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Monitoring Appliances Sensor Data in Home Environment: Issues and Challenges

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Abstract

In this paper our focus is on issues and challenges faced in monitoring energy consumption in the domestic sector and way forward to deal with these challenges. Implementing a sensor network to monitor energy consumption of household appliances in a meaningful way requires sophisticated network design. Such network has to deal with large amount raw sensor data coming from multiple sources. The challenge is how to collect necessary data and store it for producing intelligent advice on economical energy usage for household. One way of dealing with this challenge is to have smart sensor devices embedded in home appliances, however currently a vast majority of domestic appliances do not have even dumb sensor devices to enable access to their energy consumption data. In a typical home environment we can expect sensing devices with various capabilities ranging from passive device to intelligent and proactive devices. Raw data streams received from these devices need to normalised and represented in semantically equivalence manners.

1. Introduction

Global warming is one of the serious issue modern industrial world is currently facing. Increased industrialisation and our life style of relaying heavily on increased number of household appliances and devices have drastically increased the energy consumption per capita. This energy consumption is directly linked to the emission of CO2 which is a major contributing factor in global warming. Initiatives like United Nation sponsored Kyoto Protocol [1] which legally binds the member states to reduce greenhouse gases and European Climate and Energy Package agreed by EU to reduce greenhouse emission in EU by 20% by 2020 [2] came into existence aiming at addressing the issue of global warming. In this paper we focus on issue of monitoring energy consumption in household appliances specifically and generally on CO2 emission caused by these appliances. We also briefly discuss the technologies used to produce intelligent advice to households so they could reduce their energy consumption without cutting on essential services.

Household energy consumption accounts for 27% of overall CO2 emission in the UK [3]. In an attempt to reduce CO2 emission resulting from household appliances the UK government has set up an initiative called Energy Efficiency Commitment (EEC) [4]. EEC places obligation on energy suppliers to reduce energy consumption by achieving target of efficient energy usage.

This paper is a part of our ongoing project The Digital Environmental Home Energy Management System (DEHEMS) [5]. DEHEMS is an EU funded Framework 7 project investigating ways in which state of the art technologies can be used to improve domestic energy efficiency and hence reduce CO2 emission. The main objective of DEHEMS is to support households to reduce their energy usage through better management and analysis of their energy consumption.

The first and fundamental step in achieving this goal is to have devices for monitoring the energy consumption of household appliances. In order to assess the energy consumption of household

appliances, heating and cooling systems we need to have access to their energy consumption data.

DEHEMS uses monitored energy consumption data to provide live feedback to household on their energy consumption and provide advice to household on efficient use of energy.

Currently a majority of household appliances are not equipped with sensing devices for reporting their energy consumption. We need to attach sensing devices to such appliances in order to bring all devices into a home sensor network. The heterogeneous natures of these sensing devices attached to household appliances make it a challenging task to obtain their energy consumption information in a unified way.

DEHEMS's one of the objective is to provide user advice on how to use their energy efficiently without comprising on level of their comfort. This problem can be formulated as constraint satisfaction problem where comfort of home occupant is treated as a hard constraint and various types of energy consumptions are treated as soft constraints.

The paper is organised as follow in section 3 we give brief description of the problem. Section 4 describes the challenges. Section 5 describes the energy consumption data storage, retrieval and their associated issues. Section 6 gives a brief discussion of embedded devices and real-time web services. In section 7 we discuss high level system architecture and its essential components and finally section 8 provides conclusion of the paper.

3. Problem Domain

The problem domain (DEHEMS) is concerned with home energy management. This is multidisciplinary problem, involving electrical technology, sensor networks, Software Engineering, Artificial Intelligence, and Human Machine Interaction etc. DEHEMS's one task is to monitor energy consumption of households in a municipality and store energy consumption data in a central database. The data from central database is used from various purposes ranging from displaying households' current energy consumption and its associated CO2 footprint to providing intelligent advice on efficient energy use based to historical data.

DEHEMS will use four groups each consist of 50 households for energy consumption monitoring. Three groups belong to UK's cities and one to a Bulgarian city. In its first phase DEHEMS monitors energy consumption of 20 households in each group and the number of households will be increased to 50 in each of four cities after necessary equipments and sensors installation is complete.

In DEHEMS project we get energy consumption reading of appliances every six seconds. These readings are then aggregated and sent to server, which then stores these reading in central database. The database maintains energy consumption record of hundred of households. The server receives six hundred readings per hour for each household. A 500MB data per sensor is stored in database. DEHEMS will also incorporate house occupancy, temperature and thermal sensors at next stage.

DEHEMS uses web services standards for interaction of devices and users with the server. The main purpose for using these standards is to allow seamless integration of the energy monitoring devices into the system.

