Smart Digital Door Lock for the Home Automation

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Abstract— **In this paper, we propose a smart digital door lock system for home automation. A digital door lock system is equipment that uses the digital information such as a secret code, semi-conductors, smart card, and finger prints as the method for authentication instead of the legacy key system. In our proposed system, a ZigBee module is embedded in digital door lock and the door lock acts as a central main controller of the overall home automation system. Technically, our proposed system is the network of sensor nodes and actuators with digital door lock as base station. A door lock system proposed here consists of RFID reader for user authentication, touch LCD, motor module for opening and closing of the door, sensor modules for detecting the condition inside the house, communication module, and control module for controlling other modules. Sensor nodes for environment sensing are deployed at appropriate places at home. Status of individual ZigBee module can be monitored and controlled by the centralized controller, digital door lock. As the door lock is the first and last thing people come across in entering and leaving the home respectively, the home automation function in digital door lock system enables user to conveniently control and monitor home environment and condition all at once before entering or leaving the house. Furthermore, it also allows users to remotely monitor the condition inside the house through Internet or any other public network. The biggest advantage of our proposed system over existing ones is that it can be easily installed when and where necessary without requirement of any infrastructures and proper planning.**

Keywords-Digital door lock system; home automation; ZigBee; Sensor node;

I. INTRODUCTION

HOME automation system is a computerized, intelligent network of electronic devices, designed to monitor and control the home appliances and lighting systems in a building. It allows users to remotely monitor and control consumer electronics through the external network such as Internet. Home automation is the emerging field that has attracted the attention in both the commercial and research field. Although wired home networks were famous at the early developments of home automation systems, nowadays wireless communication is replacing the wired system which are very messy and also difficult to setup. Fig. 1 shows the comparison between the typical wired home server and our proposed smart digital door lock system. As shown in the figure, wired system requires proper planning and construction works for efficient and clean design. It is the reason wireless communications are replacing the wired ones. Furthermore, wireless system provides more flexibility and extensibility. That is, its installation is free from construction works since it requires no cabling works. Although many of wireless network solutions such as Bluetooth, Ultra Wide Band (UWB), Wireless Ethernet, and many more, are in the area of home networking, ZigBee, a newly developing protocol for wireless sensor networks based on the IEEE 802.15.4 specification, has become the most attraction technique in the research and commercial domains because of open standard, low-cost, and low power characteristics [1]-[3]. Therefore, comparing to the other wireless technologies, ZigBee protocol is suitable for system environments, which demands less power consumption and lower data-rates requirements.

The recent release of standards in the field, such as IEEE 802.15.4 and ZigBee, brought the technology out of research laboratories and stimulated the development of numerous commercial products such as home automation, building automation, and utility metering [2]. ZigBee has been widely used in sensor network applications and recently, it is also been used for building home automation systems. [4] shows the commercial application that can be built over ZigBee. Considerable works have been done in home automation built over ZigBee and some organizations are also providing their works commercially [5].

Although the ZigBee based home automation system is in the early development phase, most of the works till date focus primarily on home automation providing limited or no security for home. Thus, we come up with the novel approach of integrating home security with the home automation. Apart from the inherent door security provided by legacy door lock, our system push the security one step further by protection home against the different unnatural condition such as burglary, fire breakout, gas leakage, and similar calamities. Furthermore, it builds up home automation by providing the master control panel for major home appliances and lighting system at digital door lock and switching the home appliances on/off depending on people presence and absence.

In this work, we have taken ZigBee network as the backbone of our system. We propose a digital door lock based home automation system, which exploits the full capacity of ZigBee sensor network by integrating home security with home automation. In our proposed system, a ZigBee module is embedded in digital door lock and the door lock acts as the central main controller of the entire system. Our proposed

This work was supported by 2009 Small and Medium Business Administration funded by Korean government.

