A RF4CE-Based Remote Controller with Interactive Graphical User Interface Applied to Home Automation System

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With the increase in commercial electronic equipment and its complicated control interfaces, how to design an effective and user-friendly control interface has become a topic for many researchers. This research introduces two-directional communication of an interactive graphical user interface on a universal remote control (URC). It is different from current URCs where users must often spend huge amounts of time setting the command codes and encoding each device. With the increase in the number of appliances that the controller needs to manage and the complicated and numerous control buttons, using such controllers often causes difficulties for users. This research employs a cross-platform with integration theories, so when a user wants to connect an appliance, both the appliance end and the controller end will build a two-directional connection through pairing over Radio Frequency for Consumer Electronics (RF4CE). After connection, the system will automatically set the communication protocol between the controller and the device. The appliance will automatically transmit its current state and service in the form of bundles to the controller, then the controller will project it onto an LCD screen. The controller can also show the number of appliances connected to the current position of the user, allowing the user to use one controller to control all home appliances with ease, achieving a simplified and instinctive control interface to build the integrated control environment for commercial appliances.

Categories and Subject Descriptors: C.3 [Special-Purpose and Application-Based Systems]
General Terms: Design
Additional Key Words and Phrases: RF4CE-based remote controller, interactive graphical user interface, home automation system

ACM Reference Format:
DOI = 10.1145/2423636.2423648 http://doi.acm.org/10.1145/2423636.2423648

This research was supported by the MKE (The Ministry of Knowledge Economy), Korea, under the ITRC (Information Technology Research Center) support program supervised by the NIPA (National IT Industry Promotion Agency) (NIPA-2011-C1090-1131-0004), and was supported in part by the NSF CNS-1249223 and the University of Kentucky Start-Up Fund.

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© 2013 ACM 1539-9087/2013/02-ART30 $15.00
DOI 10.1145/2423636.2423648 http://doi.acm.org/10.1145/2423636.2423648

1. INTRODUCTION

With the advancement of technology, there are more and more home appliances (like television, DVD, air conditioners) and appliance manufacturers each with their own specialized controller. Users often need to spend time learning each type of controller. Therefore, building a complete and user-friendly control system has been discussed and studied by many researchers. The traditional infrared radiation (IR) transmission type of URC works by recording different formats of encoding and control codes or by a learning-type setting, but the complicated settings and learning is a major fault, which is why these controllers are not popular. A wireless personal area network (WPAN) is a wireless network that allows the devices in a personal area to send messages to each other. With the development of WPAN, digital home systems start to build wireless network systems. More commercial appliances also start supporting wireless transmission; hence how to use a wireless network to build a wireless universal device controller interface is a major research topic. Building a wireless universal controller has a few obstacles that need to be overcome.

1. Suitable Wireless Transmission Interface. When choosing a commercial wireless electronic network environment in a digital home, the transmission medium must accommodate low power, low costs, and confidentiality. The most commonly used is Bluetooth [Jia and Cheng 2004; Jianfeng et al. 2009] and ZigBee [Jinsoo et al. 2010]. J. R. Chang Chien et al. have built a wireless home network control system through a Bluetooth PCM voice communication encoding function to control the home electronic system. ZigBee is mostly used to build wireless home network systems [Anders et al. 2009; Egan 2005; Li 2006]. Erdem and Uner [2009] introduced a multi-channel remote controller, using the data transmission interface of the Internet, GSM, and telephone lines and combined them into an integrated system. Through this system, the user can choose an adequate transmission method, to prevent system failure.

2. Compatibility with the Commercial Electronics. Currently most commercial appliances do not have wireless network modules so how to change the appliances to build a wireless network environment is a major consideration. Erdem and Uner [2009] and Wan et al. [2007] have both structured such a control system through a ZigBee2IR transformer. They use ZigBee to build a wireless transmission system and then use the ZigBee2IR transformer to convert ZigBee signals into IR signals to control the existing appliances.

