KAMPALA INTERNATIONAL UNIVERSITY
KIU
Journal of Science, Engineering and Technology

KJSET Research Article

Remote control of home electronic equipment using dual tone multi-frequency signals

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Paper history:
Received 28th November 2024
Accepted in revised form 14th December 2024

Keywords
DTMF, GSM, microcontrollers, networking, automation, electrical sockets, signal

Abstract
The majority of electrical appliances rely on a switch as a fundamental mechanism for activation, deactivation or adjustment of appliances operation based on their requirement. It ensures safe and efficient flow of electricity or power to these devices. With the rapid advancement of technology, automation and wireless control systems have gained significant popularity. The current conventional automation regards remote control of appliances is based on Infra-Red transmission technology. The challenges associated with Infra-red technology includes short distance of transmission or operating range, inability to penetrate solid barriers, limited line of sight, inability to communicate to the user the current status of the appliance, and complete lack of security as any other person can use the remote to operate the device. By leveraging the capabilities of modern smartphones, this equipment aims to provide a user-friendly solution for remote management of electrical appliances, further enhancing the efficiency and comfort of modern homes. The work primarily presents the design and functionality of a device that wirelessly regulates home electrical equipment through the integration of GSM and an 8051 microcontroller. The system functions by having an authenticated signal transmitted from the user's mobile phone via the Global System for Mobile Communication (GSM) network to a designated phone connected to the control equipment. This signal, or code, contains specific information about the operation to be executed, such as which electrical sockets need to be turned on or off. Upon receiving the Dual Tone Multi Frequency (DTMF) signal from the user's mobile phone, the receiver phone relays it to the integrated DTMF decoder. The decoder interprets the signal and converts it into a digital output signal, which is then forwarded to the 8051 microcontrollers. Based on the received digital signal, the microcontroller activates the appropriate relays connected to each electrical socket through the ULN2003 Darlington transistor array. This activation effectively controls the power supply to the targeted sockets, enabling the user to manage their electrical appliances remotely with precision and convenience. Comprehensive testing was performed on each circuit diagram module, and notable results were achieved for the overall system. The system's unique features allow end-users to conveniently control and isolate tasks using a mobile phone. By pressing specific buttons, users can easily manage various operations remotely, enhancing the system's functionality and flexibility in a range of applications.

Nomenclature and units

Ω	Ohms
V	Volts
μF	Microfarads

1. Introduction

The advent of ICT, pervasive computing, and home automation systems has rapidly allowed for ubiquitous access to various equipment from anywhere around the world. Smartphones are becoming a very popular tool, and almost everyone has access to them (Rather and Rather, 2019). Smartphones have become an important consideration in home automation systems (Singh *et al.*, 2021). It was used for power outage detection and sending out Short Messaging Service (SMS) notifications to ICT personnel on duty (Salau *et al.*, 2017), which is also key in-home automation drives. Home automation systems have become very imperative because of the importance of helping physically challenged and elderly people who have difficulty with mobility. Home automation has also helped in saving money and energy, reducing the risk of damage to home appliances due to power surges, reducing routine-based tasks, confirming appliance status with remote access, and increasing entertainment.

Pervasive computing is an emerging technology in which users can access and control information remotely while ensuring security and privacy issues and concerns are well managed. The technology is applicable to a wide range of sectors and environments, including industrial, manufacturing, and residential settings. Its wireless control capabilities enable users to remotely operate and manage various types of equipment and machinery in industries and factories, enhancing efficiency (prompt response), safety, and convenience. A smart environment is designed to interact with and manage the physical world by employing a network of sensors and intelligent controllers. These sensors are responsible for detecting and measuring various aspects of the environment, while the collected data is analyzed and processed with the use of smart controllers, which make informed decisions and execute appropriate actions.

The conventional approach to remote control of appliances is the use of infrared transmission technology. However, the infrared technology is characterized by a short operating range, being unable to penetrate barriers, a lack of security, and no status report on device states, among others. Dual-Tone Multi-Frequency (DTMF) is a telecommunication signalling method functioning within the voice-frequency band. It's employed by telephone equipment and switching centers, originally conceived by the Bell System in the United States as "Touch-Tone. DTMF-based home automation systems leverage the principle of decoding touch tone.

The research primarily concentrates on the development and implementation of remote monitoring and control mechanisms for home electronic appliances utilizing mobile cell phones or smartphones as the primary interface. This project aims at designing and implementing a prototype of a Remote Control of Home Electrical Sockets Using the Dual Tone Multi Frequency (DTMF) Technology via a Mobile Phone with which the user will be able to communicate remotely with the system via tone dial to accomplish the purpose of remote monitoring and control of Electrical Sockets. Users can control multiple devices on sockets by dialing suitably formatted tone or code to the microcontroller-based system which interprets and validates the tone commands before executing them. The System also continually monitors the status of all the electrical sockets outlet. It is essential that both the user and the remote-control system are situated in areas with adequate signal reception from the Global System for Mobile Communication (GSM) network. Controlled devices contain ports that will make communications possible, and the controlled devices will have power sources attached to them at all times. The user will only communicate through a cell phone with tone dial and the SIM module will always be on subscription (i.e. airtime must always be available in the SIM module. The research proposed a means of controlling home electrical sockets in the premises of user that is limited only to ON and OFF functions. The appliances that will be considered for this project are limited to Light, Fan, DVD Player and TV set which are common to every household. The appliances will be plugged directly to the power socket outlets which are controlled by the relay functions.