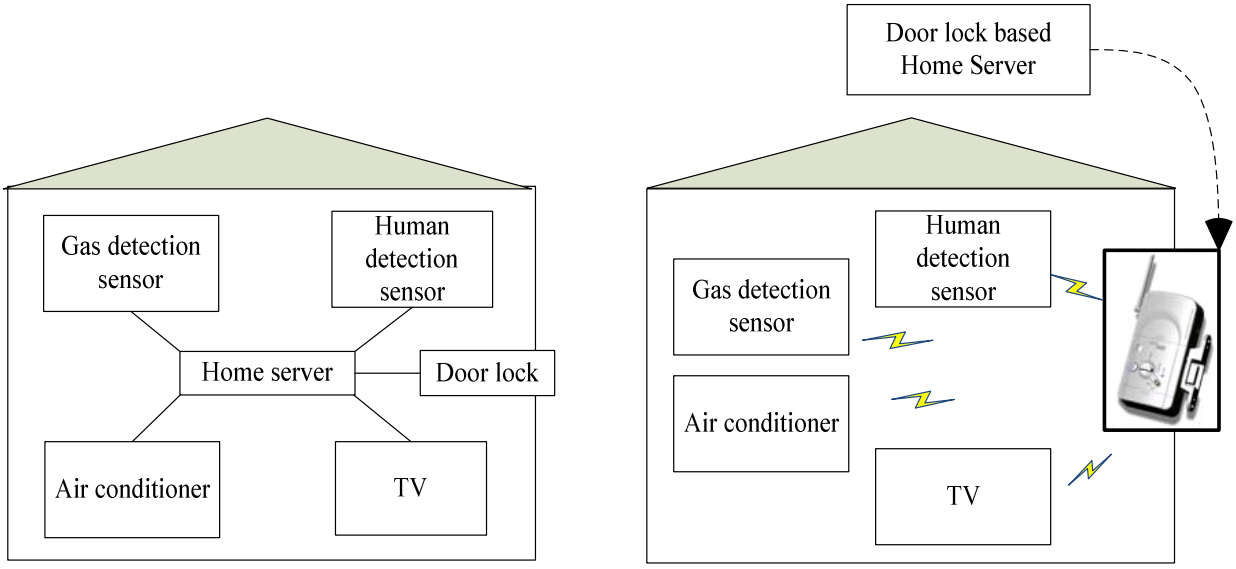


Figure 1. Typical wired home server system VS. proposed smart door lock based server system.

system is the network of sensor nodes with digital door lock as base station. Sensor nodes are deployed at appropriate places at home. Also, ZigBee modules accompanied by ZigBee relay module are attached to the major home appliances for controlling the power condition. The entire network can be monitored and controlled through the digital door lock. As the door lock is the first and last thing people come across while entering and leaving the home respectively, the home automation function in digital door lock system enables user to control and monitor home environment and condition from a single master control panel before entering or leaving the house. Furthermore, it also allows users to remotely monitor the condition inside the house through Internet or any other public network. Our proposed system can be easily installed anywhere (old or new buildings) without requirement of any infrastructures and planning which is the biggest advantage over existing ones.

The remainder of the paper is organized as follows: Section II provides the structure of the proposed smart digital door lock system. Section III presents the operation of the system. Section IV shows the design of smart digital door lock. Finally, conclusion is presented in Section V.

II. Structure of Proposed Smart Digital Door Lock System

In this section, we first provide the brief description of proposed system followed by the operation of the ZigBee module, the digital door lock, and the sensor module. We use the term ZigBee module to refer to the communication module in ZigBee and sensor node to refer to the integrated node consisting of ZigBee module, sensors, actuators, and other supplementary circuits.

A. System Overview

Smart digital door lock is a system to monitor and control several devices in the home. Our smart digital door lock system operates over wireless sensor network. It is a network of sensor nodes with digital door lock as sink node as shown in Fig. 1. The smart digital door lock system can be divided into five parts: the control module, the motor module, the sensor module, the communication module and the I/O module. The control module consists of MCU embedded in the digital door lock, which is the brain of the system. The locking operation is controlled by the motor module. The communication module is for communication between devices and the control module. The user can access to the door lock system through I/O module. The I/O module includes RFID reader and digital dialpad for authentication, TFT Touch LCD for controlling individual device and displaying the relevant information.

