

Robotic System for Detecting Landmines

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ABSTRACT

Landmines remain a critical humanitarian challenge, causing thousands of civilian casualties each year and obstructing postconflict recovery. Traditional demining methods are slow, dangerous, and resource-intensive, which highlights the urgent need for safer and more efficient solutions. This study addresses the problem by developing a low-cost robotic system designed to detect landmines remotely. The system integrates a Bluetooth-based control application, Arduino microcontroller, ultrasonic sensors for obstacle avoidance, and a metal-detection circuit to identify buried mines. Experiments conducted under controlled conditions demonstrated stable wireless communication, reliable navigation, and clear frequency shifts in the sensing circuit when metallic objects were present. These results confirm the feasibility of using simple, affordable robotics for mine detection. While the prototype is limited by the absence of field testing and sensitivity to environmental factors, it provides a proof of concept with significant potential for future development. Enhancements such as multisensor fusion, autonomous navigation, and machine learning integration could strengthen its accuracy and scalability. Overall, this work contributes to advancing robotic demining technologies and offers a pathway toward safer and more effective clearance of mine-affected regions.

1. Introduction

Landmines pose a serious threat beyond their impact on human life. Many people around the world suffer from landmines that cause disabling injuries or deaths. The populations most at risk from landmines are noncombatants in countries such as Sudan, Palestine, Ukraine, Iraq, Afghanistan, and Syria, which still have active landmines from wartime that have long outlived their purpose but still lie hidden beneath the surface, waiting to take innocent lives. This unintended effect on people living nearby and the mine's inability to discriminate against noncombatants led to the near-global ban on landmines in 1977. Unfortunately, despite this ban, landmines continue to appear in conflict zones around the world. To prevent the maiming and killing of more innocent people, viable solutions are needed for both the detection and removal of landmines from conflict zones around the world.

According to the press service of the State Emergency Service of Ukraine (SESU), owing to Russian military aggression, approximately 30% of the Ukraine territory has been mined, and as of the start of 2023, over 40% of the territory has been mined. The estimated time required for full humanitarian demining of the territory ranges from 5–10 years. During this period, areas that have been mined will severely restrict chances for safe passing, active use for economic processing, or as a spatial foundation, which will considerably slow the rate of economic development and restoration of Ukraine [1].

Manual detection is a very slow and inefficient process. It can take hours to find a small number of land mines. It is estimated that a person can clear between 20 and 50 meters of mined field per day. It is also a dangerous process; deminers can be killed or seriously injured if they make small mistakes during the demining process. One proposed solution is to automate the mine detection process.

For centuries, the idea of a mine was invented in military circles and meant digging a tunnel under enemy fortifications, where improvised explosive devices were placed to destroy these fortifications. The term mine was then used for any explosive device buried directly under the surface of the earth and powered by an explosive device that detonates at the enemy's doses. It was used in World War I (1914–1918) as a means of defense against tanks, and its use led to their development, transforming them into stationary models. Some of them were highly developed, especially after

The manufacture of TNTs, which served as the beginning of the first-generation anti-tank mine industry, became part of the armament of various armies. This was used with great efficiency in World War II, with over 300 million anti-tank mines being used by either the Allied forces or the Axis powers. The place of mines in the arsenals of armies was thus consolidated.

The disadvantage of using mines during World War II was that they were easily detectable due to their large size, and the enemy could easily remove them and confiscate them for their own use. Therefore, the first generation of anti-personnel mines was created, which were planted with anti-tank mines and are auxiliary weapons that work hand in hand with them, ensuring that enemy personnel do not approach the removal of essential mines. The development of mines and their means of detonation continued in the early 1960s and into the early 1970s, the second generation of antipersonnel mines (remotely delivered mines), which could be deployed from long distances using aircraft, especially deep into enemy defenses and behind them, to cause casualties during their retreat and cut off their supplies. It was used by American forces in the Vietnam War, and thousands of them were dropped in Laos, Cambodia, and Vietnam.

