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DEVELOPMENT OF A REMOTELY CONTROLLED VEHICLE

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ABSTRACT

An estimate of more than a hundred million landmines laid across multiple countries is undetonated, while lots of new landmines are being planted to this day. Through history, people have been investing effort in developing safe and accurate technologies in response to the ever-increasing figures of landmines. Some of these technologies include animal detection, prodding, mine clearing vehicles, ground penetrating radar and hand-held metal detectors. Although these technologies have each had their success in reducing the landmine count across the world, they still do have disadvantages. In the process of developing a novel technology, this paper covers a literature review on existing technologies and highlighted that their critical shortfall pertain to the safety of the operator. Most of the existing technologies require operators to move the detecting systems in places where landmines are to be uncovered, thus putting their life at risk. The paper provides an overview of research done into metal detectors. The paper then describes the design of a remotely controlled vehicle dedicated for landmine detection. The system design describes how the different parts of the design comes together to create a working system. Each major component is thoroughly described along with the motivation behind the component selection. Firmware, circuit design and each aspect of the design are detailed. The paper concludes that a fully functioning and collision-avoiding prototype has been successfully developed to detect landmines using a webpage and a built-in metal detector. Finally, a room for improvement on the design has been indicated.

KEYWORDS: *Colpitts Oscillator, Embedded Systems, Industrial Revolution 4, Landmine Detection, Mechatronic, Robotics*

Article History

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INTRODUCTION

Throughout human history, there have been countless wars leaving millions, dead or injured. However, these injuries do not always happen only while the armed conflict is active. Antipersonnel land mines have been present in most armed conflicts during history and even dates to 1277, China during the later years of the Song Dynasty (Croll, 1998). To this day, there are more than 110 million undetonated mines under the ground in countries all over the world. During a United Nations General Assembly – Fourth Committee in 2005 a Canadian representative, it was revealed that an average of 15000 to 20000 people is killed or injured annually due to landmines (Meyer, 2005).

Although thousands of dollars are invested into researching viable land mine detecting method to minimize risk of injury and increase detection success rate, the most common methods of detecting land mines are still hand-held metal detectors, but this method of land mine metal detecting poses a serious threat to the operator's life (Abdul-Aziz, ElBakry, Elmogy, M.M, n.d).

The research problem of this study derives from the fact that current process of detecting landmines accurately use humans and animals lives and put their lives in danger, as they have to be in the place where the mines are likely to be found. Most landmines contain some form of metal-based object. The authors of this paper define the purpose of this study as to design a system that can detect metal-based landmines, remotely allowing the operator to be at a safe distance while effectively being able to cover a large area in a short time period. While the vehicle is detecting it must be able to wirelessly communicate its movements and when it detects a metallic object.

In the process of system design, a set of research questions were taken into account including the following:

- Why is this topic worth researching?
- What is the work in place or being developed around this topic?
- What limitations do the current technologies have?
- What can be done to improve on current technologies?
- What is the basic concept of wireless metal detection?
- How can one model the landmine detection?

The aim of this study is then to design a metal-detecting vehicle that can be remotely accessed through a webpage on a user's handheld device or personal computer.

A number of objectives were considered towards the design of a remotely controlled landmine detector vehicle. The first objective of this project was to review the current technology on landmine detection to determine what improvements the design herein can provide. The second objective was to research and design a metal detector that would be able to signal the presence of a landmine. The third objective is to design a vehicle control system with Wi-Fi capabilities. The last objective is to combine the vehicle control system with the metal detector to complete the design of a remotely controlled vehicle with built-in metal detector.

To better organize the research and design of this project, a certain set of steps need to be followed. These steps include:

- To provide the background research on the rationale of the research problem.
- To conduct a literature review on the current landmine detecting technologies.
- To determine the limitations of these current technologies.
- To devise techniques to bridge the gap picked from existing technologies.
- To complete the circuit and firmware design.
- To test the different parts of the design.
- To adjust the design where needed.