Once the user is authenticated by the system, user can monitor and control the home appliances from the central control panel. To interact with the visitor, the door lock is equipped with camera module, microphone, and speaker. The touch LCD is provided at the both sides of the door. Thus, user can easily monitor and interact with visitor other side of the door through these devices.

B. ZigBee Module

ZigBee module includes RF communication module and is used in digital door lock and sensor nodes. Fig. 2 shows the structure of ZigBee moodule attached to home appliances. The main componets of ZigBee module are ZigBee transceiver and MCU. The ZigBee transceiver utilizes the commercial RF chip,which has a modem for implementing the medium access control (MAC) and physical (PHY) layers of IEEE802.15.4 operating in 2.4 GHz. MCU is a controller, which controls a ZigBee transceiver, and execute programs [3]. ZigBee contains a program memory for implementing the MAC, a network layer, and an application layer. Whereas PHY and MAC layers of the ZigBee stack architecture follows recommendations of IEEE802.15.4, interface of application layer is defined by the ZigBee Alliance.

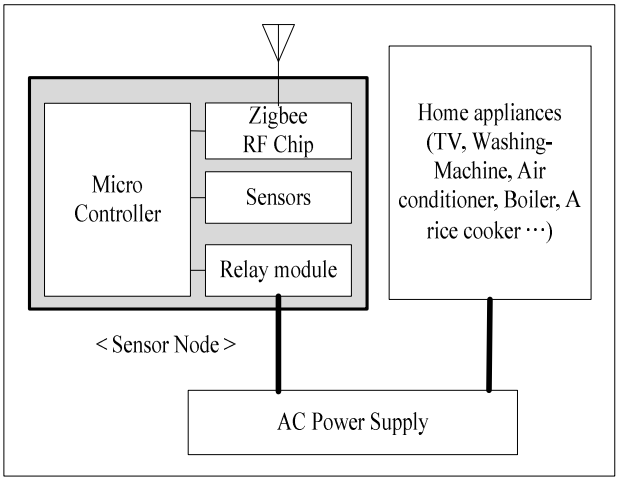


Figure 2. ZigBee module connected to home appliances.

C. Digital Door Lock

The control module, I/O module, and the motor module reside inside the digital door lock. The structure of the digital door lock and interconnection of the components are shown in Fig. 3. The digital door lock is composed of a main processor, a ZigBee module, door lock controller, CDMA module, camera module, card reader, microphone, and speaker. The control module is the brain of the system. The control module performs two major functions. Firstly, it controls the door lock. And secondly, it controls and monitors entire network. Open/close button in door lock controller activates a digital door lock for the open/close actions. The control module controls the motor drive circuit which operates the motor as actuator. Card reader is used for authentication though cards and RFID tags. The touch LCD is used for entering and changing the authentication password, changing the setting of sensor nodes, and also for displaying relevant information on the screen. The ZigBee module in digital door lock is the interface between sensor nodes and the control module. The information between sensor nodes and control module is exchanged through ZigBee module. CDMA module is used to notify user about emergency situation through short message service (SMS) and multimedia message service (MMS). And finally, microphone, speaker and camera module is used for interaction between visitor and user before opening the door.

D. Sensor Module

Sensor nodes are designated two major tasks. The first task is to monitor the environmental condition around the home and second task is to switch power status of home devices. For monitoring the environmental condition, such as temperature, gas leakage, burglary, fire and so on, corresponding sensors are attached with ZigBee module. For devices which power status has to be controlled, ZigBee module is accompanied with ZigBee relay module in sensor node as shown in Fig. 2. ZigBee relay module is used for switching on or off the home appliances. The sensor nodes continuously upload their current status and relevant data to the digital door. Also, sensor nodes send response messages including operation results, as there are commands from digital door lock.

