Advanced Remote Robotics: Mobile Phone-Controlled Solar-Powered System with Intelligent Navigation for Surveillance, Security, and Rescue Missions

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Abstract: This research aims at developing a robotic system that utilizes mobile phones and dual-tone multi-frequency (DTMF) technology for remote control. The system addresses the limitations of current radio frequency (RF) circuits by offering robust control, a wide operating range, and multiple control options. The proposed system integrates various hardware components, including a mobile receiver, DTMF decoder, microcontroller, camera unit, motor driver unit, sensors, firing mechanism, mechanical arm, solar panel, and battery. The mobile receiver captures DTMF signals from the user's mobile phone, which are then decoded by the DTMF decoder. Acting as the central control unit, the microcontroller connects and controls all system components. The camera unit enables live video streaming, and the motor driver unit simplifies DC motor control. Sensors detect incidents and trigger appropriate actions and the firing mechanism and mechanical arm facilitate targeting, shooting, and object manipulation.

The system receives DTMF signals, verifies the password, and executes commands. It controls robot movement, records movements, activates the auto-retrace mode, aims and shoots with the revolver, and picks up and relocates objects with the mechanical arm. Incidents are detected by sensors, which trigger appropriate responses. The system utilizes a GSM network to track its location on Google Maps. This research presents a versatile robotic system utilizing mobile phones, DTMF technology, and embedded technology principles. It offers remote control capabilities, robust control, and a broad operating range, making it well-suited for applications in surveillance, security, exploration, and rescue missions.

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1. INTRODUCTION

Robots are electromechanical machines or devices that use computer programming or electronic circuitry to perform a variety of tasks. Scientists have consistently developed new concepts and inventions in robotics over time. Robots have become a vital and integral part of human life in today's society (Shift et al., 2014). The ability of robots to carry out diverse tasks under computer programming and wireless control from remote locations provides immense benefits. Robotic technology enables automation in a variety of fields, including hospitals, offices, and factories. It is additionally utilized in defense forces, entertainment, space exploration, security systems, and dangerous mission execution (Kaur & Kumar, 2014).

Humans cannot always be employed to gather information from remote and dangerous locations. Robots aid in outdoor and indoor surveillance, monitoring key locations and reaching suspicious areas for close observations. They help save human lives by eliminating the need for individuals to enter hazardous and dangerous environments (Rao et al., 2019).

The anti-terrorist robot integrates DTMF operation, a mobile camera, a revolver, and a laser gun to combat terrible terrorist attacks. Due to its small size, the robot can easily infiltrate enemy sites, enabling the identification of enemy positions. It is equipped with a laser gun for neutralizing terrorists, as well as a metal detector for bomb detection (Dhande et al., 2023). Additionally, the robot is fitted with an arm capable of handling objects during rescue operations (Zaman et al., 2015).

Spy robots have a wide range of applications, including gathering sensitive intelligence and carrying out covert missions. Equipped with appropriate sensors and cameras, these robots can be remotely operated for tasks such as reconnaissance and patrolling. They can transmit captured videos and images wirelessly back to the operator (Maheshwari et al., 2015).

However, the current radio frequency (RF) circuits used for controlling robots remotely have some drawbacks, such as limited frequency range, operating distance, and control precision (Sanchit et al., 2022). To address these limitations, this paper presents a new approach for controlling robots using mobile phones and dual-tone multi-frequency (DTMF) technology. The DTMF-controlled robot utilizes mobile DTMF technology based on dial tones. The DTMF controlled robot utilizes the DTMF technology, which is based on dual-tone multiple frequencies. By combining specific frequencies, DTMF tones are generated. In this technology, 8 different audio frequencies are assigned to the rows and columns of a keypad. Pressing a key creates a tone by combining the high and low frequencies associated with that key (Sifat et al., 2014).

The proposed approach enables users to remotely operate robots by sending DTMF signals from their mobile phones' keypads, providing robust control, a wide operating range equivalent to the telecom coverage area, and up to twelve to sixteen controls without interfering with other controllers. (Callahan, 1979) (Nayem et al., 2018). This research aims to improve the quality of device operation, reduce time consumption, and increase overall efficiency by utilizing microcontroller features, embedded technology concepts, and mobile communication systems.

