A GSM, Internet and Speech Controlled Wireless Interactive Home Automation System

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Abstract — *The home automation today needs to make use of the latest technological components available. In this paper, we present the design and implementation of a home automation system where communication technologies GSM (Global System for Mobile Communication), Internet, and speech recognition have been used. All these techniques are successfully merged in a single wireless home automation system. This system offers a complete, low cost, powerful and user friendly way of real-time monitoring and remote control of a house.* [1]

Index Terms – Home automation, Speech recognition, GSM, Internet, Wireless, RF communication.

I. INTRODUCTION

As the integrated circuits and microprocessors become more and more accessible and the Internet communication is a fact of today with the improved availability of cellular networks, these advancements naturally should find use in modern home automation systems. These systems provide the consumers increased security and safety, economic benefits and convenience by giving them control over all the appliances in the house.

Designing a home automation system for monitoring and controlling various devices in remote locations can be done through a variety of communication options such as wireless LAN technologies, dial-up modems, private radio networks, satellite communication, Internet, cellular network and so on. Several studies on home automation have been done using different types of control methods. [1] and [2] are examples of a M2M (Machine-to-Machine) system using GSM (Global System for Mobile Communication) cellular communication network for remote controlling. Speech controlled automation systems are proposed in [3][4]. The studies in [5][6][7] are some examples of the Internet based automation. However, they are not too feasible to be implemented as a low cost solution [8]. Recently [9] introduced a low cost Java-Based Home Automation System, without highlighting the low level details of the type of peripherals that can be attached. In [10], a similar system also based on the Internet with hardware implementations is proposed. It is also a low-cost solution and has a scalable structure which allows new appliances to be added with no major changes to its core.

The weakness of the above systems is their lack of alternative control mechanisms. In our model we proposed three remote controlling methods which are via;

- GSM Network,
- Internet,
- Speech.

The first two of these methods are designed for the users when they would like to remotely access the devices in the house whereas the third one is designed for the users while they are inside the house.

The real time monitoring has been an important feature that can be used in the home automation systems. As a change in the status of the devices occurs, the user can be informed in real time. Thus, our main objective for using GSM network for the communication between the home and the user is its wide spread coverage which makes the whole system online for almost all the time. Another advantage of using the GSM network in home automation is its high security infrastructure which provides maximum reliability so that the information sent or received can not be monitored by an eavesdropper.

Although using GSM network has all these important advantages over other communication methods, it would be a tedious, time and money consuming task for the user to use his mobile phone each time he/she needs to communicate with the system when the user is already at home. So we suggested and implemented another method which uses the voice of the user to control the system. In our model, the user can interact with the system by giving commands with his/her voice. This method greatly simplifies the interaction with the appliances when the user is at home.

The communication between the home appliances is carried out by the RF communication protocol. Unlike a system using wired communication methods such X10, an RF system has the advantage of installation and maintenance. Moreover, it has a lower cost when compared to other wireless communication methods such as using Bluetooth[7].

The next section shows a brief overview of the automation system while in the third section the operation of the whole system is discussed in detail. The last section is the conclusion.

II. SYSTEM OVERVIEW

The block diagram of the system is shown in Fig. 1.

[1]

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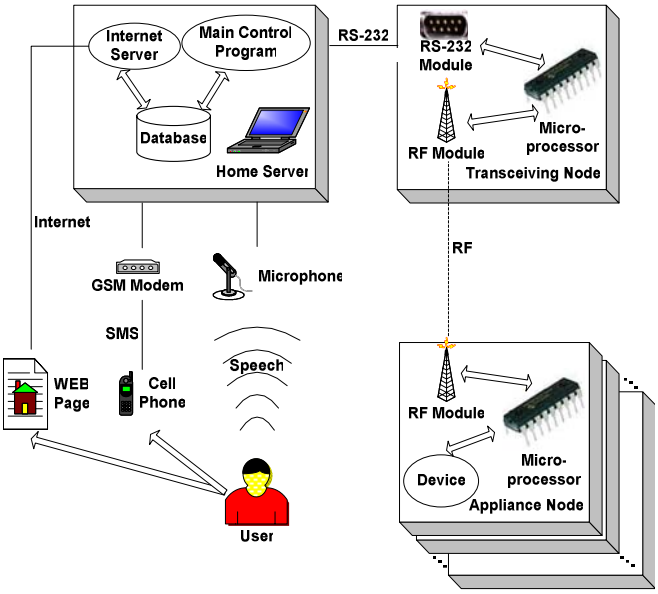


Fig. 1. Block diagram of overall system

The communication between the user and the system is established by the three methods; via a mobile phone, the Internet or speech.