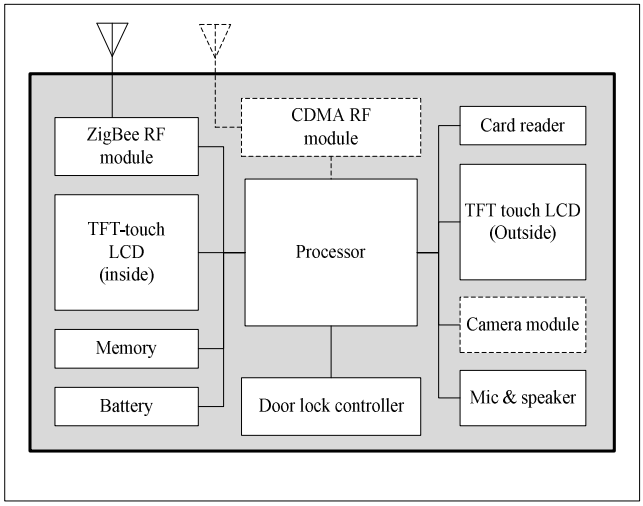


Figure 3. Structure of digital door lock.

III. Operation of Proposed Smart Digital Door Lock System

A. Communication

Smart digital door lock system works in two communication modes: centralized mode and emergency mode. In centralized mode, digital door takes the control of overall communication in the network and sensor nodes act accordingly as instructed by door lock. This type of communication is generally done in normal situation when everything is all right. This communication mode reduces unnecessary communication between sensor nodes and central controller and also saves energy consumptions.

On the other hand, when there is emergency situation such as burglary or fire, the communication is in emergency mode. Upon detection of the emergency mode by the sensor node, the respective action is taken such as releasing water for fire, turning buzzer on for burglary and immediately that event is reported to the door lock without any initiation from door lock. Door lock in turn reports the event to the end user through SMS or MMS.

B. Smart Digital Door Lock System

Once the person is authenticated through password or RFID tag, the door lock is opened and the LCD displays the status of different appliances in the home. User can choose to change the current status of the appliances or leave them as it is. For the convenience of the end user, our system can operate in two operational modes: manual and automatic. Smart digital door lock system can have three events: person entering the home, person leaving, and the emergency situation as shown in Fig. 4. Both operational modes will be explained on the base of these events.

C. Modes of Operation

1) Outgoing Event

Fig. 5 shows the flow chart for outgoing event i.e., the case of person leaving the home. As digital door lock is the last thing user will encounter before leaving the house, when the user presses the door lock button, door lock request all sensors

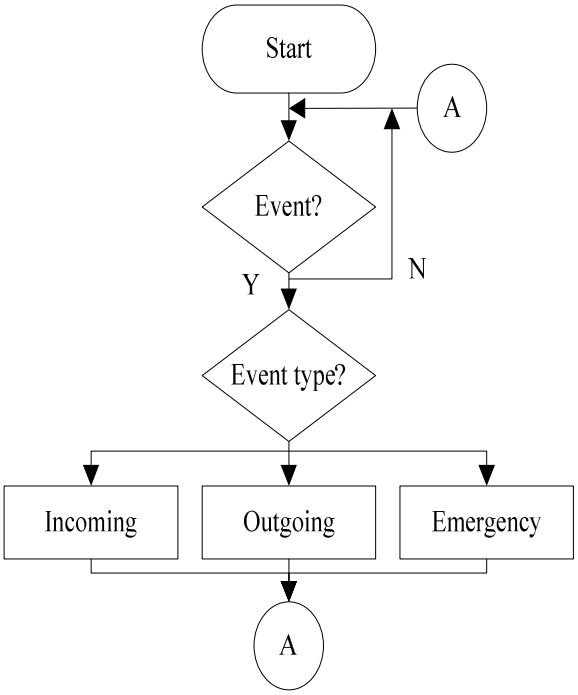


Figure 4. Events in smart digital door lock system..

to send their fresh status and the touch LCD displays them on the screen. Initially, the system enters into the manual mode. In manual modes, users can choose from the menu which home appliance to turn on/off manually. With manual mode in operation, the users now don't have to bother of checking the status of individual home appliances physically. He can leave everything as it is in his room and finally select which devices to turn on or off from the door. If user finds that TV is on, he can turn it off from the door.