3. User Control Interface. To attain control of most commercial electronic appliances, the controller itself usually has numerous control buttons, and the user must first do the settings for the controller devices. This is an inconvenience and the main obstacle especially for the elderly and children. To solve this problem many researchers have introduced PDA or a human body detection device to build a user-friendly interface [Youngjae and Dongman 2006; Laehyun et al. 2010]. Hsien et al. [2009] introduced an audio-visual device virtualization system environment which manages a home audio-video equipment control service through a virtual machine. Users can avoid the complicated settings, and this provides a solution to the integration and expansion of commercial electronics. Though in past research [Wan et al. 2007; Laehyun et al. 2010], ZigBee wireless transmission system builds a complete URC, but it still uses single directional transmission methods. The system cannot receive the device service and control function, so the user must first set the function interface for every device and then set the transmission encoding for each IR setting with different protocols. The extra work for setting a new device is not ideal for an expansion environment. This research introduces a wireless two-directional URC, using a wireless transmission system, introduced by the ZigBee Union Institute, called ZigBee radio frequency for...
consumer electronics (RF4CE), which has low power and low costs that are ideal for modern commercial electronic appliances. This system performs two-directional communication through the consumer electronics control (CEC) protocol and the existing home appliances. It displays all the service functions and interface that each appliance can provide by transmitting the functions to the controller. The user doesn’t need to do any preparation learning or setting to use the device. When a user touches a panel to choose the desired appliance, the controller and device can both communicate with an automatic connection and exchange information, making it easier to control different types of home appliances with one controller. The controller doesn’t need the user to set additional settings in order to add new appliances, since a state request mechanism automatically allows devices to send its state and commands back to the controller, thus creating a complete control system.

The main contributions of this research are the following.

**Building a Two-Directional Communication Self-Set Mechanism.** Since RF4CE doesn’t have a two-directional communication control method, by the implementation of this mechanism, when users choose the control device, the controller will send a request. The requested device will provide the service and control interface. After obtaining the device data, the system can build a convenient user interface using the data, equipping the user with an interactive control interface to easily control all types of appliances in the home with zero configuration, as well as submitting a type of two-directional communication control prototype for home use of future commercial electronic products.

**Compatibility with Modern Electronic Devices.** When the system receiving end receives commands from the controller through an HDMI terminal using CEC protocol to communicate with electronic devices, it provides a great compatibility mechanism for the wireless universal controller.

**Implementation Proof of Low Power and Achievability on an Embedded Platform.** Unlike past research with PDA implementation, our research will realize this mechanism on an embedded platform to prove its achievability and thus successfully solve the high-power consumption problem for PDA implementation.

**Convenient User Interface.** Compared to most universal controllers, which are inconvenient to use because of their different transmission methods and function choices (such as too many buttons or complicated control menus), this research uses a two-directional communication mechanism, which not only builds a universal control system, but also shows the appropriate command listings on the LCD display according to the function listings provided by the device. This provides a more intuitive control interface that lessens the time the user has to spend getting used to the controller.

The article is organized as follows. We introduce the ZigBee RF4CE standard with a Consumer Electronics Remote Control (CERC) profile as well as a CEC protocol in the second chapter. In the third chapter we explain the two-directional communication control system, including the software structure of the controller and the communication process between the device and controller. The fourth section presents our implementation of the system environment as well as the power testing results. We conclude our article in Section five.

### 2. BACKGROUND KNOWLEDGE

To allow readers who are not familiar with this field to fully understand the research, this section will briefly introduce the related techniques including the RF4CE standard, the CERC profile, and the CEC protocol. The references at the end of the article provide a more detailed understanding of the specs and research.