2. Related Work

Sharma *et al.* (2007) used DMTF to design a tele-remote system leveraging on existing telephone lines. The system uses either landline or handset to control devices and can be used in mining industry, home, spying purposes, general lightning and security. It is able to minimize cost substantially and range issues imposed by Bluetooth and infrared systems. However, it was designed to accommodate only eight devices which can be solved by the use of dedicated controllers.

Getu *et al.* (2015) used DTMF technology was employed to facilitate the remote operation of agricultural pumps situated in distant locations. The system controlled four pumps was designed to manage four pumps through a combination of discrete passive and active electronic components. The system's functionality and performance were thoroughly evaluated and simulated using a specialized software program called Multism. It was noted that the system successfully responded to specific commands, allowing users to switch on or off a particular motor pump or all four motors concurrently. Kaur (2015 showcased the application of DTMF technology in managing the movement and functions of a small-scale vehicle (toy). The mobile phone stacked on the toy car receives the call from the mobile phone. It is coupled with a microcontroller to make decisions on driving motors either in the forward, backward, left or right direction. The research did not use a receiver or transmitter unit. However, stability and ability of the system can still be improved on. Human interference can also affect the system which is a critical area of improvement in future.

Mittal *et al.* (2018) used DTMF to control speed of low power DC motors remotely. In this setup, a mobile phone was linked to the motor, allowing for control through an Android platform or a personal computer. The research also included the use of a camera to provide visual feedback on the motor's operation. A button pressed on the phone sends a signal to the microcontroller which transmits the signal to the motor driver circuit and is used to regulate the speed of the motor. However, high power DC motor was not considered in this work.

Darji *et al.* (2018) developed a DTMF decoder and tone generator to control electrical appliances wirelessly and remotely. The device could control 10 devices only and also depends on network and data carrier. The module does not consider security and linking to a mobile app for accessibility.

Dhongade *et al.*, (2019) used relay and DTMF Decoder to control four devices LED, Fan, Bulb and buzzer from anywhere with the low-cost technology. Chaudhary *et al.* (2021) created a home automation system leveraging DTMF technology. The system includes an Android-based application that enables users to switch appliances and lights on or off as needed. The data generated by the Android application is decoded and stored in a flip-flop component. This digital data is then used to activate relays via relay drivers. The touch tones are used for control of appliances once GSM network is available. The home automation system was designed using a decoder and integrated circuits (ICs), making the implementation both cost-effective and convenient.

Pandey *et al.* (2022) propose a solution to address the challenge of managing household appliances remotely which utilizes DTMF (Dual Tone Multi-Frequency) technology in conjunction with cell phones. A power supply, relay modules and a DTMF decoder (MT8870) were employed to develop a mobile-based control system. On pressing some specific keys, the tones produced are converted into binary signals, which drive relays for activating various appliances. This system had a wider range compared to infrared or radio links and therefore enabled controlling more devices from a distance. Each keystroke on the phone activated the appliances as per the decoder output. But the system does not seem to be without limitations, such as not being able to keep the appliance states during power cuts and no use of microcontrollers for extra efficiency and even the absence of security features like password protection. The solution put forth is a big progress to be made for the remote control of appliances.

This study is intended to eliminate some major shortcomings associated with existing infrared home automation systems such as limited range, inability to go through obstruction, insecurity, and failure to give status feedback from the appliances concerned. In contrast, it improves further the management, accessibility and operability of household electrical appliances through marriage to GSM technology using DTMF signaling and microcontroller-based automation. Certainly, there is the obvious advantage of effective and easy management of home appliances but there is the added benefit that this really comes into its own for the mobility impaired. Also, the system is based on a flexible and scalable architecture capable of supporting many other applications in addition to home automation.

3. Materials and Method

3.1 Overview of System Design

A typical architecture of the home automation system can be divided into five main stages which are modem, DTMF Decoder, Peripheral Interface Controller (PIC), Microcontroller, switching, and power supply. The system consists of two primary components: hardware and software. The hardware architecture is centered around a stand-alone embedded system based on an AVR GSM handset, a GSM module, and a driver circuit. The GSM module enables communication between the homeowner and the system through tone dialing. Homeowners can send dial codes as commands to be executed, and these codes have a predefined format. The GSM module receives these code signals via the GSM public network, extracts the commands, and forwards them to the AVR for execution. The system interprets these commands and adjusts the electrical sockets accordingly using the switching module.

