

Low-Cost Embedded System Design for Smart Home Automation Using RF Technology

Erdem Yavuz*

Department of Computer Engineering, Faculty of Engineering and Natural Sciences, Bursa Technical University, Bursa, Turkey

Abstract – Applications for smart home technologies can be described as the adaptation of control systems used in industrial areas to modern living environment of people. Home automation systems are the systematic and seamless adaptation of smart home technologies to the individual's personal needs and desires. Smart homes encompass a range of technologies designed to cater to the needs of residents, simplifying their daily routines and contributing to a more comfortable and secure way of life. Nowadays, most buildings are constructed with expensive, built-in smart home technology. However, when it comes to old buildings without smart home technology, integrating this technology into those structures can be challenging due to the requirement for intrusive overhead wall modifications necessary for installing the technological infrastructure. In this study, a radio frequency based low-cost embedded system is designed to bring intelligent technology to existing homes or old buildings. Various sub-units have been designed and established to be situated in different places of the house. Physical events and situations that occur in the house are sensed by the sub-units and transmitted to the main control unit by means of a specially developed communication protocol via radio frequency signals. This removes the cable clutter and creates a more flexible and easy installation environment.

Keywords – Embedded system, microcontroller, radio frequency, smart home automation.

I. INTRODUCTION

The desire of many people, amidst a busy work schedule, is to perform some of the time-consuming tasks more easily or avoid overloading their minds with numerous tasks. An individual who ensures that most of their operations are carried out automatically, either with a single button press or at a predetermined time, in a scenario akin to procedural logic in a computer, also gains more time to interact with their social environment. To provide this convenience to individuals, technological devices that can be used at homes, factories, and workplaces have been developed, and smart control designs that coordinate them have been created.

“Smartness” literally means “the ability to reach a certain level or adapt to changing situations”. “Smart buildings,” as defined by the Smart Buildings Institute, are “structures that provide a productive and economical environment through four fundamental elements: structure, systems, services, and

management, and the communication between them” [1]. Automation forms the basis of intelligent designs. Automation is the ability of a system to perform desired operations according to a specific scenario without the need for any operator [2]. Home automation involves adjusting technological devices in the home according to individual needs and requests. Smart home automation should not only meet individual needs but also be capable of adapting to environmental needs and changes.

Typical smart home technology includes the air conditioning system, energy-saving system, security system, control system, multimedia system, irrigation system, lighting system, and the protocols and communication lines used between these systems to achieve comfort, savings, security, and remote control. Smart homes are technological systems that utilise many interconnected systems in a coordinated manner, process signals received from environmental sensors according to previously prepared programs or scenarios to meet the needs of individuals, and make adjustments in the output modules [1]. Smart home systems were developed based on the idea of applying industrial control systems to personal homes. Smart homes extensively utilise electronic and computer technologies [2]. In smart homes, most operations are carried out using scenarios or programs. Therefore, it is crucial to establish well-designed scenarios in smart homes. Given the busy and fast-paced lives of today's people, there is a growing need for smart home technologies that not only simplify life but also offer a high level of living comfort in both work and living spaces.

Smart home can be classified into three general categories: controllable homes, programmable homes, artificial intelligence homes. Controllable homes are systems that provide more functional control of many devices in the house than normal. With these systems, most devices in the house can be controlled from a single point. They can also be managed with a remote control and provide synchronised operation by transferring data between many devices (TV, camera, computer, and speaker) [3]. Programmable homes can be examined in two classes. One is a programmable home that can react based on time and simple sensors. The other is the

*Corresponding author's e-mail: erdem.yavuz@btu.edu.tr
Article received 2024-01-20; accepted 2024-07-15

house that processes and implements predetermined scenarios. Programmable homes, which can react according to time and simple sensors, are systems that interpret the changes in the information received from the sensors and control the devices in the house according to what needs to be done in compliance with these changes. Examples of this include the activation of a fire alarm when the smoke sensor in the house detects smoke, or a home automation system that calls the fire department and sends the necessary messages [3]. In homes that process and implement predetermined scenarios, predesigned static scenarios should be available. When users activate a scenario, the requirements of that scenario are automatically carried out at home. An example of this is a scenario that automatically closes the gas valves and water valves in the house and activates the alarm system when a predetermined holiday scenario is activated while going on vacation. Houses with artificial intelligence are more advanced than programmable houses [4]. While scenarios must be entered by users in programmable homes, there is no such requirement in homes with artificial intelligence. These systems require software capable of learning such as in [5]–[12].

In this study, smart home modules with a modular structure that can communicate wirelessly with computers have been designed, and a main control circuit that controls these modules has been implemented based on a microcontroller. The designed modules have features that can be easily installed in any home. Each module can operate for an extended period with a 9V battery. In the designed system, it is exemplified that one of each module communicates with the main control circuit, but any number of modules can be easily integrated into the system. The names of the designed smart modules are Door-Lock Module, Plug Socket Module, Lamp Module, Doorbell Module, Motion Detection Module, Light Sensing Module, Fire/Smoke Detection Module, and Computer Communication Module. The aim and contribution of this study are to develop an affordable embedded system based on radio frequency technology designed to add smart capabilities to pre-existing homes. In the present day, the majority of new constructions incorporate high-priced integrated smart home systems. Nonetheless, retrofitting these technologies into older buildings presents a significant challenge, as it typically requires intrusive wall modifications to install the necessary infrastructure.

The rest of the paper is organised as follows: Section II describes the challenges with RF communication. Section III presents the design and implementation of a smart home automation system, encompassing the details of the embedded software systems developed for this system. Section IV briefly provides the results and discussion. Finally, Section V concludes the study.

II. CHALLENGE WITH RADIO FREQUENCY (RF) COMMUNICATION

The section introduces the problem encountered in wireless smart home automation design and the solution to this problem, i.e., modules controlling the operation at home. The

section mentions RF transmitter and receiver used in the smart home automation, and also describes the problem encountered in the design and implementation, and presents the solution to the problem.

A. Radio Frequency

Radio waves or radio signals cover a wide frequency range from 3 kHz to 3000 GHz. Figure 1 shows the frequency distribution of the radio waves on the electromagnetic spectrum and the nominal band spacing. Only certain parts of these bands are used in communication applications. The ISM (Industrial Scientific Medical Band) is a band that can be broadcast in many countries in compliance with a specific output limitation, without a certificate or license. In our country, commonly used frequencies of the ISM band are 315 MHz, 418 MHz, 433.92 MHz, 868 MHz, 915 MHz, and 2.4 GHz. In the study, transmitter and receiver components with a frequency of 433.92 MHz, available in the market, are used. In the study, TXC1 transmitter and RXB1 receiver components operating at 433.92 MHz frequency, manufactured by Keymark company, are used for RF communication, seen in Fig. 2.

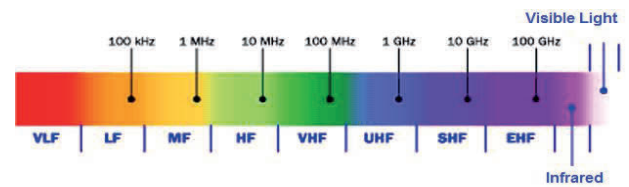


Fig. 1. Electromagnetic spectrum.

