INTELLIGENT HOUSEHOLD ENERGY MANAGEMENT RECOMENDER SYSTEM

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Abstract: Recent years have seen extensive research in home energy management systems to address the issues of rising energy prices and global warming. The focus of these research efforts is to create a smart environment which integrates household energy consumption appliances and devices into a home area network. This home area network collects energy consumption data constantly in real time in order support data analysis, decision making and enable the householders to have a transparent view of their energy consumption. The ultimate goal is to use Information and Communication Technologies (ICT) to help householders to reduce their energy consumption while maintaining level of their comfort. The proposed recommender system is a subsystem of an integrated energy management system which involves innovative technologies to monitor and analyse energy consumption of households in real time and enables them to have more detailed picture of their energy consumption and also provide them advice on efficient energy usage. The recommender system is supported by the monitoring system which consists of a network of energy consumption monitoring sensors. These sensors read energy consumption of household appliances in real time and send the data to a central server for storage, analysis and query purposes. In this paper we present a recommender system which provides advice to householders proactively by taking in account their energy consumption patterns and also provides answers to their queries regarding efficient use of energy.

1 INTRODUCTION

The number of appliances, lightings and other electronics equipments being used in household are continue to rise. This increase is due to householders' continuous desire for increased comfort, convenience and security. According to International Energy Outlook the projected growth of world energy demand is 44 % from 2006 to 2030 (IEO). It is a challenging issue to meet such demand while minimising CO_2 emission and optimising the energy consumption.

UK domestic sector is responsible for 30% of the total energy consumption [DTI]. In absence of efficient energy consumption management we expect a gradual increase in domestic energy consumption due increased use of energy consumption appliances and increase in population. One of the effective ways to address this challenge is to minimise the energy consumption by optimising the energy consumption and influencing householders' behaviour towards their energy consumption. In this paper we present an energy consumption recommender system. The proposed system aims at helping householders to take control of their energy consumption by allowing them to have appliance level view of energy consumption and providing them advice on how to reduce energy consumption without scarifying their comfort level.
The proposed system is a part of a larger project "The Digital Environment Home Energy Management System" (DEHEMS) (DEHEMS) which is FP7 EU funded project. The objective of DEHEMS is to investigate various ways of using

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ICT to improving household energy efficiency and reduce CO2 emission and save money. The DEHEMS aims at putting households in control of their energy consumption by enabling them to view and understand their energy consumption patterns and helping them actively to reduce their energy usage, costs and carbon emissions.

AIM (AIM) is another 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 (Barbato, 2009).

Rui et.al, proposed an architecture for home energy appliances management and control (Rui , 2005). 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 behaviour (Jussi , 2008, Wood 2007).

There are a number of freely available web based tools for providing householders advice on their energy consumption (PowerMeter, Hohm, i-measure). There are also a number of commercial ICT based energy management system available (Plugwise, Plogg, Agilewaves). These tools and systems broadly focus on issues of energy consumption monitoring, displaying energy consumption data and basic statistical analysis of the data. The recommender system on the other hand semantically encodes the energy consumption activities of home environment and provides intelligent and tailored energy saving advice to householders using heuristic rules.

The paper is organised as follow. In section 2 we briefly describe the DEHEMS system high level architecture and its features. Section 3 discusses the proposed energy saving recommender system and its components and finally section 4 concludes the paper.

2 DEHEMS SYSTEM 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 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 their energy consumption activities in real time.

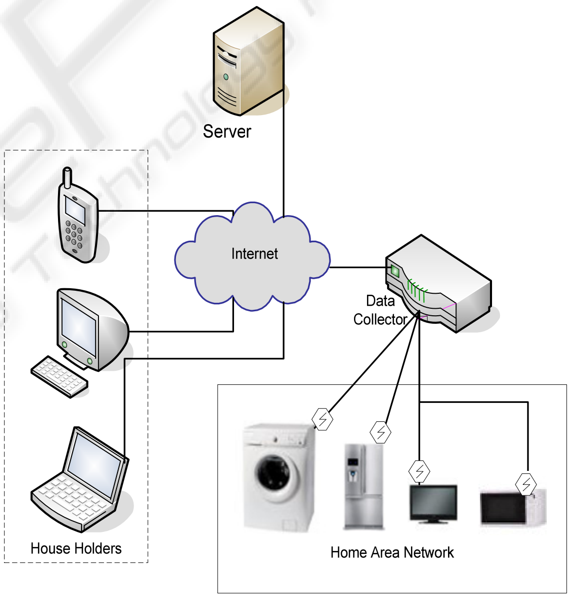

Figure 1: DEHEMS System Architecture.

