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Smart Home Energy Management System

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Abstract: ***The development of 'demand-side load management' is the outcome of the smart grid initiative. Due to the significant amount of loads in the residential sector, home energy management has received increasing interest. In the country like India, we are lagging behind, in the power sector as the demand is much more than the supply. Moreover, there is not a single initiative, which has been taken for the deployment of smart suppliers and smart users. Here, I propose a hardware design of smart home energy management system (SHEMS). With the help of this proposed design, it is possible to have a real-time, price-responsive control strategy for domestic loads such as electrical water heater (EWH), illumination (Lights), air conditioning (Fan), dryer etc. Consumers may interact with suppliers or load serving entities (LSEs) to facilitate the load management at the supplier side. This system is designed with sensors to detect human activities and the behavior is predicted by applying a machine learning algorithm in order to help consumers reduce total payment on electricity. Finally, for the verification of the hardware system, simulation and experiment results will be checked based on an actual SHEMS prototype.***

Keywords: Demand side load management, Load Serving Entity (LSE), Smart Home Energy Management System (SHEMS), Smart Grid.

1. INTRODUCTION

The electricity prices in the power market are closely related to the consumers' demand. However, because of the lack of real-time pricing (RTP) technologies, there are challenges to electricity market operators to optimize the signal usage and respond to scarcity as electricity cannot be stored economically. Few years ago, because of the deployment of advanced metering infrastructures (AMI) and communication technologies, RTP is technically feasible [1]. RTP reflects the present supply-demand ratio and provides a means for load-serving entities (LSEs) in order to solve the issues related to demand side management such as peak-load shaving. Applications of RTP enable consumers and suppliers to interact with each other, which creates an opportunity for consumers to play an increasingly active role in the present electricity market with optimal control strategies at the demand side.

For further optimization of the residential load consumption, it is reasonable to design a smart home energy management system (SHEMS) based on RTP response to reduce the total electricity payment cost for consumers, and meanwhile, to flatten demand peaks.

This paper presents a SHEMS hardware design which is integrated with a machine learning algorithm to achieve dynamic price response. Thus, this system considers both interests from the electricity supplier side and the customer side. Particularly, this paper presents a hardware design of a SHEMS system with sensing technology, communication and machine learning.

Organization of this paper is as follows. Section II is the description of the literature survey, Section III analyzes the functions that the proposed SHEMS design needs to implement. Section IV presents the details of the SHEMS hardware design. Section V discusses the machine learning algorithm applied to this work as a software part.

2. SURVEY OF VARIOUS TECHNOLOGIES

The literature includes broad range of previous works which are related to SHEMS. There also they worked on the hardware prototype for SHEMS and they pointed out that SHEMS will be the essential component for future smart grid applications. The different technologies are described below:

2.1 Dynamic Price Response:

In the paper [1], the author proposed a system which will function in a similar manner to SHEMS. Here the Stellaris LM3S9D96 MCU is used as controller.

The design proposed in [1], is purely a smart grid application at the consumer's side. It is not applicable for the traditional environment. For the places where the distribution system is only a one sided communication, this product cannot work.

2.2 Smart Meters:

In the paper [2], an intelligent trading, metering and billing system is introduced. Here the system is able to control functions such as check real time prices and remotely switch on/off home appliances. This functioning again makes the consumers to participate in the load management. Here the customers can adjust their demands by setting the operating time.

Here the system is not comfortable for consumers, as the setting time has to be given by the consumers every time. Also there is no auto conversion from one mode to other as it is a manual input taken from the consumer.

2.3 Weighted Average Price Prediction Filter:

In the paper [4], the framework has been proposed for residential consumption. The objective is to achieve a trade-off between reduction in payment and reduction in waiting time for the operation of home appliance based on user's needs.

In this, the weighted average price prediction filter is applied. The combined result of the scheduler and the filter causes the reduction in payment. Moreover it does not provide a smart usage of the power.

