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Electrical Power Management System in Domestic Application Based On 802.15.4 Communication and IR Controls

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Abstract: This paper describes more efficient domestic energy management system to reduce power consumption in domestic area. We consider the room easily controllable with an IR remote control of a domestic device. The room has automatic standby power switch-off outlets, a light source, and a 802.15.4 hub. The 802.15.4 hub had an IR code learning function and educates the IR remote control signal of a domestic device connected to the power outlet. While the power outlets and the light in the room can be controlled with an IR remote control. This type of automatic standby power cut-off outlet has a waiting time before cutting off the electric power. It consumes standby power during that period of time. To eliminate the waiting time, we turn off the domestic device and the power outlet simultaneously with an IR remote control through the 802.15.4 hub. This method reduces the standby power. The proposed HEMS provide easy way of addition, delete, and move domestic devices to other power outlets. When a domestic device is moved to the different outlet, the energy information of the domestic device is kept consistently and seamlessly regardless of location change. The proposed design structure gives more efficient energy-saving HEMS.

Keywords: 802.15.4 hub, HEMS, power cut-off, IR remote control.

I. INTRODUCTION

As more and more domestic appliances and consumer electronics are installed, house usage energy consumption tends to grow rapidly. A large number of domestic devices increase power consumption in two features, standby power and normal operation power. These two kinds of power consumption are proportional to the number of domestic devices. As a result, operational cost in domestic area is also increasing. Standby power is electricity used by appliances and equipment while they are switched off or not performing their primary function. As around 10 % of a total household power is consumed during standby power mode, the decrease of standby power is greatly necessary to reduce the electricity cost in domestic. Many researches were performed to reduce standby power in the region of chip, circuit, board, and system. Those various technical researches contributed to the reduction of standby power of domestic devices. Normal operation power of domestic devices is also important to reduce the energy cost in domestic. Domestic appliances and consumer electronics account for about 27 % of domestic energy consumption. 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 domestic devices, service-oriented power management technology was proposed for an integrated multi-function domestic server. Although advanced integrated circuit (IC) chipset and hardware technologies enhance the standby power reduction and the normal operation power reduction of domestic devices, the current energy crisis and green house effect require more efficient energy management technology in domestic area. The capability of controlling and power monitoring of domestic devices are indispensable to achieve efficient domestic energy management in addition to the technology of standby power reduction and normal operation power reduction. The network capability is also needed to connect domestic devices with each other and to manage them remotely. The technology to manage domestic energy more efficiently with the network capability is known as domestic energy management system (HEMS). A PLC-based HEMS combining domestic network and the Internet was proposed. Architecture of domestic energy saving system based on energy-awareness was proposed for real-time domestic energy monitoring service and reducing standby power of domestic appliances. The embedded remote mong and controlling power socket was developed for automatic and power management of domestic appliances. However, the previous works just monitors and controls domestic devices, and shows the domestic energy information. Their standby power reduction method is passive. To reduce and manage domestic 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 802.15.4 communication and infrared remote controls. In section II, we describe several previous works related to

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our paper. In section III, we propose and discuss a more efficient domestic energy management system. In section IV, we show the implementation results. Finally, in section V, we conclude and summarize our paper.

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 domestic devices. Although domestic devices consume a very small amount of power in the standby mode, it is more efficient to totally cut off the electric power supply to those domestic devices. An automatic standby power cut-off outlet can contribute to the reduction of domestic energy cost. Fig. 1 shows the architecture of the automatic standby power cut-off outlet and the state transition diagram of it. The microcontroller is supplied with electrical power through the AC/DC circuit and includes 802.15.4 Radio Frequency (RF) module to communicate with 802.15.4 controller. 802.15.4 is a low-power and low-cost wireless personal area network standard (WPAN) based on IEEE 802.15.4 to configure wireless sensor networks. The monitoring circuit measures the power consumption and converts it into voltage. The microcontroller digitizes the voltage and calculates the consume power.