User commands are transferred to the home automation server (which is done by a PC) via one of these three alternatives. In the home automation server the incoming commands are processed, then digitized and sent to the relevant unit to be processed. In each unit there are separate low-cost microcontrollers to receive the commands from the transceiver and apply these to the appliances they are attached to. These devices have also the capability of sending their status back to the transceiver node which is connected to the home automation server thus they can be monitored in real-time. After receiving the feedbacks from the appliance nodes, the home automation server interprets them and performs the necessary tasks.

A. Communication Methods

1. GSM

The GSM is an excellent choice in establishing a communication from remote locations where Internet may not be available. The communication between the user and the home is established by the SMS (Short Message Service) protocol. A GSM modem is connected to the home automation server. The communication between the home automation server and the GSM modem is carried out by the AT (Attention) commands. Sending and receiving SMS messages are all performed in the PDU (Protocol Description Unit) mode since the text mode may not be available on all GSM modules.

For the mobile part, an interactive software has been developed in J2ME [11][12] platform as shown in Fig. 2. This software can be used in any mobile phone that supports Java. By using this software, the user can interact with the house simply by choosing the right commands from the menus. An example is demonstrated in Fig. 2.

Fig. 2. Step by step usage of the mobile control program

The user chooses “Door Lock” from the main menu and then “Lock the Door” command from the sub-menu. As a result, the main door will be locked by the system and an appropriate feedback SMS will be sent back to the user as a confirmation.

The details of the “Lock the Door” command is as follows:

1. An SMS message is created which has a content of “Lock the Door” command in an encrypted way.
2. This message is sent to the GSM modem which is connected to the server.
3. The main control program running on the server decrypts, reads and interprets the message content.
4. An appropriate command is sent to the door lock system via the transceiver node and the door is locked.
5. A feedback SMS message (e.g. “The Main Door is Locked at 04.07.2006 at 11:58.”) is sent back to the user.

The same mechanism is also used to inform the user about a status change in any device. The feedback status is an essential building block of the home automation system. For example, if a motion is detected, this information is sent from the motion sensor directly to the home automation server. Then a warning SMS message is created and sent immediately to the registered GSM number in the system.

2.Internet

In order to achieve interaction with the home automation network from the outside, the other option is to use the Internet. To accomplish this, a web server is built to take requests from remote clients. The clients can send requests to the home appliances. The home appliances can send their statuses to be displayed for the remote client through the server.

A web page is constructed as an interactive interface where commands can be submitted by the client to change and also monitor the status of the devices.

3. Speech

A speech recognition program is written to control the house by means of human voice. In our system we found that the Dynamic Time Warping (DTW) algorithm [13][14][15][16][17] to be most suited for our application. The advantages of using DTW are its high performance, simplicity, and adaptability to our system and it is used extensively used in speech recognition. To use DTW in speech recognition, first, the input data (user command word) has to be converted into a template. Then, this input template is compared with the speech templates stored in the database by the use of DTW. The DTW algorithm outputs distances between the input and each of the database templates. The template which gives the lowest distance is the recognized word [18].

The input and database templates have multiple elements so the distance measure is calculated by using the Euclidean distance metric. Therefore the local distance *d* between the two template elements x and y is given by,

$$d(x,y) = \sqrt{\sum_i (x_i - y_i)^2}$$

B. System Elements

1. Home Automation Server

This is the central control point. This is currently handled using a PC in our system. In general, the duty of the Home Automation Server is to take commands from the user and to make decisions according to them as a manager unit. The Server communicates with the microcontrollers to send and/or receive data depending on the task. We have developed several engines running on the home automation server. These are:

- Web Server
- Database
- Main Control Program
- Speech Recognition Program

The control of the devices is established and their condition can be monitored through the main control program as well as from the Internet and GSM.

Due to the basic methods and high compatibility of .NET environment [19], ASP.NET and C#.NET technologies with .NET Framework 2.0 are used to manage and control the system's operation [20][21]. The engine running on the server is written in C#. The main function of this engine is to communicate with the devices via the main control program. This engine consists of a collection of active server pages and Visual C#.NET components. Building this engine with .NET has several advantages. First, the home automation system requires dynamic home pages and user interfaces (as shown in Fig. 3 ad Fig. 4). In this case, ASP.NET is more powerful and could be preferred over other tools in this task.