Methods of placing and scattering antipersonnel mines continued to develop, and in the 1980s, artillery shells, ground missiles, and aircraft-carried grenades were developed. The detonation methods also evolved to be "electronic and timed." Development included the outer shell of the mine, the explosive materials, and the main filling. With the development of mines, their technology, and their low cost (\$3–30 per mine), with the exception of high-tech mines, "weapons of choice are becoming indispensable in military operations or internal conflicts. In reports by the International Committee of the Red Cross (ICRC), mines have been compared to combatants who do not carry visible weapons but who never miss their target, indiscriminately injure their victims, and continue to kill long after the fight has ended. The natural consequence of the massive expansion in the use of mines, especially antipersonnel mines, and the fact that the terrain is not cleared with sufficient precision has led to an increase in the number of civilian casualties. In World War I, 15% of casualties were caused by mines; by the end of World War II, this percentage had risen to 65% of all civilian casualties during the war.

2. Literature Review

2.1. Types of mines

a) Landmines

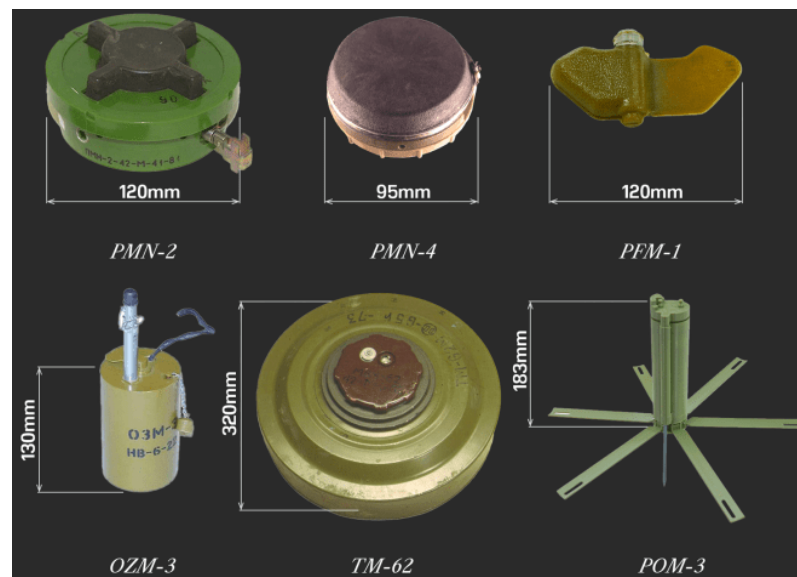


Figure 1 Mine types [2].

- **Anti-personnel mines**

Perhaps this type of mine is not dangerous at all, and this is the fundamental problem. Global agreements have been signed that criminalize the use of anti-personnel mines, but this is still a problem. This is because there are types of mines that have wires connecting them to each other, as there are multiple explosive charges. The location of minefields changes over time because of desert torrents and the movement of vegetation in the area, making it difficult to determine where mines begin and end. An international treaty has been issued to ban the manufacture of antipersonnel mines, but the problem has persisted in most parts of the world.

- **Anti-tank**

These mines are usually designed to repel tanks (see Figure 1). They usually explode if their weight is greater than 150 kg, so it is possible for soldiers and individuals to pass over them safely without exploding. They also explode if many personnel carriers pass over them.

- **Chemical mines**

They release poisonous gas when they explode. This kills or infects soldiers who are not wearing protective clothing.

- **Controlled mines**

They are planted in their designated position before combat. They explode via remote control when enemy forces approach them.

- **Nuclear mines**

Contain small nuclear devices, which are used to blow up concrete bridges or block mountain passes. Such tasks require several tons of conventional explosives, but nuclear mines are so small that they can be carried by two people or transported inside a car.

- b) **Naval mine**

Naval mines used as anti-submarine and boats, cruisers, and naval explode during a certain time or go off when you approach it or collide with it.

2.2. Mine clearance

Mine clearance is the process of removing mines placed in the ground. A similar term for mine clearance is called preclearance, which is the process of detecting mined sites. There are two types of mine clearance that are carried out for different purposes and in different ways (humanitarian and military).