2.1. RF4CE Standard

RF4CE is a convenient, low-cost, low-power wireless transmission protocol set by both the ZigBee Union and the RF4CE Association especially for the commercial electronics market. Similar to ZigBee, it is built from the standard specs of the networking layer and application layer implemented by the IEEE 802.15.4, that is, with the MAC Layer, PHY Layer, and RF transceiver as the basis for implementation. It is different from ZigBee in that it does not have a complicated Internet routing protocol and multiple transmission communication mechanisms. RF4CE is a simpler protocol, targeting the wireless control systems built into commercial electronics. Figure 1 shows the four main parts of the stack architecture of RF4CE: the PHY/MAC layer, the Internet layer, the profile layer and the application layer.

—**PHY/MAC Layer.** In the physical layer, RF4CE follows the IEEE 802.15.4 standard with the MAC layer, the transmission frequency bandwidth at 2.4GHz, and three channels as 15.20.25. When a device activates the network, it can detect all signal states of every channel and choose the suitable channel and in the transmission process, it can change the communication channel according to the strength of the channel signal.

—**Internet Layer.** To meet the demands of the commercial electronic market, RF4CE removed the point-to-point method used in routing transmission and set a simple low-cost Internet communication structure in order to increase power savings and to strengthen the security code transmission mechanism. This provides a low-cost low-power wireless Internet structure.

—**Profile Layer.** This layer is between the Internet layer and the application layer. It offers functionality to the upper layer by allowing the application layer to add the needed functions to this layer. It sends commands to the Internet layer and defines the commands or processes of actions that allow each node with the same profile to be able to communicate. Beyond the standard profile set by RF4CE, RF4CE also allows vendors to define their own specific profile.

—**Application Layer.** This layer allows developers to develop on their own, offering users the service interface that they need.
As for the Internet topology structure, RF4CE uses every Personal Area Network (PAN) as one division. In a PAN, messages can be transmitted simultaneously from several different PANs as shown in Figure 2. In a PAN, each device is defined as a Node. Node states can be classified as Target Nodes and Controller Nodes. A Target Node has the ability to start a network, and it can decide its own transmission channel depending on channel signal strength. A controller node is responsible for the discovery and pairing with Target Nodes. In our defined area, most nodes are defined as controllers.

### 2.2. Consumer Electronics Remote Control Profile

Consumer Electronics Remote Control (CERC) Profile is the standard profile set by the RF4CE Association. It defines a set of operational control commands especially for consumer electronics, including the commands and processes of different actions for controlling home appliances. Figure 3 shows the frame format transmitted by CERC, including the CERC head and CERC payload. CERC head describes the process of actions for the controller including requests for pressed, repeated, released, and discovery type actions. The CERC payload slot only needs to be filled when the controller state is pressed. When users press different buttons sending the respective command codes, such as power on or off or even tuning volume, the payload follows the CEC protocol standard, mainly for integrating the entire commercial electronic appliance system.

### 2.3. CEC Protocol

CEC originated in Europe on the SCART interface, but the HDMI interface standard is slowly overtaking SCART by using the CEC technology to increase functions, mainly by direct or indirect methods of connecting and communicating with different home appliances. CEC in the HDMI interface is a one-line two-directional transmission mechanism. The entire device structure can be classified into root, branch, and leaf, each of which can send messages to each other. For every device in the CEC there is a physical address and the local position is used to prevent collision errors. In CEC the devices send messages to each other through frames. As shown in Figure 4, every frame contains a start bit, a head block, and, at most, 16 data blocks. The start bit shows the start of a frame, while the headblock is used to describe the position of the device sending the signal (called the initiator) and the position of the device receiving the signal (called the destination). The block includes...
4 bits of initiator local position, 4 bits of destination local position, and 1 bit for both the end of message (EOM) and the acknowledgement (ACK). The datablock contains 8 bits of information data with EOM and ACK. The content includes descriptions of the message about the device action and the parameters needed by the device. RF4CE uses the information data protocol in the CEC as the standard communication protocol between each device.