Users may interact with the system anytime via PC, or mobile phone in order to see their energy consumption in real-time and seek advice from system on efficient use of energy. For example user may ask system queries like how to reduce energy consumption by 10% or what impact it will have on energy consumption by changing appliance A with appliance B of better energy efficiency rating. A household may also ask system for various statistics on energy consumption relative to other household with similar houses/appliances.

4. Challenges

In household environment we expect various kinds of sensors; these may include appliance energy consumption sensors, thermal sensors and light sensors. These sensors may transmit data at various time intervals and data may differ in format too. Data from all sensors have to be collected and stored in central database. There are two data servers one in the UK and other in Bulgaria to back up each other.

Receiving energy consumption, temperature and thermal data from hundred of houses can cause bottleneck in server and traditional database management engines. Such a huge number of hits per second may cause system's performance degradation. The challenge is how to maintain system performance while dealing effectively with incoming data in real-time.

There are number of possible alternatives that we intend explore in this project in order to address this challenge. Our goal here is to minimise the frequency of appliances energy consumption and other data transfer to the server while not losing important information. There are two candidate approaches to this problem. One approach could be to pre-process the data at gateway before sending it to server. The second approach is applicable to next generation of household appliances containing embedded sensing devices and DPWS [6].

The current generation of domestic appliances does not have embedded sensing devices. We are using external sensing devices to monitor energy consumption of household appliances. Some smart appliances are appearing with embed sensing devices and in near future we will see more smart appliances with such capability. Although that may result in data filtering and reduced data traffic, but there is still tendency in performance degradation of reasoning process.

The advice generation process essential take into account energy consumption and occupancy of home in order to generate an effective advice. Home occupancy data contributes towards more complexity of the reasoning process. Reasoning over large data results in the increase of response time, which is not a desirable factor.

5. Energy Consumption Data Storage and Retrieval

It is essential to have historical data on energy consumption of households in order to be able to generate efficient energy consumption advice for them.

The energy consumption data stored in the central database indicates the users' energy consumption habits over a period of time.

Having millions of records of energy consumption data coming directly in real time from hundred of household poses the performance problem for data storage, retrieval and reasoning.

One of the solutions to data storage and retrieval is TimeSeries DataBlade® [7]. TimeSeries DataBlade® has advantage over traditional RDBMSs in organising and manipulation time-stamped data. The application of TimeSeries DataBlade® provides potential solution to performance degradation of reasoning process that result from reasoning over huge volume of data.

DEHEMS uses "Current Cost System" [8] for monitoring home energy consumption. The transmitter sends energy consumption reading every six second to monitor, which then sends the reading to DEHEMS' server. This six second transmission of data create large amount to data to be transmitted to the server and then get stored in the database. Soon database grows to million of records and most of these records do not play any significant role in reasoning process. The raw sensor data of energy consumption of devices need to be pre-processed in order store only useful data for long term usage. The steps involved in from pre-processing raw sensor data to data used by reasoning process are shown in Figure 1, data is pre-processed before storing and reasoning process retrieves pre processed data from repository. We believe that using TimeSeries DataBlade® alone will not deal with the performance issue unless we have a pre-processing mechanism to pre-process the raw sensor data of home energy consumption before sending it to server.

In order to make reasoning process efficient we need to split the home energy data consumption into different categories and semantically tag this data. This will allow reasoning process to use classes of data rather then conducting an exhaustive search.

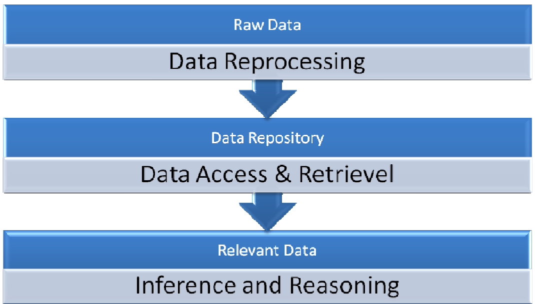

Figure 1: Data Processing

6. Embedded Devices and Real-time Web Service

The processing and communication capabilities of embedded devices have continued to increase during last decade. The fundamental issue in collaboration and communication of these devices is heterogeneity in terms of hardware and software; and their ability to discover and interact seamlessly with their peers. Service Oriented Architecture Device Architecture (SODA) [16] provides answer to this issue, SODA implementation uses existing devices standards and SOA standards. SODA treats devices as services and enables integration of devices in enterprise systems. Web services protocols require more computational resources in order to enable device to device communication [17]. Microsoft defined a light weight subset of web services protocols called Devices Profile for Web Services (DPWS) [18] for constrained resources of embedded devices.

