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

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With the increase of commercial electronic equipments and their respectively complicated control interfaces, how to design an effective and user-friendly control interface is the topic for many research discussions. This research introduces a two-directional communication of interactive graphical user interface on universal remote controls. Different from the modern URCs, users usually must first spend huge amounts of time in setting the command codes and encoding of each device. With the increase of appliances that the controller needs to manage and the respectively complicated and numerous control buttons needed, using such controllers often cause difficult usage for users. This research employed cross-platform with integration theories, so when a user wants to connect with an appliance, both the appliance end and 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 device. The appliance would automatically will transmit its current state and service in the form of bundles to the controller, then controller it on the LCD screen. The controller can also show the amount of appliances to connect in the current position of the user, allowing the user to use one controller to control all the home appliances with ease, achieving a simplified and instinctive control interface to build the integrated control environment for commercial appliances.

Categories and Subject Descriptors: []

Additional Key Words and Phrases: RF4CE-based remote controller, interactive graphical user interface, home automation system

1. INTRODUCTION

With the advancement of technology, there are more and more home appliances (like television, DVD, air conditioner) and appliance manufacturers also each with their own special-
ized controller. Users usually need to spend time to learn each type of controller, which is
difficult for the elderly or young children. Therefore building a complete and user-friendly
control system has been discuss and researched by many others. In the traditional infrared
radiation (IR) transmit type URC, works by recording different formats of encoding and
control codes or works by a learning-type setting, but the complicated settings and learn-
ing is a major fault which is also why these controllers are not as popular today. Wireless
personal area network (WPAN) is a wireless network that allows the devices in a personal
area able to send messages to each other. With the development of WPAN, digital home
system starts to build wireless network systems. More commercial appliances also start
supporting wireless transmit; hence how to use a wireless network to build a wireless uni-
versal device controller interface is a main topic in research. Today, building a wireless
universal controller has a few obstacles that need to overcome.

1. The Suitable Wireless Transmit Interface: When choosing a commercial wireless
electronic network environment in a digital home, the transmit medium must suit low
power, low costs, and confidentiality. The most commonly used is Bluetooth [Jia AND
all build a wireless home network control system through Bluetooth PCM voice commu-
nication encoding function to control the home electronic system. While Zigbee is mostly
used to build wireless home network systems [Anders et al. 2009; Egan, 2005; Li, 2006].
Erdem et al. introduced a multi-channel remote controller, taking the data transmit inter-
face with world internet, GSM, and telephone lines combined into an integrated system,
and through this system user can timely choose the adequate transmit method, to prevent
not able to use in case one of the system fails.

2. Compatibility with the Commercial Electronics: Right now most commercial appli-
cances still dont have wireless network modules, how to easily change the appliances to
build a wireless network environment is a main point to consider. [Erdem and Uner, 2009
] and [Wan et al. 2007] have both structured such a control system through a Zigbee2IR
transformer. Using Zigbee building a wireless transmit system and then use Zigbee2IR
transformer to take 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 have numerous control buttons, and the user must also first do
respective settings to the controller devices. This is an inconvenience and the main fault
especially for elderly and children. To solve this problem many research introduced PDA
or human body detection device to build a user-friendly interface [Youngjae and Dong-
man, 2006; Laehyun et al. 2010], [Hsien et al. 2009] introduced an audio-visual device
virtualization system environment which managed the home audio-video equipment con-
roll services through a virtual machine. User can avoid the complicated settings, which
gave a great solution to integration and expansion of commercial electronics. Though in
past researches [Wan et al. 2007; Laehyun et al. 2010], although Zigbee wireless transmit
system builds a complete URC, but it still uses the single directional transmit methods.
System cannot receive the device service and control function, so the user must first set
the function interface for every device and set the respective transmit encoding for each IR
settings with different protocols. The extra work for setting a new device is not idea for
ease of expansion. This research introduces a wireless two-directional URC, using a wireless transmit system introduced by 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 consumer electronics control (CEC) protocols 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 touch a panel to choose the desired appliance, the controller and device can both communicate with automatic connection and exchange information, making it easier to control different types of home appliances with one controller. The controller doesn’t even need the user to set additional settings to add new appliances, through state request mechanism automatically allow devices to send its state and commands back to the controller, thus creating a complete control system.

