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Design and Implementation of Smart Energy Management System for Reducing Power Consumption using ZigBee Wireless Communication Module

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Abstract

In this paper, we propose a Smart Energy Management System (SEMS) which functions as a control using a motion sensor and setting time of power usage to reduce power consumption. The SEMS not only supplies power as the way the common power strips do but also controls sockets of the SEMS using ZigBee wireless communication. A test bed for experiment consists of a motion sensor, the SEMS and three appliances which are connected to the SEMS and the experiment was conducted for five days to measure the power consumption of three appliances with regard to both functions. The experimental result shows that the power consumption of the SEMS with two functions is considerably reduced when compared with the power consumption of the common power strip.

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Keywords : ZigBee wireless communication; socket; power strip; motion sensor

1. Introduction

Over the last several decades a large number of electrical appliances such as computers, televisions, refrigerators, printers, microwaves, various kinds of players, etc. have been used in houses and offices. Due to the rapid increase in the number of electrical appliances, wall sockets are not sufficient to accommodate all the electrical appliances. Thus power strips which are able to accommodate several electrical appliances became necessities in the houses and the offices. However, using plenty of the power

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strips caused high power consumption along with unnecessary power consumption such as standby power in particular.

Standby power is the electric power consumed by the electrical appliances while they are turned off or in standby mode before operating their main functions. That is, the power is consumed even though the electrical appliances which are plugged in the sockets are not in use. Most of the electrical appliances have the standby power ranging from less than 1W to as much as 25 W [1]. Although this is small amount of electric power, the standby power occupies approximately 10% to 15% of the total power consumption of OECD (Organization for Economic Cooperation and Development) member nations according to the IEA (International Energy Agency) [2]. The standby power can be reduced by not only decreasing the standby power of electrical appliances themselves but also using the power strips providing solutions to this standby power problem [3]. In spite of substantial efforts for research and development of the power strip to date, there is few power strips used efficiently reducing only small amount of the standby power. Moreover the power strips providing the solutions are unconditionally turned on consuming unnecessary power even though user are not using the appliances [4, 5].

ZigBee communication module is the most appropriate network module for manufacturing the wireless power strip to reduce the standby power because this is able to construct a low-cost and low-power network based on IEEE 802.15.4 standard [6]. ZigBee communication is used for data transmission over a long distance passing through intermediate devices. Furthermore, applications for a low data rate, long battery life and network security are using ZigBee communication module which operates at a rate of 250 kbps and has lower power consumption than other communication modules operating in the 2.4 GHz band [7]. Therefore the ZigBee communication modules are being widely used in building automation, security systems, remote control, remote meter reading, computer peripherals, etc. [8, 9, 10, 11].

In this paper, we propose a Smart Energy Management System (SEMS) that has two functions of using a motion sensor to check whether or not anyone is in a test bed and setting time of power usage. The proposed power strip integrates a ZigBee communication module into its architecture. The experiment was conducted with respect to the both functions to measure power consumption for five days. The result shows comparison result between the SEMS with two functions and a common power strip verifying that the SEMS is more efficient in terms of the power consumption. This paper is organized as follows. Section 2 explains the hardware structure of the SEMS in detail. Section 3 describes the operational process of each function of the SEMS. Implementation and experiment result conducted in the test bed is presented in section 4. Section 5 concludes this paper.

2. Structure of SEMS

A SEMS consists of 8-bit low-power MCU, energy metering IC, Zigbee communication module, power relay and LCD as shown in Fig 1.

