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Home Energy Control System Using Wireless Smart Socket and IoT

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ABSTRACT: To keep away from possessions on green earth being worn out much earlier by person beings, energy saving has been one of the type issues in our daily lives. In fact, energy control for some appliance is an effective method to save energy at home, since it prevents users from consuming too much energy. Even though there are numerous commercial energy-effective products that are helpful in energy saving for particular appliances, it is still hard to find an inclusive result to effectively reduce appliances' energy consumption in a house. Therefore, in this paper, an intelligent energy control scheme, named the Home energy control system is designed, which is developed on wireless smart socket and IoT technology to minimize energy utilization of home appliances without deploying sensors. The home energy control system provides four control modes, including peak-time control, energy-limit control, automatic control, and user control. The earlier two are operated for all smart sockets in a house, while the latter two are used by person smart sockets, aiming to improve the functionality of energy control. The experimental results show that the proposed scheme can save up to 40% of energy for some appliances in one weekday.

Keyword: Energy control system, Internet of Things (IoT), neural network, smart socket.

I. INTRODUCTION

To keep away from possessions on green earth being worn out much earlier by person beings, energy saving has been one of the type issues in our daily lives. In fact, energy control for some appliance is an effective method to save energy at home, since it prevents users from consuming too much energy. Even though there are numerous commercial energy-effective products that are helpful in energy saving for particular appliances, it is still hard to find an inclusive result to effectively reduce appliances' energy consumption in a house. Therefore, in this paper, an intelligent energy control scheme, named the Home energy control system is designed, which is developed on wireless smart socket and IoT technology to minimize energy utilization of home appliances without deploying sensors. The home energy control system provides four control modes, including peak-time control, energy-limit control, automatic control, and user control. The earlier two are operated for all smart sockets in a house, while the latter two are used by person smart sockets, aiming to improve the functionality of energy control. The experimental results show that the proposed scheme can save up to 40% of energy for some appliances in one weekday.

Most of the electronic machine control appliances connect a lot of sensors to sense users' locations and behavior. Some of them even use Open Service Gateway [1] or Service-Oriented design (SOD) [2] to show users' behaviors in a house, with which to control the home appliances in that house. Some previous studies [3], [4] improved operation of sockets set up in a house and connected with wireless networks to control home appliances. Sensing users' location, motion, and behavior with a large number of sensors may not be an energy proficient method since these sensors use large resources. So it would be better for them to be low cost and high coverage. According to the survey on developed countries by the International Energy Agency, the energy used by idle appliances, called standby energy, in a house is about 3% to 11% of total energy used by the house [5]. Basically, home energy can be further reduced if standby energy is effectively lowered without appreciably disturbing users' everyday lives, implying that the difference between home energy saving and user's living easy need to be balanced.

Therefore, in this paper, an intelligent energy saving scheme, named the Home Energy Control System, is proposed to reduce the energy consumption of home appliances without deploying sensors. The Home energy control system, based on wireless smart sockets and IoT technology, not only monitors/controls the standby power consumption of an individual appliance, but also manages energy consumed by all controllable appliances.

The Home energy control system also invokes the neural network algorithm to study user's lifestyle and automatically turns off the power of each smart socket connected to IoT when the electric appliances are not in use. The experiments demonstrate that the Home energy control system can save up to 40% of energy for some appliances in a weekday.

II. RELATED STUDIES

Today, many related studies of home energy control have been projected.

Mohsenian-Rad *et al.* [6] introduce a game-based approach for minimizing energy consumed by a residential building. But they did not think users' agreement degree for their able task scheduling. Best arrangement of home appliances with storage devices has been discussed in [7], in which the total cost reduction is one of the objectives of its optimization challenge. Basically these two methods were developed mainly based on deterministic and meta-heuristic methods. But they failed to consider users' simplicity and comfort levels for their cost optimization process. Moghaddam *et al.* [8]design an numeral nonlinear programming model for best possible energy use in a smart house by considering a significant balance between energy saving and a relaxed way of life. Through integration of a mixed point function under different system constraints and user preferences, the algorithm presented in [8] minimize the home energy usage and service bills, and ensured an best possible task scheduling and a thermal relieve zone for its residents. However, if IoT techniques can be used in this model, the energy can be further reduced.

