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DESIGN AND IMPLEMENTATION OF AN AUTOMATED ENERGY MANAGEMENT SYSTEM

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Abstract

This research applies pervasive computing to electricity consumption for homes down to the level of individual appliance usage. The technique allows the real-time control of home appliances with the help of internet ready devices (IRD) and embedded systems. The aim of this study is to manage household electricity consumption more efficiently using the automated energy management system (EMS). The procedure for achieving efficiency in electricity usage in households is implemented and validated with personal home page (PHP) or PHP hypertext preprocessor and MySQL, a structured query language. To investigate the efficiency of the EMS, electric consumption measurements for electric bulbs utilizing EMS were collected and compare with the electric consumption for electric bulbs without using EMS. The findings were consistent with the aims of this study. This system gives an insight to how pervasive computing can help to manage household appliance usage in a more efficient manner. This research help manage electricity consumption in homes, and reduces electricity wastages, this reducing electricity costs.

Keywords- pervasive computing; real-time; IRD; embedded systems; energy efficiency

1. Introduction

Automation is the use of control systems and information technology to control equipment, industrial machinery and processes; thereby reducing the need for human intervention. Previously, lots of works have been done on home automation system. Many lack proper monitoring, leading to excess and uneconomical use of power supply. This study is targeted at making household energy consumption reading wireless and accessible in real time. Automation plays an increasingly important role in the daily living of households and the global economy. Engineers strive to combine automated devices with mathematical and organizational tools to create complex systems for a rapidly expanding range of applications and human activities. Many roles for humans in industrial processes presently lie beyond the scope of automation. Human-level pattern recognition, language recognition, and language production ability are well beyond the capabilities of modern mechanical and computer systems. These tasks require subjective assessment offering a synthesis of complex sensory data, such as scents and sounds, as well as high-level tasks such as strategic planning, which needs human expertise. In general, automation has been responsible for the shift in the world economy from agrarian to industrial in the 19th century and from industrial to the era of supercomputing in the 20th century.

The contributions of this paper are summarized as follows:

1. The development of a specialized software for monitoring control and coordination of appliance usage in buildings.
2. The development of an intelligent device to control appliance usage in buildings.
3. Electricity costs for buildings are reduced as a result of the introduction of the energy management system.

Energy Management Systems (EMS) are intelligent systems or a system of computer-aided tools designed to monitor and control the energy consumption of homes, buildings and offices, including estates and campuses. By monitoring energy usage, EMS will be able to control the energy profile, produce trend analyses and consumption forecasts, and optimize energy efficiency. Energy management systems provide applications for reducing energy costs and consumption in buildings.

2.0 Literature Review

The growing global demand for energy is making it imperative that newer and more efficient electricity appliance use is deployed. Energy efficiency is also important because of the constantly changing electricity consumption pattern across the

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globe. These are the most important driving factors resulting in the development and implementation of different energy efficiency systems. On the basis of secondary research, the emerging trends in energy research have been identified in this study, thus providing an insight to electricity consumption efficiency. Overall, energy is a very important aspect involved and vital in the economic and social development of any nation. Since many countries require primary energy sources for sustainable development, world energy demand has increased tremendously [1]. There is a need to make adequate planning and resource allocation for energy use in order to improve energy efficiency to match with energy supply from the electricity network.

Today, it is widely applicable to many aspects of global needs, from transportation, households, industry, healthcare, education, etc. The total world energy consumption was discussed in [2], taking into consideration different energy sources, which shows an increasing demand for electricity from 1971 to the present, resulting in economic, social and technological developments. There is a need to use electric appliances in a more efficient manner so as to reduce costs. This is more so as the global energy consumption is increasing due to an increase in population, production, and.so on. The rise in energy consumption is primarily from increased energy use. A huge increase in world energy consumption has taken place over the last 50 years [3]. At present, electricity is the third largest source of world energy consumption. Due to the importance of having an efficient power management system, past studies have focused on the efficient utilization of electric appliances in households and industrial energy consumption. A study in [4] showed electricity consumers recognized and realized that efficiency in consumption is an important attribute in power usage and management, and its also an important differentiator between electric power distribution and consumption. The research concluded that industrialized countries have found ways of improving efficiency in electricity consumption which varies from the use of sensors; which regulates and control electric usage, to the efficient allocation and scheduling of electric power supply. Electricity is a key energy resource in each country and an important condition for economic development.