The sensors attached to an electrical power consuming appliances has sensory, limited computation, and wireless communication capabilities. These sensors form a Zigbee mesh network and a coordinator node coordinates the communication between data collector and sensor network.

Each sensor in the network has a unique identity that is used to identify its associated appliance. This identity is sent to a central server along with every energy consumption reading to enable the server to identify each appliance data uniquely.

The central server stores the energy consumption data over a long period of time in order to enable the households to view their history of appliances level energy consumption and enables the recommender subsystem to generate efficient usage advice based on appliance level energy consumption data.

The operation of the DEHEMS system is organised into three layers, know as service demand layer service broker layer and service provider layer. The service demand layer receives input from and provides feedback to the householder via user interface. The service broker receives the requests from service demand layer and converts them into service requests for the service provider layer. The service provider layer comprises a semantic layer which generates various applicable options to address service requests from the service broker. The proposed recommender system encodes the energy consumption activities and their relationship semantically making it a component of the semantic layer.

3 ENERGY USUAGE RECOMENDER SYSTTEM

The proposed recommender system defines a knowledge base of energy saving tips. These tips are classified based on their characteristics and the energy consumption activities they belong to. Such classification enables the recommender subsystem to produce focused and intelligent energy saving advice in response to the user's queries and their energy consumption behaviours.

Householders' engagement with the system is an essential factor to make them aware of the consequences of their energy consumption behaviour and hence influence their behaviour towards efficient energy usage. For example a when a householder asks the system to provide energy saving advice on washing activity. The system interactively asks user questions to acquire essential data to produce a more accurate and intelligent advice rather than providing random tips on washing. The recommender system is also able to acquire this data from the system once enough statistically significant is available in the system.

Although the system provides user choices for getting more specific advice, but it also allows the users to get general advice on energy saving regarding specific activity. For example in case of washing activity the system may ask a householder if he/she wants advice on washing temperature, washing load, fabric types or overall advice on washing and then generates advice based on his/her response. In case the householder wants advice on washing temperature the system then ask him/her about their current temperature setting (eventually these values will be acquired from appliance ontology). The system then perform reasoning to conclude applicable piece of advice and the amount of energy that the householder would be able to save by changing washing temperature to a suggested temperature. This process is depicted in figure 2. A simple formula below shows that one of three advices will be picked based on value of the washing temperature supplied.

$$output = advice\ ((Tw > Ti) \mid (Tw < Ti) \mid (Tw = Ti))$$

Where Tw is current washing temperature and Ti is ideal washing temperature.

The recommender system also informs the household about the effect of one energy consumption activity to another energy consumption activity. For example if the tumble dryer is left to over dry the clothes this will have effect on ironing activity as the ironing of over dry clothes causes increased consumption of energy in ironing activity.

A proactive function of recommender system is to display the energy saving advice concerning current activities being performed by the household. When a household log into DEHEMS system the recommender detect his/her current energy consumption activities and displays the energy saving advice in a context sensitive way.

The recommender system has access to an ontology which defines the various energy consumption activities in a home environment and their associated energy saving tips. The main objective of the recommender subsystem is to enhance the household engagement with the system by providing them customised and context specific advice on their energy consumption there by influencing their energy consumption behaviour.

The energy consuming appliances in domestic environment vary greatly in terms of their efficiency size and operating characteristics. Such variations make it difficult to produce one-size fit all energy saving advice. In order to address this issue the recommender system also makes use of energy consuming appliances ontology. The energy consumption appliances ontology enables the recommender system to take into account various characteristic of the appliances while generation energy saving advice for householders.