The tools used for mine clearance are numerous, and their historical sweep and discovery have included methods based on trained animals such as dogs and rats; however, most demining operations are now carried out with metal detectors and special vehicles with many mechanical machines, and many strange methods have been suggested and attempted, such as the use of bacteria and acoustic waves.

2.3. Military demining

In combat zones, demining is carried out militarily, usually by combat engineer units in the army (a branch of military engineering units). Unlike humanitarian mine clearance, the highest priority in military mine clearance is opening a safe route through which soldiers and vehicles can pass without being injured. Because time is essential during wartime, the speed at which this route is opened is very important, as speed is important for tactical reasons and the units that need to cross the minefield may be under enemy fire. In such cases, there is a strong need for both pedestrian protection and vehicle clearance.

Military officers of combat engineers may request that they come to clear mines at any time, including in weather conditions and at any time interval, which may expose combat engineers to serious dangers. Sometimes, a military command may accept a mine clearance operation even if it is expected to cause casualties. In some cases, it is also acceptable for the demining process to be quick and inaccurate so that casualties are expected as a result of undetected mines. However, the task of removing military mines can be easier than removing humanitarian mines because, in this case, engineers are dealing with newly planted minefields, so their reactions can be easily predicted, and their locations, which have not changed owing to wind and soil movement, are predictable. In general, military demining operations tend to rely on faster means of clearance but at the same time are less accurate.

2.4. Humanitarian demining

When demining is carried out after wars and conflicts have ended, it is called humanitarian mine clearance (see Figure 3). This is usually a comprehensive demining process, requiring considerable time and effort to ensure that all mines placed on land or at sea are removed, and it is essential that the process be accurate and complete (see Table 1). Any lack of precision in the process—even if only a few mines are left behind—would actually cause an increase in human casualties, as civilian analysts would previously have avoided the area but, after clearance, would return freely, believing it to be safe. In areas where former military conflicts have taken place, materials known as explosive remnants of war, such as unexploded ordnance and landmines, are often scattered [2].



Figure 3: Map of countries that have signed the Ottawa Treaty.

Table 1 Landmine clearance in Sudan between 2011 and 2015 (km2) [3].

Year	Area cleared	Released by NTS & TS	Total area released
2015	0.42	0	0.42
2014	2.47	1.18	3.65
2013	0.77	9.16	10.38
2012	0.55	0	0.55
2011	1.49	0.15	1.64
Total	5.7	10.49	16.64

3. Methods

3.1. Communication phase

In the communication phase, the robot can be controlled in two ways: through a Bluetooth remote-control application or through infrared remote control. In this work, the main focus is on the Bluetooth remote-control application (TSCINBUNY), which connects to the BT05 Bluetooth module (see Figure 2) installed on the robot. After installing the application and pairing it with the BT05 sensor, the connection is configured by selecting the ZYC0098 option, which then provides access to the control panel for operating the robot. This setup enables a reliable and efficient wireless link between the application and the Arduino microcontroller, allowing full remote control of the robotic vehicle.

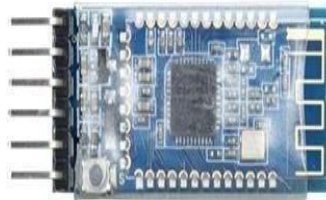


Figure 2 Bluetooth module.

Getting Bluetooth Basics for your project Bluetooth allows devices to communicate with each other wirelessly over short distances via radio waves [4]. It is very common in everything ranging from telephones to medical devices. About setting up Bluetooth in our car: Comes with a BT05 Bluetooth module that includes a dedicated remote control app. Important note about the connection: the module has 4 pins - connect them correctly or they can get damaged! The app gives you wireless control - perfect for controlling your project from a phone or tablet. The connection between the Bluetooth module and our main board is shown in Table 2.

Table 2 Bluetooth module configuration.