The Main Contributions of this Research
1. Building a two-directional communication self set mechanism: Since RF4CE doesn’t have a two directional communication control method, through 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 then the system can build a convenient user interface using the data, letting the user to equip with an interactive control interface to easily control all types of appliances in homes with zero configurations. As well as submitting a type of two directional communications controlled prototype for future home use commercial electronic products.
2. Compatibility with Modern Electronic Devices: When the system receiving end receives commands from the controller through HDMI terminal using CEC protocol to communicate with the modern electronic devices, it provides a great compatibility mechanism for the wireless universal controller.
3. Implementation Proof of Low Power and Achievability in Embedded Platform: Different from the past researches through the results of PDA implementation, this research will realize this mechanism on embedded platform to prove the achievability and successfully solve the high power consumption problem for PDA.
4. Convenient User Interface: Compared with most universal controllers today which has the problem of inconvenience due to fitting different transmit methods and function choices (such as too many buttons or complicated control menus), this research using the two directional communication mechanism not only builds a universal control system, but also can show the appropriate command listings on the LCD display according to the function listings provided by the device. Hence building a more intuitive control interface that can lessen the time the user has to spend getting used to the controller and increase convenience.

In the rest of the sections, we shall introduce the Zigbee RF4CE standard with CERC profile as well as CEC protocol in the second chapter. While 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 will show our implementation of the system environment as well as the power testing results. Finally our conclusion for our system is in section five.
2. BACKGROUND KNOWLEDGE

To allow readers not familiar with this field to fully understand this research, this section will briefly introduce the related techniques including RF4CE standard, CERC profile, and CEC protocol, for more detailed understanding of the specs and research can read the attached referenced documents.

2.1 RF4CE Standard

RF4CE is a convenient, low cost, low power wireless transmit protocol set by both the ZigBee Union and RF4CE association especially for the commercial electronics market. Same with ZigBee it is build from the standard specs of the networking layer and application layer implemented by the IEEE 802.15.4 MAC Layer, PHY Layer and respective RF transceiver as the basis. In other words this is a standard very similar to ZigBee. The difference from ZigBee it doesn’t have a complicated internet routing protocol and transmit communication mechanisms, through simpler protocol the standard target being the wireless control systems built in commercial electronics. As figure 1 shown the stack architecture of RF4CE, the main parts were separated into four main parts: the PHY/MAC layer, internet layer, profile layer and application layer. PHY/MAC Layer: RF4CE in the physical layer follows the IEEE 802.15.4 standard with the MAC layer, the transmission frequency bandwidth at 2.4 GHz, and have three channels as 15.20.25. When the device activates the network it can detect all signal states of every channel and choose the suitable channel and in the transmit process can change communication channel according to the strength of the channel signal. Internet Layer: ZigBee RF4CE for meeting the demands of commercial electronic market, removed the point to point method used in routing transmit and set a simple low costs internet communication structure and increased the power saving and security code transmit mechanism. This allowed a low costs and low powered wireless internet structure. Profile Layer: This layer is between the internet layer and application layer. It offers functionality to the upper layer allowing the application layer to add the needed functions on this layer. While it sends commands to the internet layer and defines the same commands or processes of actions for allowing each node with the same profile to be able to communicate. Other than the standard profile set by RF4CE, RF4CE also allows different vendors to define their own specific profile. Application Layer: This layer allows developers to develop themselves, offering users the service interface that they need.

As to topology structure of the internet, RF4CE uses every Personal Area Network (PAN) as one division. In a PAN network can allow star topology messages transmit, and in the same area different individual PAN as shown in the topology graph in figure 2. In a PAN, Every device is defined as a Note. Node states can be classified into Target Node and Controller Node. Target Node has online decision ability to be discovered and start a network in its own right, and can decide its own transmit channel depending on channel signal strength. Controller Node is responsible for discovery and pain. In our defined area mostly these 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 ZigBee RF4CE association. It defines a set of control operation commands especially for consumer electronics, including the commands and processes of different actions for
controlling home appliances. As shown in figure 3 which is the frame format transmitted by CERC, including the CERC head, CERC payload. CERC head describes the process of actions for the controller including requests for pressed, repeated, released, and discovery type actions, while 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 started with the Europe SCART interface standard, while HDMI interface standard is slowly using CEC standard to increase functions, mainly by direct or indirect ways to connect and communicate with different home appliances. CEC in the HDMI interface is a one line two directional transmit mechanism. The entire structure devices can be classified into root, branch and leaf, which can send messages to each other. In every device in the CEC includes a physical address and the local position 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. Start bit shows the start of a frame. While the headblock is used to describe the position of the device sending the signal (called initiator) and the position of the device receiving the signal (called destination). The block includes 4 bits of initiator local position and 4 bits of destinations local position and 1 bit for both end of message (EOM) and acknowledge (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 said device. RF4CE uses the information data protocol in the CEC as the standard communication protocol between each device.
2.4 Interactive Graphical User Interface