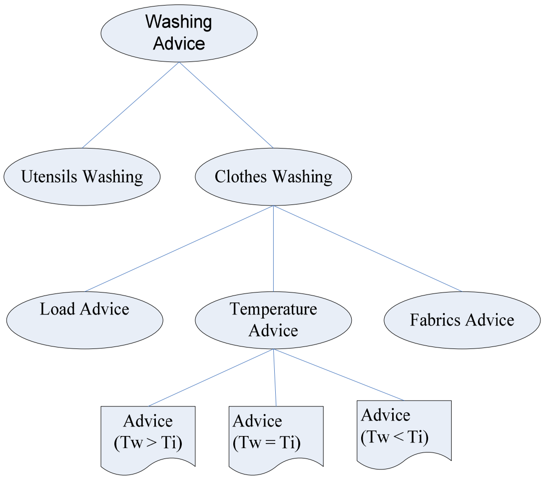

Figure 2: Advice generation process.

The declarative knowledge of the energy consumption activities in domestic environment is encoded using protégé [protégé] knowledge-framework. The encoded knowledge is made of energy consumption related concepts and relationship between these concepts. Jess [Jess] rule engine is used to encode reasoning rules which operate on knowledge encoded in the ontology.

The problem solving method used by the recommender system employs heuristic classification approach (Clancy, 1985).

The following two subsections briefly describe the ontology of energy consumption activities of and heuristic classification approach used in recommender system.

3.1 Classification of Home Energy Consumption Activities

There are various ways in which energy consumption activities of household appliances can be classified. Figure 4 represents an activity based appliance classification in which appliances energy consumption activities are grouped together based on a high level energy consumption activity.

These activities are treated as domain's concepts and represented by frames in ontology. We have used following three types of links to create relationships amongst the concepts.

a. Instance: An instance represents is-a relationship between a concrete instance and its associated concept. For example relationship between "clothes washing" concepts and its all concrete instances.
b. Sub-class: A sub-class relationship represents the child parent relationship.
c. Property: It is used to represent characteristics of a concept.

Figure shows 3 a frame and its relation to properties and other frames. Each energy consumption activity has its start time end time and its energy consumption during this period. As shown in figure 3 the clothes washing activity has hasClothWashingTip relationship to clothWahingTips frame, which in turn has slots relating washing temperature and load for which this tip is appropriate to. Every energy consumption activity concept has at least one energy saving tip associated with it and there is no upper limit on number of energy saving tips that an energy consumption activity can have.

The hasEffect slot represents the other energy consumption activities that could be affected by this activity, i.e. clothes not properly spun by clothes washing activity have effect on energy consumption of the tumble dryers.

Frame: {Clothes_Washing}
hasEffectOn: washing
washingTemp: integer
startTime: String
endTime: String
consumption: integer
standby: integer
hasWashingTips: Frame

Frame: {ClothWashingTips}
hasLoad: int
hasTemperature: int
description: string
Priority: int

Figure 3: Ontology Frames and Slots Relationships.

3.2 Heuristic Classification Approach

The reasoning process in recommender system is based on heuristic classification (HC) problem solving method. HC is a well understood and a widely used problem solving method. A number of well-known expert system are based HC (Shortliffe, 1976, Bennett, 1978).

In HC approach, programs employ an inference structure that systematically relates data to a pre-enumerated set of solutions by abstraction, heuristic association and refinement (Clancy, 1985). A heuristic classification approach includes four main components in its knowledge base : data, data