3.2 Hardware

The hardware aspect of the home automation system primarily revolves around the circuitry design, which processes the information received from the user's phone and actuates the appropriate electrical sockets based on the request. The key components of the circuit include the microcontroller, DTMF decoder, relays, transformer, bridge diode, capacitors, regulator, lead wire, and panels for circuit assembly. The transformer, bridge diode, capacitors, and regulator together form the rectifier circuit, which plays a crucial role in converting the incoming AC voltage into a stable DC voltage. This regulated DC voltage is essential for the proper functioning of the microcontroller. The microcontroller serves as the central processing unit of the circuit, receiving input signals from the user's mobile phone in the form of code signals. It processes these signals and sends appropriate commands to the relays. The relays act as electrically operated switches, providing power to the device sockets based on the instructions received from the microcontroller.

3.2.1 The Microcontroller Stage

The PIC16F84A microcontroller was chosen for this design due to its lower power consumption compared to other available microcontrollers. The PIC16F84A features a program memory with a 1 Kilobyte capacity, allowing it to store up to 1024 instructions. Each 14-bit program memory word has the same width as each device instruction, ensuring efficient memory usage and execution. The microcontroller also includes 68 bytes of data memory (RAM) for storing temporary data during operation. In terms of connectivity, the PIC16F84A offers 13 Input/Output (I/O) pins that can be configured based on the user's requirements.

The microcontroller processes binary signals from the Decoder to manage the activation or deactivation of connected devices. Upon receiving activating data, the microcontroller transmits a high logic signal to the respective transistor that controls the relay, while deactivating data prompts the microcontroller to send a low logic signal. A 4 MHz crystal, specifically the XTAL2, provides the required frequency for the microcontroller's operation. Furthermore, the microcontroller is powered by a 5-volt Direct Current (DC) supply. The communication between the decoder and microcontroller is facilitated through PORT A, whereas the transistors are linked to PORT B of the microcontroller.

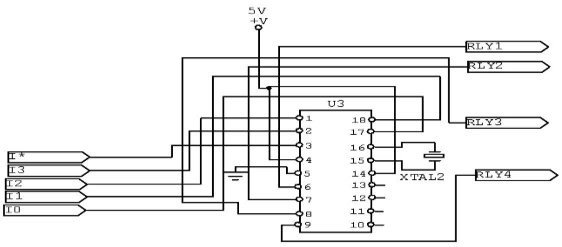

Figure 1: **Circuit Diagram of PIC16F877A Microcontroller Section**

An excellent option for creating a GSM-based home power management system is the PIC16F877A microcontroller, an 8-bit CMOS FLASH-based microcontroller that is strong and simple to program. As shown in Figure 1, this microcontroller comes in a 40-pin Dual In-Line Package (DIP) and boasts internal peripherals. The 40-pin configuration simplifies the use of peripherals, as their functions are well-distributed across the pins.

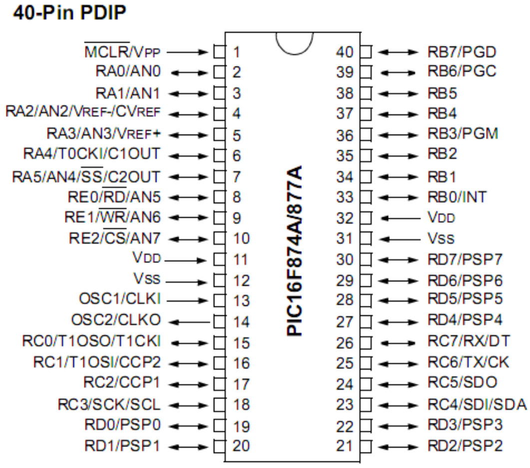

Figure 2: Pin configuration of PIC 16F877A (Micro-Controller)

3.2.2 Modem (The Mobile Phone)

The GSM-based household power management system utilizes a regular mobile phone as a modem due to its affordability and accessibility. The mobile phone's Subscriber Identity Module (SIM) card connects to the desired network, enabling its number to serve as the device's access number. This configuration allows the phone to automatically answer incoming calls, reducing power consumption and minimizing the need for additional circuitry. The audio output of the mobile phone connects to a Dual-Tone Multi-Frequency (DTMF) decoder, which interprets the received signals. The phone's charging port is connected to a 5V power supply to prevent battery discharge. To establish the connection between the user and their household devices, a SIM card from any network is required. This SIM card facilitates a link using a 3.1 kHz audio signal squeezed between 5.6 and 13 kbits/s. In summary, the GSM-based household power management system uses a low-cost mobile phone as a modem, with a SIM card enabling communication between users and their household devices. The DTMF decoder interprets signals, while power supply management prevents battery discharge. This configuration provides an efficient and accessible solution for remote control and monitoring of household appliances.

The GSM module receives external power through the VCC pin in the serial port. For safe operation, the nominal voltage for this module is 3.6V, with a tolerance range between 3.3V and 4.0V. The VCC pins, numbered 1, 3, 5, 7, 9, and 11, provide the module with the necessary external power. Any additional voltage requirements are generated internally within the module. Proper power supply to the VCC pins ensures optimal functioning of the

GSM module for effective communication in the GSM-based household power management system.

