More Efficient Home Energy Management System Based on ZigBee Communication and Infrared Remote Controls

Jinsoo Han, Chang-Sic Choi, and Ilwoo Lee

Abstract —*This paper describes more efficient home energy management system to reduce power consumption in home area. We consider the room easily controllable with an IR remote control of a home device. The room has automatic standby power cut-off outlets, a light, and a ZigBee hub. The ZigBee hub has an IR code learning function and educates the IR remote control signal of a home device connected to the power outlet. Then the power outlets and the light in the room can be controlled with an IR remote control. A typical automatic standby power cut-off outlet has a waiting time before cutting off the electric power. It consumes standby power during that time. To eliminate the waiting time, we turn off the home device and the power outlet simultaneously with an IR remote control through the ZigBee hub. This method actively reduces the standby power. The proposed HEMS provides easy way to add, delete, and move home devices to other power outlets. When a home device is moved to the different outlet, the energy information of the home device is kept consistently and seamlessly regardless of location change. The proposed architecture gives more efficient energy-saving HEMS*[1].

Index Terms — Home Energy Management, ZigBee, Remote Control, Standby Power, Energy Saving

I. INTRODUCTION

As more and more home appliances and consumer electronics are installed, residential energy consumption tends to grow rapidly. A large number of home devices increase power consumption in two aspects, standby power and normal operation power. Those two kinds of power consumption are proportional to the number of home devices. As a result, operational cost in home area is also increasing. Standby power is electricity used by appliances and equipment while they are switched off or not performing their primary function [1]. As around 10 % of a total household power is consumed during standby power mode [1], the reduction of standby power is greatly necessary to reduce the electricity cost in home. Many researches were performed to reduce standby power in the region of chip, circuit, board, and system [2]-[9]. Those various technical researches contributed to the reduction of standby power of home devices. Normal operation power of home devices is also important to reduce the energy cost in home. Home appliances and consumer electronics account for about 27 % of home energy consumption [10]. Therefore, the products with ENERGY STAR label are recommended to minimize the cost of operating the products during their lifetime. To reduce the normal operation power of home devices, service-oriented power management technology was proposed for an integrated multi-function home server [11]. Although advanced integrated circuit (IC) chipset and hardware technologies enhance the standby power reduction and the normal operation power reduction of home devices, the current energy crisis and green house effect require more efficient energy management technology in home area. The capability of controlling and power monitoring of home devices are indispensable to achieve efficient home energy management in addition to the technology of standby power reduction and normal operation power reduction. The network capability is also needed to connect home devices with each other and to manage them remotely. The technology to manage home energy more efficiently with the network capability is known as home energy management system (HEMS). A PLC-based HEMS combining home network and the Internet was proposed [12]. Architecture of home energy saving system based on energy-awareness was proposed for real-time home energy monitoring service and reducing standby power of home appliances [13]. The embedded remote monitoring and controlling power socket was developed for automatic and power management of home appliances [14]. However, the previous works just monitors and controls home devices, and shows the home energy information. Their standby power reduction method is passive. To reduce and manage home energy more efficiently, a more active standby power reduction method is needed and the controlling of the power outlets with a remote control should be enabled. A user-friendly and reconfigurable HEMS user interface (UI) is greatly necessary.

In this paper, we propose more efficient HEMS based on ZigBee communication and infrared remote controls. In section II, we describe several previous works related to our paper. In section III, we propose and discuss a more efficient home energy management system. In section IV, we show the implementation results. Finally, in section V, we conclude and summarize our paper.

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II. Related Works

A. Automatic Standby Power Cut-off outlet

As described in the introduction, various technical researches were conducted to reduce standby power of home devices. Although home devices consume a very small amount of power in the standby mode, it is more efficient to completely cut off the electric power supply to those home devices. An automatic standby power cut-off outlet can contribute to the reduction of home energy cost. Fig. 1 shows the architecture of the automatic standby power cut-off outlet and the state transition diagram of it [15], [16]. The microcontroller is supplied with electrical power through the AC/DC circuit and includes ZigBee Radio Frequency (RF) module to communicate with ZigBee controller. ZigBee is a low-power and low-cost wireless personal area network standard (WPAN) based on IEEE 802.15.4 to configure wireless sensor networks [17]. The monitoring circuit measures the power consumption and converts it into voltage. The microcontroller digitizes the voltage and calculates the consumed power. The power outlet has four kinds of state: boot, on, normal, and off. After booing, the power outlet goes to the on state. After the guard time elapses, the normal mode starts and the microcontroller monitors the consumed power. When the measured power is below the threshold value for the predetermined time, the microcontroller decides the connected home device is in the standby power mode and turns off the relay to cut off the power supply to the connected home device. It goes to the off state. When it receives a wake-up command from the ZigBee controller, it goes to the on state. This state transition repeats continuously.