Bluetooth Module	Main board (Arduino)
RX	TX
TX	RX
GND	G
VCC	V

Arduino (see Figure 3) is used because of its reliability, affordability, and superior compatibility with a variety of sensors needed for mine detection; thus, we chose to use the Arduino Uno development board for this project. With its 14 digital input/output pins, 6 analog inputs, and 16 MHz operating frequency [5], this board, which is based on the ATmega328P microcontroller, provides enough features to meet the requirements of the proposed system. To transmit commands to the motors according to the sensed environment, Arduino Uno was responsible for collecting and processing signals from proximity sensors installed on the robotic vehicle. The Arduino IDE development environment allows code to be written in a simplified C/C++ language that is easy to test and adapt. In addition, the board was very useful in the prototyping phase, allowing rapid changes to the software and hardware configuration. The Arduino Uno was successfully integrated into this project and suited the needs of the application well because of the extensive online community and resources available.

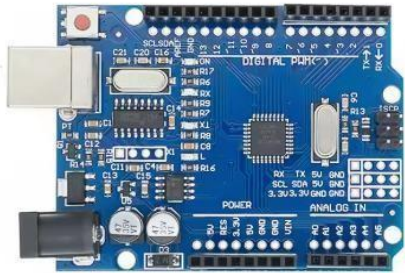


Figure 3 Arduino Uno.

This includes a motherboard that incorporates the infrared modules and the motor driver, and its pins, including those of the Bluetooth module, are neatly arranged and wrapped and an LED indicator.

3.2. Building the robotic machine

All the components necessary for mine detection, including sensors, a control board, and a power supply, are mounted on the robotic vehicle, which serves as the main mobile platform of the project. Its four-wheeled chassis, powered by DC motors, provides stability and the ability to traverse fairly rough terrain. The vehicle's (see Figure 4) lightweight and modular design enabled the efficient integration of all the mechanical and electronic components. An Arduino Uno board coordinates the control system, processes sensor data and sends commands to the motors so that the car can move completely or partially on its own. In addition, the vehicle is easily scalable, allowing the addition of new functions such as wireless communication modules, video cameras or more sensors. The robot maneuvered under controlled conditions throughout the test phase, avoiding obstacles and mimicking the detection of potentially dangerous objects below ground level.



Figure 4 Robotic machine.

For low-power robotic applications, the TMI8549 (see Figure 5) motor driver is the perfect integrated circuit for controlling DC motors. By changing the direction of the electric current, this driver, which operates on the basis of the H-bridge concept, allows the direction of rotation of motors to be adjusted. The chip is safe and reliable for embedded applications, as it can control two motors simultaneously and has built-in protection against short circuits, overheating and excessive voltages. TMI8549 receives logic input signals from a microcontroller.

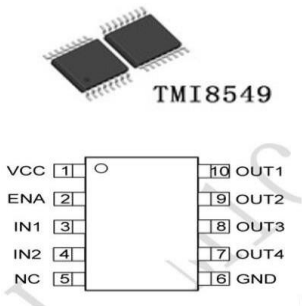


Figure 5 TMI8549.

The motor driver module includes ten pins, each serving a specific function block diagram, as shown in Figure 6. The Vcc pin (Pin 1) supplies the operating voltage, which is stabilized with a capacitor connected to the ground. Pin 2 (ENA) enables or disables the device; when it is low, the driver enters standby mode, and when it is high, it activates the output stage, also supporting PWM input with a built-in 100 k Ω pull-down resistor. Pins 3 (IN1) and 4 (IN2) are control inputs that determine the behavior of the output channels (OUT1–OUT2 and OUT3–OUT4, respectively), which are both capable of receiving PWM signals and equipped with internal pull-down resistors. Pin 5 (NC) is not connected, whereas Pin 6 (GND) provides the ground reference. The output stage consists of four pins: OUT1 (Pins 10) and OUT2 (Pin 9) form one motor coil connection, whereas OUT3 (Pin 8) and OUT4 (Pin 7) form the second motor coil connection, enabling bidirectional control of two DC motors.