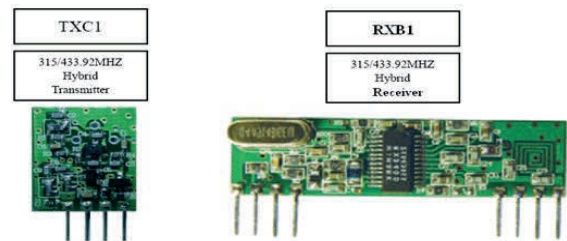


Fig. 2. TXC1 transmitter and RXB1 receiver components used in the system.

B. Radio Frequency Operation Principle and Data Format

The communication carried out using the radio frequency modules can generally be represented by the diagram in Fig. 3. The data to be transmitted wirelessly from one unit to another is sent as digital signals to the transmitter module. The RF transmitter module sends the received electrical signals as electromagnetic signals through the antenna. On the receiver side, the RF receiver module receives electromagnetic signals from the environment and converts them to electrical signals. The electrical signals are evaluated by the receiver unit to obtain the essential data to be sent by the transmitter unit.

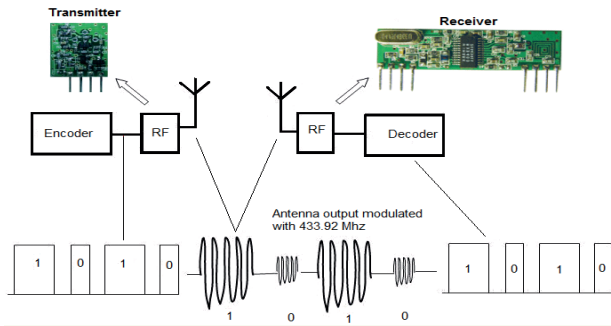


Fig. 3. General structure of communication via RF modules.

Even in the simplest communication systems, it is necessary to use a preamble for the beginning of the message to be sent. For the RF transceiver modules used, a bit sequence consisting of consecutive 1's and 0's is sent as preamble information. This preamble information can be hexadecimal 5 (byte) 0x55 or 0xAA. Preamble data provides hardware synchronisation of the RF transmitter and receiver modules. The transmitted sync data provides synchronisation of the software. This data is used to provide bit synchronisation and to correctly determine the beginning of the message. The length of the bit string that constitutes the sync information may generally be 5 (byte) 0x00 and/or 0xFF, depending on the application requirements and constraints. After sending preambles, actual data is sent and no spaces should be entered when sending data. The preamble and sync information should be sent again in the case of space. The data format mentioned above is illustrated in Fig. 4.

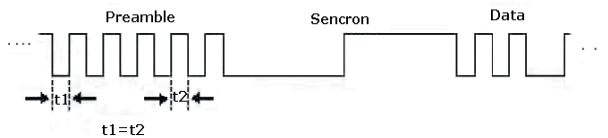


Fig. 4. RF data format.

Data is sent via RF transmitter in the sequence “**Preamble** + **Senkron** + **Data1** + ... + **DataN**” and the subroutine for sending data is depicted in Fig. 5.

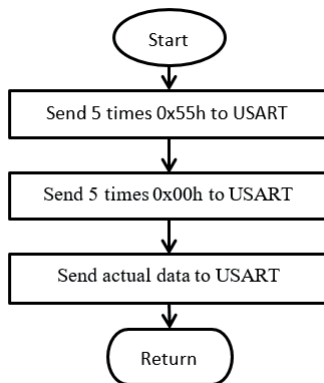


Fig. 5. RF data submission subroutine.

C.Problem Encountered in RF Communication and its Solution

Generally, there is no problem in using RF transceiver modules in applications where one-way communication with a single transmitter and receiver is performed. In systems with a single transmitter-receiver, there will be no problem as the signal of a single transmitter will spread in the environment. If an analogy is to be made between communication with RF modules and communication over copper cable, the medium (air) in wireless communication corresponds to the copper cable in wired communication. In the light of this analogy, in the RF communication system where there is a single receiver and transmitter, the receiver and transmitter units are not different from the two normal units located at both ends of the copper cable and want to communicate with each other. In other words, in this example, the environment (air) can be thought of as a copper cable installed between the communicating units (RF receiver and RF transmitter) only for this communication. In this case, there is no problem in communication since there is only one RF transmitter (sender) in the environment, i.e., the information sent by the transmitting unit is received correctly by the receiving unit on the opposite side. Figure 6 shows the schematic of the system with a single transmitter-receiver condition.

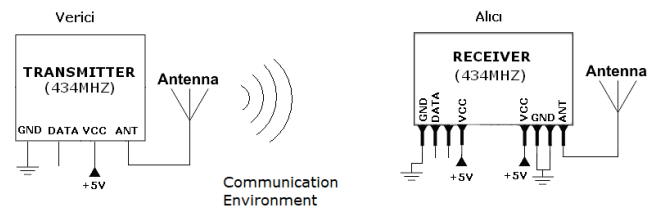


Fig. 6. System with single transmitter-receiver.

Description of the problem: In systems with more than one RF transmitters and receivers operating at the same frequency, interference occurs in the environment due to the RF transmitter modules in the system. Due to this interference in the environment, communication between units becomes impossible. It has been observed that when only one RF transmitter module in the system sends data (i.e., it is active) and at the same time, when all other RF transmitter modules in the system are passive, communication does not occur. In other words, it has been understood that there is interference in the environment due to the RF transmitter modules that are currently inactive and this interference distorts the data to be sent by the active transmitter. Figure 7 shows the diagram illustrating that the transmitted data is distorted due to the interference in the environment in the system with more than one transmitter-receiver.

It is inevitable to have more than one transmitter and receiver RF modules in a smart home automation system consisting of wireless modules. If all the transmitter-receiver modules used operate at the same frequency, the above-mentioned problem is encountered. It can be considered to use RF transmitter-receiver modules operating at different frequencies for each module; but the number of RF modules

operating at different frequencies available in the market is very limited. For this reason, it is generally necessary to use RF transmitter-receiver modules operating at the same frequency for all units in the system. In order to implement the wireless smart home automation system with transceiver modules operating at the same frequency, the above-mentioned problem must be solved first, described as follows.

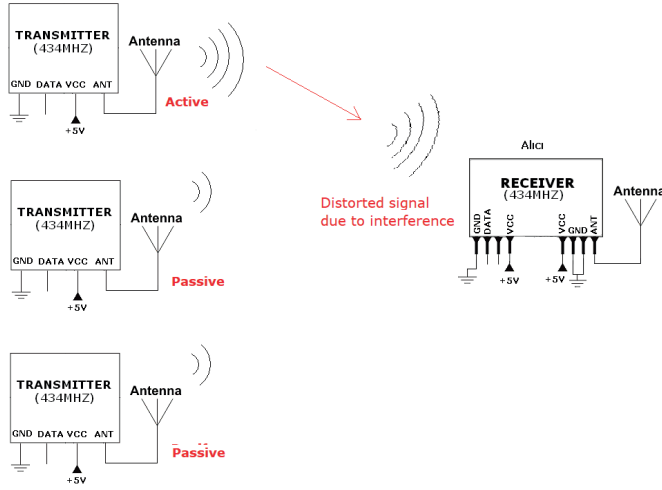


Fig. 7. Interference effect in the system containing multiple transmitter-receivers setting.