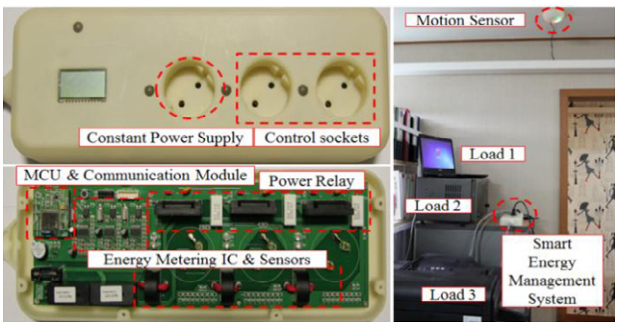

Fig. 1. Structure of SEMS and a test bed for experiment

Fig 2 presents the block diagram of the SEMS in detail. The detailed block diagram shows three more components which are AC/DC switching module power supply, AC current transformer sensor and buzzer. The MCU analyzes and processes input data and communicates with the server using 2.4GHz Zigbee communication module. The AC/DC switching module power supply has function of supplying power to the MCU or the peripheral components by converting AC power to DC power. Energy metering IC measures power consumption of each socket based on collected data via the current transformer sensor. After receipt of the power consumption data from the energy metering IC, the MCU considers whether to control the sockets or not depending on the value which the user set through analysis of the power consumption data. The MCU then transmits control command to each solid state relay and the relays control the sockets in accordance with transmitted control command. Real time power consumption and accumulated power consumption of each socket can be seen via LCD. Furthermore, the users are capable of receiving warning signals using buzzer.

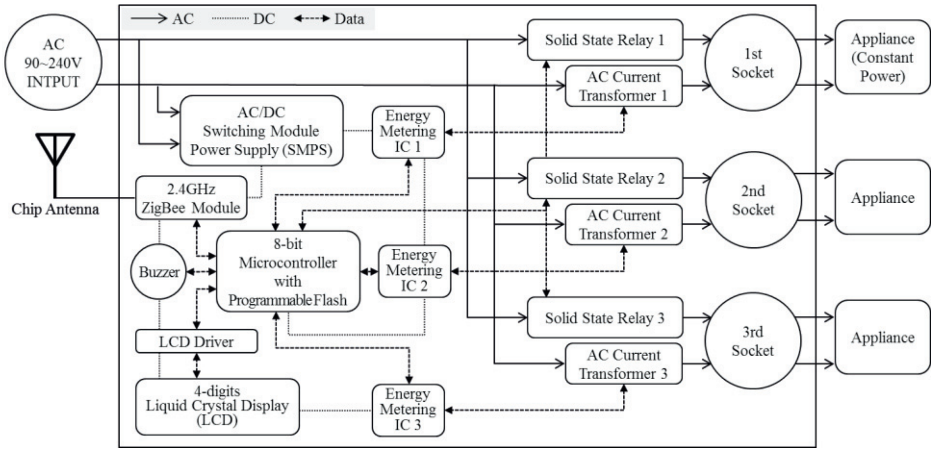

Fig. 2. Diagram of SEMS components

3. Operational process

The SEMS functions as not only existing power strips, but power interruption by communication with the server or the motion sensor using ZigBee wireless communication. Fig 3 shows the packet data format composed of eleven parts which are start code (1 byte), HOP count (1 byte), sequence number (1 byte), destination address (1 byte), source address (4 bytes), command and message type (2 bytes), control code (1 byte), expansion length (1 byte) expansion filed (8 bytes), check sum (1 byte) and end code (1 byte) totaling 25 bytes. Data such as maximum power consumption, maximum power, time, etc. can be entered in the expansion filed part.

Start Code (STX) (1 Byte)	HOP Count (HOP) (1 Byte)	Sequence Number (SEQ) (1 Byte)	Destination Address (DST) (1 Byte)	Source Address (SRC) (4 Bytes)	Command and Message Type (MT, CT) (2 Bytes)	Control Code (CC) (1 Byte)	Expansion Length (EL) (1 Byte)	Expansion Filed (EF) (8 Bytes)	Check Sum (CS) (1 Byte)	End Code (ETX) (1 Byte)

Fig. 3. Packet data format between devices

The first socket of the SEMS supplies constant power for the appliance required to be turned on consistently, the rest of the sockets have two functions. The first function is using the motion sensor and detecting whether or not anyone is in the test bed. Fig 4 shows a flow chart using first function in the SEMS. As a first step, the motion sensor checks whether or not anyone is in the test bed and turns on the sockets in case of detecting anyone. And then the motion sensor repeats this process every 10 minutes. If the motion sensor detects nobody, the sockets are turned off and repeat this process every 10 minutes. The motion sensor, however, turns on the sockets if the motion is detected by the sensor only while the sockets are turned off and wait the rest of 10 minutes. The SEMS is controlled through this process. That is, the motion sensor turns off the sockets otherwise anyone is in the test bed more than 10 minutes and turns on the sockets as soon as anyone comes in the test bed. By doing this, the power consumption can be reduced in the absence of anyone for a long time.