2.4 Coordinated Scheduling of Energy Resources:

In the paper [3], an algorithmic enhancement is proposed to a decision support tool so that residential consumers can optimize energy services. Again this focuses on the reduction of electricity usage. The optimization in the usage is not discussed. Also the smartness of the system is missing.

3. FUNCTIONAL REQUIREMENTS

In this section, the functions of the proposed SHEMS system are discussed. From the consumers' point of view, the essential goal of SHEMS is to reduce their total electricity payment while satisfying their needs. Specifically, the control strategy provided by SHEMS is to adjust the control settings of each load i.e. appliance at home in accordance with the consumer's preference, total payment. As shown in Fig. 1, the primary function of the proposed SHEMS includes:

a) To receive information and messages from various loads for e.g. RTP, human activities at home, consumers' preference etc.

b) After the analysis of the received information, generate the optimal strategy

c) Adjust the settings of the loads according to the strategy generated.

d) To feedback data back to the Load serving entity (LSE).

Moreover, the detailed requirement analyses about data collection, processing and control are discussed below.

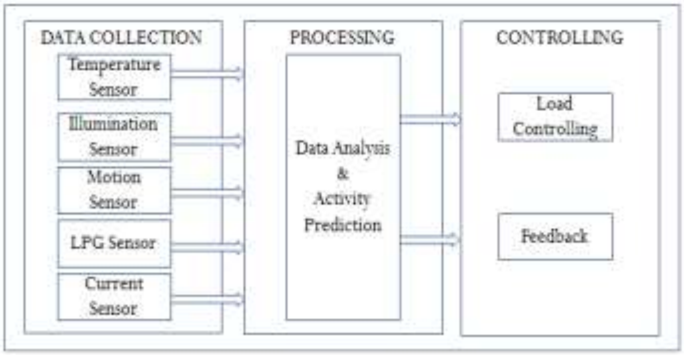

Figure 1: Functions of proposed SHEMS 1

3.1. Data Collection

Fig. 2 summarizes the data collection part. Here all the data i.e. the status of all the sensors is received.

1) Real Time Pricing: A personal computer is necessary for reading the RTP signals from the sensors or LSE of the residential load. Therefore, ZigBee module should be included in the proposed SHEMS design.

2) Messages: This function is designed to respond to extreme scenarios. For this LPG sensor will sense if there is leakage of the gas and immediately the consumer will receive an SMS about this.

3) Consumers' Preference: In order to obtain the consumers' preference, a GUI is developed for consumer to manually change the settings at home.

4) Human Activities: Motion sensors need to be installed to collect useful data of human activities at home. By applying machine learning algorithms in the processing part, the consumer activities related to energy consumption can be predicted.

5) Status of Loads and Home: Interfaces need to be developed to obtain the status of loads at home. For prototyping we are taking loads such as EWH, fan, hair dryer, and light. Temperature and illumination sensors are also needed and perhaps deployed in a number of, if not all, rooms to monitor the environmental parameters.

3.2. Processing

1) Receiving Data: Status of all the sensors is displayed on the GUI in PC. However, as far as the sensors and load interfaces are concerned, they are designed with a wireless connection with the PC.

2) Event Analysis: The processor reminds the consumer about the messages from the utility supplier through a specific user interface. SHEMS should alarm the consumer about whether the comfort level will be significantly impacted under any inclement event.