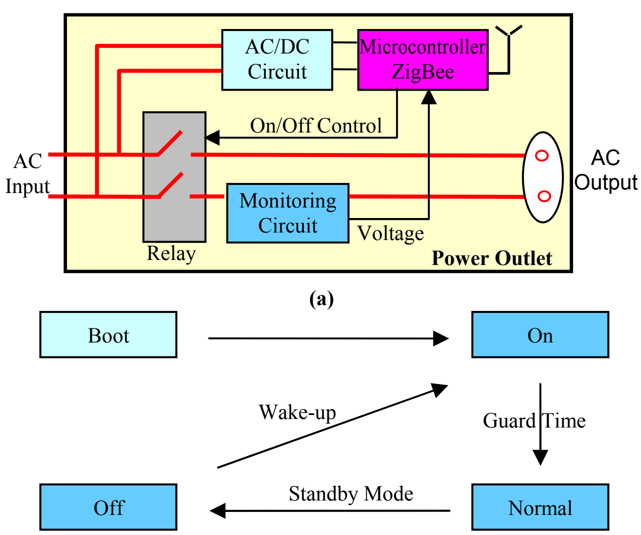


Fig. 1. Automatic standby power cut-off outlet. (a) Architecture (b) State transition diagram

B. ZigBee Controller and Remote Control

To control and wake up the power outlets, it is necessary to equip the ZigBee controller. Fig. 2 shows the configuration of the ZigBee controller and the connected end devices [15]. Each button is assigned to the power outlets. A user can wake up the target power outlet by pressing the assigned button. To wake up the power outlet without pressing the button, the ZigBee controller has an IR code learning functionality. Each button of the ZigBee controller can be assigned to the button of an IR remote control. A user can control and wake up the power outlet without coming close to the ZigBee controller by using the IR remote control.

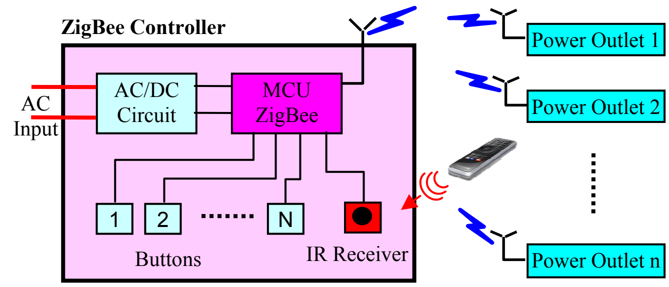


Fig. 2. ZigBee controller connected with power outlets.

C. Home Energy Management System

Energy monitoring systems can influence residents by informing them of the real-time home energy usage with a graphical interface. If the breakdown energy usage of each home appliances and consumer electronics is displayed on a wall pad, a computer, or a television, residents can make an effort to reduce the home energy. Furthermore, web-based monitoring and control systems were developed to enable users to view home energy data and control home devices remotely through the Internet [18], [19].

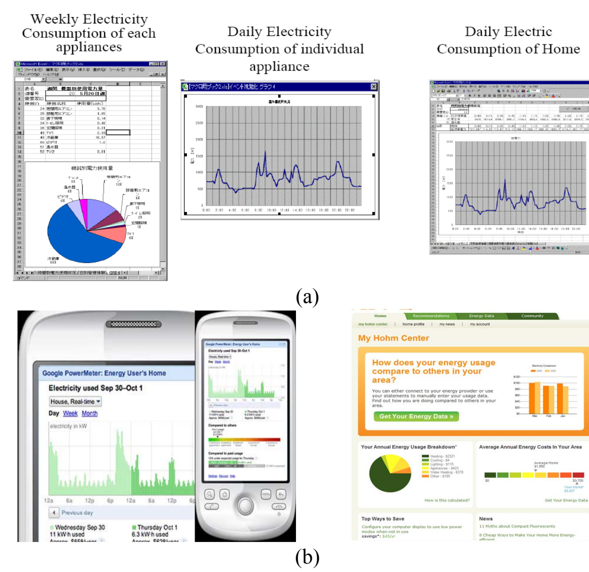


Fig. 3. Web-based home energy management systems.