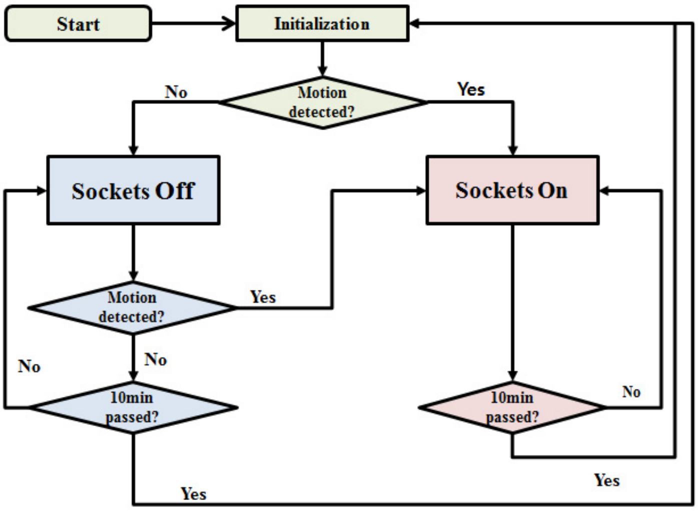

Fig. 4. Flow chart of SEMS using motion sensor

The second function is setting time of power usage. The program installed in the server computer for this function is shown in Fig. 5. This function demands setting port using the program as a first step. User then set time whenever the user wants the sockets to be turned on. The sockets are turned on only during the time user set and are turned off for the rest of the time. Furthermore, users are capable of setting maximum power consumption for preventing excessive power usage and setting maximum power to avoid fuse blow. When the power consumption and power exceed the limitation, the sockets are turned off from low priority to high priority.

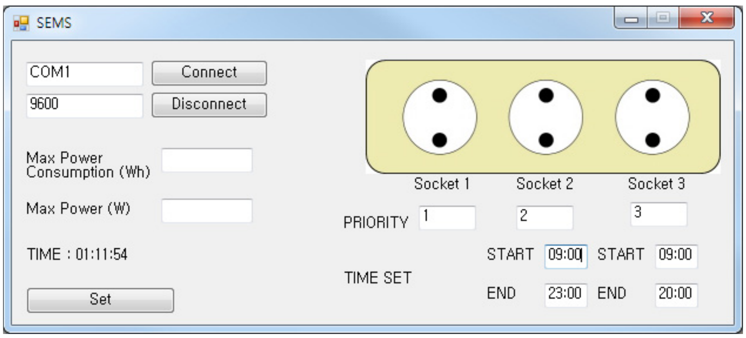

Fig. 5. Program for setting time of power usage

4. Implementation and experiment

For performance experiment of the SEMS, we used our laboratory as a test bed. Three electrical appliances which are a copy machine, a microwave and a server computer were connected to the SEMS in the test bed as shown in Fig 1. The server computer was connected to the first socket of the SEMS that supplies constant power. The copy machine which has higher standby power than other appliances and the microwave which has longer standby mode than usage time were connected to the second socket and the third socket respectively. The experiment was conducted in two cases that are a function of using the motion sensor and the function of setting time of power usage under the same conditions for five days. The experimental device (AD Power Co.Ltd., HPM-300A) was used for measuring the power consumption in watt-hour(Wh).

Table 1. Power consumption of the SEMS using motion sensor

Appliance	Day 1	Day 2	Day 3	Day 4	Day 5	Total
Copy machine	1.284 kWh	1.001 kWh	1.680 kWh	1.563 kWh	1.093 kWh	6.621 kWh
Microwave	0.666 kWh	0.585 kWh	0.949 kWh	0.444 kWh	0.565 kWh	3.209 kWh
computer	0.161 kWh	0.145 kWh	0.208 kWh	0.148 kWh	0.161 kWh	0.823 kWh

Table 2. Power consumption of the SEMS by setting time of power usage

Appliance	Day 1	Day 2	Day 3	Day 4	Day 5	Total
Copy machine	1.554 kWh	1.190 kWh	1.470 kWh	1.624 kWh	1.288 kWh	7.126 kWh
Microwave	0.664 kWh	0.584 kWh	0.947 kWh	0.442 kWh	0.563 kWh	3.200 kWh
computer	0.161 kWh	0.145 kWh	0.208 kWh	0.148 kWh	0.161 kWh	0.823 kWh