If the user did not touch LCD screen for certain amount of time after locking the door, then the system enters into automatic mode. For automatic mode to work, we have to set the priority setting of device beforehand. The priority setting here means deciding which device should be on or off in the absence of user. The device with priority 1 means it should remain on and priority 0 means should be turned off. Therefore, user decides which device should be turned on and off in his absence through the touch LCD screen. This is one time process but can be done any time when felt necessary. Therefore, when the system enters into automatic mode, it turns off all those devices which priority is 0 if it is still on. With the implementation of this mode, now user doesn't need to bother about the power status of the devices in his room whenever he leaves the home. He can leave lights and TV on when leaving the home. Our system eventually switches them off.

2) Incoming Event

Fig. 6 shows flow chart for incoming event i.e., person entering the home. Incoming event can also be operated in manual and automatic mode. After being authenticated, the system unlocks the door. Then the system requests the fresh status of all devices and checks for the emergency situation.

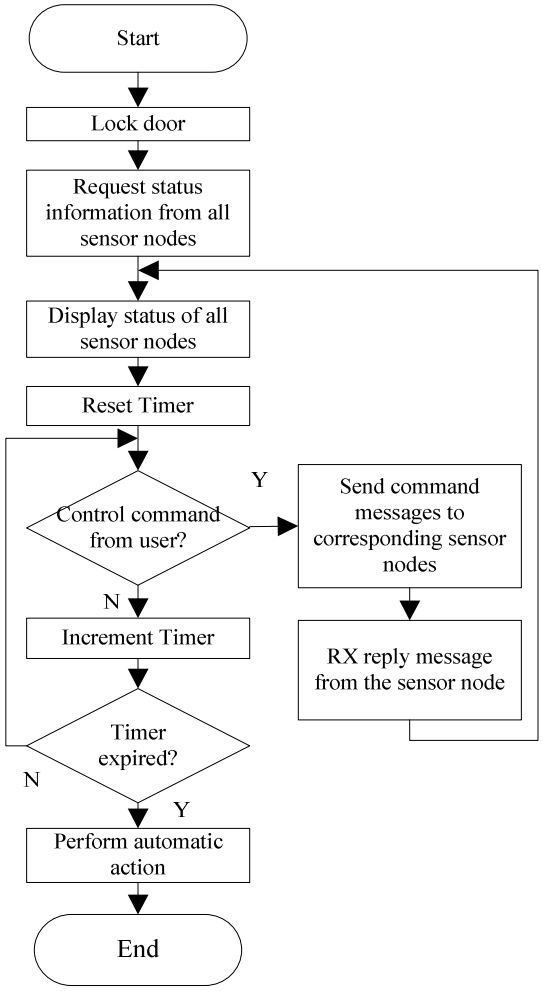


Figure 5. Flow chart for outgoing event.

If there has been some emergency situation, the corresponding emergency message such as fire, burglary, and various other alert messages are displayed on LCD. In other case user can see the status of the room in the touch LCD. The current environmental condition of home can be easily viewed in the LCD. In the manual mode user can switch on/off the individual device though the touch LCD. Suppose he finds the room is hot, thus he can switch on the air conditioner though the LCD.