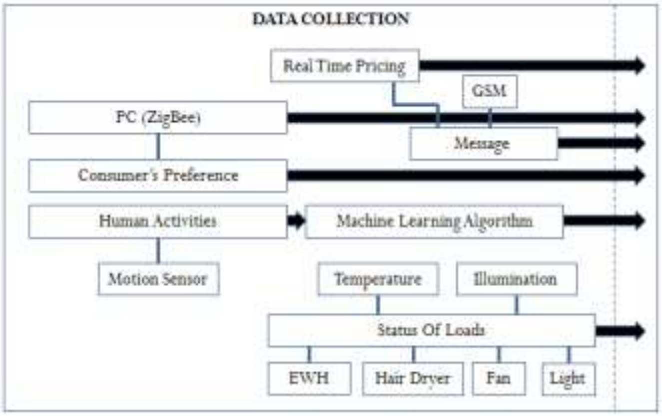

Figure 2: Data Collection Part

a) Human Activity Prediction: Machine learning algorithms will be implemented to analyze and predict human activities based on data collected by motion and flow sensors. The longer the system is in use, the more accurate the predictions can be.

b) Load Optimal Strategies: Since all the useful information including RTP, special events, consumer needs, and human activities can be obtained, different optimal strategies are applied for each load based on the modes.

3.3. Control

The functions for the control part are load control and information feedback as shown in fig. 3.

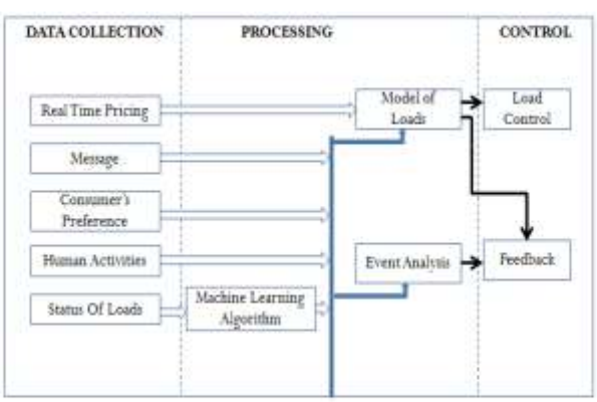

Figure 3: Processing Part

1) Load Control: Proposed design has load interfaces to obtain the real-time status of all appliances. Load interfaces are also expected to modify the settings of appliances according to the results calculated from the processing part.

2) Feedback: The status of appliances and the event information will be shown to the consumer on the GUI.

4. PROPOSED HARDWARE DESIGN

The objective of SHEMS is to minimize the consumer's total electricity payment cost meanwhile satisfying the consumer's needs in comfortableness. SHEMS will identify optimal load control strategy responsive to the electricity RTPs, the consumer's needs, also for extreme scenarios. Further, SHEMS should also have the ability for administrators (utility suppliers) to monitor and analyze the real-time status of a specific area or home.

Following fig.4 shows the proposed hardware design for SHEMS.

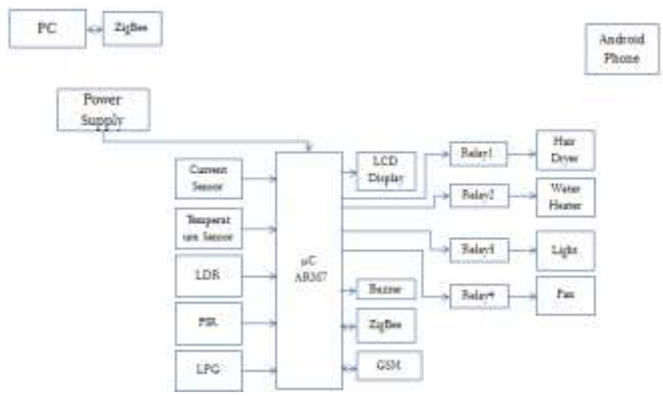

Figure 4: Proposed Hardware for SHEMS

SHEMS will identify optimal load control strategy responsive to the electricity RTPs, the consumer's needs, and will respond to the extreme scenarios. It should also have the ability for administrators (utility suppliers) to monitor and analyze the real-time status of a specific area or home. From the hardware design perspective, the SHEMS shall have following main components:

4.1 PC & GUI

This is the brain of SHEMS and will solve issues in three aspects. The processor communicates with other parts to obtain necessary information and coordinates the works among those parts. The processor is in charge of realizing various algorithms, which include machine learning, pattern recognition, and customized tasks for different types of loads based on their own individual characteristics and models. The processor serves as the GUI, from which the consumer is able to perform remote operations

4.2 Communication Interface

Several different hardware modules related to communication are needed. ZigBee module is essential for reading RTPs, communicating messages with suppliers, and ensuring the remote control to function.