The method developed to eliminate the interference problem mentioned above is shown in Fig. 8. A weak RF signal is continuously sent to the environment in order to eliminate the interference effect created by the passive (not sending data) transmitters in the system, which includes RF transmitter modules operating at the same frequency and causing the data to be distorted in the environment. The weak signal sent to the communication medium minimises the interference effect in the environment and ensures that the sent data reaches the receiving unit without being distorted.

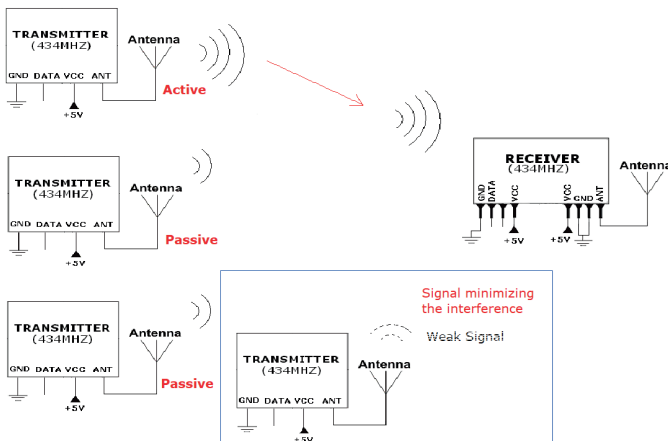


Fig. 8. Prevention of interference effect in a system containing multiple transmitter-receiver settings.

Based on the experiments in practice, the circuit producing this weak signal should be as in Fig. 9. By changing the value

of the Rcc resistor in this circuit, the range of the weak signal produced by the circuit to affect other units can be changed.

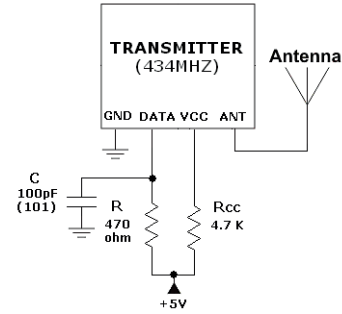


Fig. 9. Circuit generating the weak signal that prevents the interference effect.

III. DESIGN AND IMPLEMENTATION OF SMART HOME AUTOMATION SYSTEM

The designed smart home automation system consists of various electrically isolated units as shown in Fig. 10. The designed system comprises Lamp Module, Plug Module, Door-Lock Module, Light Detection Module, Motion Detection Module, Door Bell Module, Fire/Smoke Detection Module and Computer-Connection Module. In addition to these modules, any device in the house or new modules can be easily added to the system to control a particular new situation.

Generally speaking, the designed system consists of a main control module and sub-modules communicating wirelessly with the main module. Since the modules designed to control devices, plugs and lamps in the house communicate wirelessly with the main control module, it is easy to add new modules to the system or to diagnose faults and troubleshoot them in case of possible faults.

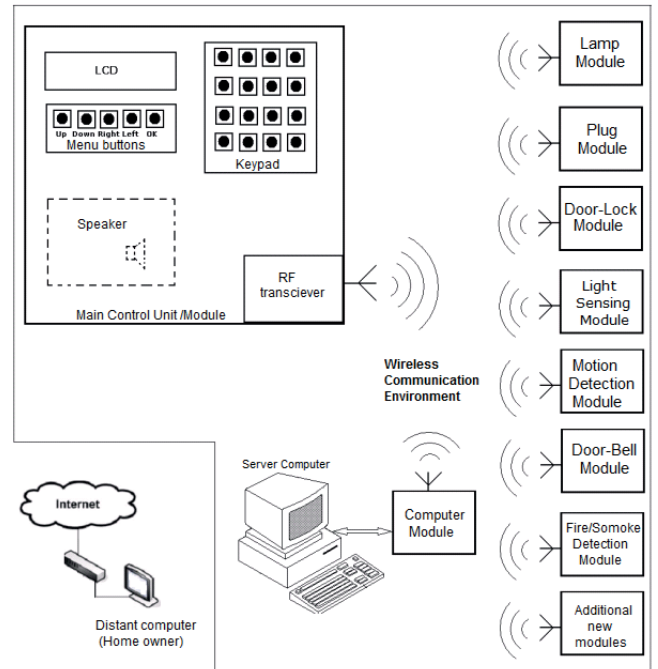


Fig. 10. General structure of smart home automation system designed.

In the implemented smart home automation system, separate electronic circuits are designed for the devices, lamps and plug sockets to be controlled. In the following subsections, details about the designed units are given.

A. Main Control Unit

In the most general sense, the main control unit is the processing unit responsible for managing the units to be controlled by interpreting the data from all units placed inside the house. The main control unit has a keypad that allows programming of peripherals. In addition, an LCD (Liquid Crystal Display) screen is used to show the settings and changes made in the system to the user. There is a real-time clock circuit in the main control unit, which is used to enable the plug sockets and lamps in the house to turn on and off at the desired time intervals. There is an RF transmitter-receiver pair that provides wireless communication with peripherals. 18F4620 from the Peripheral Interface Microcontroller (PIC) family is used as a controller in this unit. The photograph of the implemented main control unit is shown in Fig. 11.

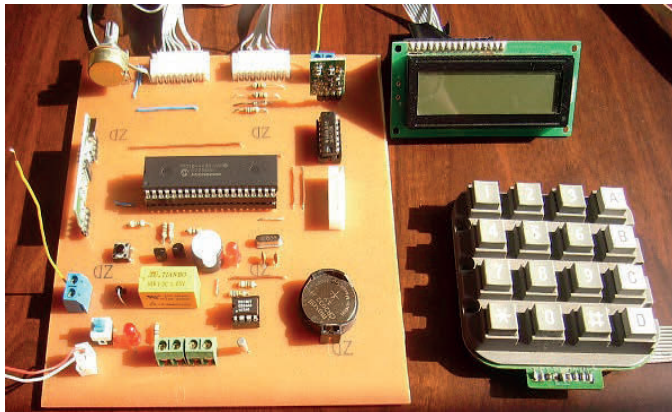


Fig. 11. Photograph of the Main Control Unit board implemented.

The block diagram of the circuit of the main control unit is shown in Fig. 12. Information such as the on/off times of home appliances, lamps and plug sockets, and the days of the week they will work can be set via the keypad. In addition, system clock adjustment and password operations for users at home are also done by means of this keypad. Thanks to the LCD used, all kinds of settings made regarding the home and the warning and alarm messages resulting from the changes in the situation at home are reflected to the user. The real-time clock section in the circuit is used to store and maintain the time and date information even when the electricity is cut off. With the RF receiver module in the circuit, information about the changing situations in the house is received from the peripheral units. After the evaluation of the data received from the peripheral units, the control information that needs to be sent to the peripheral units is sent with the RF transmitter module. The circuit of the main control unit must be powered by a 5V power supply. The schematic circuit diagram of the electronic board designed for this unit is shown in Fig. 13.