The energy costs savings for electric water pumping systems was explored in [5]. In the study, a simulation model was developed for measurements obtained from the existing system, considering pump scheduling and the effects of changing control strategy on energy consumption. The study indicated a substantial electric cost savings of about 14,069 USD per year. One factor which has impacted greatly on a sustainable manner on energy consumption, generation and distribution is electricity consumption. To fully portray these issues, [6] proposed that buildings are responsible for approximately 40% of the total global annual energy consumption. The paper suggested that most of this energy is used for the provision of lighting, heating, cooling, and air conditioning. The research considered it desirable to reduce energy consumption and decrease the rate of depletion of world energy reserves and pollution of the environment. It suggested that a way of reducing building energy consumption is through the design of energy-efficient buildings, which are more economical in their use of energy for heating, lighting, cooling, ventilation and hot water supply.

In essence, the introduction of control mechanisms to electricity consumption usage plays an important role in minimizing electricity wastages and reducing the cost of electricity. Applying control techniques to electric appliances would improve efficiency in the use of electricity. To illustrate the application of control techniques on electric appliances for efficient electric use, data was collected from single-family households to investigate the spatial effects of the adoption of energy-efficient measures on heating, ventilation, and air conditioning (HVAC) systems [7]. The selected control variables affecting energy-efficiency in the buildings were as follows: neighborhood amenities, distance to central business district (CBD), building occupancy, population density and percentage of households that were renters. From the outcome of the study, newly built, newly restored buildings, middle income houses and higher population density areas tended to adopt energy-efficient measures in appliance usage. Furthermore, households with greater wealth, but paying lower tax rates on their properties were more likely to adopt energy-efficient in their appliance usage.

3. Methodology

This section consists of the different methods used in this study, consisting of the hardware and software requirements. In designing a home automation system, one or more suitable platforms are used in order to build a reliable and flexible system that can be easily operated and adapted for controlled household appliance usage. In deploying the energy management system to household usage, individual communication capabilities and location of households are taken into consideration. It is appropriate to consider the overall communication infrastructure as a hybrid network architecture. This hybrid network architecture is a combination of various types of networks such as the internet, wireless sensor networks, and wireless mesh networks (WiMAX). The communication network can be dynamically self-configured.

3.1 Implementation Platforms

There are several available platforms over which an automated energy consumption reading system can be implemented. Of the current available platforms; XAMPP, Prehypertext Processor (PHP) and MYSQL were found appropriate for implementing the system due to their low cost, availability and simplicity. XAMPP is a web server solution stack package consisting mainly of the Apache hypertext transfer protocol (HTTP) Server, and interpreters for scripts written in PHP programming language. MYSQL is a relational database management system, while the Apache HTTP Server is a cross-platform webserver software.

3.2 System Design and Architecture

As illustrated in Fig. 1, the XAMPP uses information stored in MySQL database to control appliances in households. The appliance database consists of electricity measurements of appliances whose usage is being controlled. The home database consists of electricity measurements of all appliances in the household. The XAMPP Apache Server serves as the internet connectivity between electricity measurements for appliances in the household and the energy management software.

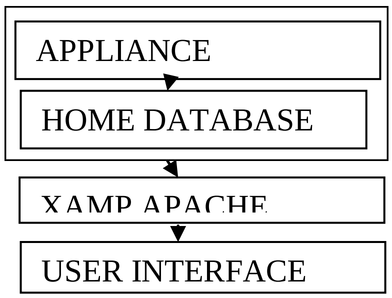

Fig. 1. Proposed Energy Management System Design Model

The system architecture of this study is designed in order to successfully implement the energy management system. The functions and components of the architecture are flexible and suitable for all operations performed in the system. These modules are logically linked together through menu and command control to perform one operation or the other. The modules are illustrated in Fig. 2. In using the energy management system, appliances can be switched on, and those not in use can be switched off. Appliances to be included for monitoring and control can be added to the system, while those not under consideration can be deleted from the system. The electricity consumption details of any appliance in the household can be checked using the EDIT appliance icon. Also, the maximum electricity to be consumed by each appliance can be preset. This is to reduce wastages in electricity consumption and to reduce electricity costs.

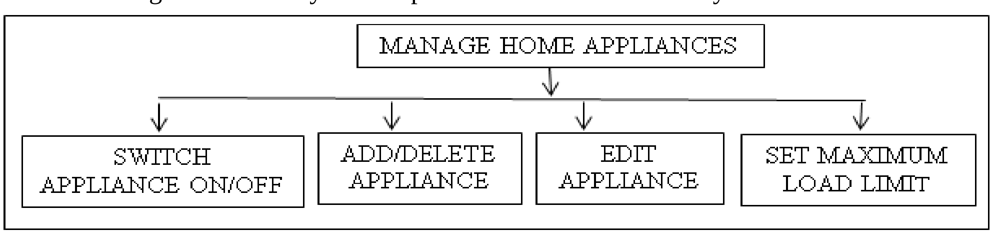

Fig. 2. System Architecture

3.3 Storage Design

MySQL database is used as back-end for the new system because of its flexibility, reliability, efficiency and capability. MySQL provides a powerful set of tools that allows for fast tracking, reporting and sharing information in a manageable environment. Setting up the MySQL database is relatively simple. This is done in two ways; by (i) writing the MySQL code, or (ii) the use of phpMyAdmin which has a graphics user interface (GUI) for user friendliness. It is controlled entirely using MySQL scripts. The graphical user interface is used to setup the database.