A recent study found that 10 % of energy saving was achieved with a monitoring system providing real-time energy information [20]. Fig. 3 (a) shows the home energy information UI on the web in [18]. It illustrates daily and weekly energy consumption of both total home and each home device. Fig. 3 (b) shows other examples of web-based home energy management system provided by Internet companies. A user can access the HEMS UI of his own home via a smart phone and is encouraged to control home devices to reduce home energy usage because he figures out home energy usage information of both total home and each home device simultaneously.

III. Proposed Home Energy Management System

Fig. 4 shows the architecture of the proposed HEMS. The home has two rooms and each room is equipped with one dimming light, two power outlet, and one ZigBee hub. The dimming light and the power outlets include a power measurement function to measure the power consumption and the capability of ZigBee communication. The ZigBee hub is connected to the dimming light and the power outlets. The home server communicates with two ZigBee hubs. Through the configured ZigBee network the home server can monitor and control the lights and the power outlets. When a home device is connected to the power outlet, a user can register the home device in the HEMS UI of the home server by assigning the outlet number to it. The HEMS can monitor the energy usage of the home device according to the information from the corresponding power outlet. As a result, the HEMS of the home server can monitor and control the lights and the home devices. It displays hourly, daily, weekly, and monthly energy usage of each home device and encourages users to make efforts to save home energy. The HEMS can also display the real-time active power consumption and the accumulated power consumption of each home device. A user can figure out which home appliance is unnecessarily turned on through the real-time active power consumption and how much power each home appliance consumes in this month through the accumulated power consumption. He can also analyze the energy usage of each room through the ZigBee hub. A user can access the HEMS through the Internet in the remote area and turn off unnecessarily turned-on home devices.

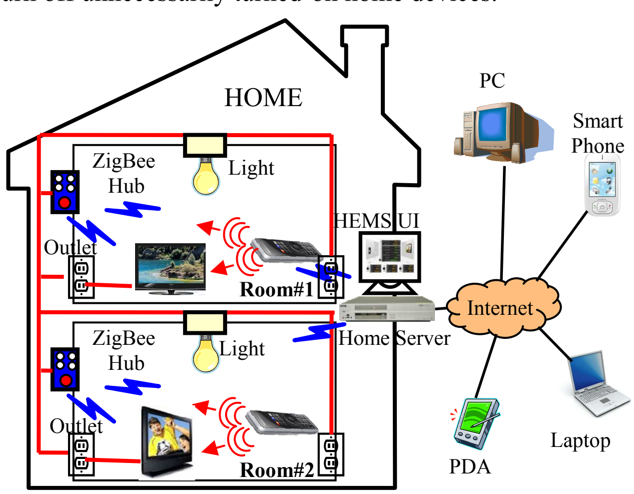


Fig. 4. Proposed HEMS architecture based on ZigBee communication and remote controls.

When a user moves the home device to the other power outlet, it is necessary to change the assignment of the home device. He can change it in the user-friendly HEMS UI by clicking buttons several times. The accumulated energy usage information of the home device is managed seamlessly and kept consistent regardless of location change. Fig. 5 shows consistent accumulation of energy usage information according to the change of location.

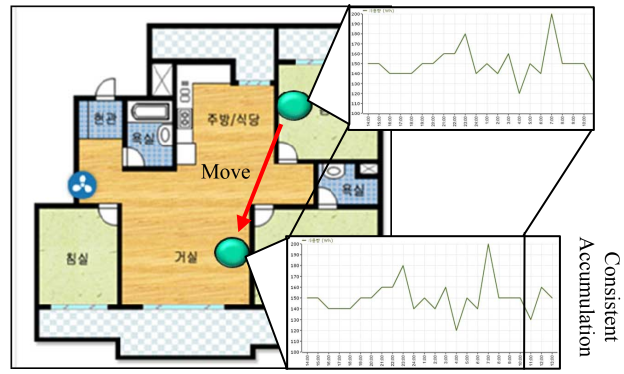


Fig. 5. Consistent accumulation of energy usage information.