3.2.3 DTMF Decoder

The system works on tone dialing mode. Pressing a button on a telephone keypad produces a unique signal comprising two simultaneous tones. These tones originate from a combination of a row and a column frequency, creating a distinct Dual Tone Multiple Frequency (DTMF) signal for each key press. Every DTMF signal is made up of two distinct audio frequencies that aren't harmonics of one another when combined. When these DTMF signals are transmitted to the telephone exchange via cables or wireless means, the exchange server recognizes these distinct signals and establishes a connection with the intended call recipient. This process ensures accurate and reliable communication between telephone systems.

With the Dual Tone Multiple Frequency (DTMF) system, a combination of a low frequency and a high frequency is assigned to each key on a telephone keypad, creating a distinct signal. These frequency pairs are carefully selected to avoid creating harmonics of each other, ensuring that each DTMF signal accurately represents the pressed key and facilitates reliable communication between telephone systems. The DMTF decoder circuit diagram is depicted in figure 3.

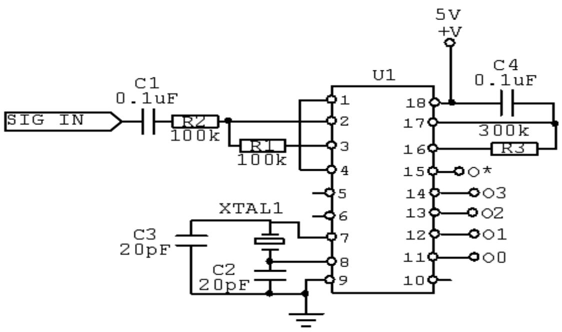

Figure 3: Circuit Diagram of HT 8870 DTMF Decoder

Upon dialing the system number, the modem responds automatically and awaits further input from the user. Pressing '1' on the keypad generates a DTMF tone that passes through capacitor C1 for filtering and resistors R1 and R2 for signal division. Crystal XTAL1 generates the operating frequency for the decoder, while capacitors C2 and C3 filter any oscillations. The response time of the tone is controlled by capacitor C4 and resistor R3. The core of the system is the DTMF decoder integrated circuit (IC), designated as U1 and consisting of an HT8870 chip. This IC operates on a maximum voltage of 5V DC and processes the incoming DTMF tones to interpret user commands.

3.2.4 Switching Transistor Stage

When in class A mode, the transistor operates as a switch, directing the relay to power the load. When the microcontroller (PIC16F84) provides a HIGH output, the relay is activated. A base resistor ensures the transistor operates in saturation for optimal switching performance. To protect the transistor from potential damage due to back Electromotive Force (EMF) generated by the inductive load of the relay coil, a diode is connected across the relay. This configuration enables efficient and secure control of the load through the relay and transistor combination.

The collector resistance (Rc), which is 400 Ω for the relay type used in this work, acts as the resistance of the relay coil.

The following are the parameters that were utilized in this work:

Rc is Relay coil resistance.

V_+ is Regulated voltage from the power supply stage.

V_{BE} is Silicon.

V_{CE} is when transistor is switched off.

V_{IN} is from multivibrator.

H_{FE} is from data sheet for C9103.

$$R_c = 400$$
$$V_+ = 12V$$
$$V_{BE} = 0.6V$$
$$V_{CE} = 0V$$
$$V_{IN} = 5V$$
$$H_{FE} = 300$$
$$V^+ = 12V$$

$$V^+ = I_C R_c + V_{CE} \quad (1)$$
$$V_{CE} = 0V \quad (2)$$
$$V^+ = I_C R_c$$
$$12 = 400 I_C$$
$$I_c = \frac{12}{400}$$
$$I_c = 3A$$
$$V_{IN} = I_B R_B + V_{BE} \quad (3)$$
$$4 - 0.6V = I_B R_B \quad (4)$$
$$H_{FE} = \frac{I_c}{I_b} \quad (5)$$
$$300 = \frac{3}{I_b}$$
$$I_b = \frac{3}{300}$$
$$I_b = 0.01A$$
$$3.4 = I_B R_B \quad (6)$$
$$R_B = \frac{3.4}{0.01}$$
$$R_B = 340\Omega \quad (7)$$

The PIC16F84's output activates the transistor switching stage, which in turn controls the ON and OFF states of the load circuit. Due to the potentially insufficient current provided by the microcontroller (PIC16F84) to drive the relay directly, a switching circuit is implemented.

Figure 4 presents the schematic transistor switching-based circuit diagram of the system.