If the user did not touch LCD screen for a certain amount of time after unlocking the door, then our system enters into automatic mode. Here also, for automatic mode to work, we have to set the priority setting of devices. Priority here is not the same with the priority used in previous outgoing event. Therefore, the system stores two priorities information for individual device. Here, the device with priority 1 means it should be on and priority 0 means should remain off. This is also one time process but can be done any time when felt necessary. Therefore, when the system enters into automatic mode, it turns on all those devices which priority is 1 if it is still off. User can set priority of devices such as air conditioner and TV to 1 so that they are on as soon as user is at home.

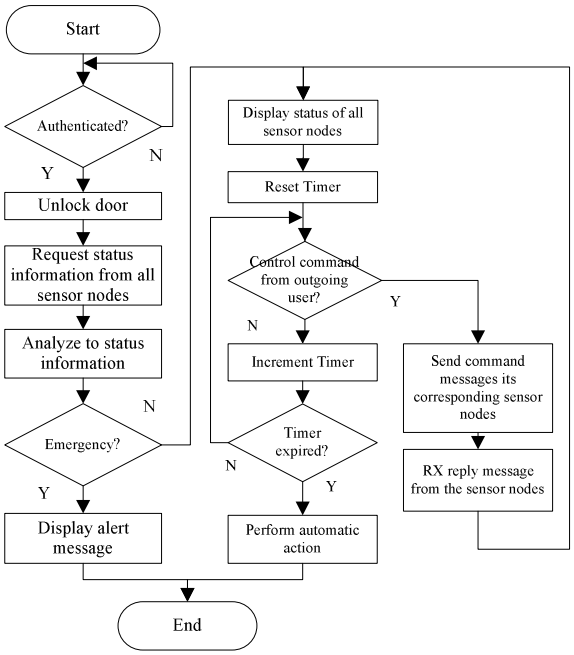


Figure 6. Flow chart incoming event.

3) Emergency Event

The system may encounter emergency situation such as burglary, fire and so on. Fig. 7 shows the flow chart of emergency situation for both sensor nodes and digital door. Fig. 7(a) is a flow chart for sensor node whereas the Fig. 7(b) is for digital door lock. On detecting the emergency situation by sensor node, the corresponding information is immediately notified to the door lock. Also, at the mean time, the sensor node triggers the actuators for handling the current emergency situation. At the door lock side, after being informed about the emergency situation, the door lock sends the SMS to the user notifying about the situation. The system also triggers the alarm. For example, sensor node, perceived when gas leaked, transmits current situation through a door-lock, downs the power of electric home appliances connected to nodes by conveying a signal.

4) Relay Node

Using the smart digital home server, we expect that home automation will be satisfied. But there is still a problem of RF signal power attenuation frequently occurred at indoor environment such as home or office. This unreliable RF signal would be worse at home which micro-oven and consumer electronics using similar frequency bands exist. In order to support reliable RF signal transmission, we built ZigBee RF repeaters which are arranged in the entrance of each room. Also, these nodes can be used to lock and unlock the door of each room.

IV. Design of Smart Digital Door Lock System

We implemented a prototype system for home automation based on digital door lock with ZigBee network protocol. Fig. 8 shows implementation of central controller of our smart

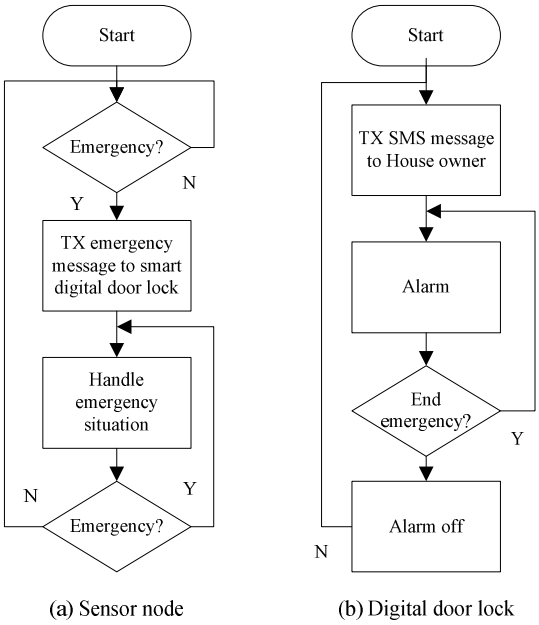
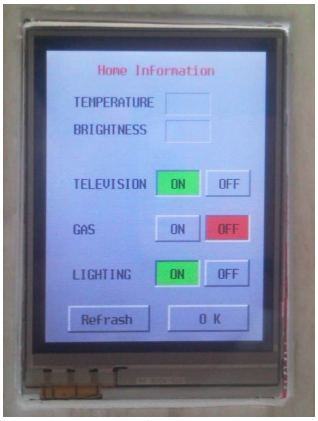