2.4. Interactive Graphical User Interface

An interactive graphical user interface is an interface system for transmitting orders and commands between humans and machines, enabling more complete communication between them [Coleman 2009]. For an interactive multimedia system, a satisfactory interactive graphical user interface is a necessary component. One type of multimedia control service is accomplished through multitouch [Yu et al. 2010; Xing et al. 2009], while another convenient interactive graphical user interface system is achieved by eye movement [Sandnes et al. 2010]. 3D multimedia services have been studied extensively in recent years. Sreeram et al. [2007] have proposed the idea of a 3D virtual world, and employed Wii remote in the virtual environment by performing hand gestures for “Yes” or “No” to facilitate communication. Due to the advantages of convenience and portability, the data glove [Chen et al. 2008; Zaletelj et al. 2009],
3. SYSTEM ARCHITECTURE AND DESIGN
In this section we will introduce the entire system structure and then explain both the wireless universal remote control and receiving end device designs as well as the two-directional communication processes.

3.1. System Overview
Given many home appliances and different services, designing a simple yet effective control system is an interesting and useful challenge. RF4CE offers commercial electronics a low-cost and low-power wireless transmission interface, but, according to the current standards, a control system using two-directional communications has yet to be realized. This research proposes a two-directional wireless control system structure using RF4CE as its base. When the user is choosing a device, the controller can automatically ask the device for the control interface and the respective actions. Once the controller has the data, it analyzes the data and does the module settings. Then the controller shows the usable control interface and the user can easily control all types of appliances at home. As shown in Figure 5, the entire wireless control system includes a controller in RF4CE standards with a set of RF4CE receivers. The controller and receiver build a connection platform with each other through the RF4CE standard. The CERC Profile implements the Internet layer communication, including commands like discovery, pairing, and command transmissions, which allows the controller to access the device service, current status, and the respective control commands. This research designs status requests, including the status request between the device and RF4CE node, as well as data analysis of the communication between the RF4CE Internet layer and the controller. This allows the controller to get the device state and the currently available commands and to structure a control interface. The receiver, upon receiving the command through CEC, will then request the control interface and transmission command from the device and package the device service as a Consumer Electronics Bundle (CEB). The CEB then transmits to the controller and registers on the Profile layer. After registration, the controller can then access the complete service status of the device and build a control menu to provide to the user. The user would not need to
do other settings for end devices. This research will provide a two-directional universal control system for digital home system Internet service.

3.2. Design of RF4CE Remote Controller

This section introduces the controller structure and power saving mechanism designed in this research. Figure 6 shows the controller hardware platform and the entire design structure. The hardware platform uses Ti CC2531 RF4CE USB Dongle to transmit and receive the RF4CE signals. Then it transmits the signals to the Cortex microprocessor unit (MPU) for processing with the core structure comprised of RF4CE note, state parser, state manager, event engine, power manager, and pattern layout. Each of these will be discussed in detail in this section.

3.2.1. RF4CE Note.
RF4CE note is responsible for transmitting packages in RF4CE standard format with their respective functions, excluding the functions defined by related actions according to the RF4CE standard and CERC profile, for example, discover, pairing, and button functions. For transmitting the device state functions, this research defines a state transmission function (as shown in Figure 7), which, through the two-directional communication transmission mechanism receiving end, can package the control interface functions provided by a device into a CEB to transmit the device’s state and commands to the controller. One such function, the State_request function, is used to request transmission of the function of the device data from the Internet layer. PairingRF is the reference for the pairing table function. Profileid and Vendorid are the IDs used for the data functions profile and vendor, while Statelength is the length of the data about to be transmitted. Ptr_state is the structure pointer of the state data; the detailed status data structure will be explained in the next section. Currentstate is the ID for the current status. Txoptions is the option for the transmission method, including broadcasting, transmission address, and safety mechanism. State_indication is the function for transmitting from the Internet layer to the target application layer. Other than the parameters already sent, it also includes the transmission quality parameter as well as a transmission flag to ensure the correctness of the transmission. State_confirm is used by the Internet layer to reply to the application layer to see if the data was transmitted successfully.

