ON THE DESIGN OF SMART WIRELESS POWER OUTLET TOWARDS INTELLIGENT HOME ENERGY MANAGEMENT

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ABSTRACT

Along with the concept of "smart home" developed in recent years, utilize the energy with a more intelligent and efficient manner is one of its key issues. In this paper, we exploit the home energy management system and present a design solution of wireless based power outlet and control terminal which could measure the energy consumption and carry out control actions with adopted strategies through the wireless-based home communication network. The suggested solution can greatly improve the energy utilization efficiency at home with greatly flexibility.

KEYWORDS

Home Electric Quantity Monitoring; Measuring Outlet; ARM Terminal; RF Devices.

1 INTRODUCTION

In recent years, along with the technological advances of "smart home" and "smart building", much research effort has been made towards relevant automation devices design and implementation (e.g. [1-2]). Through deploying a collection of sensors for different measurement proposes and actuators, a more human friendly environment can be established in homes or buildings with enhanced convenience, security and entertainment. However, they neglect one important field——electric quantity monitoring, which once exists only in large electric power systems. When the industrial civilization becomes more advanced, power quality problems appear also in domestic load fields, and affect the daily life and the useful life of domestic appliances. So, the electric quantity monitoring should be concerned as one important field of the smart home research. For single domestic consumer, the newly-released RF standard can meet our needs to build wireless control and monitoring applications that can guarantee the low cost, low power, and high reliability.

At present, power outlets or sockets are probably the most commonly-used electrical devices in modern home environments. If we want to build a home electric quantity monitoring system, those devices are the necessary modules that should provide electrical connections, electric quantity data measuring and even switch functions. It is not a new idea to design a power outlet or socket with electric quantity data measuring and switch functions. Many power outlet products that can provide electric quantity data measuring and switch functions are available now in commercial markets. However, it should be noted that most of these products can only support point-to-point wireless communication and the sampled data is only displayed on the outlet screen. Every power outlet must be equipped with a remote control for the remote operations. It will be very inconvenient to control those power outlets when you have to handle many remote controls at the same time, and examine their electric consumption. Even worse, at most of time, households have no knowledge or at least detailed information of their power consumption of their appliances.

There are various options of wireless communication technologies have been deployed in buildings, factories, enterprise and home automation networks, e.g. Zigbee [3], GPRS [4], WiFi [5], and Bluetooth [6]. In [7], the researchers have proposed a Zigbee based universal remote control unit and a Zigbee to IR conversion module for controlling multiple legacy consumer electronics devices. It is difficult to be compatible with different IR codes from so many vendors. Also, it is not easy to persuade the home appliance manufactures to integrate those modules into their products due to cost and other non-technical reasons. Transferring the wireless transmission and control into the power outlets is a good idea. A wireless-controlled power outlet module based on Bluetooth was proposed and presented in [8]. However, this solution is greatly constrained in the scenario of large networks and bidirectional data communication due to the limitations of Bluetooth technology. In addition, adding a large number communication interfaces to the end devices also greatly increases the system complexity and cost. Compared with RF, Zigbee, GPRS and WiFi have more great capacity to construct a larger network efficiently and transmit the pack-data more reliable for further distance, but the system cost and complexity are also increased sharply. For residential customers, the maximum control and transmission distance is less than 100 meters with cost-effective performance, so RF is often sufficient to meet our design requirement.

This paper presents a RF-based wireless smart power outlet and terminal to be used in the home energy management system. The proposed power outlet module integrates an electric quantity measuring module and a RF module into its architecture. The terminal is designed based on ARM technology to carry out the data acquisition and supervisory control of the distributed power outlets. The terminal is developed in accordance with the design criteria by using Linux, QT and Berkeley DB technology. This terminal integrates all appliances switch functions and the administrating strategy of the home power load. Each outlet acts as an actuator node in the home automation networks to perform the remote monitoring and control operations. The system architecture, the design of the wireless monitoring power outlet modules and the evaluation experiment test-bed are presented and discussed in details in Section II-IV.