Interactive graphical user interface is an interface system for transmitting orders and commands between human and machine, enabling more complete communication between them [Coleman 2009]. For an interactive multimedia system, a satisfactory interactive graphical user interface is a necessary component. The multimedia control service is accomplished through multi-touch [Yu et al. 2010; Xing et al. 2009] and a convenient interactive graphical user interface system is achieved by eye movement [Sandnes et al. 2010]. 3D multimedia services have been studied more extensively in recent years. Sreeram Sreedharan et al. [Sreeram et al. 2007] proposed the idea of a 3D virtual world, and employed Wii remote in the virtual environment by performing hand gestures for Yes or No gestures in order to facilitate communication. Due to the advantages of convenience and portability, the data glove [Chen et al. 2008; Zaletelj et al. 2009], along with its sensors or other interface devices, has become a widely used interface for digital multimedia services.

3. SYSTEM ARCHITECTURE AND DESIGN

In this section we will introduce the entire system structure, and then explain the both the wireless universal remote control and receiving end device designs as well as the two directional communication processes.

3.1 System Overview

Having a lot of 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 transmit interface, but according to the current standards a control system using two directional communications still has to be realized. This research proposed a two directional wireless control system structure using ZigBee RF4CE as base. When the user is choosing the device, the controller can automatically ask the devices for the control interface and the respective actions. In getting the data after analysis and module settings, the controller will show 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 receiver. Controller and receiver build a connection platform with each other through the ZigBee RF4CE standard. CERC Profile implements the internet layer communication, including implements of commands like discovery, pairing, and command transmissions, to allow controller to be able to know the device service, current status, and the respective control commands. This research designs status request, including the status request between the device and RF4CE node as well as the data analysis for RF4CE internet layers communication with the controller. This allows the controller to get the device state and the currently available commands and structure a control interface. The receiver upon receiving the command through CEC will then request the control interface and transmit command from the device, and package the device service as a Consumer Electronics Bundle (CEB). Then the CEB transmits to the controller for registration on Profile layer. After registration the controller can then know the complete service status of the device and build a control menu to provide for the user. User wouldn’t need to do other settings for end devices beforehand.

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. The figure 6 below is 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 micro processor unit(MPU) for processing with the core structure comprised of RF4CE note, state parser, state manager, event engine, power manager, pattern layout. Each will be shown in detail later in this section.

3.2.1 **RF4CE note.** RF4CE note is responsible for transmitting the packages in RF4CE standard format with the respective functions, excluding the functions defined by the related actions according to the RF4CE standard and CERC profile, for example discover, pairing, and button function. For transmitting the device state functions, this research also defined a state transmission function (as shown in figure 7) which through the two directional communication transmit mechanism receiving end can package the control interface.
functions provided by the device into an CEB, to transmit the devices state and respective commands to the controller. One of such functions the `State_request` function is used to request, from the internet layer, transmitting of the function of the device data. `PairingRef` is the reference into pairing table. `ProfileId` and `VendorId` are the ID 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, detailed status data structure will be explained in the next section. `Currentstate` is the ID for the current status. `Txoptions` is the option of transmit method, including broadcasting, transmit address, and safety mechanism. `State_indication` is the function for transmitting from the internet layer to the target application layer. Other than the parameters send before, it also includes the transmit quality parameter as well as the transmit flag to ensure the correctness of the transmit. `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 to analyze the status data of the received CEB. Home appliance state and commands relationship graph is shown in figure 8. The status linked with one another can be shown as a linked list structure to structure the entire status state. Let every command or state defined as a node. The type of the structure shows this node as a state Node or a command Node, and the data as the data content which defines the next node and the node before. Using this structure can allow complete state restructuring of the device state and respective commands, then according to the current state parameter can find the state before. After building the complete status structure, send it 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 the devices,
as shown in the figure 9. After analyzing the data received from the stage parser, the state manager will record the complete status data. When the user chooses to control the device, the state manager will transmit the respective available commands for the current state of device to the command table and offer a pattern layout reference and event engine for choosing. When the user chooses a function button, the system will transmit the selected command to the RF4CE node for command transmit when receiving a reply, the state manager will then automatically transmit to the respective state list and renew the command table.