The power outlet has the automatic standby power cut-off function [15]. The power outlet periodically monitors the power consumption of the connected home device. As soon as the monitored power consumption of the home device is below the threshold value for the predetermined period, the power outlet automatically cuts off the AC power to reduce the standby power consumption. The ZigBee hub has several buttons and an IR receiver. The buttons are assigned to the power outlets and the light. Its IR learning function enables the buttons of an IR remote control to correspond to the power outlets and the light. A user can control the light and the power outlets with both the buttons of the ZigBee hub and the IR remote control. When a user turns off a television with a remote control, the automatic standby power cut-off outlet waits for the predetermined period before transiting to the off state. Unfortunately, it consumes the electric power during that period. To reduce the power consumption during the decision time, we modified the ZigBee hub firmware in [15]. When a user presses the power button of an IR remote control to turn off a television, the IR signal can be simultaneously received by a ZigBee hub because the emission angle of a remote control is wide or the reflection of IR light is strong enough to reach the ZigBee hub. When the ZigBee hub receives a power button signal of a remote control and the monitored power consumption of that outlet is below the threshold, it decides that a user turned off a home device and commands the power outlet to cut off the AC power. If the ZigBee hub does not receive the IR signal, it operates according to the typical automatic standby power cut-off algorithm. This method actively reduces standby power consumption by turning off a home device and the power outlet simultaneously. Fig. 6 shows the firmware process flow chart of the ZigBee hub to control the power outlet connected to a home device. With an IR remote control, a user can command the home server to display the power consumption information of the room through the ZigBee hub and then check it at the home server.

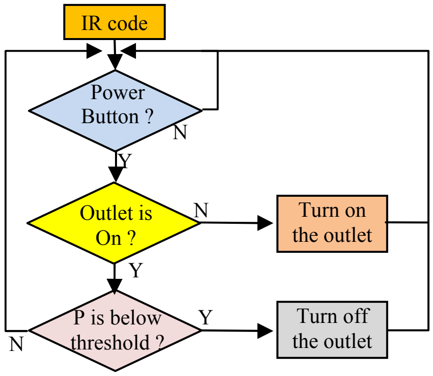
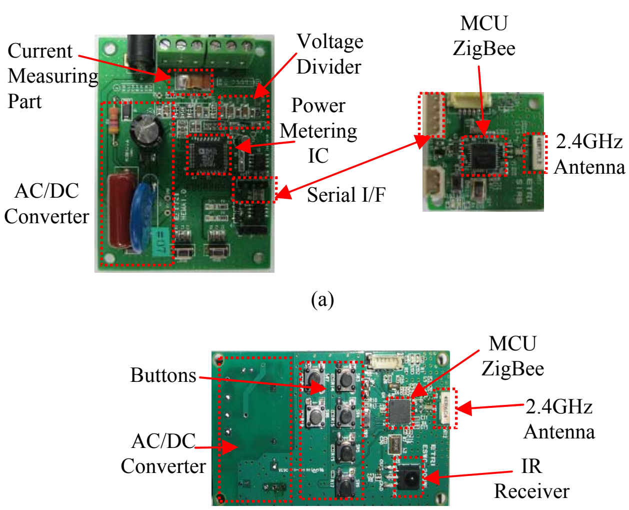


Fig. 6. The firmware process of the ZigBee hub to control the power outlet.