ASP.NET technology provides an easy way to create dynamic web pages and makes it simpler to build up web

(a)

(b)

Fig. 3. (a) The login page created by ASP
(b) Web control interface

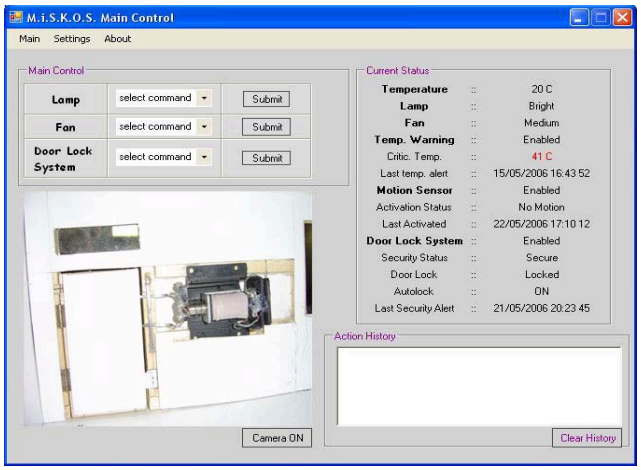
applications with all its visual components and short-cut methods. Moreover it gives an opportunity to work with a wide variety of web servers and browsers.

The main control program is also written in Visual C#.NET platform. Since serial transmission provides an accurate and fast communication with microcontrollers, it has been advantageous to use serial data transmission between the main control program and the transceiver node. The .NET Framework 2.0 (a development and execution environment that allows different programming languages and libraries to work together) makes it easier to access the serial port with the "System.IO.Ports" namespace containing classes for controlling serial ports. The most important class, "SerialPort", provides a framework for synchronous and event-driven I/O, access to pin and break states, and access to serial driver properties [16].

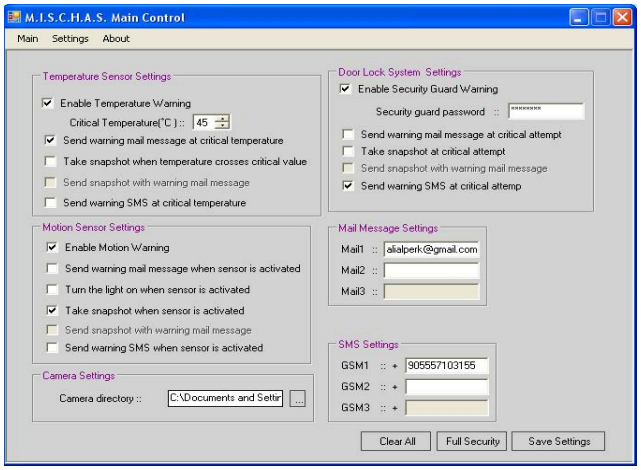
The main control program monitors the current status of all appliances and enables the user to adjust several settings for the automation system. All the device status are taken from the transceiver node via the serial port and monitored in the main control program as shown in the Fig. 4.a. In addition, it generates an action history for all actions or emergency alarms while the program is running and monitoring the system. The user can also command the appliances by submit buttons in this main control program. The main control program also

checks for incoming messages (commands from the remote cell-phone) to the GSM modem connected to the server via another serial port.

SQL Server and Microsoft.Jet.OLEDB.4.0 are used for database management. A database was created to preserve several setting arguments for smart home appliances as shown



(a)



(b)

Fig. 4. (a) Main control program user interface (b) Settings menu

in Fig. 4.b. All these settings are stored by OLEDB. SQL Server provides web based security and login/password based authentication which is set up to prevent unauthorized accesses.

Another engine that we have developed is the speech recognition engine. The recognition program using this engine has a user friendly menu (Fig. 6-a) from which the user can add/change sounds, delete sound database, and start the recognition process. The first step is to choose *"Add/change sound from microphone"* option from the main menu to create the sound database from the *"add sound"* menu as in Fig. 6-b. Once the database is created, the user can start the program by choosing the *"Recognition for home"* option.