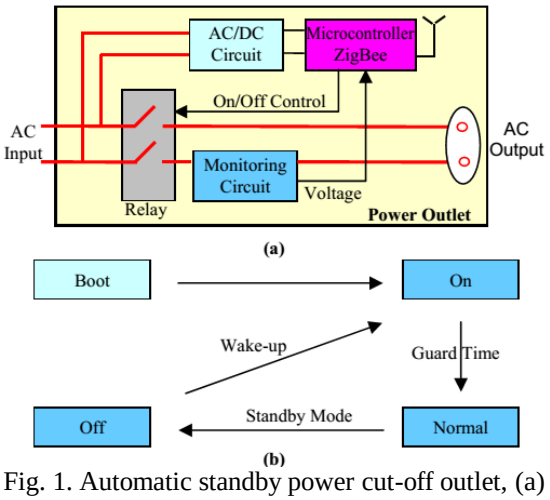

Fig. 1. Automatic standby power cut-off outlet, (a) Architecture , (b) State Transition diagram.

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 processed, 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 chooses the connected domestic device is in the standby power mode and turns off the relay to cut off the power supply to the connected domestic device. It goes to the off state. When it receives a wake-up command from the 802.15.4 controller, it goes to the ON state. This state transition repeats continuously.

B. 802.15.4 Controller and Remote Control

To control and wake up the power outlets, it is necessary to equip the 802.15.4 controller. Fig. 2 shows the configuration of the 802.15.4 controller and the connected end devices . 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 802.15.4 controller has an IR code learning functionality. Each button of the 802.15.4 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 802.15.4 controller by using the IR remote control.

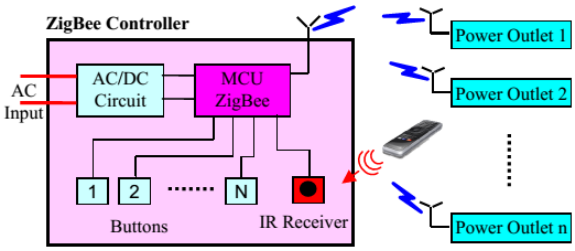

Fig. 2. 802.15.4 Controller connected with power outlets.

C. Domestic Energy Management System

Energy monitoring systems can influence residents by informing them of the real-time domestic energy usage with a graphical interface.

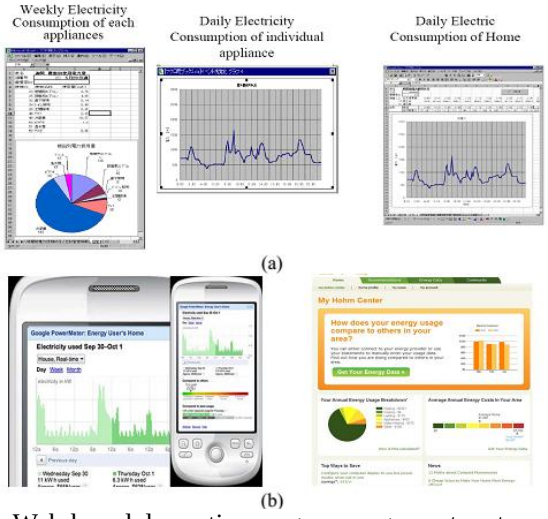

Fig. 3. Web-based domestic energy management systems.

If the breakdown energy usage of each domestic appliances and consumer electronics is displayed on a wall pad, a computer, or a television, residents can make an effort to reduce the domestic energy. Furthermore, web-based monitoring and control systems were developed to enable users to view domestic energy data and control domestic devices remotely through the Internet. A recent study found that 10 % of energy saving was achieved with a monitoring system providing real-time energy information.

Fig. 3 (a) shows the domestic energy information UI on the web in. It illustrates daily and weekly energy consumption of both total domestic and each domestic device. Fig. 3 (b) shows other examples of web-based domestic energy management system provided by Internet companies.

A user can access the HEMS UI of his own domestic via a smart phone and is encouraged to control domestic devices to reducedomestic energy usage because he figures out domestic energy usage information of both total domestic and each domestic device simultaneously.