The phpMyAdmin login interface is required to access the MySQL database environment Interface. After inputting the login details, access is granted by XAMPP into the database environment. The login details allows the program connect with the database. The login detail is then authenticated by the XAMPP Apache Server. This interface shows lists of existing database within the database. The database is used by the program to interface with the energy management system. The database contains a list of tables needed for the program to run. The appliance usage database is created within the MySQL / XAMPP environment. The tables include different appliances, various households and the user logs for each household. Each table has a relational schema that links them together for efficient use by the energy management system.

3.4 System Implementation

The first stage of systems implementation is the system documentation, consisting of logical steps to be taken for the actualization of the energy management system. The second stage of the implementation process is to develop the systems specification into program codes. PHP language (script) is chosen to develop the server, while HTML is chosen to develop the client side. For successful implementation of the energy management system, the Intel Arduino is programmed for communication with the computer. The Intel Arduino consists of the Arduino UNO module, which is a microcontroller circuit. The Arduino Uno board is powered via USB connection and an external power supply. This is shown in Fig. 3.

Fig. 3. Intel Arduino

The Arduino Uno is programmed using the Arduino software. A sensor is used to achieve automation and control of individual electric appliance usage in households. The sensor coverts real world data (analog) into data that a computer can understand using the analog digital converter (ADC). An alternating current (AC) sensor is shown in Fig. 4.

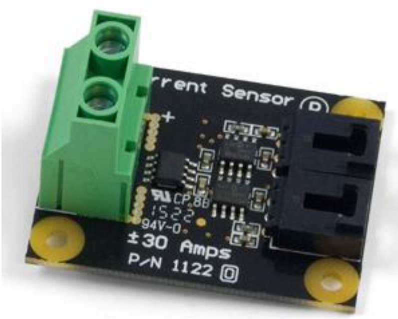

Fig. 4. AC Sensor

3.5 Impact of Automated Energy Management System on Electriicty Consumption

This section estimates energy savings using the automaated energy management system (EMS) for an electric appliance in order to investigate the cost-effectiveness of the proposed system. This takes into account energy consumption for electric bulbs in a building. This research utilized the energy management system for electric bulbs over a period, where its electricity consumption measurements were collected.

The estimation process involves calculating energy savings for appliance usage using the automated energy management system. Energy savings (CAES) is defined as:

$$CAES = TCSEB - TCSEB\_C \qquad (1)$$

where

TCSEB is the total electricity consumption for electric bulbs in the building without using the energy management system, and TCSEB_C is the total electricity consumption for electric bulbs in the building using the energy management system.

4. Results and Discussion

In this section, results obtained using the proposed energy management system are presented. The energy management system is used to control the consumption of electric appliances in various households. The energy management software collects measured data for each appliance usage and integrating it to the computer codes used to develop the software. This approach is guided by two main factors: the benefits to the electricity network and benefits to electricity consumers. In terms of the electricity network, adequate allocation of energy resources can be made if the estimate of actual consumption for individual appliances and in households is known. This will improve planning by stakeholders. For the consumers, being able to identify electricity consumption for individual appliances will improve controlling for electricity use in order to save energy costs. The maximum electricity to be consumed by each appliance can be determined. This will reduce wastages in electricity consumption and reduce electricity costs. Fig. 5 shows the home screen of the energy management system. In real life scenario, any appliance must be associated to a home, office, building or industry. The essence of the home screen is to select a home to be managed.

In the usage of the energy management system, households can be added to the software. The purpose of this module is to include a home that would be managed to the system. With this process, several houses can be managed by the system concurrently. Each home would have its own distinctive energy status indicated on its icon. The energy management system shows all available appliances to be managed in each household. The module shows the cumulative energy consumed by appliances and their net consumption per hour in watts/hour. Each appliance can be turned off and on by simply clicking on the image which will blur to indicate the off-state of the appliance and sharpens to indicate the on-state of the appliance. Each appliance indicates the power ratings and power consumption per hour individually. The reset icon turns off all the appliances at once.

Also displayed by the module are the add appliance, edit appliance and delete appliance features of the system. The add appliance includes an appliance whose electricity consumption is to be controlled into the system, the edit appliance allows the change of properties specified to the appliance, while delete appliance erases an existing appliance completely off the system. The energy management software has an icon where the maximum load limit of each appliance can be set. The essence of this feature is to automatically shut down energy consuming appliance during peak periods. Once the peak limit is set and the limit is exceeded, a prompt "breaking point will be carried out" pops up, and the appliance is switched off automatically. Furthermore, the energy management system shows the activity log of appliances within a household. The activity log is color coded. Red indicates that an appliance has been switched on; black indicates that a reset has been carried out; green indicates that an appliance has been switched off. These processes, as depicted in the energy management system, are illustrated in Fig. 5.