The developments of the IoT and wireless sensor networks come up with new solutions for home management. In such a home management system, a fix IP address is essential, and distant users need a high-speed connection to access the system. Yeoh *et al.* [9] established an e2Home organization which enables distant users to control smart home appliances, and uses emails as the communication medium. The advantage is that a user does not have to establish a high speed Internet connection before he/she can efficiently control home appliances. However, the complex email services result in the fact that the system is a little hard to be constructed. Das *et al.* [10] published an adaptive versatile home planning which creates a rational mediator as a home servant to look for a process that can maximize inhabitant comfort and minimize operation cost for users. Choi *et al.* [11] developed a context-aware middleware that provides users with an automatic home service inside a smart home following the users' preference. This middleware uses open service gateway as the framework of the home network, and employs sensed data to predict the users' preference for home appliances. This sensed data includes pulse, body temperature, facial expression, room temperature, time and location.

On the other hand, Robles *et al.* [12] proposed a smart water management model which integrates IoT technologies with business process coordination and decision support systems. Wang *et al.* [13] demonstrated a smart home control system consisting of an embedded controller, signal converters and terminal devices. With this system, users can control multiple systems via a smart phone. Then the synchronizer of this system will send user commands to all systems. Suh and Ko [14] introduced an active sensor network to sense user activities and control the on/off state of home appliances.

Although these IoT systems and technologies are relatively novel, there are still many untapped applications areas that need to be developed, and numerous technical challenges and issues that can be further improved and broadly explored [15]. The area of home energy control by using IoT has also been widely proposed. Aram *et al.* [16] contributed to the energy conservation approaches by reducing the amount of required communication. The method predicts the amount of sensed data by using non-linear autoregressive neural networks. Its performance is evaluated by using data obtained from temperature and humidity sensors under different conditions, indicating that the method indeed substantially reduces power consumption for wireless sensor networks. Lee *et al.* [3] designed an intelligent power management device which adopts user's locations, motion detection, and living patterns as its parameters to reduce the energy consumed by some appliances, like lights and humidifier. As a sensor-based system, it could achieve 7.5% of power saving.

Also, Han and Lim [17] introduced a home energy control system developed based on IEEE 802.15.4 and ZigBee to provide users with intelligent services to enrich their lives. This system integrates diversified physical sensing information and controls various home devices to assign various home network tasks to appropriate components. Besides, the authors also presented a disjoint multipath-based routing protocol to improve the system performance. Lien *et al.* [18] proposed a wireless power-controlled outlet module which manages home power with a scalable mechanism and integrates multiple AC power sockets and a microcontroller as a part of a power outlet to turn on/off the power of the sockets.

Park *et al.* [4] developed a control scheme to minimize the power consumed by a home gateway by employing a sleep and wake-up mechanism, which changes its mode depending on whether or not any user service traffic is now being delivered or any embedded services are serving users through the home gateway.

In [19], the deployment of a common client/server architecture focusing on monitoring energy consumption is described, but no control action is mentioned. Most previous home control systems gathered information from various sensors, such as temperature sensor, distance sensor, position finder, passive infrared sensor, and ambient light sensor to sense the users' related data, even lifestyle. Although they can have higher accuracy in predicting users' behaviors, the cost and power consumption of a huge number of employed sensors are big problems needed to be solved. Pawar [20] designed a smart socket for power optimization in home energy management system using ZigBee module but it work on short range and have lower data transmission speed. Tsai*et al.* [21] designed a wireless smart socket and IoT based system but in this system security is a big issue for secure data transmission. Tong *et al.* [22] worked on the intelligent home energy control system based on Wi-Fi for smart home market. This system works for short distance using Wi-Fi network on the Android platform. Kaur et al[23]an energy-efficient architecture for IoT has been proposed, which consists of three layers, namely, sensing and control, information processing, and presentation. This mechanism allows the energy-efficient utilization of all the IoT resources. The experimental results show a significant amount of energy saving in the case of sensor nodes and improved resource utilization of cloud resources.

Table 1: Wireless technology transmission range.

Name	frequency	distance	Power consumption
Bluetooth	2.4GHz	10m	low
XBee	2.4GHz	<30	low
Wifi	2.4GHz	50-100	low

III. ARCHITECTURE OF HOME ENERGY CONTROL SYSTEM

A. System Overview

In this system, no sensor is used, and the information of appliances power use is collected by smart sockets through mobile app and IoT. The appliances which are regularly staying in their supply states will be turned off by switching off using mobile app the related power supply embedded in their smart sockets with an electronic approach. After getting user defined energy limit for a smart socket, the system gives a one-day energy quota to the smart socket, and according to this quota controls the energy consumed by those appliances connected to the socket.