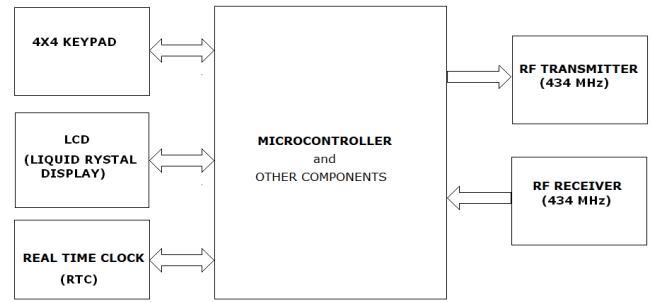


Fig. 12. Block diagram of Main Control Unit circuit.

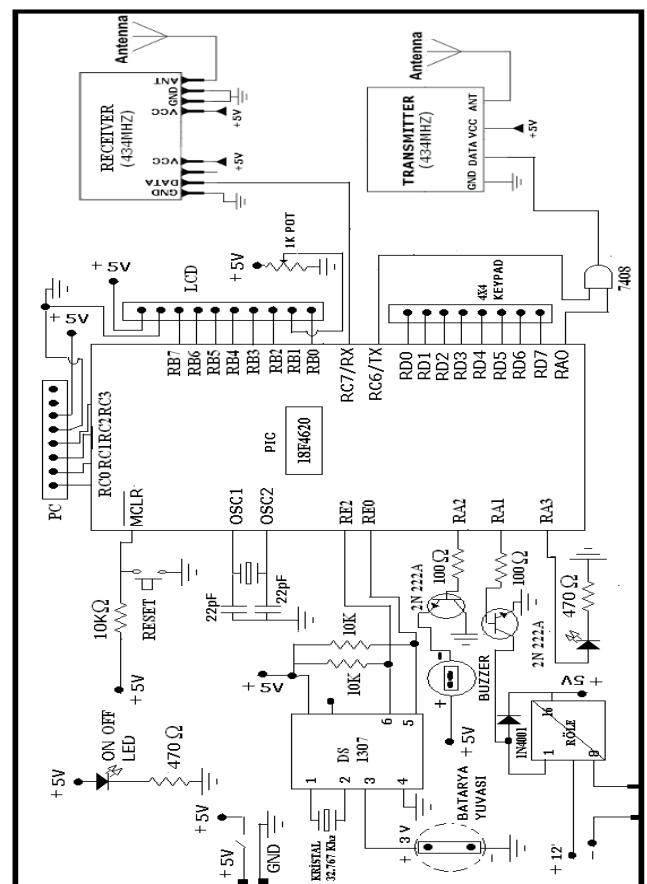


Fig. 13. Schematic diagram of Main Control Unit circuit.

B. Lamp Unit

The block diagram of the designed lamp unit/module is shown in Fig. 14. This unit, which allows the lighting lamps in the house to be controlled from a single centre with the designed smart home automation system, is planned to be placed between the switch and the utility wiring pre-installed in the building, and it communicates with the main control module. With this process, a previously manually controlled lamp is integrated into the designed smart home automation system. Thanks to this designed module, features such as switching on and off manually at any desired time or at a pre-programmed time or depending on whether the outdoor environment is light or dark are added.

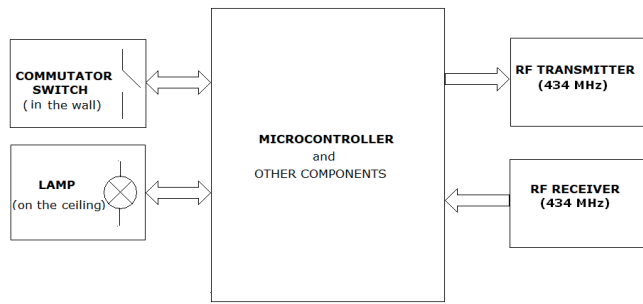


Fig. 14. Block diagram of the Lamp Unit circuit.

C. Plug Socket Unit

The photograph of the designed plug socket unit is shown in Fig. 15. The socket unit allows the existing sockets in the house to be controlled according to the user's request. This unit is planned to be placed between the pre-installed socket and the installation cables in the construction of the building. This allows this unit to communicate with the main control unit. With this process, it is ensured that a normal socket is included in the designed smart home automation system. Thanks to the added socket unit, operating features such as whether the socket to be controlled is energized at a pre-programmed time or according to whether the outdoor environment is light or dark, is added on that socket.

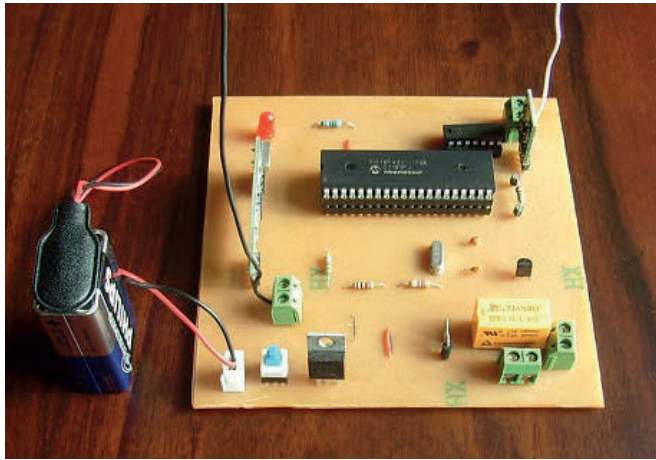


Fig. 15. Photograph of the Plug Socket Unit board implemented.

The block diagram of the socket unit, which allows the plug sockets in the houses with the electrical wiring preinstalled to be controlled from a single centre by being included in the designed smart home automation system, is shown in Fig. 16. In order for the wall socket to be included in the designed smart home automation system, the wall socket is first removed. When the wall socket is uninstalled, two electrical wires will be free. These cables must be connected to the relevant terminals on the electronic board of the designed socket unit. The two ends of the removed socket must be connected with a cable to the corresponding terminals on the plug socket unit board designed. The supply voltage of the

socket unit is 9V provided by a battery. The circuit diagram electronic board designed for this unit is shown in Fig. 17.

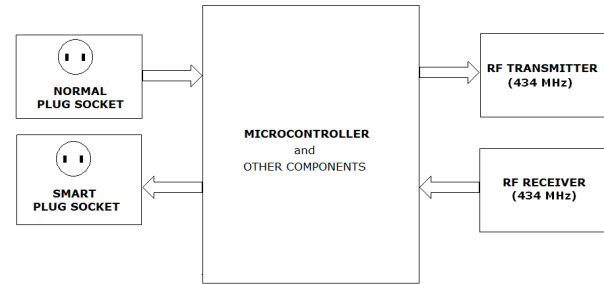


Fig. 16. Block diagram of the Plug Socket Unit circuit.

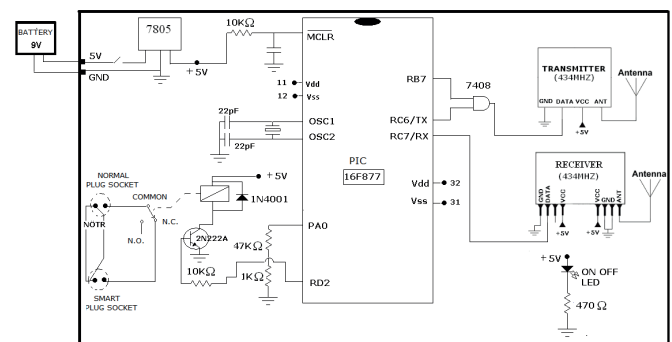


Fig. 17. Schematic diagram of Plug Socket Unit circuit.