The novelty of this study lies in the application of DTMF technology, embedded technology principles, and mobile communication systems to control robots, resulting in a versatile and powerful tool for delivering services from any location at any time. The multisensory robot is designed to detect humans, noxious gases, bombs, metals, and fire in remote and war-torn areas, as well as provide assistance in terrorist arrest and rescue operations. (Kaur & Kumar, 2015).

The proposed system is an intelligent and efficient one that integrates motion sensors, light-dependent resistors (LDR) for security and exploration purposes, a camera for video calling, and a solar panel for uninterrupted power supply (Zadid Shifat et al., 2014). Furthermore, the system includes a weapon for military operations, and it can retrace the robot's path and display it on a map using GSM networks, adding a unique and valuable contribution to the research (Ranjan et al., 2022).

2. MATERIALS AND METHODS

The technical design and operation of the proposed and implemented system can be divided into design and operation sections to describe the system.

2.1 Design and framework of hardware subsystem

The hardware of the system can be divided into several parts. All parts are described in several subsections.

2.1.1 Mobile Receiver and DTMF decoder

The mobile receiver is connected to a DTMF decoder MT8870 via an audio jack. The DTMF decoder converts analog signals into binary digits. DTMF uses eight different frequency signals transmitted in pairs to represent sixteen numbers, symbols, and letters. When a key is pressed on the handset, a unique DTMF signal is generated, consisting of two frequencies - one in the higher frequency range (>1KHz) and the other in the lower frequency range (<1KHz). The resulting tone is a convolution of these two frequencies. The frequencies and their corresponding frequency are shown in Table 1

Table 1: DTMF keypad and associated frequency (Rashid et al., 2016)

Frequency	1209 Hz	1336 Hz	1477 Hz	1633 Hz
679 Hz	1	2	3	A
770 Hz	4	5	6	B
852 Hz	7	8	9	C
941 Hz	*	0	#	D

The DTMF signal is generated by combining two pure sine waves of low and high frequencies that are superimposed on each other. Each of these tones represents a specific digit on the telephone keypad. Mathematically, the generated DTMF signal can be expressed as follows (Rashid et al., 2016):

$$x(t)= A_H(\text{Sin } 2\pi f_H t)+ A_L(\text{Sin } 2\pi f_L t)$$

Where x (t) represents the DTMF signal waveform.

A_H and A_L are the amplitudes of the two sinusoidal tones.

f_H and f_L are the frequencies of the high and low tones, respectively.

t represents time.

The MT-8870 is a DTMF Receiver that combines band split filter and decoder functions into a compact 18-pin DIP package. It is fabricated using CMOS process technology, offering low power consumption (maximum 35 mW) and precise data handling capabilities. The decoder in the MT8870 utilizes digital counting techniques to accurately detect and decode all 16 DTMF tone pairs, providing a 4-bit code output as shown in Figure 1. The system picks up the DTMF signal from the user's mobile phone via the tip and ring of the microphone, and specific resistors and capacitors are used for gain control and setting the "guard time" for accurate tone recognition. The "Q-test" signal (pin 15) indicates the detection of a valid DTMF tone.

2.1.2 Microcontroller (MCU)

The Atmel ATmega32A is an 8-bit microcontroller based on the AVR enhanced RISC architecture, designed for low-power applications. With its ability to execute powerful instructions in a single clock cycle, the ATmega32A achieves high throughputs close to 1MIPS per MHz. Our robot employs the Atmega32 microcontroller, connecting it to sensors and other system components. It serves as the central control unit, managing and executing tasks for the entire system. It is interconnected with various sensors and components of the system, allowing it to control all aspects of the robot's operation. The MCU takes input and gives desired commands based on input and direction given by the program.