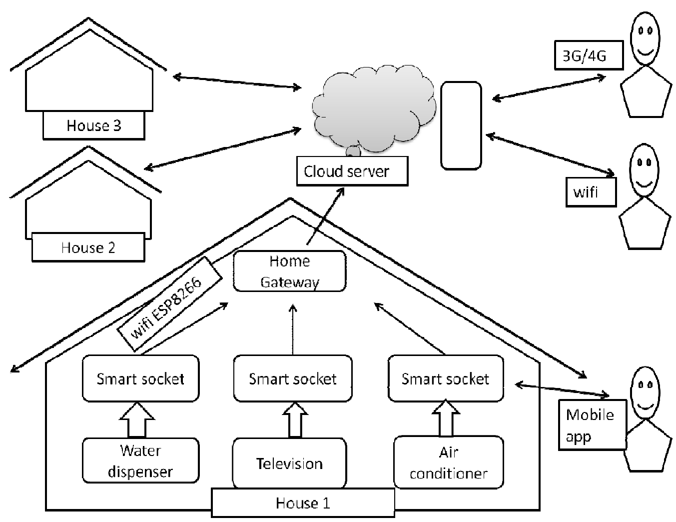

Fig. 1. The IoT based system architecture of home energy control system.

Fig. 1 shows the system architecture of the home energy control system, in which the smart sockets measure connected devices' electricity data, including voltage, current, power, etc., which are acquired by home gateway and then sent to the energy controller. On receiving a ``turn on" or ``turn-off" command issued by the energy controller, home gateway transmits it to the target smart socket which will accordingly turn on/off its power supply. Energy controller implemented in a cloud server, besides storing electricity data, also determines the state of a socket, communicates with users, manages the energy consumption of a house and so on. Furthermore, users can set energy limit, and control smart sockets manually.

The wireless communication protocol between smart sockets and home gateway is Bluetooth and WIFI which consumes very low power and is often employed by personal area networks. The communication protocols between the cloud server and home gateway (and users) can be 3G, 4G or Internet, since the data transmitted between them is often large and long-distant.

In general, IoT has three layers, i.e., sensor layer, network layer, and application layer. From the IoT viewpoint, the sensor layer in the architecture of the home energy control system is the smart sockets, and the network layer is WIFI and Bluetooth, 3G, 4G, etc., whereas the application layer is the smart grid and energy management mechanism.

B. System Control Modes

The home energy control system has four control modes, including peak-time control (PTC), energy-limit control (ELC), automatic control (AC) and user control (UC). The PTC and ELC mode are exclusively used to control all smart sockets in a house, meaning at any moment, only one of the PTC mode and ELC mode can be utilized. In the PTC mode, the home energy control system controls each socket's on/off state according to the user-defined peak time and its peak-time energy limit. When the total energy consumption of the underlying house exceeds the energy limit, low priority sockets will be turned off to reduce the peak power consumption, and a warning message will be sent to the users. On the other hand, after the user sets the energy limit of a house for the following 4 weeks, the ELC mode will be triggered. Then the home energy control system calculates one-day quota for each socket according to the energy consumption history of all sockets. Once the energy consumption of a certain smart socket in a specific weekday or weekend exceeds its quota, the home energy control system follows the ELC-mode policy to turn off its power supply.

The Automatic control and user control modes are applied to control each and every smart socket following automatic control policy and user-defined control policy, respectively. Like the exclusion between PTC and ELC modes, at any instance, either AC or UC can be used to control a smart socket. The home energy control system in its AC mode determines the on/off state of a smart socket based on the socket's energy usage history in the last 4 weeks. The home energy control system in its UC mode provides an interface with which users can flexibly set up the on/off state of a certain socket. Note that the automatic control/user control mode of a smart socket can co-exist with the PTC/ELC mode of the energy controller. For example, the energy controller of a house is now in its peak time control mode, and a smart socket in the house is in its user control mode or Automatic control mode. Details of Automatic control and user control modes will be described later.

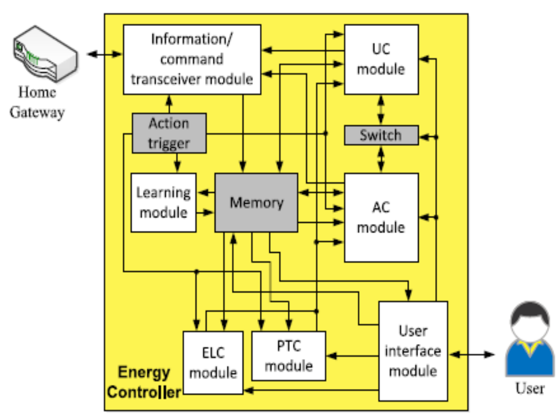

Fig. 2. The components of the Home energy control system (in the cloud server).