4.3 Sensor Interface

SHEMS has various sensors to collect all the real-time information that the processor needs. This part should be extendable in case the system needs to measure new parameters due to the addition of a new appliance. The present version has: temperature sensors - detect the temperature of rooms and the water in EWH, motion sensors – to record human activities, illumination sensors - to detect indoor brightness. The data collected from those sensors will be sent to processors via ZigBee.

4.4 Load Interface

This part is also extendable. A designated load Interface transfers the strategies generated by the processor to control signals, which loads can accept. Eg: the load interface for EWH has a relay to turn it on and off; and the load interface for HVAC should work as a remoter to set the temperature and operating modes.

To facilitate user's operation on this system, the prototype is designed with three quick, built-in setting modes for users to realize the "Easy Setting" feature.

1) **Comfortable mode:** In this mode, the highest priority of SHEMS is to ensure the most comfort level for consumers.
2) **Smart mode:** In this mode, SHEMS will make a tradeoff between the comfort level and the payment saved.
3) **Saving mode:** In this mode, the highest priority of SHEMS is to save the total electricity payment.

5. MACHINE LEARNING ALGORITHM

A machine learning algorithm is implemented in the proposed SHEMS prototype design to analyze and predict human activities based on data collected by the sensors. However, machine learning for SHEMS is not like other machine learning applications such as the voice or handwriting recognition where users can help with updating the training set. Learning user's living habit is difficult, because SHEMS is not supposed to correct its own judgment by making frequent queries to users. Here hidden Markov model (HMM) is implemented to generate a practical solution. Specifically, HMM is employed to learn and predict user's living habits.

Hidden Markov Model: Markov matrix, the matrix of transition probabilities can be generated by the given training data set. Then, Markov matrix and NBC can update each other during the actual use of SHEMS to learn the consumer's behavior. Fig. 5 is an example showing how this works. The diagram within the red, dashed rectangle shows the general architecture of an instantiated HMM. Also, *x(t)* is the hidden state at time *t*, which stands for the present activity of the user, and *y(t)* is the observation at time *t*, which stands for the data collected by the sensors.

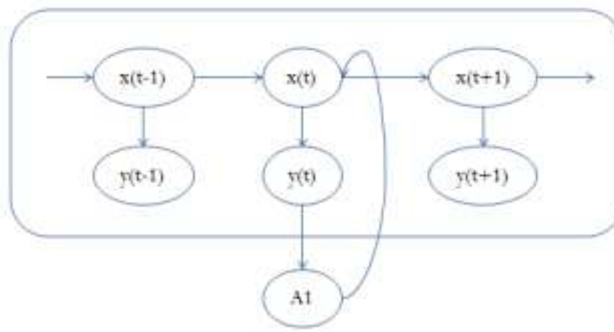

Figure 5: Learning Process of SHEMS

Assume that at time *t*, system detects an on-going activity A. However, *x(t)* obtained by HMM is different from A1. As discussed before, SHEMS is not supposed to ask the user for any correction. Thus, *x(t)* and A1 demonstrates a probabilistic characteristic in HMM. Without losing generality, we may call them a and b for A1 and *x(t)*, respectively. Therefore, we have three scenarios:

1) If the values of a and b are very close within a given threshold, SHEMS will record the event and wait for user's input for final judgment.

2) If b is much greater than a, SHEMS will record the correspondence between *x(t)* and *y(t)*, and update the training set.

3) If a is much greater than b, SHEMS will record the correspondence between A1 and *y(t)*, and update the training set of HMM to eventually update the Markov matrix.

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