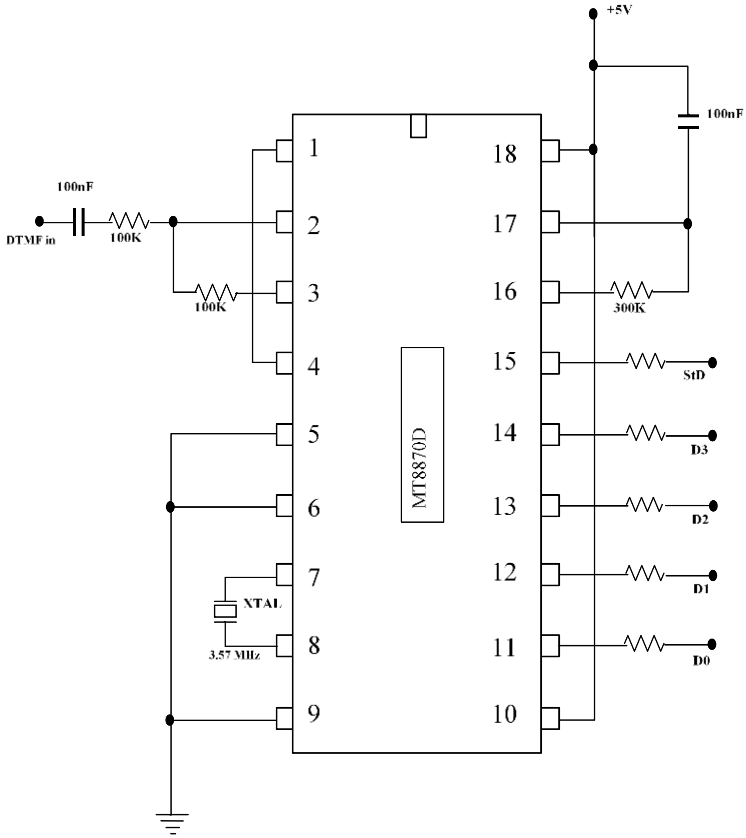

Figure 1: Circuit diagram of DTMF decoder

2.1.3 Camera Unit

The robot is equipped with a camera phone for real-time video streaming, utilizing Skype video calls through internet connectivity. Any smartphone or camera phone supporting video calls can be used with the system. Additionally, IPwebcam software enables video streaming through WiFi. By entering the onboard mobile's IP address into a web browser on a remote internet device, video can be streamed. WiFi connectivity allows control of flashlight, focus, sound, and motion detection, but the range is limited compared to the wider range of robot control through GSM.

2.1.4 Motor Driver Unit

The L293D is a high-current, quad half-H driver designed for bidirectional drive currents up to 600 mA at voltages ranging from 4.5V to 36V. It simplifies the control of DC motors by providing four drivers. Enable pin 1 activates drivers 1 and 2, while enable pin 2 activates drivers 3 and 4. When enabling input 1 is high, the outputs corresponding to drivers 1 and 2 become active. Similarly, enable input 2 enables drivers 3 and 4.

Table 2: DTMF output and robot direction

Key	DTMF Binary Output	Motor rotation	Robot direction
5	0101	Both clockwise	Forward
0	1010	Both anticlockwise	Backward
*	1011	Right clockwise	Left
#	1100	Left clockwise	Right

2.1.5 Sensors

The system utilizes various sensors to detect incidents such as movement, metal, or fire. These sensors provide inputs to the MCU, which triggers appropriate actions.

PIR Sensor

Detects movement and triggers actions accordingly. It is connected with a buzzer and LCD.

Metal Detector

The metal detector detects the presence of metal and triggers actions accordingly. It is linked to a buzzer, which emits a distinct sound when it detects metal, allowing for easy differentiation from other sounds.

Temperature Sensor

The temperature sensor detects excessive heat. If excessive heat is detected, the robot stops moving forward. Temperature Sensor LM35 integrated with flame sensor R2 686 is used to detect fire-restricted areas.

Light Sensor

The Light Dependent Resistor (LDR) senses low light levels, triggering the activation of the flashlight to ensure clear video capture in such conditions.

2.1.6 Firing Mechanism and Mechanical Arm:

The user can activate the firing mechanism by pressing the "3" key when necessary. A laser gun is attached to the system to target objects. The camera captures the location indicated by the laser beam, and with a dedicated key press, the system can fire at the target.

2.1.7 Solar Panel and battery:

The system is powered by solar energy. A 5W solar panel is installed on the robot's roof to charge the 12V battery, providing an extended power supply. A charge controller is included to optimize the charging voltage and current for the battery. The battery stores the solar-generated power and supplies it to the entire system. To power the entire system, a voltage regulator known as the 7805 is employed. This regulator converts the higher voltage to a stable 5V supply. The tilt angle of the solar panel is automatically adjusted to optimize energy capture.