C. The Energy Controller

The energy controller (i.e., the cloud server) of the home energy control system, as shown in Fig. 2, consists of Memory, action trigger and seven modules, including learning module, user interface module, information/command transceiver module (WiFi), automatic control (AC) module, user control (UC) module, energy limit control (ELC) module, and peak-time control (PTC) module.

The Memory, consisting of a Dynamic Random Access Memory (DRAM) and a hard disk, is used to store smart sockets' data, output of the learning module, user-defined energy limit, user commands, etc. Old data is stored in the hard disk and retrieved to DRAM when necessary. Action trigger is an internal system clock utilized to send trigger signals to the learning module, information/command transceiver module and four control modules (including the AC module, UC module, ELC module, and PTC module) to trigger further activities.

The frequency of sending a trigger signal to each of the 4 control modules is once per 10 minutes throughout a day, i.e., at 00:10, 00:20, 00:30, and so on. The purposes and functions of the seven modules will be described below.

Learning Module. The learning module, as the essential part of energy controller, is implemented by using the neural network algorithm for learning and calculating a smart sockets' operation time. The action trigger sends trigger signals to the learning module at 12:30 and 00:30. On receiving the first trigger signal (i.e. at 12:30), the learning module requests energy spending histories of all smart sockets, and the peak-time periods set by users for the smart sockets as its input to calculate the time periods in which a smart socket will be turned on or off for the time duration from 00:00 to 12:00 (i.e., AM) of the next day. The time periods as the output of this module are stored in the Memory for easily being accessed by other modules. When the second trigger signal arrives, of course, at 00:30, the inputs and outputs are equals to those when receiving the first trigger signal. But this time, the calculation is for the time duration from 12:00 PM to 00:00 of current day.

User Interface Module. This module provides interfaces for users to check the energy consumption, accumulated energy consumption and the on/off state of a socket, and accumulative energy used in a house. User can also check the energy consumption history of a socket by mobile app connected with the Bluetooth module. Besides, when receiving user's commands from user which may be energy limit, peak-time settings, a socket's priority, automatic control/user control mode switching, etc., this module sends a data request or control signal to the corresponding control module or stores data into the Memory. For example, if user sets the energy limit via user command processing module, then the value will be sent to energy limit control module to control the total energy consumption of smart sockets. User can also control the smart socket using mobile app or received data from socket such as energy limit control signal and warning alert message on the mobile app.

Information/Command Transiever Module. The information/ command transceiver module provide a connection between smart socket and the home gateway through the Internet using wifi modem or Bluetooth module so that smart sockets' data can be sent to cloud server and mobile app, and system's/user's commands can be transmitted to the home gateway or mobile app connected with Bluetooth module. As mentioned before, the action trigger activates this module every 10 minutes. Once activated, the module sends a data request to home gateway and mobile app. On receiving the reply, the module stores the received data with the smart socket's ID in the Memory.

Automatic Control Module. If the system is now in its automatic control mode, according to output of the learning module, the automatic control module turns on/off the power of smart sockets for particular time periods. Besides, when total energy consumption of a smart socket exceeds user defined limit, the AC module will receive requests issued by peak time control or energy limit control module and then accordingly turn off those low priority smart sockets.

User Control Module. The user control module provides user friendly control system, with which users can send control commands via user mobile phone (Bluetooth control),when the system is now in its automatic control or user control mode. Using mobile app connected via Bluetooth module, the commands will be sent to user control module to set a particular socket into on/off state. Besides, the user control module also controls any selected smart socket energy consumption following user-defined energy limit.

Energy-Limit Control (Elc) Module. When a user sets a 4-week energy limit, a socket's one day quota actually is calculated by the energy limit control module. If the energy controller is now in its energy limit control mode, the energy limit control module will control a socket's one-day energy limit based on the fact that today is a weekday or weekend. When the energy consumption of a day exceeds the quota, if the socket is now in its automatic control mode, the energy limit control module sends a control signal to automatic control module to turn off the corresponding socket. But if the socket is now in its user control mode, the energy limit control module will send a warning signal to user control module to alert the user.

Peak-Time Control (Ptc) Module. On receiving the user-defined peak-time periods and a socket's priority (also defined by user), the PTC module sends signals to AC and UC modules to control the on/off state of a socket. As mentioned above, when the total energy consumption of a house exceeds its peak-time energy limit, lower priority sockets will be turned off.