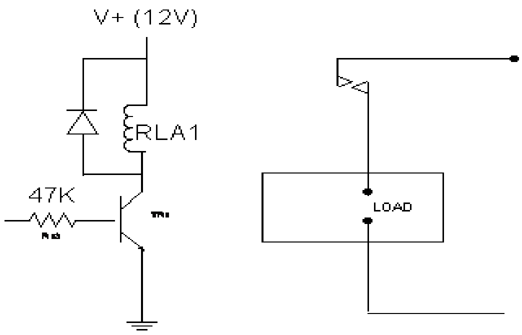

Figure 4: Schematic Diagram of a Transistor Switching with Relay

The system requires both 12V for the relay and 5V DC for other components. To meet these requirements, a linear power supply stage is utilized, incorporating a step-down transformer, filtering capacitor, and voltage regulator. Figure 5 depicts the circuit diagram of this setup. Incoming 220V AC mains power is initially reduced to 12V AC by transformer T1. Diode D1 then converts the AC voltage to DC, which is further smoothed by capacitor C5. Finally, the voltage is regulated to a stable 5V output by voltage regulator U2.

$$Output\ current\ I_O = 0.5A\ with\ load$$
$$Output\ voltage\ V_O = 12V$$
$$Input\ current\ I_1 = ?$$
$$Input\ voltage\ V_1 = 220V$$
$$Power = VI \quad (8)$$
$$I_1 = V_O I_O \quad (9)$$
$$I_1 = \frac{12\ X\ 0.5}{220} = 0.027A$$
$$Power = 1.2VA$$
$$Peak\ voltage\ V_p = V_O\ X\ \sqrt{2} \quad (10)$$
$$Peak\ voltage\ V_p = 12\ X\ \sqrt{2} = 16.97V$$
$$Ripple\ voltage\ V_R = V_P - V_O$$
$$Ripple\ voltage\ V_R = 16.97 - 12$$
$$= 4.97V \quad (11)$$
$$C = Capacitance\ of\ filter$$
$$I_1 = \frac{I_O}{(2\ X\ F\ X\ V_R)} \quad (12)$$

$$f = 50HZ, I_O = 0.1A, V_R = 4.97V\ from\ above$$

$$C = \frac{0.5}{(2\ X\ 50\ X\ 4.97)} = 0.001f$$
$$= 1000\mu f \quad (13)$$

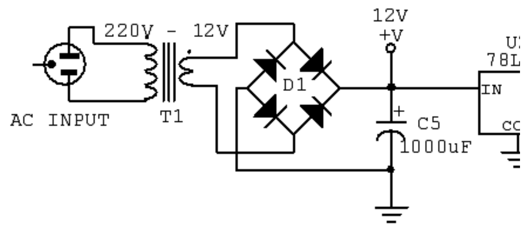

Figure 5: **Power Supply Stage**

To ensure stable operation, a 2200µF capacitor is selected to account for potential variations caused by manufacturing tolerances, temperature fluctuations, and other factors. In addition, a 7805-voltage regulator is selected to give the microcontroller a continuously steady 5V supply. This regulated voltage is crucial for the microcontroller's effective performance in managing the GSM-based household power system.

3.2.5 Components used in Research Work

In this work, the following components were used in the design of the work:

(i) The Rectifier Circuit

Figure 6 illustrates the rectifier circuit used in the system, which comprises several essential components: Transformer, Bridge diode, Voltage regulator and Wires. These components work together to provide a reliable and regulated DC voltage for the system.

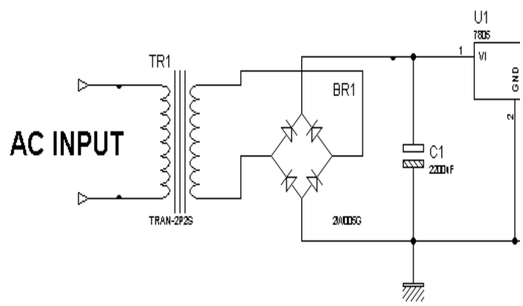

Figure 6: Rectifier Circuit

(ii) **The LM7805 Regulator**: The series of low dropout voltage regulators used in this system have a dropout voltage of 1.2V when the load current is 800mA. The LM7805 offers current limiting and thermal shutdown. In this project, an LM7805 was used to regulate the input voltage to a level acceptable by both the microcontroller.

(iii) **Relay Switches:** A relay is an electrically operated switch that typically features five terminals: two DC terminals for power supply, a Pole (P) terminal that connects to the load, and two auxiliary terminals, Normally Open (NO) and Normally Closed (NC).

(iv) **Resistor** is used in the input terminal of the relay and the Light Emitting Diode (LED).

(v) **Capacitors** play a crucial role in the filtration and smoothing of unwanted AC ripples in the power supply unit, ensuring clean and stable power delivery to various components within the system. They are also primarily used for blocking direct current from the GSM module

(vi) **Light Emitting Diodes (LEDs)** are used to indicate how each gadget is operating. This design makes use of 12 LEDs. Ten LEDs—one for each device—are used to show if any of the devices are in use. The microcontroller uses one to function, while the other one indicates if the phone, modem, or module is connected to the microcontroller.

(vii) The system's electricity is supplied via the **PVC cable**. By inserting the plug into the socket, one may establish a connection to the primary source via the cable.

(viii) **Data cable** is used as a connection to link the microcontroller and modem (GSM phone). It serves as a conduit of communication between the two devices.