D. Door-Lock Unit

The designed door-lock unit is shown in Fig. 18. This unit enables the user to enter the house by using the password that he/she has defined before, when entering the house via a keypad. There is an LCD screen on this module. Thanks to this screen, the passwords entered by the user and the warnings they may encounter are visually reflected to the user. If the password is entered incorrectly three times in a row, the system detects this entry as an attempted theft and activates the alarm system. With this unit, a password valid at certain times of the day can be given to the cleaning staff who comes to the house to clean, and entrance and exit to the house can be arranged.

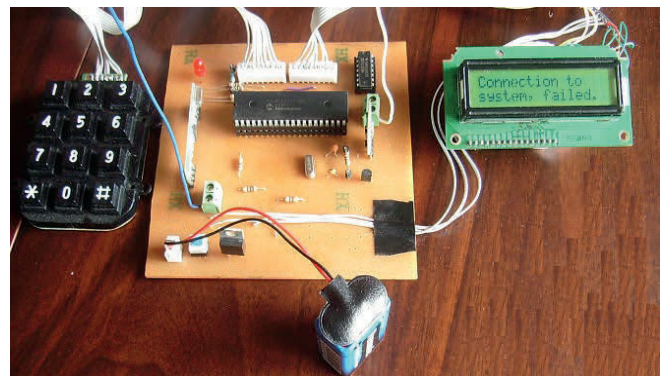


Fig. 18. Photograph of the Door-Lock Unit board implemented.

The block diagram of the circuit of the Door-Lock Unit is shown in Fig. 19. The supply voltage of this unit is provided by a 9V battery. The circuit diagram of the electronic board designed for this unit is shown in Fig. 20.

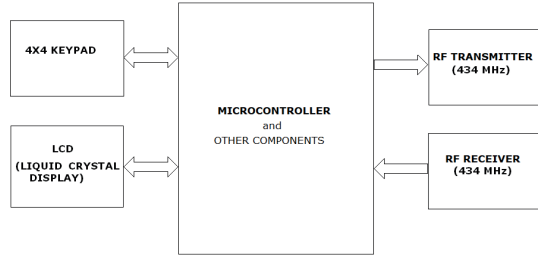


Fig. 19. Block diagram of the Door-Lock Unit circuit.

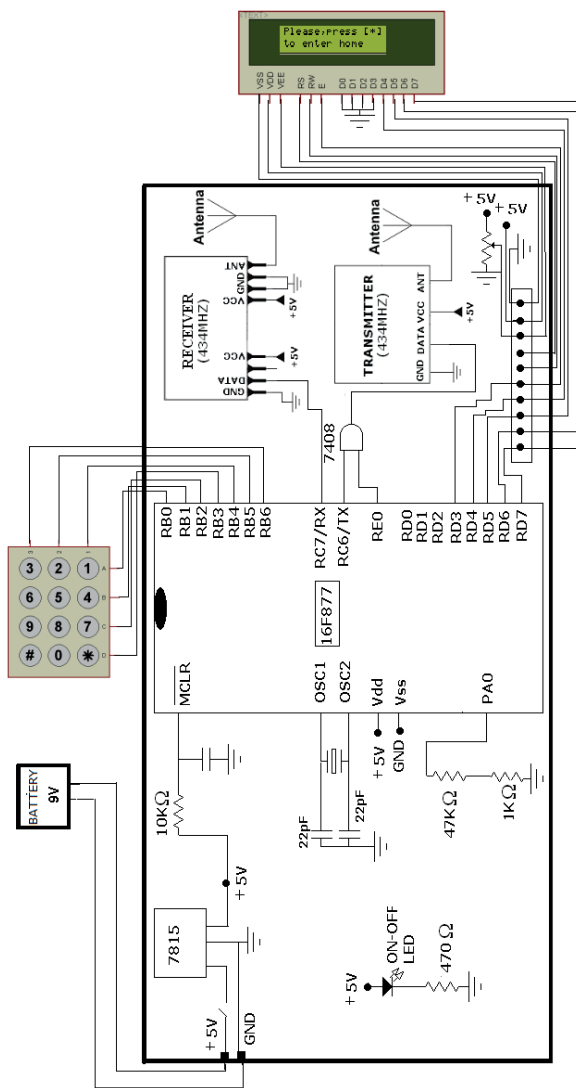


Fig. 20. Schematic diagram of Door-Lock Unit circuit.

E. Light Sensing Unit

The light sensing unit detects whether the outside environment is light or dark and performs the task of sending this information to the main control unit. The block diagram of

the circuit of the light sensing unit is shown in Fig. 21. LDR (Light Dependent Resistance) was used to detect the changing light intensity. The voltage level received across the LDR, which changes according to the light, is evaluated by converting it into digital data with the internal ADC (Analogue-to-Digital Converter) inherent in the microcontroller used in the circuit. As a result of the evaluation, the day and night times are determined according to the light intensity in the environment. The supply voltage of this unit is provided by a 9V battery. The circuit diagram of the electronic board designed for this unit is shown in Fig. 22.

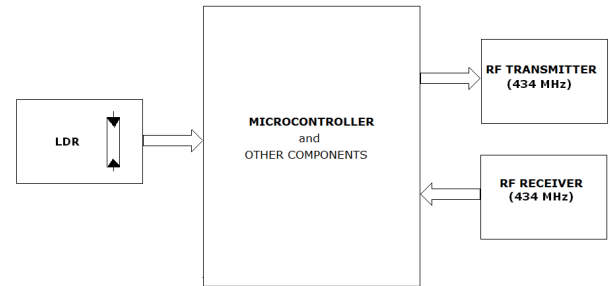


Fig. 21. Block diagram of the Light Sensing Unit circuit.

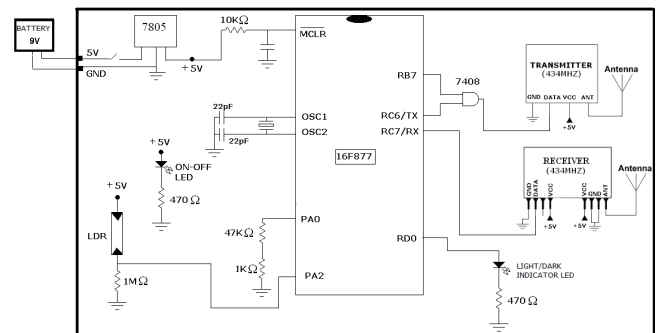


Fig. 22. Schematic diagram of Light Sensing Unit circuit.

F. Motion Detection Unit

The motion detection unit notifies the main control unit when any movement is detected in the house while the family members are not at home. Upon receiving this information, the main controller activates the alarm system on the grounds of suspicion of theft. The block diagram of the motion detection unit circuit is shown in Fig. 23. In the motion detection unit, a motion detection module, which is a passive infrared (PIR) sensor kit, is used to detect the motion in the house. The contacts of the relay on this ready module change its state when any motion is detected. The supply voltage of this unit is provided by a 9V battery. The circuit diagram of the electronic board designed for this unit is shown in Fig. 24.