Table 3. Power consumption of common power strip

Appliance	Day 1	Day 2	Day 3	Day 4	Day 5	Total
Copy machine	1.884 kWh	1.452 kWh	1.888 kWh	2.256 kWh	1.789 kWh	9.269 kWh
Microwave	0.686 kWh	0.605 kWh	0.969 kWh	0.464 kWh	0.585 kWh	3.309 kWh
computer	0.158 kWh	0.150 kWh	0.201 kWh	0.161 kWh	0.155 kWh	0.825 kWh

Firstly, in case of a function which uses the motion sensor, we set the function on control using the motion sensor and plugged the appliances in the SEMS. The experimental result is shown in Table 1 and a decrease in power consumption can be easily verified when compared to the power consumption of the copy machine and microwave of Table 3. Above all, the power consumption of the copy machine dropped nearly 29 percent. Secondly, in case of a function which sets time of power usage, we set the function on control using time setting program. In accordance with the usage patterns of the SEMS, we set time range from 9 am to 23 pm in the second socket and time range from 9 am to 20 pm in the third socket and measured the power consumption for five days. The time we set was simply for experimental measurement and thus the time can be set whenever a user want to use the appliances using the function of setting time of power usage. Table 2 is the experimental result of the function of setting time of power usage. It is confirmed that the power consumption is reduced compared with Table 3 in the same way as Table 1. Additionally, a comparison is conducted between Table 1 and Table 2 presenting that the function of using the motion sensor is somewhat more efficient than the other function. However, not all of the power consumption shows this result. The power consumption of the copy machine in the third day of Table 1 and Table 2, for example, shows the opposite result that the power consumption of the function using the motion sensor is higher than the other function. This is because the sockets are turned on if the motion sensor detects anyone even though the user doesn't want to use the appliances causing unnecessary power consumption. Thus, it is efficient if one of the functions is appropriately chosen depending on preference of users. Total power consumption per day for five days with respect to the two functions and a common power strip is shown in Fig 6, which shows distinct reduction in power consumption when the functions are applied.

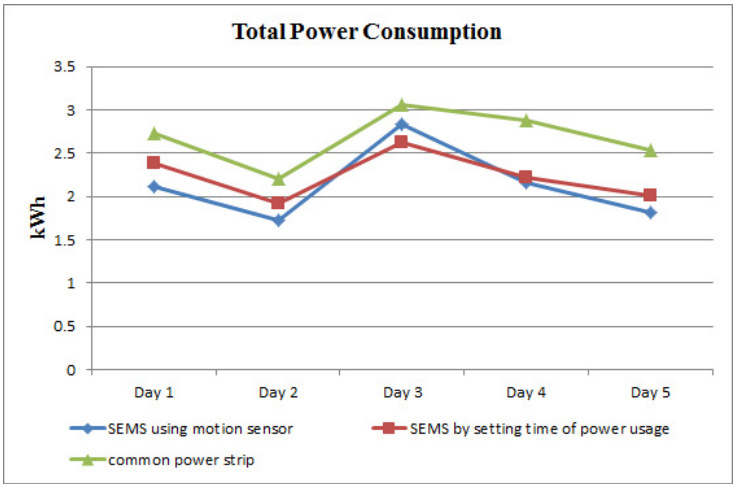

Fig. 6. Total power consumption of the SEMS with two functions and common power strip

5. Conclusion

In this paper, SEMS which has two functions of using a motion sensor and setting time of power usage is proposed. Today's power strips only supply power or reduce a little standby power. However, the power waste indeed arises when nobody is in the places leaving the appliances turned on and in case that the appliances are turned on even though users don't want to use the appliances. Therefore, the sockets are turned off in the absence of anyone for a long time and users are able to control the sockets of the SEMS by setting time of power usage while anyone is in the place having no thought of using the appliances. The experiment was conducted in the test bed for five days with respect to the two functions and the result shows that the power consumption using two functions was reduced substantially compared with the common power strip. It is certain that using the SEMS in offices and households by choosing suitable function will bring about considerable decrease in the power consumption according to the result.

Acknowledgements

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