3.2.2. State Parser.
When the controller receives the CEB, the state parser is responsible for analyzing the status data of the received CEB. The home appliance state and the commands relationship graph are shown in Figure 8. Status links can be shown as a linked list structure to structure the entire status state. Every command or state is defined as a node. The type of the structure defines this node as a state node or a command node and the data as the data content which defines the next node and the
preceding node. Using this structure allows complete state restructuring of the device state and respective commands. Then according to the current state parameter, the previous state can be found. After the complete status structure is built, it is sent to the state manager for processing.

3.2.3. State Manager. State manager is the core of the structure which is responsible for storing and managing the services, state lists, and control functions for all devices, as shown in the Figure 9. After analyzing the data received from the state parser, the state manager will record the complete status data. When the user chooses to control a device, the state manager will transmit the respective available commands for the current state of that device to the command table and offer a pattern layout reference and event engine for selection. When the user chooses a function button, the system will
transmit the selected command to the RF4CE note for command transmission. When a reply is received, the state manager will automatically transmit to the respective state list and refresh the command table.

3.2.4. Event Engine and Pattern Layout. Event Engine and pattern layout are responsible for touch commands and display productions. When the user touches the command options, the event engine will activate an interrupt and identify a command function according to the touch coordinate position and layout pattern, then send it to the state manager and RF4CE node to the respective device. The LCD pattern layout and related parts are shown in Figure 10. The LCD data driver is responsible for receiving the current command data from the state manager. The LCD function represents the supported graphic function of the LCD such as lines, frames, and circle. The LCD configuration is for the resolution and display frequency supported by the LCD screen. ASCII database is the character data supported by the LCD. The LCD device driver is the driver function for the hardware. When pattern layout receives the command data, it calculates the number of commands and decides the icon numbers it will use.

Fig. 9. State manager.

Fig. 10. Diagram of pattern layout and event engine.
for the LCD function to design the user interface and display the control commands on the LCD.

3.2.5. **Power Manager.** To meet the low-power consumption demand of commercial electronics, this research designs a power saving mechanism suitable for the controllers for this system. First this research defines the controller state in three different parts, action, standby, and sleep. Action means the controller is being used. Standby is a time frame when no functions are received, and the system will automatically shut down the touch panel backlight. In this mode, the system will use the backup clock instead of the main clock. Sleep mode is when no command is received by the system for a long period of time, and the system shuts down the CPU and clock system. The entire process is shown in Figure 11. In the first setting, the counters are set in this design, the default counter1 is 5 seconds and counter2 is 10 seconds. After these settings are done, the system enters sleep mode, waiting for the user touch panel to send an event. When the system enters action mode, the system can send discover and pairing commands. Then the user can control the devices. When the system receives an event, counter1 will activate counting and will reset when it receives another event before counter1 is up. If no event is received within 5 seconds, the system enters standby state. In standby state the touch panel power and main clock will be turned off and use the low-powered backup clock, which can save unneeded power costs. The system at the same time will activate counter2. If after a set period of time no events are received, the system enters the sleep mode and shuts off the CPU and all clocks and leaves only the event engine to wait for the user to carry out control commands.
3.3. Design of RF4CE Receiver

In the current market, there are still commercial electronics that are not built with the RF4CE standard. This is why this research has developed an interface to make these devices compatible with the RF4CE structure: When an RF4CE signal is received through the HDMI interface, the HDMI CEC is used to communicate with the existing electronic device without the RF4CE standard. For future RF4CE home appliances, the receiver end can exclude the signal transmission step to directly control from the controller end, building a well designed wireless control signal. The receiver hardware platform and structure graph, classified as RF4CE note, CEC note, command parser, command buffer, and RF4CE-CEC command relay, is shown in Figure 12.

3.3.1. RF4CE Note and CEC Note. RF4CE Note and CEC Note are responsible for receiving RF4CE and CEC signals. When the receiving end uses the RF4CE Dongle USB interface to transmit to the RF4CE signal, the system will use the built-in virtual com chip to convert the USB format into UART format in the RF4CE Note. After this transmission processing, it is transmitted to the end device through the CEC Note. The two-directional communications mechanism used to achieve this has already been introduced in the last section and will not be discussed again here.