We believe that DPWS compliant embed devices for monitoring energy consumption of household appliances have potential to limit the amount of data that is transmitted from home environment to server. Since we monitor and transmit household energy consumption in real time and send reading to server, the underlying real time operating system is necessary for predictable scheduling of tasks for communication and for controlling the hardware [17]. In our project currently household energy monitoring sensors transmit energy consumption data from hundred of homes to server. DPWS supports event subscription, allowing devices to register with each other to receive notification when a specific event occurs. The subscription capability can be exploited to reduce amount of data traffic. For example events like start and stop of an appliance can be subscribed, and device sends energy consumption rate of appliance and its start and stop time to server. Knowing start stop time and energy consumption rate of an appliance following formula is used to calculate energy consumption.

$$ECt = (te - ts) * Acr$$

Where ECt is total energy consumption in kilowatts ts is start time, te is stop time and Acr is energy consumption rate of the appliance.

If a household wants to check energy consumption between ts and te interval, the appliances status will be obtained in real-time in order to answer household query otherwise server will receive start and stop event notification for an appliance and its energy consumption rate. In this way we can reduce data traffic considerably.

7. Architecture

The high level system architecture is shown in Figure 2. The energy consumption of each appliance is measured in Watts. Sensor attached to each device transmit reading to data box, which convert the energy consumption reading in XML format and send it to server via web. Server then stores energy consumption data in a persistent storage. User can access their energy consumption data and associated statics via Web. Each user has to log in using his name and password before requesting any information. Users can also view their CO_2 footprint based on their energy consumption and they can also view their energy consumption comparison with other similar household in the same locality.

Users may also request various types of information such as their energy consumption over a period of time, energy saving advice and answer to various what if scenarios. Advice on efficient use of energy and answers to what if scenarios involve reasoning process to be invoked and energy consumption data retrieval simply involves a query to be sent to database.

Following sub-sections describe various components of the architecture.

7.1 Reasoning

The aim of this component is to provide an integrated platform to support the development of semantic services. It includes a mechanism to model and manage the ontologies by supporting adding, updating, and deleting concepts in the ontology. These concepts are linked with production rules, so that these concepts can be declared as facts for reasoning. The fuzzy terms should be able to be defined and represented in the knowledge base and these terms should be compatible with the ontology and the production rules, so the knowledge contained in the terms can be exchanged and shared. The semantics of the data set are represented in a knowledge base for reasoning and to facilitate the interaction between the system and users. In addition, the knowledge base also provides a mechanism to retrieve the data set regardless of its location and data structure.

The knowledge base system accommodates knowledge expressed in rules, facts, and functions. In addition, it communicates with other components in the system in order to form an integrated semantic system platform.

7.1.1. Semantic Service Management UI. It is realized by Protégé [11]. The Protégé system is an open-source ontology editor and knowledge-base framework developed by Stanford Medical Informatics. It uses a frame-based representation formalism. The Protégé system utilizes the Graphical User Interface library in Eclipse to support friendly ontological construction and management. It also provides a plug-in facility to accommodate third party software.

7.1.2 Semantic Services. These services include the facilities for knowledge representation and reasoning by integrating different computational components.

Figure 3 shows the overall component architecture. The ontologies are stored in RDF [9] files and the rule, procedure and fuzzy knowledge are saved in the .CLP file. The interface for interacting with other systems which are sited outside of semantic services can be Web Service Description Language (WSDL) [10] or Java. There are four general areas of packaging included as the semantic elements in this component. These are: semantic service management UI; semantic services; ontology, rule and fuzzy representation, and, ontology and knowledge base storage.

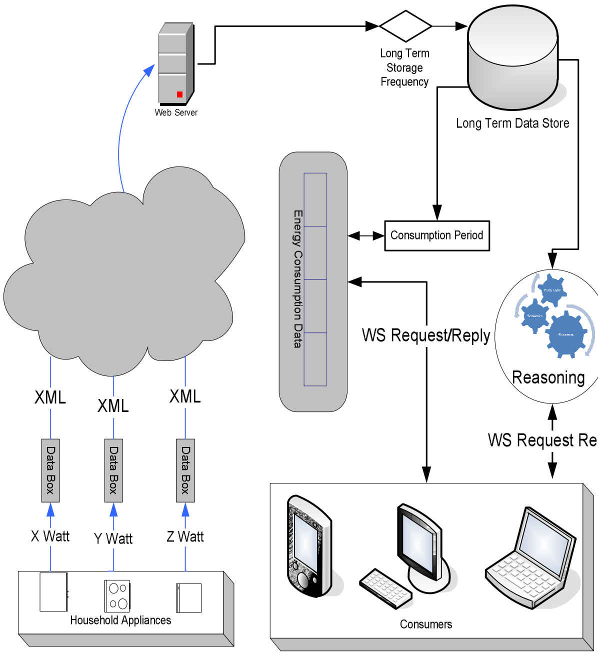

Figure 2: High Level System Architecture

7.1.3 Ontology, Rule and Fuzzy Representations. The ontology modelled in Protégé can be stored in two knowledge representation languages namely RDF and OWL [12].