The voice activation has been tested and found to be too impractical due to constant processing overhead and false positive voice activation. As a more stable alternative, the voice input can be activated through a wireless unit the user carries along in the house. Whenever the user wants to give voice commands, he or she presses the button on the unit which enables the program to listen to the user' voice commands and the recognition process starts. Thus, the program waits in idle mode until the button is used. The overall recognition process is given in fig. 5.

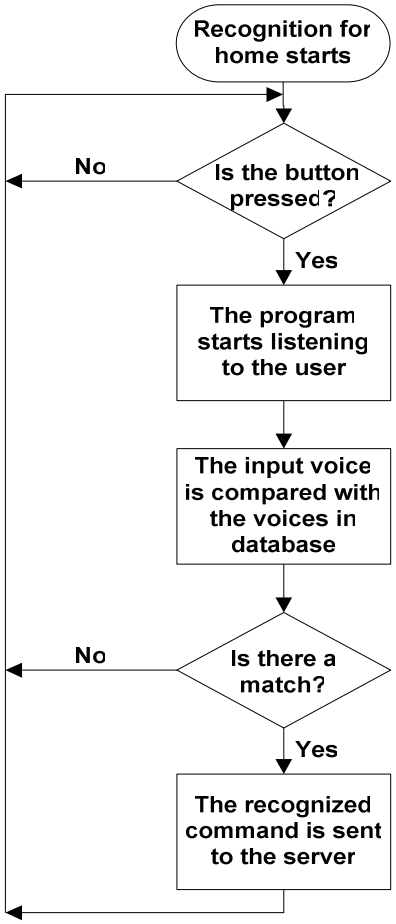


Fig. 5. Overall speech recognition process

Fig. 6. (a) The main menu of the speech recognition program
(b) Add/change sound menu
(c) Recognition of a successful command
(d) Recognition of an unknown command

To measure the efficiency of the speech recognition process the program is tested in several different noise levels. For each noise level 500 tries are made. The results are shown in table 1.

TABLE I
EFFICIENCY OF THE RECOGNITION PROGRAM

SNR Level	Recognition Efficiency
5 dB	% 44.3
15 dB	% 72.8
25 dB	% 82.3
35 dB	% 92.1
Over 45 dB	% 98.7

2. Transceiver Node

Transceiver node provides a link between the home automation server and the appliance nodes (Fig. 8). This unit consists of a microcontroller[2], an RS-232 unit[3], a transmitter, and a receiver to communicate with the home appliances via the RF communication standards.

- *Microcontroller:* It is responsible from the control of the transmission of the commands/feedbacks. The controller has an internal capability for serial transmission and has enough memory (8Kbyte) and ports to fulfill the desired operations.
- *RS-232 Unit:* The serial communication is used between the transceiver node and the home automation server. RS-232 communication method is a very suitable way to communicate with the microcontroller.
- *Transmitter and Receiver:* The UHF ASK transmitters and receivers are used for the RF communication. This communication protocol works at 434MHz frequency and 2.4Kbps speed at maximum.

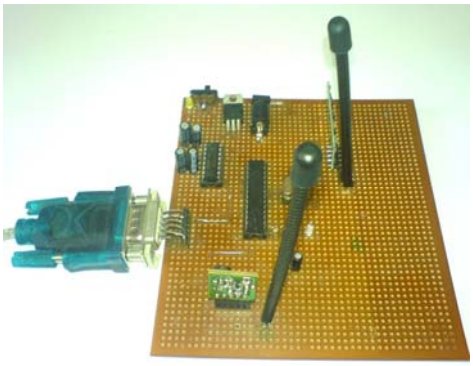


Fig. 8. Transceiver node

[2] The microcontroller used is a PIC16F876.

[3] The unit consists of a MAX232 and a connector.

3. Appliance Nodes

Appliance nodes act under the control of the main control program and each node can communicate with the transceiver unit individually. Each node consists of four parts; a receiver, a transmitter, an I/O device and a microcontroller.

- *Receiver* takes the commands from the transceiver unit.
- *Transmitter* sends feedback to the transceiver unit for the statuses of the I/O devices to be monitored in the main control program.
- *I/O devices* are the devices which perform the orders given by the microcontroller through appropriate interfaces and A/D converters where necessary.
- *Microcontroller* is responsible of applying the requests that come from the transceiver unit. In order to demonstrate the overall concept we have chosen some device controller units and some suitable sensors in our system.