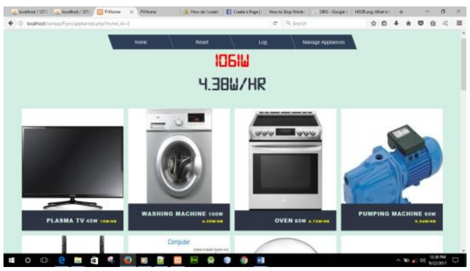

Fig. 5. Appliances Interface

In order to investigate the efficiency of the automated energy management system, the system is tested on electricity consumption measurements for electric bulbs in a building. The measurements of electric consumption for electric bulbs in a building for February 7 to March 1, 2018 are given in Table 1. The values for Equation 1 are displayed in Table 1. For example, on March 1, TCSEB was 3,193.48 kWh, while TCSEB_C on that day was 2,894.23 kWh. The CAES value is 299.25 kWh. A graph showing the relationship between electric consumption for bulbs with and without the utilization of the energy management system is given in Fig. 6.

Table 1: Energy Measurements for Electric Lightings

Date	TCSEB (kWh)	TCSEB_C (kWh)	CAES (kWh)
Feb 7	2893.21	2663.99	229.22
Feb 8	2835.32	2646.07	189.25
Feb 9	2490.54	2201.29	289.25
Feb 10	2383.52	2179.23	204.29
Feb 11	2895.77	2202.51	693.26
Feb 12	2896.92	2687.68	209.24
Feb 13	2800.87	2601.65	199.22
Feb 14	2804.69	2395.46	409.23
Feb 15	2809.94	2600.68	209.26
Feb 16	2890.38	2591.14	299.24
Feb 17	2587.53	2398.24	189.29
Feb 18	2904.21	2504.99	399.22
Feb 19	3006.51	2807.29	199.22
Feb 20	3007.07	2807.85	199.22
Feb 21	3099.65	2890.41	209.24
Feb 22	3096.84	2887.61	209.23
Feb 23	2891.17	2381.91	509.26
Feb 24	2584.02	2284.73	299.29
Feb 25	3093.87	2894.67	199.2
Feb 26	3094.66	2895.46	199.2
Feb 27	3096.78	2997.57	99.21
Feb 28	3199.42	2990.19	209.23
Mar 1	3193.48	2894.23	299.25

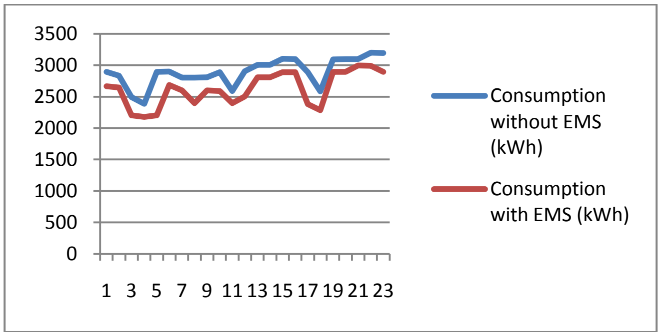

Fig. 6. Relationship between Consumption for Electric Bulbs with and without Electric Bulbs

As displayed in Table 1, there are considerable energy savings from utilizing the automated energy management systems. Fig. 6 shows that electric consumption for electric bulbs while using EMS consistently reduced for the period under study. Therefore, the utilization of EMS in households will result in more efficient usage of electric appliances. This will be beneficial to the electricity network, by more efficient allocation of electricity to households, and also beneficial to households by the reduction of electricity costs.

5. Conclusion

This research shows the application of computers to energy management. In this regard, automated energy management system, which is the creation of a highly reliable, self- healing electric system that rapidly responds to real-time events with appropriate actions, aims to maintain efficient energy usage by energy consumers. Automated energy management system consists of highly reliable computer codes that rapidly respond to real-time events with appropriate actions. The main aim of the system is to maintain efficient energy usage by energy consumers. The new system gives an insight to how pervasive computing can help to manage energy more effectively. However, the operational and commercial demands of electric utilities require a high-performance data communication network that supports both existing functionalities and future operational requirements. This brings significant advantages for electric utilities, such as low up-front costs, easy network maintenance, robustness of system, and reliable service coverage. Therefore, the design of a cost-effective and reliable network architecture is crucial, which this study is able to accomplish. The new system gives an insight to how pervasive computing can help to manage energy more effectively.

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