- Assemble the parts to create a complete prototype

SURVEY ON DEMINING TECHNOLOGIES

In 2018, there are still millions of undetonated land mines in the ground across the world as seen in Figure 1 below. Due to the large number of casualties caused by these undetonated mines, research into mine detection and improvement of current technology remains an important topic.

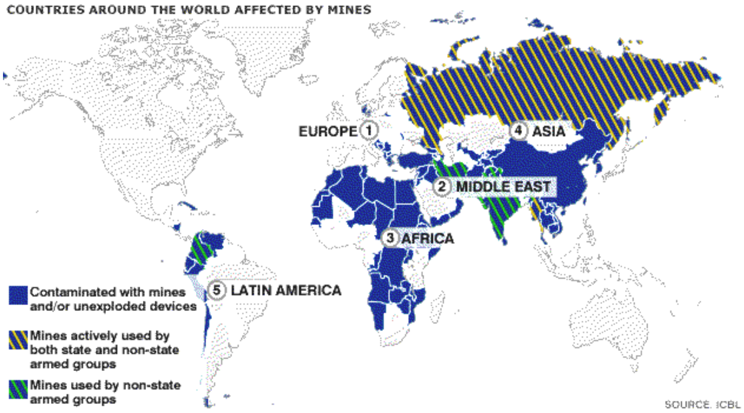

Figure 1: Mine Affected Countries [3].

During the literature review phase of my thesis, I reviewed multiple sources to get a better understanding of the current technology used for detecting mines and what disadvantages these technologies might have.

This review will cover the following:

- Animal detection
- Mechanical clearance
- Ground Penetrating Radar (GPR)
- Hand held metal detection

Animal Detection

Animals were first used to detect landmines in the late 1980's when RONCO Consulting Corporation used dogs in humanitarian demining in Afghanistan. Later, in the late 1990's, the use of large cane-rats also became popular for detection (Poling, Weetjens, Cox, Beyene, Bach, and Sully, 2011)

The use of dogs for landmine detection was deemed a viable solution due to trained dogs being able to detect the smell of explosives in a landmine buried in the ground up to 60cm (Göth, McLean, and Trevelyan, 2003). Dogs were proven to be successful at detecting landmines if the search was done under certain environmental conditions. In these environmental conditions, dogs were also able to search larger areas in a shorter time than alternative methods. However, the use of dogs is an expensive solution due their purchasing price, training, handler fees and veterinary backup.

Much the same as dogs, rats were also trained to use their sensitive sense of smell to detect explosives in a landmine. Unfortunately, rats were not as easily trained as dogs. Because of this, the rats had to be fitted with a harness attached to a grid set up on the area of detection. The grid also limited the size of the area that could be detected.

Prodding

Prodding is one of the most basic methods used to locate landmines. It requires a person, referred to as a deminer, to use a prodder to penetrate the ground in the hopes of locating buried landmines. When a deminer comes across an unusual object, they assess the shape and feel of the object. With experience, these deminers can determine the difference between landmines and other objects (Borza and DeWitt, 2000). While being the most basic method of locating landmines, it is also one of the most dangerous. Prodding requires the deminer to be in very close proximity to the buried mine as these prodders are generally 25cm long. Figure 2 shows in which step of this method an accident is most likely to occur.

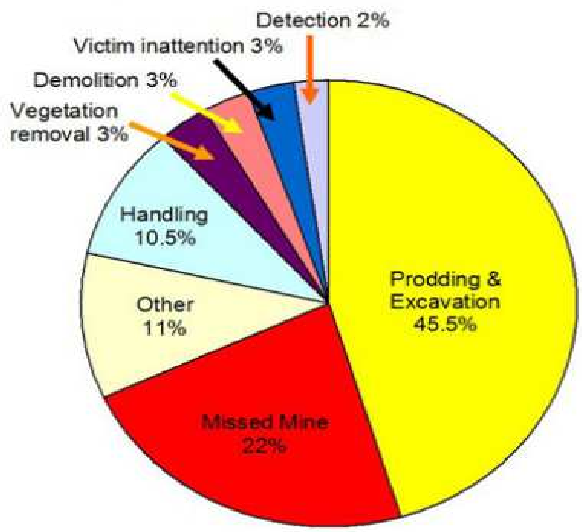

Figure 2: Prodding Activity When Accidents Occur (Adapted From Smith, 2014).