### 3.2.4 Event Engine and Pattern Layout
Event Engine and Pattern Layout are responsible for touch commands and display production. When the user touches the command options, the Event Engine will activate an interrupt and identify a respective 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. LCD function represents the supported graphic function of the LCD such as lines, frames, and circle. LCD config is for the resolution and display frequency supported by the LCD screen. ASCII database is the character data supported by the LCD. LCD device driver is the driver functions for the hardware. When pattern layout receives the command data, after calculating the number of commands and decide the icon numbers will use 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 controllers for this system. First this research defines the controller state as three different parts, action, standby, and sleep. Action means the controller is being used. Standby is a time frame not receiving any functions, where the system will automatically shut down the backlight of touch panel, and the system main clock will use the backup clock instead. Sleep mode
A RF4CE-based Remote Controller with Interactive Graphical User Interface Applied to Home Automation System

is when for a longer period of time no command is received the system will shut down the CPU and clock system. The entire process is shown in figure 11. In the first setting, first set the counters, in this design the default counter1 will be 5 seconds and counter2 as 10 seconds. After setting 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 the event counter1 will activate counting and will reset upon receiving another event before counter1 is up. If no receiving any event after 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 back up clock which can save unneeded power costs. The system as the same time will activate counter2. If after a set period of time of not receiving events the system enters the sleep mode and shut off CPU and all clock and leave 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 not built with the RF4CE standard, which is why this research after receiving the RF4CE signal through the HDMI interface then using the HDMI CEC to communicate with the existing commercial electronics to build a compatibility with the RF4CE structure. Also for future RF4CE home appliance, the receive end can exclude the signal transmit step to directly control from the control end, building a well designed wireless control signal. As shown in figure 12 is the receiver hardware platform and structure graph, mainly classified as RF4CE note, CEC note, command parser, command buffer, and RF4CE-CEC command relay.

3.3.1 RF4CE Note and CEC Note. RF4CE Note and CEC Note are responsible for receiving RF4CE and CEC signals. When receiving end use RF4CE Dongle USB interface to transmit to the RF4CE signal, the system will use the build-in virtual com chip to transmit the USB format into UART format into the RF4CE Note. After transmit processing then transmit to the end device through the CEC Note. To achieve the two directional communications mechanism has already been introduced in the last section and will not be shown here again.
3.3.2 Command Parser and Buffer. The RF4CE transmit mechanism contains internet connection and data transmit. Internet connection is the protocol of the pairing, unpairing, and discover in RF4CE. Data transmit is the command messages send by the application programs. Command parser is responsible to analyze the command of the transmitted data and save it in the command buffer for format transformation as shown in figure 13. RF4CE parser will analyze the frame in Frame_Type, which are classified as standard data, NWK command, and vendor specific data. Profile_Identifier can be classified as to which profile providing the service. RF4CE parser will take the standard data and vendor specific data and reference them with the Profile_Identifier to find the suitable fram data and take the payload data and first store it into the command buffer for function transformation.

3.3.3 RF4CE-CEC command relay. Even though RF4CE uses the similar data standards, but under different internet transmit layer might have different headers or reference data. RF4CE-CEC command relay is responsible for the data transmit transformation between the two. Data block section of every frame in CEC has 8 bits. Then will need to find the data size from the msduLength section from RF4CE, then fill this into the CEC data block. Then CEC data will wait for the EOM signal to appear to write the data into the RF4CE frame payload.

3.4 Control Flow and Procedures

Below figure 14 is the flow chart of the entire process, which includes, discovery, pairing, state data transmission and command. RC system through auto discovery process will find the usable device information, and then will build the connection through pairing.
After connection completes the device will automatically send its own State Data to the control end. The controller will build the respective control menu, and the user will control the device through the touch panel control menu. Complete steps will be explained as followed.

3.4.1 **Discovery.** During discovery, the controller interval (nwkDiscoveryRepetition-Interval) will send discovery request in 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, the related explanation is shown as below.

1. **Node capabilities:** describing the Node state being the controller or target, this Node is the main power source or back up power source, also whether or not it supports security mechanisms.
2. **Vendor and Application information:** Explain 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 discovery the controller will display each node 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 should 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 dis-
tance 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; \(X_\sigma\) denotes the shadow fading effect, which is a Gaussian random variable with a mean of 0 and standard deviation of \(\sigma\); and \(X_\sigma\) 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 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, \(d\).

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

\[
\alpha = \frac{-\sum_{i=1}^{n}(PL(d_i) - PL(d_0))}{\sum_{i=1}^{n}10(\log(d_i))} \tag{2}
\]

3.4.2 Pairing. When the user chooses the device, the controller sends a pairing request to ask to build a pairing link with the RF4CE receiver. The end device can choose whether to or not 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 to build 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 shown below: 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 of each other.