3.3 Software implementation

The GSM-based household power management system employs a program developed in the MikroC Integrated Development Environment (IDE) to control the microcontroller's response to signals or messages received from the phone. The main objective of this MikroC software is to facilitate communication between the phone (module) and the microcontroller. The C programming language, which is considered a middle-level language, is well-suited for this application due to its ability to effectively communicate with both hardware components and users. This allows for efficient management of the system's functions based on user input and ensures seamless interaction between the various system components.

4 Results and Discussions

4.1 Hardware Construction

Initially, the circuit was constructed on a breadboard and verified to be functional before being transferred to a Vero board through soldering. The power supply was soldered first, followed by the remaining stages. Each stage was soldered one after the other, and after each stage, testing was conducted to confirm its functionality. The microcontroller (PIC16F84) and decoder (HT8870) were not connected straight to the Vero board. Rather, the decoder and microcontroller ICs were placed into 14- and 16-pin IC sockets that had been soldered beforehand. as seen in figure 7.

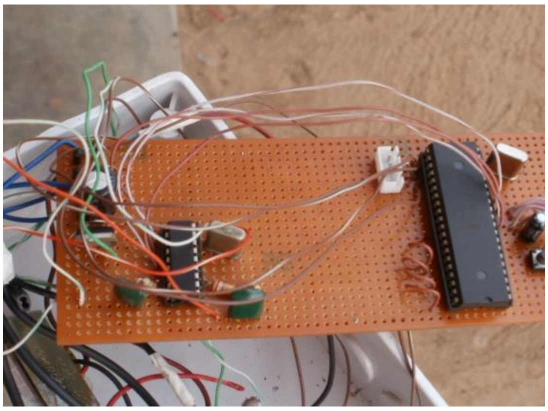

Figure 7: Microcontroller with other Components on Construction Board

4.1.1 Building The Power Supply and Interfacing the Relay

A 220/9V 300mA 50Hz transformer, a 1000µF, 25V capacitor, a bridge rectifier, and a L7805CV 5V voltage regulator were used to build the power supply. The transformer's 9V secondary side was connected to the input pins of the bridge rectifier, which received alternating power, while the primary side was connected to a 220V AC mains. The 5V voltage regulator receives the DC output generated by the bridge rectifier. This regulator guarantees a steady and reliable 5V provision for both the PIC16F84 microcontroller and the MT8870DE DTMF decoder.

The relay operates on a 12V supply, whereas the other components utilize 5V DC. The power supply segment adopts a linear configuration, comprising a step-down transformer, filtering capacitor, and voltage regulator to deliver the required voltage levels. The diagram is shown in figure 8.

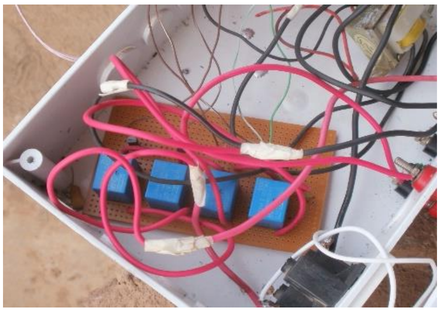

Figure 8: Power Supply and Relay Connection

4.2 The DTMF Detection Unit

The system in this study was able to translate DTMF signals sent by the user via a house phone into BCD digits by using an MT8870 DTMF decoder. The 4–16-line decoder/demultiplexer then receives these digital codes as input and uses them to pick the appropriate output from one of the 16 output lines. It requires inversion to provide a logical high output since it is an active low output integrated circuit. A hex inverter (IC 7404) is used to accomplish signal inversion. The DTMF detecting device is set up as shown in Figure 4.3. To complete its internal clock circuit, an ordinary television color burst crystal or ceramic resonator resonating at 3.579545 MHz is incorporated. The TOE bit indicates the presence of dial tones, and the output pins Q4, Q3, Q2, and Q1 are associated with the particular dial tone that the phone system has detected.

4.3 Principle of Operation

Upon connecting the GSM-based household power management system to the mains supply, the 220V AC input is stepped down to 12V AC by transformer T1. The bridge rectifying diode then converts this AC voltage to DC, which is subsequently filtered by capacitor C5 for smoother output. Finally, the voltage regulator regulates this voltage to a steady 5V, providing the necessary power for both the DTMF decoder and the microcontroller in the system.

This circuit allows a mobile phone to be remotely controlled via another phone by dialing its SIM number. When the caller presses '1', a DTMF tone is sent, activating the circuit. The signal is filtered and decoded, triggering a microcontroller to turn on a transistor, which in turn activates a relay, supplying power to a load. Pressing '0' deactivates the circuit, turning off the load.