IV. SYSTEM HARDWARE DESIGN

The wireless smart socket based hardware mainly includes intelligent controller and wireless communication module. The intelligent controller includes ATMega328 microcontroller, power supply circuit, relay circuit, detection circuit and alarm circuit; this parts is mainly responsible for data processing, system power, work load control. The wireless communication parts contain WIFI communication module and Bluetooth module; this part is used to transmit and receive signal, which is a bridge between the user and the intelligent controller and plays a leading role in the user interface.

A. Power Circuit Design

The smart socket circuit includes power supply circuit. The power supply circuit is used to power supply in the smart socket. Stable power supply for the system provides a safe and correct operation. The system chip voltage supply has two types 5V and 3.3V. We design a power conversion process. The electricity AC 230V step-down to AC12V by transformer, and then turn the AC12 into DC12V through the D1 (bridge).Because of the residual voltage, it needs to filter through EC1 capacitor filter, and then gets the stable DC12V voltage through the LM7812 (three regulators). The voltage needed in the system chip is DC5V and 3.3V. We firstly convert DC12 to DC5V then convert 5V to 3.3V by the 1117CST chip.

V. SYSTEM SOFTWARE DESIGN

The overall system software flow diagram is shown in Figure 5. When the system powers on, the system is firstly initialized, and then detects the load voltage. If the voltage is within the threshold range, then it gives master control judgment. If the master control is open, it can control the working state of smart socket by mobile app or wireless server. We can achieve the same function through the mobile phone APP. When we are at home, the Bluetooth module of the APP can be link to the smart socket and data communication. During operation, if the voltage (low pressure) over load the abnormal state, the relay will immediately disconnect and cut the load power supply, give sound and light alarm, and the alarm information can be sent to the designated mobile phone and the cloud server of IoT.

A. Wireless Control

WIFI and Bluetooth communication modules are used in this system wireless; it mainly achieves time correction, system master control, timing time, limit power adjustment, socket switch and other functions. We use the data query modem that is, we send the appropriate command to the Uart buff register by using the phone APP software or IoT server. When the system detects that command it indicates that the input is valid, and then the program starts to query the corresponding implementation function, which can ensure that the signal is handled correctly and can reduce the misjudgment. If the sent command is valid, the program will automatically return Set OK, which indicates that the setting is successful. In order to facilitate the operation of the program, the timing function uses the real-time comparison syntax. Through the mobile phone APP input timing time, control command send to the hardware. The design can enter valid data. We give priority to the Bluetooth module at home, and use IoT server outside (remote).

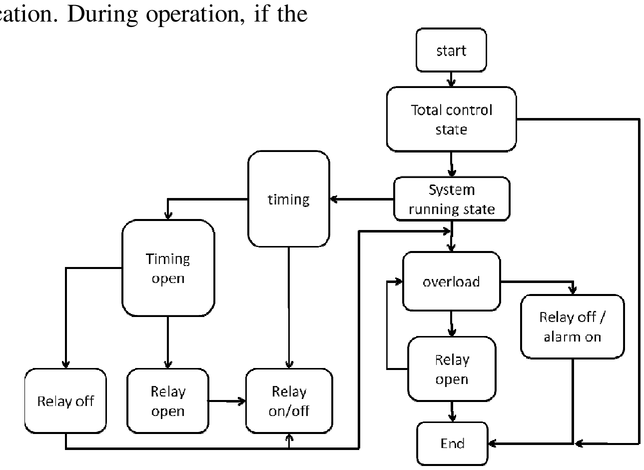

Fig. 3. Process of system software.

VI. RESULT AND ANALYSIS

This system operated by mobile app and IoT server. Bluetooth and Wifi module are Wireless communication medium between smart socket and home gateway. Smart socket, home gateway and energy controller are three main parts are used to control and measure the energy consumption of home appliances. Bluetooth module used to control the home appliances using mobile app to overcome the manual operating function and secure data transmission using password based authentication. Wifi module used to increase the communication range between smart socket and home gateway. Energy controller unit measure the power consumption of the home appliances, store data into the memory and display on mobile app and IoT server.

VII. CONCLUSION

This paper presents a wireless smart socket and IoT based home energy control system. It is based on WIFI technology to increase communication range and Bluetooth technology for secure data transmission for register mobile app. Energy consumption is measured by energy controller. After the test, the home appliance controlled using mobile app connected with Bluetooth and IoT server. Measure the energy consumption by home appliances and store this data in the memory and display on mobile app and IoT server.

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