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III.PROPOSED DOMESTIC ENERGY MANAGEMENT SYSTEM

Fig. 4 shows the architecture of the proposed HEMS. The domestic had two rooms and each room is equipped with one dimming light, two power outlet, and one 802.15.4 hub. The dimming light and the power outlets include a power measurement function to measure the power consumption and the capability of 802.15.4 communication. The 802.15.4 hub is connected to the dimming light and the power outlets. The domestic server communicates with two 802.15.4 hubs. Through the configured 802.15.4 network the domestic server can monitor and control the lights and the power outlets. When a domestic device is connected to the power outlet, a user can register the domestic device in the HEMS UI of the domestic server by assigning the outlet number to it. The HEMS can monitor the energy usage of the domestic device according to the information from the corresponding power outlet. As a result, the HEMS of the domestic server can monitor and control the lights and the domestic devices. It displays every hour, daily, weekly, and monthly energy usage of each domestic device and encourages users to make efforts to save domestic energy. The HEMS can also display the real-time active power consumption and the accumulated power consumption of each domestic device. A user can figure out which domestic appliance is unnecessarily turned on through the real-time active power consumption and how much power each domestic appliance consumes in this month through the accumulated power consumption. He can also analyse the energy usage of each room through the 802.15.4 hub. A user can get to the HEMS through the Internet in the remote area and turn off unnecessarily turned-on domestic devices.

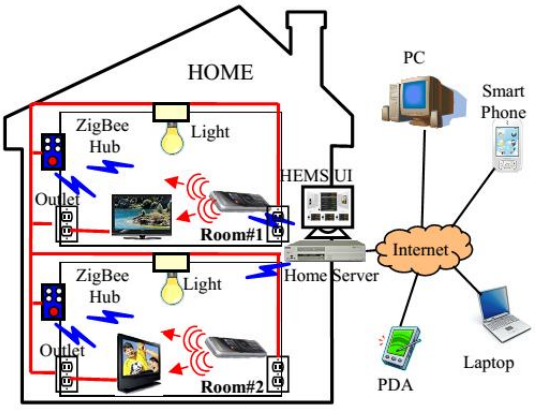

Fig .4. Proposed HEMS architecture based on 802.15.4 communication and remote controls.

When a user moves the domestic device to the other power outlet, it is necessary to change the assignment of the domestic device. He can change it in the user-friendly HEMS UI by clicking buttons several times. The accumulated energy usage information of the domestic 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.

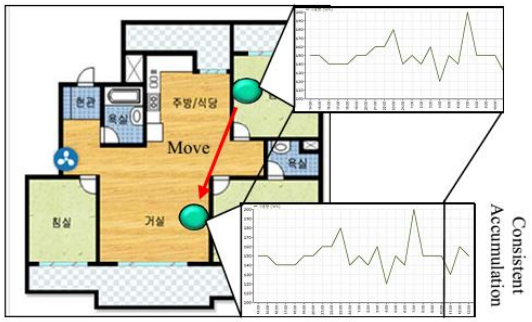

Fig. 5. Consistent accumulation of energy usage information.

The power outlet has the automatic standby power cut-off function. The power outlet periodically monitors the power consumption of the connected domestic device.

As soon as the monitored power consumption of the domestic 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 802.15.4 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 802.15.4 hub and the IR remote control. When a user turns off a television with a remote control, the automatic 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 802.15.4 hub firmware in . 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 802.15.4 hub because the emission angle of a remote control is wide or the reflection of IR light is strong enough to reach the 802.15.4 hub.

When the 802.15.4 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 domestic device and commands the power outlet to cut off the AC power. If the 802.15.4 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 domestic device and the power outlet simultaneously. Fig. 6 shows the firmware process flow chart of the 802.15.4 hub to control the power outlet connected to a domestic device.

With an IR remote control, a user can command the domestic server to display the power con information of the room through the 802.15.4 hub and then check it at the domestic server.

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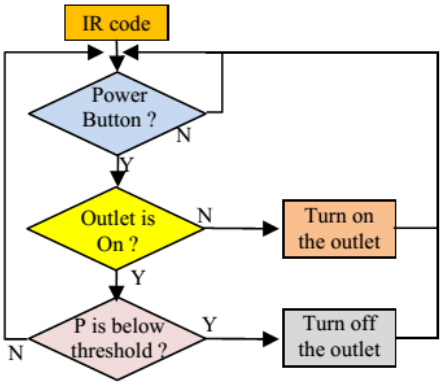

FIG. 6. THE FIRMWARE PROCESS OF THE 802.15.4 HUB TO CONTROL THE POWER

IV. IMPLEMENTATION RESULTS

Fig. 7 shows the implemented power outlet with power measurement function, a 802.15.4 communication module, and a 802.15.4 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 802.15.4 communication module has one microcontroller with 802.15.4 RF module and 2.4 GHz antenna. The power outlet communicates with the 802.15.4 communication module via a serial interface. The 802.15.4 hub has an AC/DC conversion part, six buttons, an IR receiver, a 2.4 GHz antenna, and one microcontroller with 802.15.4 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.