2 SYSTEM OVERVIEW

In "smart home" systems, one of the key underlying requirements is that various home appliances or devices can be are easily controlled and managed. With the aim of implementing the remote control and data transmission functionalities, antennas with appropriate configurations are adopted to transmit the RF signals. By integrating the antennas in the designed power outlet devices, it becomes scalable to upgrade home automation within the range which signal could reach. As illustrated in Figure 1, the designed home energy management system is in fact a wireless sensor-actuator application which consists of a set of wireless power outlet modules and a base station (i.e. ARM terminal). Individual power outlets are designed and considered as actuator nodes which are added to the home automation network. All power outlets effectively form a wireless multi-hop mesh network. The ARM terminal which is equipped with an appropriative RF device can perform data acquisition and supervisory control across the dispersed power outlets through data collection and control signals in nearly real time. In such a way, the remote and optimized energy management at home could be implemented and carried out with the adopted various energy regulation strategies in accordance with the home power loads and constraints.

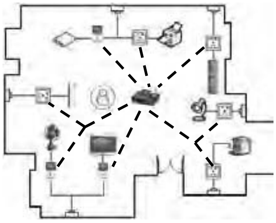

Figure 1: Smart home energy management system with wireless power outlets

Figure 2(a) The power outlet example

Figure 2 (b) RF radio modules

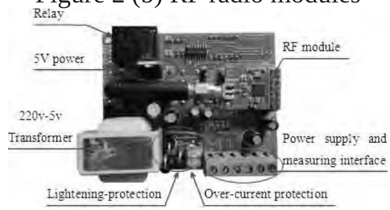

Figure 2 (c) The hardware circuit design of power outlet

Figure 2: The sample power outlet design

3 WIRELESS POWER OUTLET MODULE WITH MEASUREMENT FUNCTIONALITY

One of the key components of the home energy management system is the wireless power outlet which could measure and display the energy consumption and other parameters of the connected appliances. Through the equipped antenna, the power outlet could flexibly deliver the collected data to the ARM based terminal through wireless communication channels. The power outlet is designed to be an advanced electric energy meter with actuating functions to perform remote control actions in accordance with the distributed control strategy from the terminal. Fig 2 (a) shows the sample of the proposed power outlet module design. Fig 2 (b) present the RF module (MCU driver is nRF905 chip) applied in power outlet and the hardware circuit of the power outlet, respectively.

In the system, the RF module is connected with the ARM terminal by an expansion connector. It works at the 950 MHz frequency band and establishes wireless communication connections with other nodes within the signal radiation range. The power outlet uses a low-cost MCU – STC89C51 to implement the control logic, packeterize the collected measurement data, and to drive the RF radio to transmit the control or data signals to the terminal. The dimension of the power outlet prototype is 90×80×45mm.

During the design, to effectively avoid unnecessary electromagnetic interference, the control MCU (STC89C51) and the measurement chip RN8209 are arranged at the back-face of circuit board, as shown in Fig 2(c). The RN8209 integrates the measurement function of the manifold electric consumption parameters, including voltage, current, frequency, active power, reactive power, etc. which are maintained at the stationary memory address. There are two SPI serial interfaces on RN8209 to communicate with the external MCU. The construction drawing of measuring module is shown in Fig 3. Fig 4 gives out the software control flow of electric quantity measuring system.

