Feedback and Suggestion**

The user interface screen shot shown in figure 4 allows users to provide their experience of various tips and their effectiveness. TOPSIS use the user input and ranks the tips based on consensus criteria. This approach allows constantly reevaluating the rating and reflecting the users’ experience.

**VII. ENERGY SAVING ADVICE KNOWLEDGE BASE**

The energy saving advice knowledge base encodes knowledge about pieces of advices and their semantics. This knowledge used as facts by Jess. We classify energy consumption activities related to various electrical appliances in home environment [17] into a hierarchy. The ontological representation of hierarchy provides the semantics to these activities and provides a rich structure for reasoning rules. This classification also links the pieces of advices with activities. These energy consumption activities are distinct in a way that they are uniquely associated with various appliances. Abnormal or undesired energy consumption may be associated with any energy consumption activity taking place in a home environment.

The diagnosis process is trigged by an abnormal energy consumption event which in fact deviation from energy consumption profiles of the appliance. The system checks the profiles of the concerned appliance. Based on abnormal values the appliance the system will gather data acquired by other sensors and user profiles in order to use this data to diagnosis the underlying cause of abnormal event. The data from other sensors such as occupancy and temperature sensors provide contextual information which surround the period during which abdominal event was detected. If all necessary data required by reasoning process is not available within the system, then system will interact with user get information related to abnormal event. Once necessary information are acquired the reasoning process concludes the underlying cause of the abnormal event and generate advice for household which is...
based on recommendation and energy/money wastage of not dealing with the cause of the abnormal event. For example on detection of abnormal peak in washing machine activity the component components triggers the rule base which in turn invokes rule related to abnormalities of washing machine. The rules interact with ontology to get information regarding washing machine profiles and pieces of advice encoded in the ontology. In case underlying cause of abnormality is high washing temperature. The rule will generate the advice containing appropriate temperature and explains the consequences of high temperature.

VIII. DIAGNOSIS RULES

We have defined a set of rules for concerning various electrical appliances and abnormality that may occur. These rules are heuristic rules and based on experiential knowledge [18]. Figure 3 shows a reasoning process that occurs during diagnosis of the abnormality of the fridge. This process involves forward chaining of the rules and tries interactively to get information from user in order to reach conclusion and provide advice to household. The top box in the figure 3 represents the triggering condition for the reasoning process to start. In the expression Concp > Avg(Conpp). Conpp represents energy consumption over current period of time and Avg(Conpp) represents average energy consumption over same period in past.

The reasoning process shown in Figure 3 is encoded in fridge diagnostic rules. These rules get activated when abnormal energy consumption is detected. The current system does not have sensors to measure various physical conditions associated with fridge so conditions are interactively obtained from the household. As shown in the figure various questions are asked from the household and advice is generated based on the answers received by the system. The advice is basically suggestion of actions that households need to perform in order to take preventive measures or provide information about some conditions.

For example a faulty fridge door seal results into fridge consuming more energy than its average usage. Due to a number of uncertain factors which could lead to the fridge increasing the electricity consumption, a number of rules need to be introduced to verify the root of the causes. In order to confirm whether there is a fault in door seal, the rules will suggest a list of actions (e.g. putting a piece paper in between the door and seal or having a bright light inside the fridge facing toward the seal etc). The results of these actions will conclude if the faulty door seal exists. In a way some rule encodes knowledge like and instruction manual to guide the household to perform actions systematically. The encoding of the knowledge is distributed among rules and ontology. Experiential knowledge is encoded as rules and domain concepts and their relationships are encoded in ontology. The domain concepts are uses as runtime facts of the rule base system on which rules operate. The pieces of advice like what action to perform are encoded in ontology. All pieces of advice within ontology are linked to hierarchy of energy consumption activities.

IX. CONCLUSION

This paper presented a work in progress. The proposed work uses the energy profiles of electrical appliances to detect and diagnose abnormalities in energy consumption and recommend remedial actions to household in order to remove or minimize the effect of abnormalities. The system also allows the households to record their feedback/experience. Since different users have their subjective opinions and preferences and the process also involves multiple evaluation criteria, we adopt the TOPSIS method to identify their consensus in order to rank the recommendations. The current system is not supported by actuators yet and by incorporating actuators the system will act as a controller and will perform many of actions automatically.

REFERENCES


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