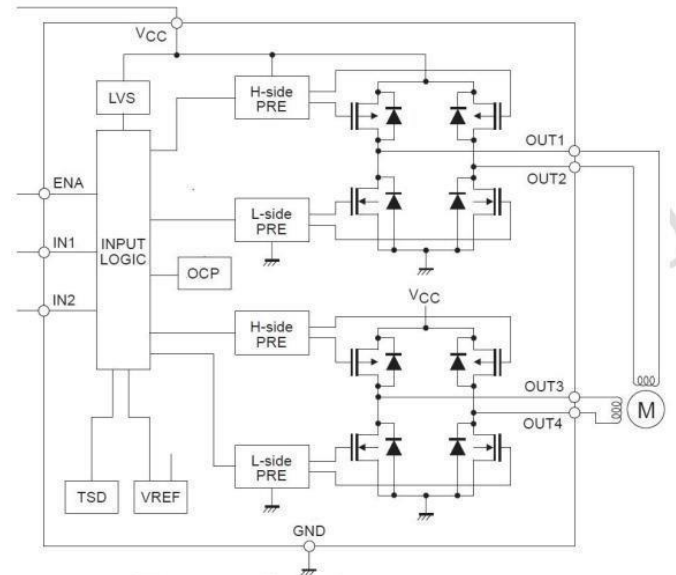


Figure 6 TMI8549 block diagram.

The motor wiring of the robotic vehicle is based on a dual H-bridge driver that connects the motor coils to the output pins of the control circuit, allowing precise bidirectional control. By adjusting the input signals through the PWM, the motors can be commanded to move forward, backward, left, or right, enabling flexible navigation over the testing terrain. To enhance autonomous operation, an ultrasonic sensor (HC-SR04) is integrated for distance measurement. This sensor emits high-frequency sound waves that reflect nearby obstacles, and by calculating the time interval between emission and reception, the system determines the distance with good accuracy. The microcontroller processes this feedback and adjusts motor motion accordingly, allowing the robot to avoid collisions while maintaining smooth navigation during the mine detection process (see Figure 7).

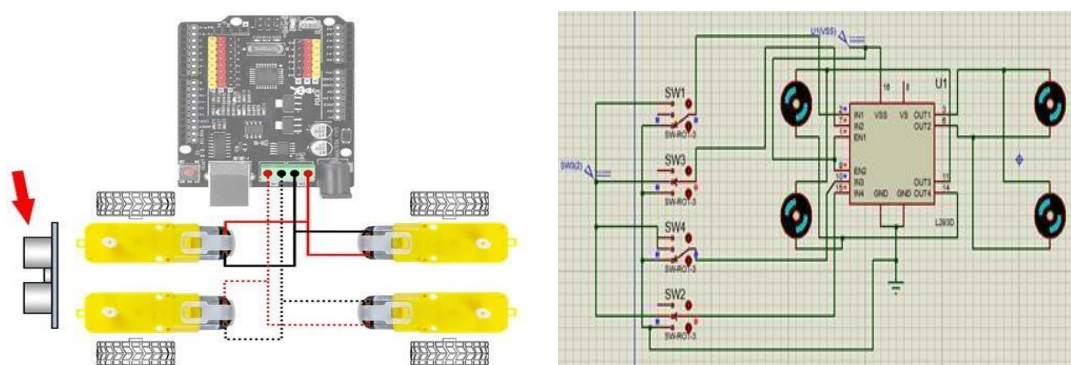


Figure 7 Motor wiring and motion diagram.

There are numerous methods for distance estimation via ultrasound. The ultrasonic module (see Figure 8 and Table 3) measurement principle of this system is to measure the time it takes for an ultrasonic wave to travel from the ultrasonic emitter through the gaseous medium to the receiver, multiply this time by the speed of sound in air, and calculate the propagation distance of the sound. The MCU starts timing at the same time that the ultrasonic transmitter sends ultrasonic waves in a specific direction. The ultrasonic waves are sent into the atmosphere and instantaneously return when they encounter obstacles, and the ultrasonic receiver immediately stops timing upon receiving the reflected waves. The distance (s) between the launch point and the obstacle can be calculated via the T recorded by the chronometer.