3.3.2. Command Parser and Buffer. The RF4CE transmission mechanism contains the Internet connection and the data transmission function. The Internet connection is the protocol for the pairing, unpairing, and discovery in RF4CE. Data transmission carries the command messages sent by the application programs. The command parser is responsible for analyzing the commands of the transmitted data and saving them in the command buffer for format transformation as shown in Figure 13. The RF4CE parser analyzes the frames in Frame_Type, which are classified as standard data, NWK command, and vendor-specific data. Profile_Identifier is classified according to which profile is providing the service. The RF4CE parser will take the standard data and vendor-specific data and reference them with the Profile_Identifier to find suitable
frame data and then take the payload data and store it in the command buffer for function transformation.

3.3.3. RF4CE-CEC Command Relay. Even though RF4CE uses similar data standards, different Internet transmission layers might have different headers or reference data. The RF4CE-CEC command relay is responsible for the data transmission transformation between the two. The data block section of every frame in CEC has 8 bits. First the data size from the msduLength section of RF4CE must be found and filled into the CEC data block. Then the CEC data waits for the EOM signal to appear to write the data into the RF4CE frame payload.

3.4. Control Flow and Procedures

Figure 14 is the flow chart of the entire process, which includes discovery, pairing, state data transmission and command. The RC system through an auto-discovery process finds the usable device information, and then builds a connection through pairing.

After the connection is completed, the device will automatically send its own state data to the control end. The controller will build the control menu, and the user will control the device through the touch panel control menu. Complete steps are explained in the following text.

3.4.1. Discovery. During discovery, the controller interval (nwkDiscoveryRepetition-Interval) will send a discovery request on three channels and wait for the device to reply. The device can choose whether or not to reply to the request. In the discovery service, note will transmit the basic device information; a related explanation is presented here.
Node capabilities. The node state must be described as either a controller or a target, whether it is the main power source or back-up power source, and whether or not it supports security mechanisms.

Vendor and application information. An explanation must be given as to the functions this node can support and the supported profile information. The controller can use the Requested_device_type to discover the needed device appliance. After completing the discovery function, the controller will display each node’s application information on the LCD screen to allow the user to choose the device he/she wants to control.

However, in this function, the distances between the controller and devices must be estimated. As shown in Eq. (1), in the wireless transmission propagation loss model, PL(d) denotes the strength of the signal, which the wireless receiver receives from d meters distance from the wireless sender (dBm), while d_0 denotes the reference distance, which is set to 1m in this study; n denotes the path loss exponent, and the attenuation index of the received signal varies with the environment, as the wireless transmission distance increases; X denotes the shadow fading effect, which is a Gaussian random variable with a mean of 0 and standard deviation of σ; and X_σ is related to the obstacle signal loss. The measured received signal may differ due to different obstacles, even if the propagation distance is the same and the emitted signal has the same strength. Eq. (2) is derived from Eq. (1), and is used to obtain the path loss exponent; n denotes the number of measurements of a single connection. When a receiver receives an RSS from a wireless sender, Eq. (1) is used to estimate the distance between the receiver and sender d.

\[
PL(d) = PL(d_0) - 10\alpha \log \frac{d}{d_0} + X_\sigma
\]  
(1)

\[
\alpha = \frac{-n_i (PL(d_i) - PL(d_0))}{n_i \log(d_i)}
\]  
(2)

3.4.2. Pairing. When the user chooses the device, the controller sends a pairing request asking to build a pairing link with the RF4CE receiver. The end device can choose whether to or not to accept the pairing request and reply back to the controller end. When the controller receives the pairing reply, it will then decide the connection path according to the path connection states for building the two-directional connection. When the two ends successfully complete pairing, they will store a pairing link in their respective pairing tables. The two ends will then transmit communication data according to the entries in the pairing table. Ever entry contains data as follows.