Some Appliance Nodes Implemented:

a) Lighting Node: With this unit the user can control the lighting intensity inside home to a desired brightness level.

b) Ventilation Node: Ventilation level can be adjusted to a desired level with this unit.

c) Door lock Node: To improve the security of the house, a password controlled lock system is built (Fig. 9) User can change the password from the main controlling unit. If three consecutive wrong attempts occur, the system sends a warning SMS message to the user through the default GSM number. There is also an auto-lock option in the system which automatically locks the door whenever the door is closed for added security,.

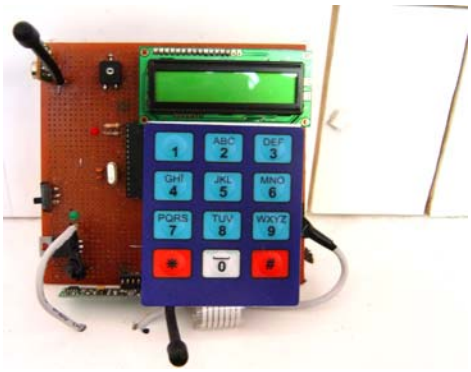


Fig. 9. Implementation of the door lock node

d) Camera: Cameras, placed in the different parts of the house, take snapshots of their surroundings instantly if a motion is detected. These pictures are transferred to the home automation server. Then the user is informed via GSM network and/or the Internet along with an appropriate warning message.

e) Temperature Node: This node, which has a sensor attached on, measures the temperature of its surrounding and can be set up to send an appropriate signal to the transceiver node for the system to warn the user if a predefined value of temperature has been exceeded. Alternatively, this difference can automatically trigger an air-conditioner through the transceiver node. This critical temperature value can be adjusted in the main control program's settings menu.

f) Motion Node: If a motion is detected, this system sends an appropriate signal to the transceiver unit. It also interacts with the whole system by taking a picture of its surrounding.

Fig. 10. Motion, camera and ventilation node

All the devices used in this automation system could be reached by one address byte and one command byte as shown in Fig. 11. Once the address byte and the device are latched, the command word determines the multivalued state. Using 8 bits for addressing provides a scalable system in which addition of a number of devices is made possible. With 8 bit command word, 256 different commands can be used for a single device.

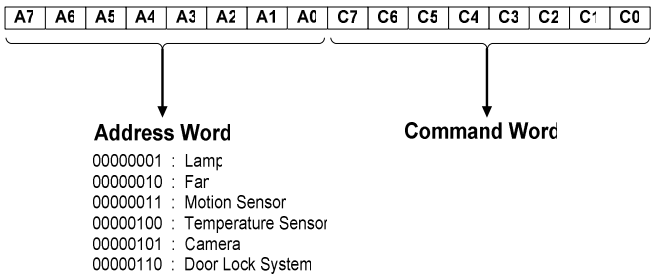


Fig. 11. Instruction format

During the transmission between the transceiver node and the appliance nodes, synchronization and Manchester coding techniques are used to ensure the integrity of the data. The *query reply* and *auto inform* communication protocols are used in the system. The nodes return their status as they are queried (receive command data from the transceiver node), and also in case of a change in their status. For instance as an example to the query reply, if the lighting node receives a command for a change in its status, first its status is changed then it replies back the same command (as a feedback) to the transceiver node. Similarly when

any other device is queried its status, a reply is sent back using the same way. For the auto inform communication protocol the motion sensor sends its status whenever a motion occurs.

All device status information is kept in the transceiver node. The main control program running on the server, takes status information via the transceiver node every second.
Synchronization and preamble bytes are used to decrease error probability and increase efficiency. The communication format is similar to [10] and will not be discussed here.

III. CONCLUSION

This paper presents the design and the implementation of an interactive home automation system with the GSM, the Internet accessibility and the speech features. The Internet provides access the full features of the system through an interactive Web interface. As the mobility in the world increases, the need to control home from remote locations also increases. The GSM is an excellent choice for this due to its extensive coverage. Since SMS is a text based protocol, even the most basic GSM systems can have an access to the status of the devices or make changes on these states. The speech makes the system an excellent choice for the motion disabled.

The whole system is secured through a login password based authentication. The design is completely wireless and integrated with the software to form a low-cost, robust and easily operable system. RF communication makes the system easy to install.

The multi-value adjustment feature is another strong point in the system enabling the devices to have distinct states rather than just on and off. In addition, the nodes in the system can easily be expanded to incorporate other devices.

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