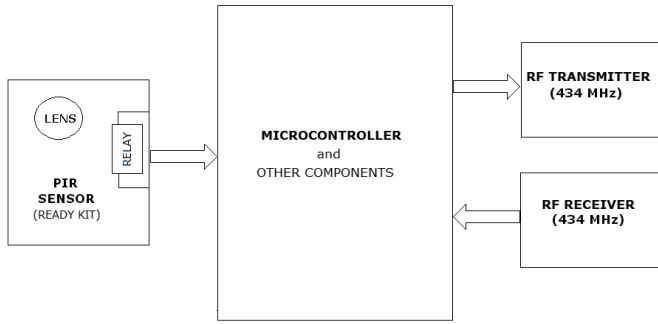


Fig. 23. Block diagram of the Motion Detection Unit circuit.

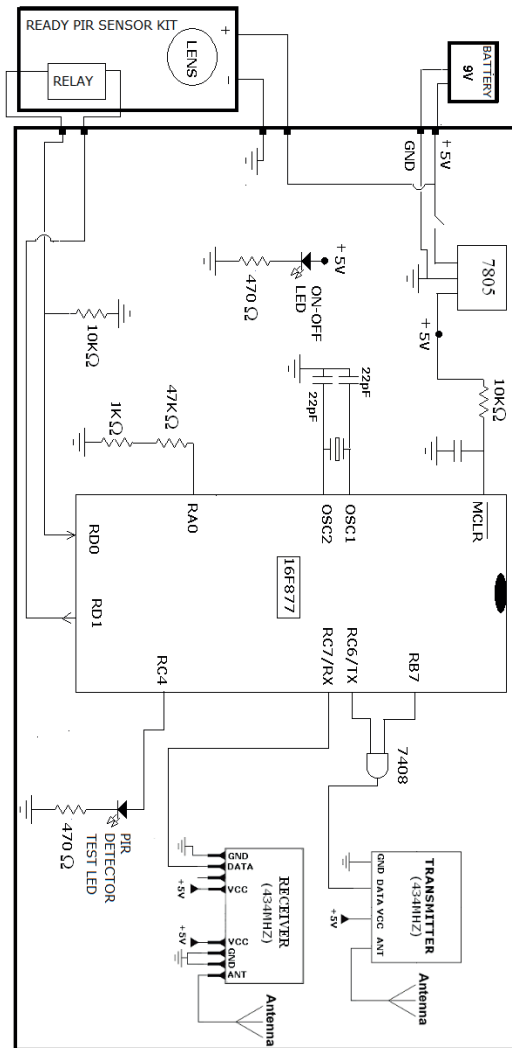


Fig. 24. Schematic diagram of Motion Detection Unit circuit.

G. Doorbell Unit

When the doorbell rings while vacuum cleaners, stereos and similar devices that make loud noise in the house are working, this unit sends information to the main control unit to automatically cut off the power of the plug sockets to which the noisy devices are connected so that people in the house can hear the doorbell. The block diagram of the circuit of the

doorbell unit is shown in Fig. 25. The supply voltage of this unit is provided by a 9V battery. The circuit diagram of the electronic board designed for this unit is shown in Fig. 26.

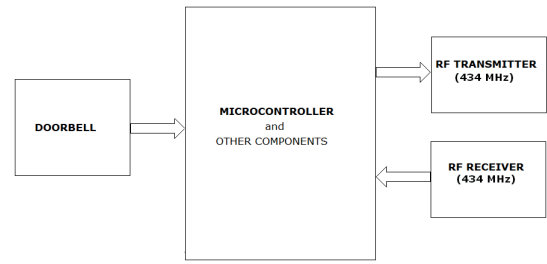


Fig. 25. Block diagram of the Doorbell Unit circuit.

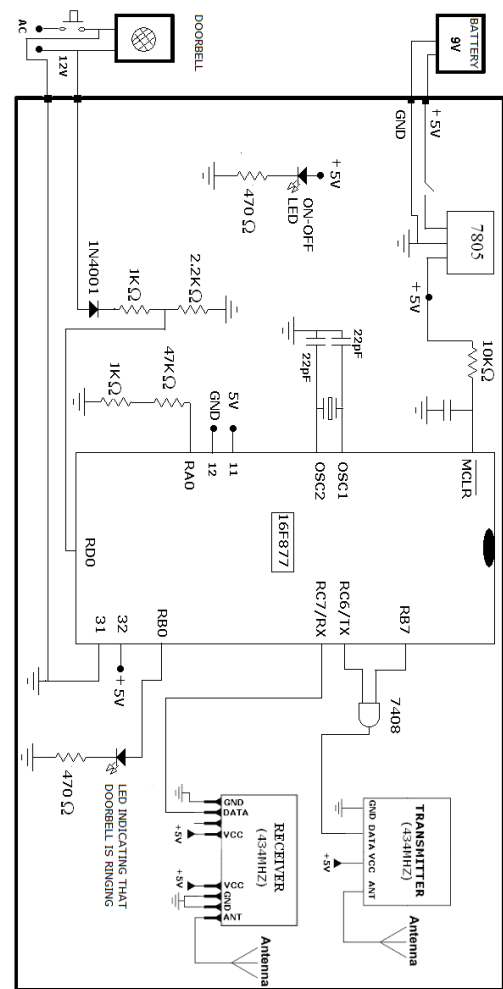


Fig. 26. Schematic diagram of the Doorbell Unit circuit.

H. Fire/Smoke Detection Unit

The fire detection unit detects the smoke that may occur in the event of a fire in the house and informs the main control unit. The main control unit activates the alarm system as a result of the incoming information. An OP-AMP (Operational Amplifier) based smoke detector, which can detect infrared

compatibility in RS232 communication, special ICs, called RS232 converters, are used for logic level conversion. In this circuit, MAX232 IC is used to provide logic level compatibility. The data coming to the computer unit via the server computer at home over the Internet must be transmitted to the main control unit that regulates the operation in the home. This data transmission between the computer unit and the main control unit is provided by cable. Wired communication within the entire designed smart home automation system was used only at this point. The supply voltage of the computer unit is provided by the main control unit.

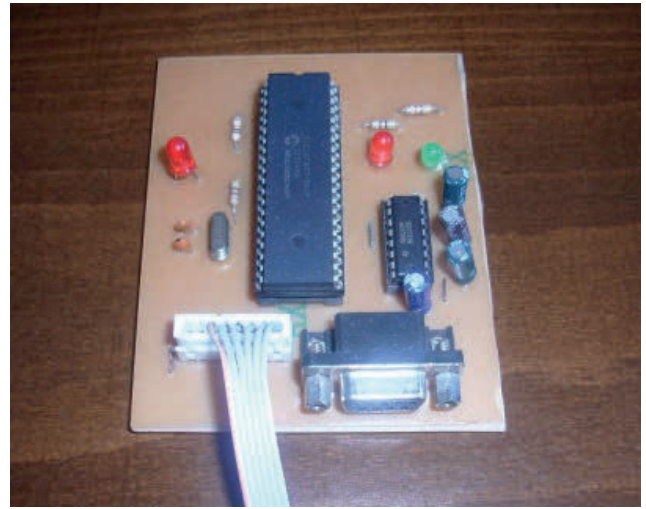
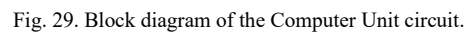


Fig. 27. Schematic diagram of the Fire/Smoke Detection Unit circuit.