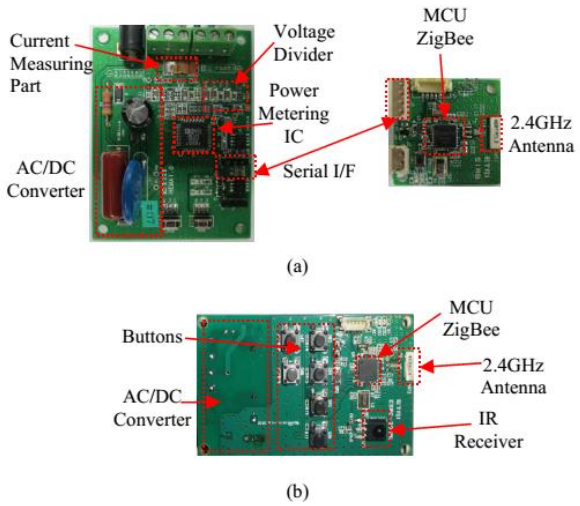

Fig. 7. Implemented boards: (a) Power outlet with power measurement function and 802.15.4 communication module. (c) 802.15.4 hub.

Fig. 8 shows the captured displays of the HEMS UI of the domestic server. Our proposed HEMS provide a mapping function between the power outlets and domestic 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 domestic 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 domestic energy usage information. He can also obtain which domestic device consumes the largest power. The proposed HEMS UI provides easy way to add, delete, and move domestic 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 domestic energy usage and control domestic devices anywhere and anytime. The HEMS helps a user make active efforts to reduce domestic energy consumption and decide what device to purchase and how to use it.

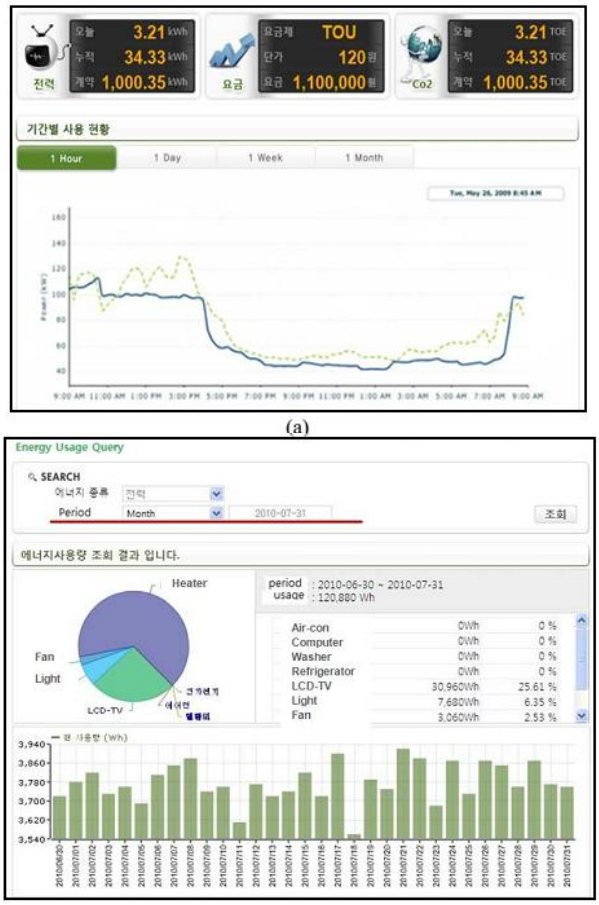

Fig. 8. The captured displays of the HEMS user interface: (a) Total power consumption trend. (b) Power consumption of each domestic device.

V. CONCLUSION

We proposed the HEMS based on 802.15.4 communication and infrared remote controls. The configured 802.15.4 network is composed of the domestic

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server, the 802.15.4 hub, and the power outlets and light. The domestic server is a central control unit. The power output and the light are the sensor nodes. The domestic server can manage the power outlets and the light through the 802.15.4 hub. The 802.15.4 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 device and the power outlet simultaneously through the 802.15.4 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 domestic energy usage information. The proposed HEMS UI provides easy way to add, delete, and move domestic devices to other power outlets. When a domestic device is moved to the different outlet, the energy information of the domestic device is consistently and seamlessly regardless of location change. We implemented the power outlet with a power measuring function and the 802.15.4 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 domestic energy usage in the future.

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