2.2 OPERATION

The mobile receiver is connected to a DTMF decoder MT8870 via an audio jack, which converts the analog signals into binary digits, which are then fed into the input port of an Atmega32. After verifying the password, the MCU sends signals to the robot to control its movement and collect data from several sensors. Additionally, a video call is established between the MCU and the robot. The system detects incidents such as movement, metal, or fire using sensors, and activates a buzzer while displaying the incident on the LCD. If excessive heat is detected by the temperature sensor, the robot stops moving forward. Additionally, the flash light is activated when low light is detected by the LDR. After password authentication, the control key allows the user to move the robot in different directions using 5 for forward, 0 for backward, * for left, and # for right. The robot's movements are stored in an array as "F" for forward, "B" for backward, "L" for left, and "R" for right. When no key press is detected for 60 seconds, the MCU receives an interrupt request and initiates the robot to move in a 360-degree direction based on previously stored data in an array until the array is empty, causing the robot to return to its initial position. During this operation, the MCU suspends the reception of decoder signals until the task is accomplished. The video camera of mobile allows the user to observe the surrounding area and adjust the laser beam towards a particular target. In an emergency, the user can activate the firing mechanism towards the target by pressing the "3" key. By pressing the "9" key on the mobile phone, the system activates a mechanical arm equipped with motors and mechanical structures, allowing it to pick up objects. Repeating the key press causes the arm to release and place the object in a desired location. A GSM network is used to trace the robot's location on a map, ensuring precise incident location. The system is powered by solar energy, and the panel's tilt angle is automatically adjusted by two axis sun tracking system. The system's main algorithm can be comprehended through a flowchart depicting the sequence of operations.