The designed computer unit is shown in Fig. 28. The computer-connection unit is designed to control appliances, lamps and plug sockets at home from a remote client computer via a computer that will operate continuously in the house where the designed smart home automation system is installed. Thanks to this unit, the home owner can control the devices included in the smart home automation system over the Internet from anywhere outside the home.

IV. EMBEDDED SYSTEM SOFTWARE

A separate program was coded and implemented for each unit by using MikroC, a C compiler belonging to MikroElektronika company, to be loaded on the controllers in the units. In this section, due to page restriction, the developed software only for the main control unit is described. 18F4620 series from the PIC microcontroller family is used as the controller in the main control unit. The reason why the PIC 18F4620 controller is preferred instead of the PIC 16F877, which is the commonly used one, is that it has a larger program capacity and EEPROM memory. 8KB of program memory for PIC 18F877 is up to 64KB for PIC 18F4620 controller. In addition, the internal EEPROM capacity of the



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PIC 18F4620 controller is 1KB. This figure is 4 times the EEPROM capacity of the PIC 16F877.

A. General Flowchart

The main control unit is the one that controls the entire operation in the smart home automation system. Therefore, the code size of the software developed for this unit grew as each new feature was added and became a program consisting of approximately 5000 lines. For this reason, just the general operation of the developed program is mentioned here. Figure 30 shows the general flow diagram of the program developed for the main control unit.

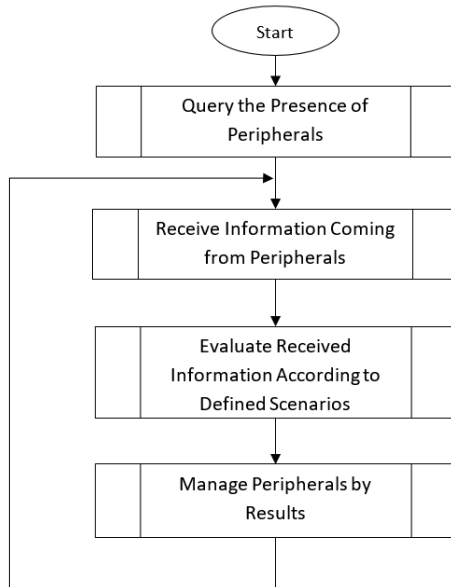


Fig. 30. General flow diagram showing the operation of the program developed for the Main Control Unit.

B. Communication Protocol

There are many units that need to exchange information with the main control unit at all times. In order for these units within the smart home automation system to communicate smoothly, unique address numbers have been assigned to all units. Units that want to exchange information can send their data to each other wirelessly using these address numbers. The communication format used is shown in Fig. 31. Since the source and target addresses are 8 bits long, a total of 254 (256 - 2) different units can be used. As mentioned before in section II.B, since 0xAA (decimal 170) and 0x00 (decimal 0) data are used for synchronisation of RF transceiver modules, the number of unit addresses that can be defined is obtained by subtracting 2 (reserved addresses) from the number of units that can be addressed with 8 bits.

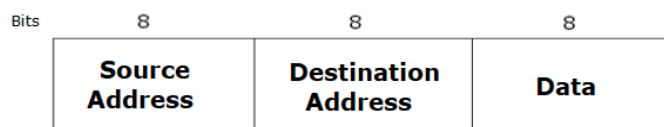


Fig. 31. Communication format.

In the designed smart home automation system, no standard protocol was used for the main control unit to communicate with other units. Using the previously mentioned RF infrastructure and the communication format seen in Fig. 31, a communication protocol that can be developed according to the details of the designed system has been created. Each message sent according to this protocol is 3 bytes long. The first byte sent in the message is the address of the unit sending the message (Source Address). After the source address, the address of the destination unit is sent (Destination Address). Finally, data that has a special meaning for the two communicating units is sent in the message. Table I shows the source/destination unit address codes, and Table II and Table III show codes with special meanings between communicating units.

TABLE I
SOURCE/DESTINATION UNIT ADDRESS CODES

Source/Destination Unit Addresses	Meaning	Source/ Destination Address Codes
MAIN Controller	Main control unit	248
MODUL all LAMPS	All lamp units	245
MODUL all MAINS	All socket units	243
MODUL all UNITS	All lamp and socket units	241
MODUL_all_SysUNITS	All units except lamp and socket units	239
MODUL LAMP1	1 st lamp unit	237
MODUL LAMP2	2 nd lamp unit	234
MODUL MAINS1	1 st socket unit	231
MODUL MAINS2	1 st socket unit	227
MODUL BELL	Doorbell unit	188
MODUL FIRE	Fire/Smoke detection unit	186
MODUL PIR	Motion detection unit	184
MODUL LDR	Light Sensing Unit	182
MODUL CODEGATE	Door-lock Unit	180
...	...	...

TABLE II
CODES WITH SPECIAL MEANINGS BETWEEN COMMUNICATING UNITS (1)

Data Sent to Units	Meaning	Data Code Byte
NoCommand_Next_is_Unit_Control_info	The data sent is control info information	19
Command Unit ON	Turn the unit on	20
Command Unit OFF	Turn the unit off	21
QUEST_AreYouOK	Information to query the presence of other units by the main control unit	25
REPLY_IamOK	Information sent by peripheral units to the main control unit to notify them of their presence	27
INFO_stage1_Completed	Data informing the peripheral units that the questioning of the existence of peripheral units consisting of sockets and lamps is over	29
INFO_stage2_Completed	Data informing the peripheral units that the questioning of the existence of peripheral units other than sockets and lamps is over	30

P_REQUEST_CanIJoin	When a unit is subsequently energized, the data that this unit sends to the main control unit to notify its presence	31
M_REPLY_YouCanJoin	Connection approval information given by the main control unit to the units that subsequently try to connect to the system	34
...	...	...

TABLE III

CODES WITH SPECIAL MEANINGS BETWEEN COMMUNICATING UNITS (2)

Data Sent to Units	Meaning	Data Code Byte
NoCommand_Next_Two_are_ParentKEY1	Data informing the peripheral units that the next two bytes of data to be sent by the main control unit are the password information of the 1st parent.	35
NoCommand_Next_Two_are_ParentKEY2	Data informing the peripheral units that the next two bytes of data to be sent by the main control unit are the password information of the 2nd parent.	36
NoCommand_Next_Two_are_ChildKEY1	Data informing the peripheral units that the two bytes of data to be sent from now on by the main control unit are the password information of the 1st child.	37
NoCommand_Next_Two_are_ChildKEY2	Data informing the peripheral units that the two bytes of data to be sent by the main control unit from now on are the password information of the 1st child.	38
P_ALERT_Family_Member_At_The_Door	Data sent by the door-lock unit informing that the person at the door is a family member	40
M_ALERT_Family_Member_Can_Enter_Home	Data sent by the main control unit to the door-lock unit, informing that the person at the door can enter the house	41
...	...	...