Figure 8 HC-SR04 ultrasonic module.

Table 3 HC-SR04 specifications [6].

specifications	
Operating voltage	DC-5 V
Operating current	15mA
Operating frequency	40KHz
Distance	2 cm ~400 cm
Measuring angle	15 °
Input trigger signal	10 USTTL pulses
Signal echo output	Output TTL level signal, proportional to the range

To obtain a DC bias voltage for the SG90 servomotor (see Figure 9), the control signal crosses the channel and reaches the receiver of the signal modulation chip. Its internal reference circuit produces a reference signal with a width of 1.5 ms and a period of 20 ms. The obtained DC bias voltage is compared with the potentiometer voltage to provide a voltage difference output.



Figure 9 Servomotor SG90.

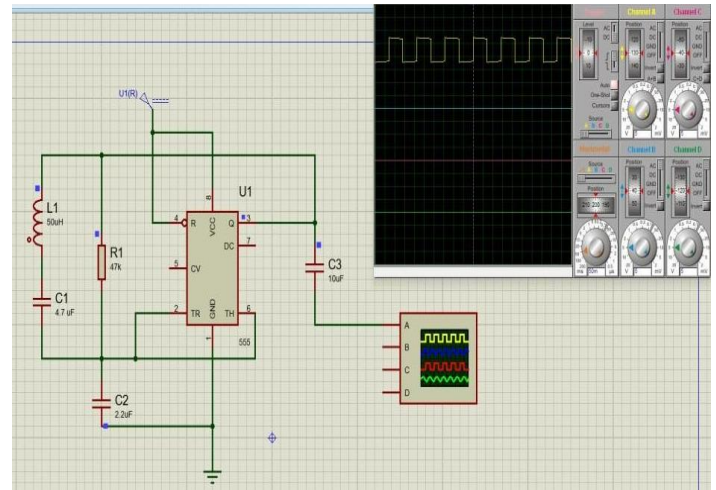
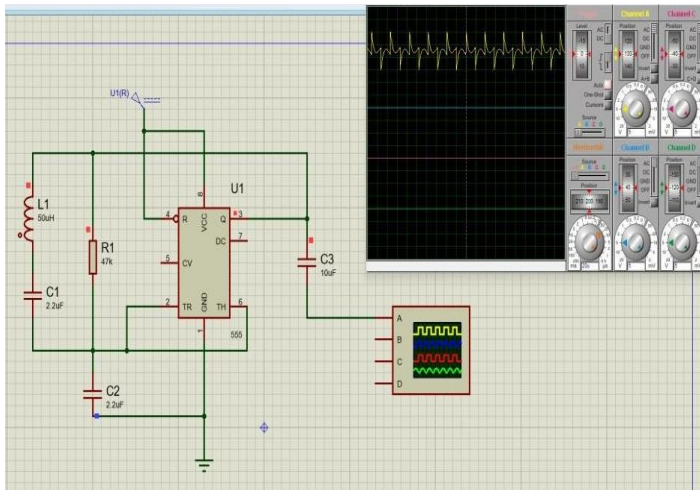
As a common voltage comparator in embedded systems, the LM393 module converts changes or thresholds of analog signals into digital outputs that the microcontroller can easily understand. Its foundation is the LM393 integrated circuit, which has two separate high-precision comparators that can operate at low voltages and react quickly to changes in input signals. The LM393 module (see Figure 10) was used in the current project to read signals from sensing sensors, such as vibration or infrared sensors, and translate them into a digital signal (0 or 1) that the Arduino Uno board can handle immediately. The ability of this module to change the sensitivity threshold via a built-in potentiometer, which allows the operation to be adapted to the type of surface or environmental conditions, is a significant advantage. As a result, LM393 greatly reduces the possibility of false signals or interpretation errors while increasing the accuracy of the mine detection system.



Figure 10 LM393 modules.