3.4.3 State data. After completing the pairing link, the controller sends a State request. After the RF4CE receiver gets the request will then 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 bundle will be built through the RF4CE and sent back to the controller. The controller receive the device state and command data will then store the related information into memory then will 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, controller can decide the user control actions and send the respective command data according to the press, repeat, release action rules defined by the CERC profile. Once the RF4CE receiver receives the command it will transform to CEC format and communicate with package terminal.

4. IMPLEMENTATION RESULTS AND TESTING

4.1 Functionality

To test the functionality, this research uses SONY to support 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 [Park J.H. et al. 2010]. 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 for researching consumer electronics. This research takes normal commercial controllers, Bluetooth controllers and PDA as samples listed in Table 1. Fluke 8845A was used to measure the power costs of each controller under different situations. Besides, we also designed the power calculation module by ourselves shown in figure 16. As shown in figure 17, by observing the current flow of each controller while in action, it can be found that normal controllers normally have a current value of around 0.08mA while 95mA during the 0.1s time when its sending a signal. The average current value for Bluetooth controller is 12mA. The PDA with Bluetooth activated is normally 70mA while RF4CE remote controller can be separated from the sleeping state having an average of 0.17mA, standby state with 5mA and working state at 12.1mA with 25mA for 0.01s while transmitting. Say the user have the controller in action for a total of three hours a day, and 50 presses in every hour, as well as assuming the time for each state with 85% sleeping, 5% for standby, 9.84% in action and 0.16% for transmitting. We can find the using time and the everyday power costs are shown as the figure 20 below. Through this experiment it can be found that RF4CE have 39.9mW power usages when in use but the command transmit saves more power than in IR controllers, also during sleep state the low power costs with the power manager designed in this research can attain a low power design to suit the low power demand of commercial electronic controllers.

5. CONCLUSION

In this research we introduced a URC built under the RF4CE standard. User wouldn’t need to any learning beforehand but just by discovery, pairing mechanisms to choose the device we 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
Table I. Types of Controllers

<table>
<thead>
<tr>
<th>Model</th>
<th>CR-99DE</th>
<th>Sony RC</th>
<th>Dopod 699</th>
<th>RF4CE RC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>Connection</td>
<td>Infrared</td>
<td>Bluetooth</td>
<td>Bluetooth</td>
<td>RF4CE</td>
</tr>
<tr>
<td>Voltage</td>
<td>3.0V</td>
<td>3.0V</td>
<td>3.7V</td>
<td>3.3V</td>
</tr>
<tr>
<td>Work Scenario</td>
<td>3 hours</td>
<td>3 hours</td>
<td>3 hours</td>
<td>3 hours</td>
</tr>
<tr>
<td></td>
<td>50 time/hours</td>
<td>50 time/hours</td>
<td>(Sleep=85%; wakl=15%)</td>
<td>(Sleep=5%; Standby=5%  Action=9.84%; command=0.16%)</td>
</tr>
</tbody>
</table>

![Image] Fig. 16. Power Calculation Module.

![Image] Fig. 17. IR Remote controller Current-Time Graph.
Fig. 18. Bluetooth Remote controller and PDA Current-Time Graph.

Fig. 19. RF4CE remote controller Current-Time Graph.

Fig. 20. Time in Use(a) and the Everyday Average Power Cost(b).
A RF4CE-based Remote Controller with Interactive Graphical User Interface Applied to Home Automation System

at home, even with installation of new appliances the user would not need to add additional setting in the controller. As long as the appliance also have RF4CE device it can be easily added to the control network for the user to control. Through the RF4CE receiver to turn the RF4CE signal into CEC command then use the HDMI transmit interface to allow compatibility with existing devices. As to the appearance of RF4CE home appliances in the future, this design only need to remove the signal transform function to suit the RF4CE transmit functions, and through experiment testing it has proved that this system is possible. While in power cost testing, through experimental proof with the device designed in this research it is found the low power cost meets power demands in the consumer electronic controllers. But due to the limit of the process speed on the remote controller, when too many devices were detected by the remote controller or items were shown on the panel board, it caused some delay occurred in the switching of the user interfaces in spite of it is more convenient than the traditional remote controller. As for future works we will research digital home systems with internet layer power management systems through the RF4CE system, it will not only provide users the easy and smooth operations of controlling devices and the long life time of using controller.

Acknowledgment

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 NSFC 61071061 and the Univ. of Kentucky Start Up Fund.

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