C. Storage of Control Data

Certain user-programmable control data must be kept in the non-volatile memory area. The internal EEPROM memory of the PIC microcontroller used is suitable for this purpose. The capacity of the internal EEPROM memory of the PIC 18F4620 controller used is 1KB. This relatively large non-volatile memory meets the needs of the designed smart home automation system. The layout of the data needed by the main control unit in the EEPROM memory of the microcontroller used is shown in Figs. 32 and 33.

Address	Unit	Data
0x00	System	First initialization info
0x01	System	Operation Mode info
0x10	System	Password1_Type
0x11	System	Password1_HighByte
0x12	System	Password1_LowByte
0x13	System	Password2_Type
0x14	System	Password2_HighByte
0x15	System	Password2_LowByte
0x16	System	Password3_Type
0x17	System	Password3_HighByte
0x18	System	Password3_LowByte
0x19	System	Password4_Type
0x1A	System	Password4_HighByte
0x1B	System	Password4_LowByte
0x1C	System	Password5_Type
0x1D	System	Password5_HighByte
0x1E	System	Password5_LowByte

Fig. 32. Main Control Unit EEPROM Data (1).

Address	Unit	Data
0x32	Unit1	Control_info1
0x33	Unit1	Control_info2
0x34	Unit1	Turn-on Hour
0x35	Unit1	Turn-on Minute
0x36	Unit1	Turn-on Second
0x37	Unit1	Turn-off Hour
0x38	Unit1	Turn-off Minute
0x39	Unit1	Turn-off Second
0x3A	Unit2	Control_info1
0x3B	Unit2	Control_info2
0x3C	Unit2	Turn-on Hour
0x3D	Unit2	Turn-on Minute
0x3E	Unit2	Turn-on Second
0x3F	Unit2	Turn-off Hour
0x40	Unit2	Turn-off Minute
0x41	Unit2	Turn-off Second
⋮	⋮	⋮
⋮	⋮	⋮
⋮	⋮	⋮

Fig. 33. Main Control Unit EEPROM Data (2).

D. User Interface Screenshots

The main control unit user interface consists of a 2×16 LCD screen and a 4×4 keypad. When power is applied, the screenshots in Fig. 34 are first encountered, the presence of peripheral units in the environment are questioned, and the detected ones are listed.

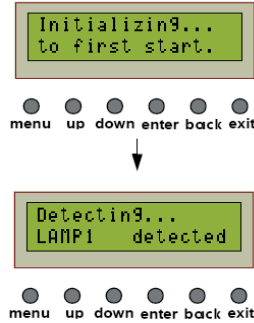


Fig. 34. Preparation and peripherals inquiry screen.

After querying the existence of peripheral units is completed, the system time and date are displayed on the screen. The system time and date screen is shown in Fig. 35.

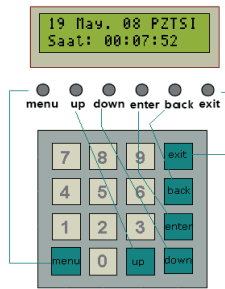


Fig. 35. System time and date screen.

Pressing the “menu” button while on the system time and date screen moves to the Select Function screen. Each time you press the “menu” button, the six main functions are displayed on the screen in order. The transition order between these functions is seen in Fig. 36.

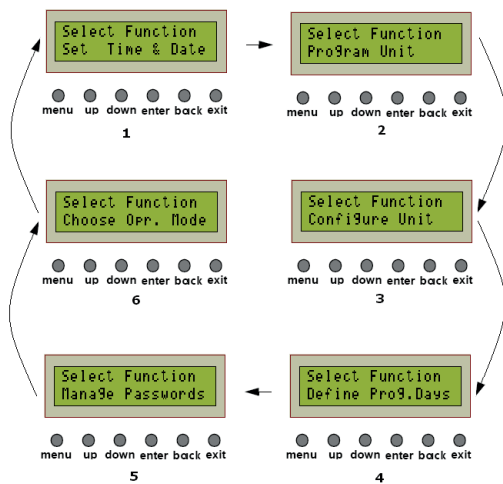


Fig. 36. Function selection screen.

V. RESULTS AND DISCUSSION

In this study, microcontroller-based and Internet-accessible modules that can be used in smart home systems were designed. The designed system generally consists of a main control module and sub-modules that communicate wirelessly with this module. Communication between the main control module and all other modules is provided by 433 MHz radio frequency signals, thereby cable confusion is eliminated. Additionally, a more flexible and easier installation environment has been created. In addition to these gains, modules that provide additional new services that may arise from personal needs in the living space can be easily integrated into the system.

Since the designed system communicates entirely via wireless communication protocol, the re-wiring problem seen in most home automation systems and the resulting wall breaking problems are prevented. Furthermore, the modular design of the system offers substantial benefits in terms of maintenance and scalability. The modularity facilitates quick detection and resolution of any malfunctions, as each module operates independently yet cohesively within the system. This makes adding new modules or replacing faulty ones straightforward and hassle-free. The system flexibility means that any device in the house can be integrated into the smart home network through a single module, streamlining the process and enhancing user convenience.

Overall, this study demonstrates that integrating wireless communication technologies into smart home systems can greatly improve the ease of installation and maintenance while enhancing user experience. The designed system improves the quality of life for users by offering convenience, efficiency and security within the home.

VI. CONCLUSION

This paper explores the exciting realm of smart home technologies and their application in our modern living environments. These technologies represent the seamless adaptation of control systems from industrial settings to the personal needs and desires of individuals, ultimately striving to enhance the quality of life by creating more comfortable and secure living spaces. While the integration of expensive, built-in smart home technology in contemporary construction is increasingly common, the challenges emerge when attempting to retrofit these innovations into older structures. The necessity of invasive wall modifications often poses a hurdle to this process. However, the study presented here offers a promising solution with the development of a cost-effective, radio frequency-based embedded system. This innovative system comprises various sub-units strategically placed throughout the house. These sub-units effectively sense and monitor the physical events and situations within the home, transmitting this valuable data to a central control unit via a specially designed communication protocol using radio frequency signals. The key advantage is the elimination of cable clutter and the creation of a more flexible and convenient installation environment. As smart home technology continues to evolve, these advancements promise

to make intelligent living accessible to a wider range of homes, ultimately enhancing the quality of life for a broader population.

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Erdem Yavuz received the B.Sc. degree with the highest honour in Teacher Training in Computer and Control from Marmara University in 2008, M.Sc. degree in Computer-Control Education from Marmara University in 2010, and PhD degree in Computer Engineering from Istanbul Commerce University in 2018. From 2008 to 2019, he was a Research Assistant with the Computer Engineering Department, Istanbul Commerce University. He is currently an Associate Professor with the Computer Engineering Department, Bursa Technical University, Turkey. His research interest includes speech processing, biomedical signal processing, artificial neural systems, machine learning, and cryptography.

E-mail: erdem.yavuz@btu.edu.tr

ORCID iD: <https://orcid.org/0000-0002-3159-2497>