The medium can be detected by the light of the induction module. It consists of two infrared transmitter and receiver tubes. The reflected infrared frequency signal is received by the infrared receiver tube when the sensing direction encounters an obstacle. The indicator light is turned on, and the signal output interface outputs a digital signal (low-level signal) after processing by the comparison circuit. It has a working voltage of 3.3 V to 5 V, an effective sensing range of 2 to 30 cm, and features such as minimal interference, simple assembly, and easy operation.

3.3. Sensing phase



This phase refers to metal detection. This phase considers the detection circuit with all its details. First, a quick overview of the components needed to realize detection is essential. In the sensing circuit, the NE555 timer IC functions as a square-wave generator, producing pulses at audible frequencies. The key element of this circuit is an air-core inductor, which is wound from 10 meters of enameled copper wire into 24 turns with a diameter of approximately 1.5 cm, resulting in an inductance of approximately 50 μH . Together with a 47 k Ω resistor and a 2.2 μF capacitor, the inductor forms an RLC circuit that serves as the metal-detection unit. The circuit was modeled and tested via Proteus simulation software (see Figure 11). Under normal conditions, when no metal is near the coil, the RLC circuit maintains a stable impedance and frequency, which is considered the reference signal by the microcontroller. However, when a metal object is brought close, it acts as a core for the air-core inductor, significantly increasing its inductance and altering the reactance of the RLC circuit. This change causes a shift in the output frequency compared with the baseline signal, which the microcontroller interprets as the presence of metal. The wiring of the circuit follows the standard NE555 configuration: pins 2 and 6, as well as pins 4 and 8, are paired together, Vcc (9 V) is applied to pin 4, and GND is connected to pin 1. The resistor is placed between pins 2 and 3, one capacitor is connected between pins 1 and 2, and the inductor and the second capacitor are connected between pins 2 and 3, completing the sensing arrangement.

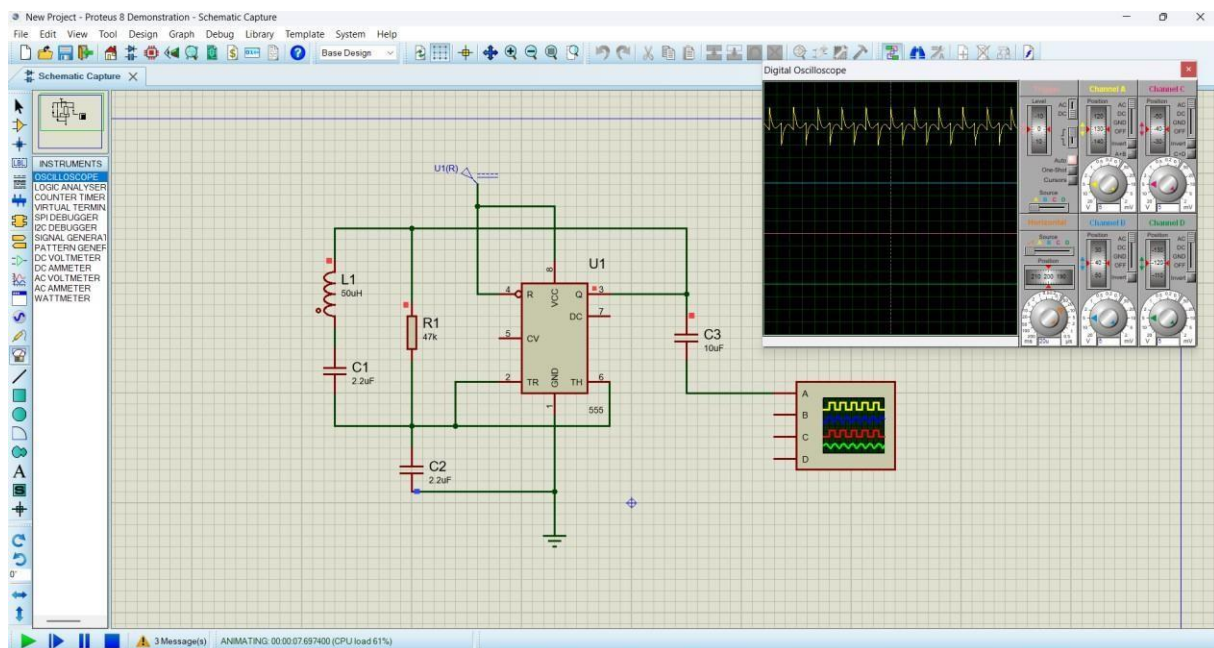


Figure 11 Sensing circuit simulation.