1. Terminal device function
2. Internet and physical address of each other
3. Connection path and pairing reference
4. Whether or not this end activates security functions and stores the security link key for each.

3.4.3. State Data. After completing the pairing link, the controller sends a state request. Once the RF4CE receiver gets the request, it will transmit the signal to CEC format and send <Menu Request> [Activate] to the device to ask to transmit the control commands. When the data is received, the data is analyzed and a bundle will be built through the RF4CE and sent back to the controller. The controller receives the device state, and the command data is then stored in memory with related information. It will then display the control list available for the device on the LCD display to provide user control.
3.4.4. Command. In the user control interface, the controller can decide the user control actions and send the command data according to the press, repeat, release action rules defined by the CERC profile. Once the RF4CE receiver receives the command, it will convert to CEC format and communicate with the package terminal.

4. IMPLEMENTATION RESULTS AND TESTING
4.1. Functionality
To test the functionality, this research uses SONY to support the HDMI CEC display as the end device and the RF4CE receiver uses the HDMI interface connection device. When the connection is built, the user can control the device through the control graph on the touch panel LCD. The control menu is as shown in Figure 15 and described by Bonhyun et al. [2011]. Through the controller end, the user can control the power, volume, and channel with an easy to use control system structured with two-directional communications.
4.2. Power Consumption
Power consumption is one of the main topics of research in consumer electronics. This research uses different types of controllers, from common commercial controllers to Bluetooth controllers and PDAs (see Table I), in investigating power efficiency. Fluke 8845A was used to measure the power costs of each controller under different situations. In addition, we designed a power calculation module, shown in Figure 16. By observing the current flow of each controller in action, Figure 17 shows that controllers normally have a current value of around 0.08mA, and this value is 95mA during the 0.1s time when its sending a signal. The average current value for a Bluetooth controller is 12mA. The PDA with Bluetooth activated is normally 70mA, while the RF4CE remote controller can be separated into the sleeping state with an average value of 0.17mA, the standby state with an average value of 5mA, and the working state at 12.1mA with 25mA as the value for the 0.01s it is transmitting. Suppose the user has the controller
in action for a total of three hours a day and does 50 presses every hour. Also assume that the time for each state is 85% sleeping, 5% for standby, 9.84% in action, and 0.16% for transmitting. We find the usage time and the everyday power costs as shown in Figure 20. From this experiment, we find that the RF4CE controller has 39.9mW of power usage when in use but the command transmission saves more power than in IR controllers. During sleep state, the low-power costs with the power manager designed in this research can attain low power suitable for the low-power demand of commercial electronic controllers.

5. CONCLUSION
In this research we introduced a URC built under the RF4CE standard. Users would not need to do any learning beforehand and just by the discovery and pairing mechanisms choose the device they want to control. This system automatically transmits the device state and available control options to the controller for display. The user can easily control all types of appliances at home, and, even with the installation of new appliances, the user would not need to add additional settings in the controller. As long as a new appliance also has a RF4CE device, it can be easily added to the control network. The RF4CE receiver converts the RF4CE signal into a CEC command, then uses the HDMI transmission interface to provide compatibility with the existing devices. As for the RF4CE home appliances of the future, this design only needs
to remove the signal transform function in order to be compatible with the RF4CE transmission functions, and, through experimental testing, we have shown that this system is possible. In power cost testing, this research has shown experimental proof that the device designed can meet the low-power cost demands of the consumer electronic controllers. But due to the limits of the processing speed on the remote controller, when too many devices were detected by the remote controller or too many items were shown on the panel board, it caused some delay in the switching of the user interfaces, but it is more convenient than the traditional remote controller. As for future work, we will research digital home systems with an Internet layer power management system through the RF4CE system, as it will provide users with an easy and smooth operation of the controlling devices and a long lifetime of controller usage.

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Received December 2010; revised March 2011; accepted March 2011