IV. Implementation Results

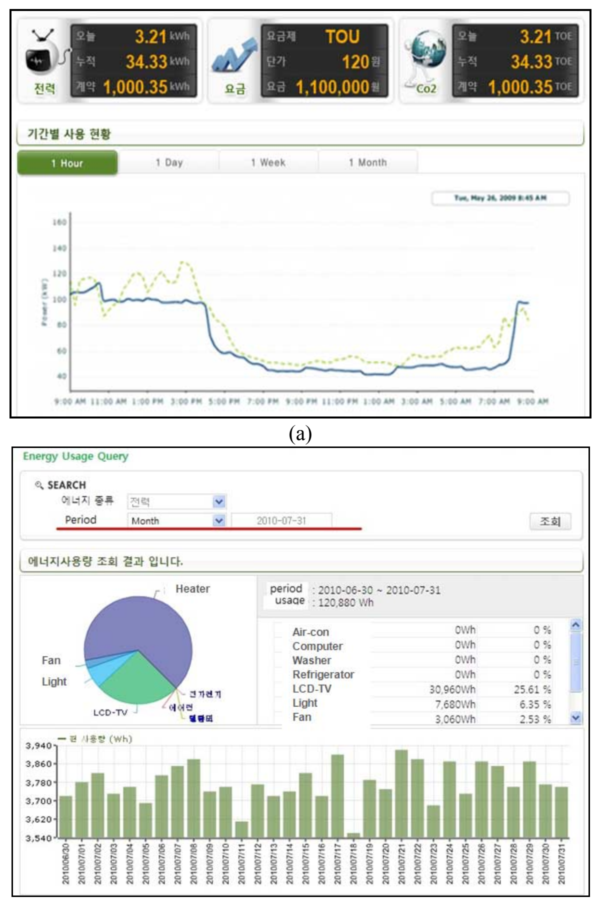
Fig. 7 shows the implemented power outlet with power measurement function, a ZigBee communication module, and a ZigBee hub. The power outlet uses an electric power metering chipset for compactness instead of an analog metering. It is composed of an AC/DC conversion part, a current measuring part, a voltage divider, a serial interface, and a power metering IC, which measures the reliable power consumption by multiplying the scaled voltage and the converted current through digital signal processing. The ZigBee communication module has one microcontroller with ZigBee RF module and 2.4 GHz antenna. The power outlet communicates with the ZigBee communication module via a serial interface. The ZigBee hub has an AC/DC conversion part, six buttons, an IR receiver, a 2.4 GHz antenna, and one microcontroller with ZigBee RF module. Six buttons are used to assign the power outlet or the light. An IR receiver plays a role of a detector for an IR remote control. A user can control the power outlets and the light with an IR remote control.



(b)

Fig. 7. Implemented boards: (a) Power outlet with power measurement function and ZigBee communication module. (c) ZigBee hub

Fig. 8 shows the captured displays of the HEMS UI of the home server. Our proposed HEMS provides a mapping function between the power outlets and home devices by use of 4 byte network node ID. It also provides time-based energy monitoring, time-based energy usage query, and time-based statistics. Fig. 8 (a) illustrates the total power consumption trend according to the time. It also shows the price and the quantity of the carbon dioxide. Fig. 8 (b) shows the result of energy usage query during the specified period. The pie chart illustrates the energy usage ratio of each home device. The right table shows each device's actual energy usage. With the help of various kinds of HEMS dashboards, a user can figure out the detailed home energy usage information. He can also obtain which home device consumes the largest power. The proposed HEMS UI provides easy way to add, delete, and move home devices to other power outlets. It is easily reconfigurable and user-friendly. Because our HEMS is a web-based system, a user can access the HEMS through the Internet web browser by using a smart phone or a laptop computer. He can monitor home energy usage and control home devices anywhere and anytime. The HEMS helps a user make active efforts to reduce home energy consumption and decide what device to purchase and how to use it.



(b)

Fig. 8. The captured displays of the HEMS user interface: (a) Total power consumption trend. (b) Power consumption of each home device.

V. Conclusion

We proposed the HEMS based on ZigBee communication and infrared remote controls. The configured ZigBee network is composed of the home server, the ZigBee hub, and the power outlets and light. The home server is a central control unit. The power outlets and the light are the sensor nodes. The home server can manage the power outlets and the light through the ZigBee hub. The ZigBee hub with IR code learning function enables a user to control the power outlets and the light with an IR remote control. Furthermore, we actively reduce standby power consumption by turning off a home device and the power outlet simultaneously through the ZigBee hub. This method eliminates the waiting time of a typical automatic power cut-off outlet. The proposed HEMS UI provides various kinds of dashboards for a user to figure out the detailed home energy usage information. The proposed HEMS UI provides easy way to add, delete, and move home devices to other power outlets. When a home device is moved to the different outlet, the energy information of the home device is kept consistently and seamlessly regardless of location change. We implemented the power outlet with a power measuring function and the ZigBee hub with six buttons and an IR learning functionality. The web-based HEMS was implemented and could be accessed through the web browser. These implemented results showed the feasibility of our proposed HEMS. The proposed HEMS is expected to contribute to reduce home energy usage in the future.

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