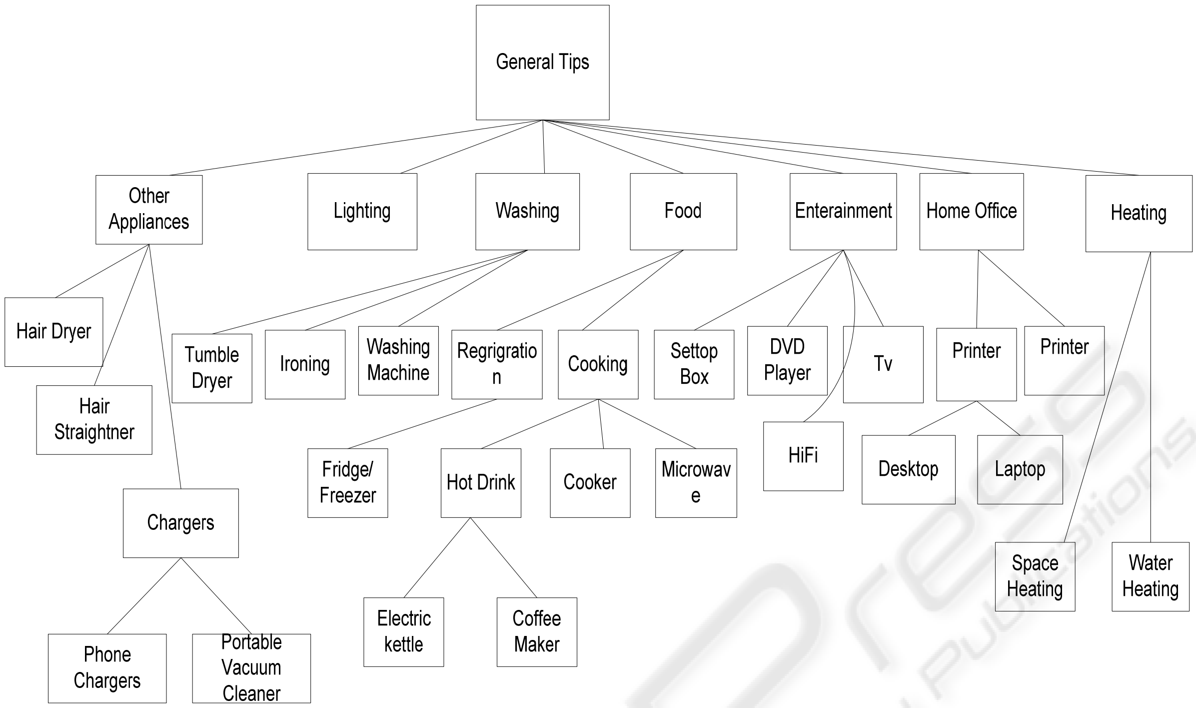

Figure 4: Activity based classification of energy consumption appliances.

abstractions, solution abstractions and solutions. When data/symptoms are observed, the system populates data/symptoms to the data abstraction; the data abstraction then matches the solution abstraction; and refines the solution. For example in energy consumption advice regarding temperature of clothes washing activity, the temperature of washing machine provides the data to be used in HC inference process. The temperature value is then abstracted to normal, abnormal or below normal data abstractions. This data abstraction is then matched to solution abstraction which is the hierarchy below washing activity. Then solution refinement is applied considering all tips related to washing temperature and advice is presented to household based on best fit.

Pseudo code of one of a Jess heuristic rule about advice regarding washing machine temperature is shown below.

Condition (LHS)

```
(temp← WashingTemperature)
    ( []applicableAdvice ← hasTips )
    ( energyConsumption ← Consumption)
```

Action (RHS)

```
(for each
        advice ← [] applicableAdvice
          if ( temperature(advice) > temp)
             [] solutions ← advice
          else if  ( temperature(advice) < temp)
             []solutions← advice
          else
             solutions ← advice
)
selected_solution ← (selection (solutions, energyConsumption, washingMachineModel) )
```

4 DISCUSSION AND CONCLUSIONS

In this paper we have presented energy consumption recommender system. The recommender system is a part of DEHEM project which aims to influence householder energy consumption in order enable householder to make efficient use of energy consumption and reduce CO2 emission. The novelty of the recommender system lies in its ability to generate customised and focused energy consumption advice using HC approach. We have implemented ontology of energy consumption activities in home environment which separates energy consumption activities from appliances ontology. Since the proposed system is a part of ongoing research, the system will be refined using statistical machine learning approaches using data collected over period of more than six months.

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