However, Protégé by default does not provide facilities to support rules and fuzzy expressions. The Jess [13] tool is a *rule engine* for the Java platform, which supports production rule knowledge representation and provides an inference engine to reason over data and knowledge from different sources.

JessTab [14] is introduced to bridge the gap between Jess and Protégé. The fuzzy logic is realized by FuzzyJ [15] toolkit which provides a capability for modelling fuzzy concepts and reasoning in a Java setting. It supports Jess by providing a set of components in the library.

7.1.4. Ontology Storage. Ontologies, rules and other knowledge structures are stored in different locations and formats to take advantage of the built-in file management provided by the systems.

7.2 Semantic Service and User Interaction

The semantic services implemented are to provide the essential functions to enable the knowledge in the ontology, fuzzy knowledge base and production rules to be represented in machine readable formats that can be used by the reasoning engine (see the components marked in dark color Figure 4). The services should also support taking the user requests into the system and replying with appropriate responses.

7.3 Monitoring/ Sensing Component

This component consists of sensors, emitters and data collection devices. Currently our research focuses on this component. The pre-processing of raw energy consumption data occurs in this component and data get semantically tagged before transmitting to server.

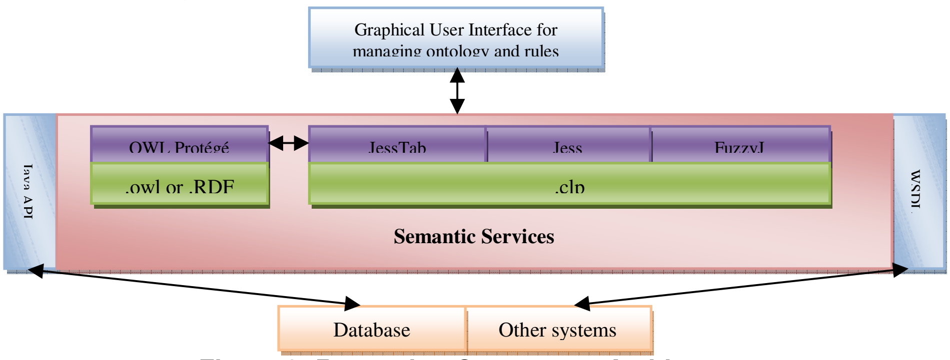

Figure 3: Reasoning Component Architecture

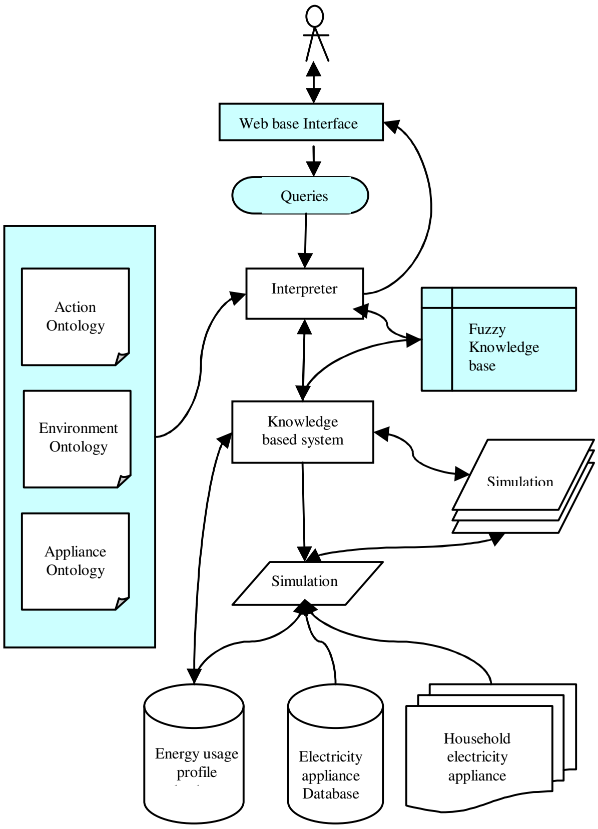

Figure 4: Procedural diagram of the Semantic Services

8. Conclusion

In this paper we have described the issues and challenges associated with monitoring sensor data of energy consumption in home environment. The paper also explores the performances related issues associated with reasoning process involved in advice generation of efficient energy use for a household. This work is part of ongoing DEHEM project and we have completed initial implementation of the system. The future work includes implementation of complete version ontology for household appliances and design and implementation of rules that cater for various what if scenarios in home energy management domain. Our preliminary research shows that TimeSeries DataBlade® has potential to deal with high volume of real-time date and DPWS provides a way to limit volume of energy consumption data transferred from hundred of homes to the server.

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