Figure 7. Flow chart for emergency event.

digital door lock system. We chose and remodeled one of commercial door lock products. All of the control circuits for locking and unlocking of door were rebuilt into our AVR controller based ZigBee system. The interface between the user and the system is provided by the touch LCD. Fig. 9 shows the snap shot of the touch LCD. Fig. 9(a) shows the interface for the user authentication. User inputs the password for authentication through this interface. Similarly, in Fig. 9(b), LCD displays the condition of the home. User can monitor and control the home environment from this interface. Fig. 10 is showing our switching module used to switch consumer electronics at home. As shown in the figure, the typical electric adaptor is connected to ZigBee relay module mounted on sensor node. This switching module is use to switch the power on and off according to commands delivered from the smart digital door lock server.

Figure 8. The door lock back view.



(a) Authentication (b) System display

Figure 9. The door lock LCD interface.

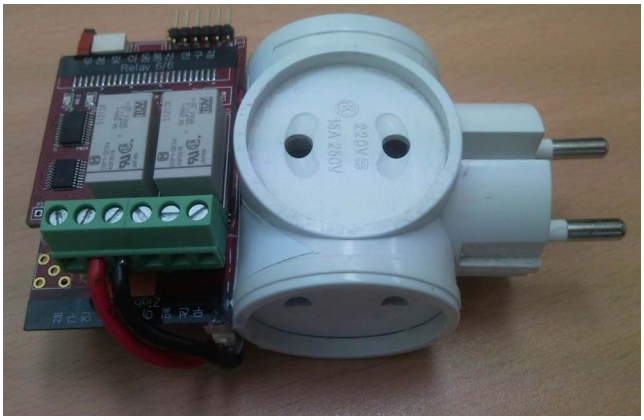


Figure 10. Sensor node with power switching module.

V. CONCLUSION

In this paper, we presented a novel home automation system based on ZigBee which integrates the home security with home automation. Our proposed system exploits the ZigBee's full capacity for monitoring and controlling home environment and condition through the digital door lock.

Since our proposed system is built over wireless sensor network, it is a cheap, flexible, and easily installable system without any overhead such as careful planning, cabling, and construction works.

REFERENCES

[1] ZigBee Alliance Document 053474r06, ZigBee Specification, v. 1.0, Dec 2004.

[2] F. L. Zucatto, C.A. Biscassi, F. Monsignore, F. Fidelix, S. Coutinho, and M. L. Rocha, "ZigBee for Building Control Wireless Sensor Networks," in proceeding of Microwave and Optoelectronics Conference, pp. 511-515, Oct. 2007.

[3] Il-Kyu Hwang and Jin-Wook Baek, "Wireless Access Monitoring and Control System based on Digital Door Lock," *IEEE Trans. On Consumer Electronics*, Vol. 53, No. 4, Nov. 2007. pp 1724-1730.

[4] A. Wheeler, "Commercial Applications of Wireless Sensor Network Using ZigBee", IEEE Communications Magazine, V. 45, N. 4, pp.:70 – 77, April 2007.

[5] Eaton Corp., "Eaton Home Heartbeat," http://www.homeheartbeat.com/HomeHeartBeat/index.htm.

[6] http://www.ZigBee.org