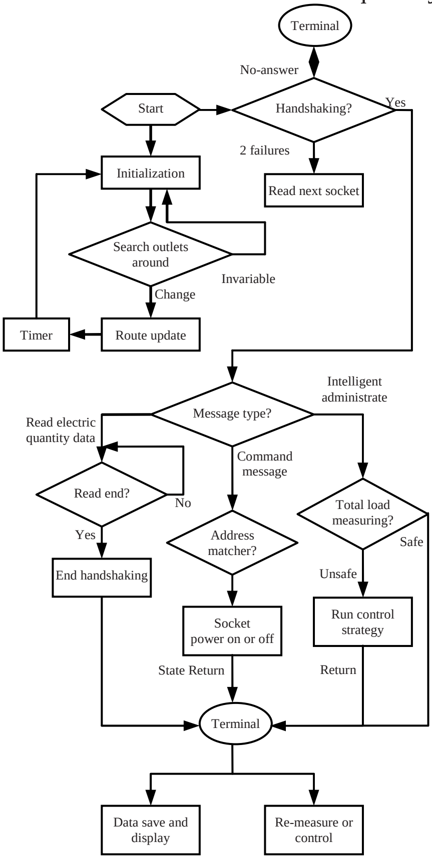

Figure 4: The software control flow of electric quantity measuring system

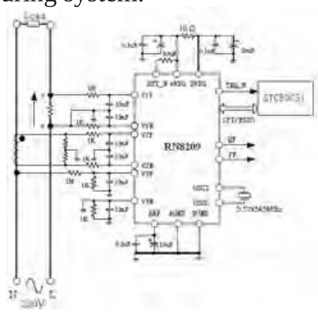
Figure.3: Construction drawing of measuring module RN8209


Figure 5: The test-bed of the wireless outlet


Figure 6: The measurement of three appliances displayed on the ARM terminal

4 SYSTEM IMPLEMENTATION

In the Electrical Automation laboratory at Zhejiang University, a simple test-bed of the home power administering system for measuring the electric quantity data and administering upon the home electrical load has been designed and implemented. As shown in Fig 5, the test-bed includes an outlet and a laptop. The outlet provides power for the computer, and all electric quantity data of this laptop is measured and displayed by the outlet. In Fig.5, we list the displaying pictures of voltage (242.65V), current (1.78mA) and active power (22.80W) when the laptop is running. The outlet communicates with the ARM terminal by the use of RF protocols and updates the electric quantity data. If there is multiple power outlets are used in the system, all outlets communicate with each other and delivery the information to the ARM terminal through WIFI or GPRS connections, and the laptops can be used as portable user terminals for controlling the home energy management system. The users can control individual devices in the home network conveniently by using the ARM or computer terminals.

Fig 6 shows the graphical user interfaces (GUI) of the implemented terminal of the home energy management system. In this scenario, three power outlets are used to supply power to air conditioner, printer and desk lamp. The ARM terminal displays the collected measurement information of the monitored appliances, including voltage, current, frequency, active power, and reactive power, and power factor, and so on. The terminal could acquire and save the measurement data from all dispersed power outlets at a pre-redefined time interval, e.g. 1 s. As a result, power consumption information can be calculated and maintained in the embedded database for different time scales, e.g. day, month or year. The control terminal can set the power on or off time for each power outlet through using different strategies and modes. Behind the scenes, the energy management strategy is performed to manage the total home power loads and energy utilization. Two main strategies are often used: (1) setting the lower limit of power factor; (2) setting the upper limit of total power load. Once the corresponding parameter exceeds the limit, the appliances with more energy consumption are power off with higher priority.

In addition, a PIR sensor module is also used to inform the terminal and instruct corresponding actions once it detects the presence of a human body. The ARM terminal sends control commands downwards to the power outlet to turn on the lamp and the electric fan. More appliances, e.g. TV and air conditioner could be integrated into the home energy management system.

5 CONCLUSION AND REMARKS

In this paper, we presented the design solution of wireless power outlet to be adopted in the home energy management system along with ARM based terminal which could monitor the energy consumption and carry out various real-time control actions. The envisioned home energy management system is underpinned by the underlying wireless mesh network formed by a set of power outlets by adding RF radio antennas. All devices are assigned with unique network address and connect with each other after matching the communication address. The expected functionalities are evaluated through the test-bed and the experiment result shows that such a home energy management system could efficiently carry out the energy consumption measurement, remote control and data processing tasks. These successfully realizes data measurement, remote control, data display and save, and intelligent home power load administration of various home appliances with little infrastructure. It provides a simpler and more flexible approach for building and deploying home power administrate network.

In respect to the future work, more control functions and strategies are under investigation to improve the home energy utilization efficiency by including different constraints, e.g. the varied electricity price and the comfort of residents into the energy scheduling optimization. Further research outcome will be presented in the future publications.

6 ACKNOWLEDGEMENT

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