4. Results & Discussion

The first stage of the experiments focused on the communication circuit, which ensured reliable interaction between the user and the robotic vehicle through the Bluetooth module. The robot responded accurately to directional commands from the control application, successfully moving forward, backward, left, and right as instructed. More advanced commands, such as continuous rotation when the northeast or northwest indicators were pressed, were also executed smoothly, confirming that the wireless communication was stable and efficient. This validates the integration of the BT05 Bluetooth module with the Arduino Uno microcontroller as a cost-effective and reliable method for remote robot navigation (see Figure 12).

In the second stage, we evaluated the first version of the metal detection circuit, which was designed with a 50 μH inductor and a 2.2 μF capacitor. The results showed that the circuit was capable of detecting metal objects at various distances, with the output frequency decreasing proportionally as the target approached the sensing coil. For example, the baseline frequency of 68.299 kHz decreased to 66.185 kHz when the metal was 6 cm away and further decreased to 60.845 kHz when the distance was only 2 cm. When the metal was in direct contact with the inductor, the output decreased to 58.448 kHz, demonstrating clear sensitivity to metallic interference. Although this first circuit successfully detected proximity, the output waveform was less stable, which suggested a need for refinement (see Figure 13).



Figure 13 Output frequency of the first detection circuit.

To improve performance, a second iteration of the detection circuit was implemented using the same 50 μH inductor but with a larger 4.7 μF capacitor. This modification enhances the output waveform and produces more distinct frequency changes in response to metal objects. The baseline frequency increased to 107.743 kHz, and as the metal approached, it decreased gradually: 106.145 kHz at 6 cm, 104.119 kHz at 4 cm, and 102.054 kHz at 2 cm. When the metal touched the coil, the frequency decreased significantly to 96.457 kHz. Compared with the first circuit, this second design provides a stronger and more stable signal, making it more suitable for integration with the robotic system and improving the accuracy of mine detection in practical scenarios (see Figure 14).



Figure 14 Output frequency of the second detection circuit.

5. Conclusion

This study aimed to develop and test a robotic system capable of detecting landmines as a safer and more efficient alternative to manual demining. The prototype integrated Bluetooth-based remote control, Arduino microcontroller processing, ultrasonic navigation, and metal-detection circuitry to achieve reliable communication, stable maneuvering, and effective mine detection under controlled conditions. The results confirmed that the system can identify metallic objects with measurable frequency shifts and maintain stable remote operation, demonstrating the feasibility of low-cost robotic solutions for demining tasks.

The significance of this work lies in its contribution to humanitarian demining efforts, where speed, safety, and affordability are critical. While the current system provides a proof of concept, it is limited by its reliance on controlled environments, the sensitivity of the detection circuit, and the absence of field testing in real mine-affected terrains. Addressing these limitations through more robust sensor integration, enhanced autonomy, and environmental adaptability will be essential to advance its practical application.

Future research should explore improvements such as multi-sensor fusion, machine learning algorithms for pattern recognition, and integration with unmanned aerial or ground vehicles for larger-scale deployment. By advancing in these directions, robotic mine detection can become a scalable and dependable tool in global demining operations.

Ultimately, this work reinforces the potential of robotics to reduce human exposure to danger and contribute to safer, mine-free communities worldwide.

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Data availability statement

The data supporting the findings of this study are included within the article and/or its supplementary materials. Additional information or further inquiries can be obtained from the corresponding author upon reasonable request.

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