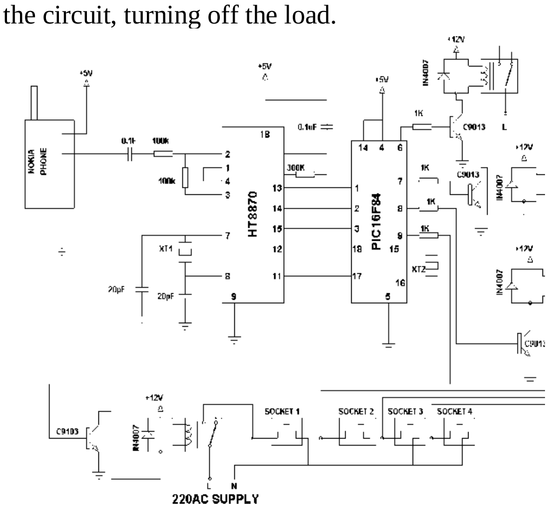

Figure 9: Comprehensive Circuit Diagram of the System

Table 1: Bill of Engineering Measurements and Evaluation BEME

S/N	Component	Quantity
1	Crystal Osc 11.98MHz	2
2	Crystal Osc 5.96MHz	2
3	192 inch 6029 Cable	1
4	Resistor	8
5	Relay	6
6	2N222 Transistor	4
7	LEDs (red, blue, white)	1 + 1 + 1
8	Power Plug	1
9	Casing BS4607	1
10	Socket	2
11	Screws (0.5inch-2inch)	4
12	Power Cable	1
13	Socket and Flex	2
14	Transformer 9V 300mA	1
15	MT8870	1
16	Diode (IN4814)	12
17	Electrolytic Capacitor (47uf, 100uf, 0.1nF, 10uf, 0.01uf	2+2+2+2+2
18	Interface Output	2
19	Power LED	2
20	Connecting Wire	5 rips
21	Variable Resistor	1
22	Output Socket	2
23	PIC16F84 Microcontroller	1
24	Reset Button	1
25	L7805CV Regulator	1
26	NOKIA 107	1
27	Labour	1
27	Miscellaneous (15%)	
	Total	

4.4 Operation of Remote Control of Home Electrical Sockets

The system features a SIM card installed in the connected phone. When a user calls the phone number associated with the SIM card, the system answers automatically and awaits a command input from the user. Pressing '1' activates the third socket, pressing '2' turns on the second device, and pressing '3' simultaneously activates both the second and third sockets. The system offers additional control options, such as pressing '4' to activate the first and fourth sockets, '5' to turn on the first, third, and fourth sockets, and '6' to power the first, second, and fourth sockets, respectively. Pressing '7' activates all four sockets, while '8' deactivates them all. Although the system is designed to control four devices, it can be expanded to accommodate more by incorporating additional relays and updating the equipment control code sequence. Furthermore, implementing a password protection feature can enhance the system's security, safeguarding it from unauthorized access.

The fundamental concept of the system hinges on the ability of Dual Tone Multi-Frequency Integrated Circuits (ICs) to both produce DTMF signals corresponding to keypad numbers or codes and detect those same numbers or codes from the received DTMF signals. In the transmitting part of the system, a DTMF generator creates two frequencies associated with each keypad number or code. These signals are then sent through communication networks, essentially functioning as a mobile phone. On the receiving end, the DTMF detector IC (such as MT 8870) identifies the transmitted number or code by analyzing the two received frequencies. By identifying the specific button pressed, the IC converts the DTMF signal into a digital equivalent, allowing the system to perform the intended action based on the received input.

4.5 The Control Unit

The control unit comprises four main sections: device status check, device switching, device status feedback, and relay driver circuit. To avoid confusion regarding a device's current status before turning it on or off, the device status check section verifies the status of any device by feeding the inverted output of the BCD decoder (representing the user's input) and the output line of the respective device (from the relay circuit) into independent AND gates. The output of these AND gates is connected to a beep tone generator (B), which produces an audible beep if the device is in the ON state. The L7805 IC is utilized in this project to provide multiple two-input positive AND gates. After confirming the device status, the tri-state buffer mode can be altered by setting the control input to high. This is achieved by pressing the '0' key, which causes the output of the 4–16-line decoder to go low, enabling the system to perform the desired operation.

4.6 Performance Metrics and Hardware Testing

Comprehensive testing was performed on each circuit diagram module, and notable results were achieved for the overall system. The system's unique features allow end-users to conveniently control and isolate tasks using a mobile phone. By pressing specific buttons, users can easily manage various operations remotely, enhancing the system's functionality and flexibility in a range of applications.

4.6.1 Software Environment

The program of the remote control of home electrical sockets, controls the entire operation of the circuit. It is written in C programming language and compiled using Keil Micro Vision. The compiled program is transferred into the microcontroller with a programmer called UNI PRO 10U PROGRAMMER. The function of the device can easily be modified by adjusting the program in the microcontroller.

Keil Micro Vision provides a single Integrated Development Environment (IDE) to develop code for embedded microcontrollers. It is a Windows-based software development platform that runs on a PC to develop applications for Microchip microcontrollers and digital signal controllers. Some noteworthy features of software include: Large device database for configuring the development tool setting, integrated made facility for assembling, compiling, and linking in an instance, full-featured source code editor with flexible customizable programmer's text editor, simple but powerful source level debugger with high-speed software simulator for 8051 family and ATMEGA devices with peripheral simulation, complex stimulus injection and register logging and lastly it is links to development tools manuals, device datasheets and user's guides. Keil IDE is used throughout the code development process for this project. It is a very powerful C language compiler. Figure 10 and 11 show the environment where C extension file was imported into the Keil Micro-Vision IDE and compiled source code to create HEX file.