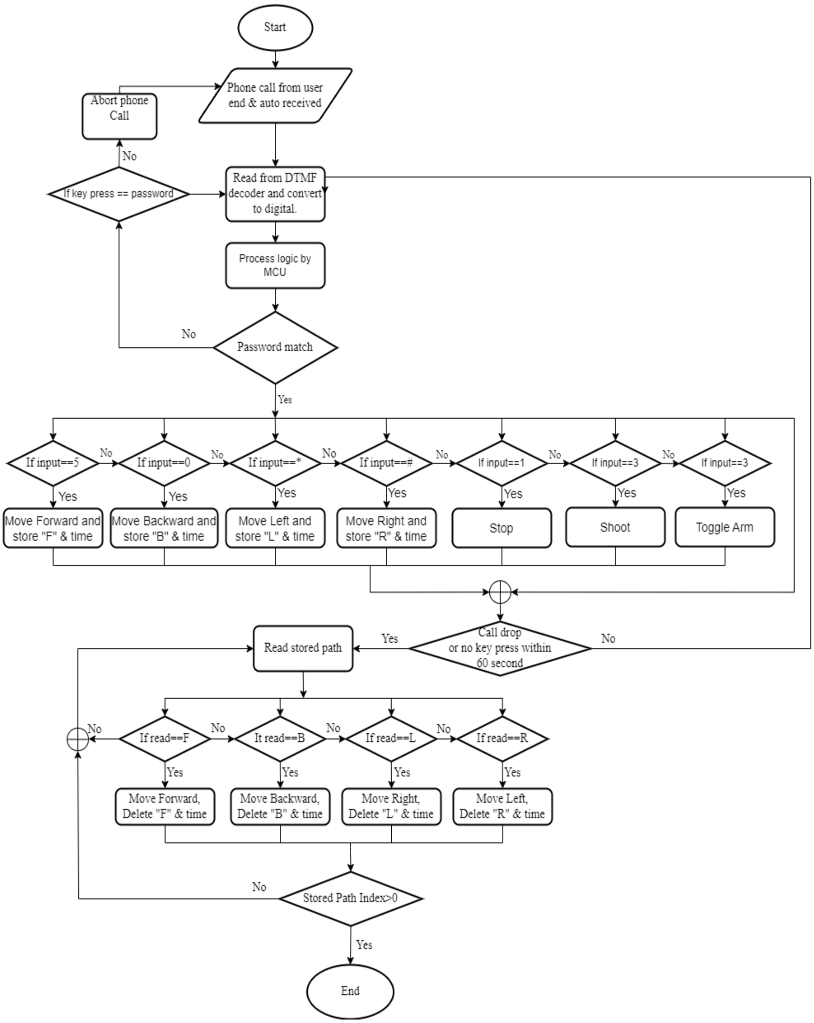

Figure 2: Flowchart of the system framework

3. RESULTS AND DISCUSSION

The explorer robot prototype uses sensors and two mobile devices for transmission and reception. It is capable of effectively receiving phone and Skype calls, enabling video transmission and the transmission of DTMF signals. After establishing a phone call or Skype call with automatic reception, the system verifies the password. If the password matches, the robot accepts commands from the user end. The robot's movement can be controlled by inputting specific keypad numbers on a cell phone, as outlined in Table 1. The Atmega 32 microcontroller interfaces with the DTMF decoder, sensors, and motor driver circuit to control the robot's motors and enable efficient control. The system activates auto-retrace mode if there is no activity for 60 seconds. While traversing the path, it records specific letters corresponding to its movements. Upon entering the retrace mode, it checks the recorded letters and navigates back to its destination point. Utilizing the GSM network, the robot's location can be tracked on Google Maps with the aid of a computer or smartphone.

The robot employs a laser and video camera to target and shoot with a revolver, utilizing the dedicated movement key to aim and the key 3 to fire. The arm is capable of picking and placing objects through a specific key combination. Pressing key 9 opens the arm's jaw to pick up an item, and pressing the same key again enables the arm to place the object. This entire process is monitored by a camera. The keypress and actions executed by the robot are given in Table 3.

Table 3: Commands given and actions taken by keypress and sensor.

Key	Decision Made
78	Password match
5	Forward
0	Backward
*	Left
#	Right
1	Stop
3	Fire with the attached revolver.
9	Toggle between picking and placing object with each key press.

When a fire or a high temperature is detected, the flame and temperature sensors notify and halt the robot. The PIR sensor sensed movement, the metal detector alarmed whenever it found metal, and the LDR triggered the flush light in low-light situations. The working summary of used sensors is given in Table 4.

Table 4: Output of sensor.

Sensor and device	Actions Taken
PIR Reading	When motion is detected, the buzzer alerts and relevant data is shown on the LCD.
LDR	Flush light activated at low light.
Flame sensor	Flame detected and sounds buzzer differently, stops moving forward.
LM35 sensor	Shows temperature and stops moving forward at high temperature.
Metal detector	Sounds buzzer differently.

The robot's batteries and system are powered by a sun-tracking solar panel that adjusts its position for optimal light exposure. The solar panel effectively generates the expected output and charges the battery efficiently. All equipment operated flawlessly, providing accurate information.

V. S. Venkatesan designed a robot with GSM, DTMF and sensors but without video calling and weapons (V. S. Venkatesan., 2014). Kaur implemented a system using a mobile video camera, GSM communication, and solar power, but it doesn't use tracking on maps, retrace algorithms and weapon integration (Kaur, T., & Kumar, D. (2015).

Nayem, Z designed a robot with common features except any weapon attached to it and sun tracking algorithm (Nayem et al., 2018).

Our proposed system incorporates both WiFi and GSM networks, resulting in a significant improvement in the quality of operation. The device's reliability is significantly improved by its ability to track on Google Maps and return to its initial position. The incorporation of sensors, retrace algorithms, sun-tracking solar panels, and the utilization of both WiFi and GSM communication collectively contribute to a reduction in operation time and an overall increase in efficiency when compared to previously developed systems.

4. CONCLUSION

This research paper has presented the design, execution, and testing of a highly versatile low-cost robot that can be operated remotely from anywhere in the globe using a mobile phone, which was successfully executed and met all specified objectives. The robot is password-protected, solar-powered, has a backup battery, and can be tracked on a map, ensuring high security and reliability. It is cost-effective due to renewable energy, DTMF, and a smartphone used as a video camera. The robot's weapon and arm make it perfect for law enforcement, military, and rescue operations where human involvement can be risky.

With its diverse applications, this robot will be an immense breakthrough in the field of robotics and will have significant future development potential.

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6. Declaration about conflict of interest

There is no conflict of interest among the authors to be declared.

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