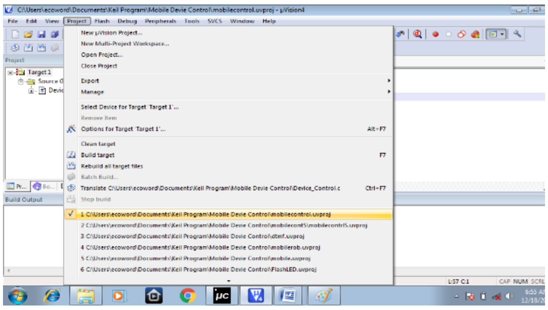

Figure 10: Importing C Extension File on Keil Micro-Vision

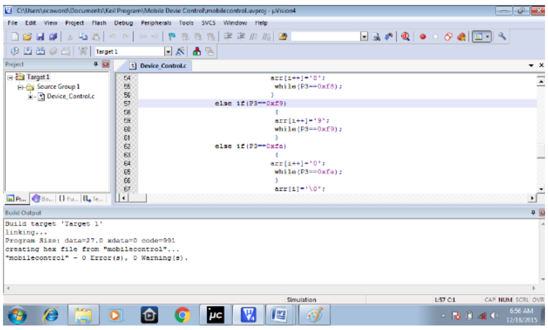

Figure 11: Compiled Source Code to Create HEX File

4.6.3 Testing the Complete Design

Once the hardware components were successfully assembled, the system underwent a series of comprehensive tests to evaluate its performance and functionality. The system may encounter an issue if the phone is connected after powering it, even with a reset attempt. This is caused by residual signals from the system to the phone that interfere with subsequent signals, despite reconnecting and resetting the system. To avoid this issue, it is recommended to connect the phone first before powering the system. However, this limitation was not a major concern during the design process, as the system was intended to have a permanently connected phone, effectively eliminating the possibility of encountering this issue under normal operating conditions.

In creating the system's casing, priority was given to protecting it from physical strain and stress during transportation and project demonstrations. A transparent plastic material was chosen over breakable glass, flimsy paper, or heavy and expensive metal options. This plastic material provides adequate protection while keeping the design economical, lightweight, and visually appealing. The casing was also constructed to enable easy detachment of the entire circuit board from the system when necessary. Figures 10 and 11 showcase the completed home electrical socket testing and the finalized system design, while Table 2 presents the output results of the prototype implementation.

Figure 10: The Home Automation System Project Testing

Figure 11: Complete Control Home Automation System Packaged Project

Table 2: Prototype Implementation and Testing Result

S/N	INPUT DIAL TONE	OUTPUT Q4	Q3	Q2	Q1
1	1	0	1	0	0
2	2	0	0	1	0
3	3	0	1	1	0
4	4	1	0	0	1
5	5	1	1	0	1
6	6	1	0	1	1
7	7	1	1	1	1
8	8	0	0	0	0
9	9	0	1	0	0
10	0	0	0	1	0
11	*	0	1	1	0
12	#	1	0	0	1

5.0 Conclusions

Home entertainment systems, air conditioning systems, lighting systems, and many more have all used the designed home electrical sockets, which have undergone extensive testing and certification to control various home electrical sockets (so long as the appliance's maximum power and current rating does not exceed that of the used relay).

However, it is recommended that:

(i) In our current system, we didn't utilize any applications on the control mobile device. However, for future improvements, it would be beneficial to create programs for mobile devices to offer additional control options and enhance security measures. We recommend enhancing the system by leveraging more functions of the microcontrollers to increase reliability and control capabilities. This includes incorporating features such as temperature regulation, enhanced security measures, and additional computational tasks, allowing the system to perform tasks beyond simple device activation and deactivation.

(ii) Moreover, to reduce expenses on mobile phones, the project could be executed utilizing standalone GSM modems, which are dedicated to specific functions such as text messaging or automatically answering phone calls. These GSM modems are frequently more economical and dependable compared to GSM mobile phones.

(iii) Ultimately, this home automation system can also be deployed using a combination of Bluetooth, Infrared, and WAP connectivity without significant alterations to the design, while still retaining the capability to control a diverse range of home appliances. Therefore, this system exhibits scalability and adaptability.

(iv) The system stopped responding after approximately four loop cycles, corresponding to four successive switch toggles. This issue stemmed from buffer overflow on the microcontroller, preventing it from processing new data transmitted by the phone following those cycles.

Declaration of conflict of interest

The authors have collectively contributed to the conceptualization, design, and execution of this journal. They have worked on drafting and critically revising the article to include significant intellectual content. This manuscript has not been previously submitted or reviewed by any other journal or publishing platform. Additionally, the authors do not have any affiliation with any organization that has a direct or indirect financial stake in the subject matter discussed in this manuscript.

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