Mine Clearing Vehicles

In some cases, a field must be cleared of landmines in a very short period. Due to those time constraints normal clearing methods would not be feasible. In these cases, large armoured vehicles are used to plough through an area and destroy any landmines in its path (Haughom, and Magnus, 1999). Although this method is much faster than the conventional methods, it does have some major disadvantages. Due to the armoured vehicles detonating the landmines by force, they could sustain major damages during the process. This would require regular repairs to be done on the vehicles causing this method to become an expensive one. Using armoured vehicles also relies heavily on the type of environment where the clearance needs to be done. The size and weight of the vehicles requires them to be operated in large areas to effectively destroy landmines and would be ineffective in smaller areas.

Ground Penetrating Radar

Ground penetrating radar (GPR) is a geophysical method used to accurately map the spatial extent of near-surface objects and produce images of those objects with the use of radar pulses. Using a GPR for landmine detection became a popular solution due to its ability to detect mines without disturbing the ground in which they are buried (Jol, 2008). Intensive research on GPR is still going on (Giannakis, Xu, Aubry, Yarovoy, and Sala, 2016).

GPR transmits a pulsed electromagnetic wave from a transmitting antenna (TX) as seen in Figure 3. These pulses are then reflected off objects and received by a receiving antenna (RX) while the time between sending and receiving is monitored. By knowing both the time and the velocity of the transmitted wave, the distance of the object below the ground can be determined.

The electromagnetic waves are reflected by any electrically inhomogeneous materials, meaning both metallic and plastic-based explosives could be detected with this method.

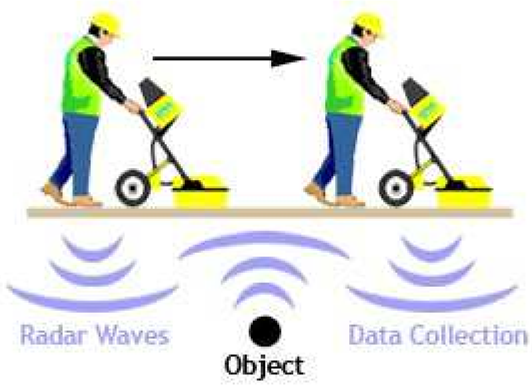

Figure 3: Working of a GPR.

GPR is a very versatile method of mine detection given its ability to detect both metallic and non-metallic mines even though it has its own disadvantages. According to Brooks (2000), the current limitations of a GPR system are ground and surface clutter causing difficulties in accurately detecting landmines. Clutter refers to detected objects that dilute the processed image received from the GPR making it difficult to accurately detect a landmine. However, clutter is not only limited to objects since moisture in the soil can be inhomogeneous making it near impossible to detect a buried landmine with this method in such a situation.

Hand-Held Metal Detector

Hand-held metal detectors work with the basic principles of electromagnetism. The detector consists of two coils, a transmitter coil and a receiver coil. When electricity flows through the transmitter coil, a magnetic field is generated. If a metallic object is subjected to a changing magnetic field, a current is induced in the metallic object. According to Maxwell, if we have a current moving through a metallic object it will also generate a magnetic field (Hambley, 2011). The hand-held metal detector makes use of these principles to detect this generated magnetic field in the metallic object with the second coil that acts as a receiver.

The hand-held metal detector requires a trained individual to manually operate and detect any metallic based object close to the surface of the ground. Therefore, this method requires a person to be in very close proximity to the landmine that poses a significant risk on the operator’s life. As these operators are required to cover large areas on foot, using a hand-held metal detector is also a time-consuming process.

RESEARCH INTO METAL DETECTORS

This section of the paper covers the design of the oscillating circuit contained in the metal detector. The literature review has shown that current method uses a metal detector that consists of two coils, where current is fed through a transmitter coil creating a magnetic field. This magnetic field then generates a current in metallic objects, which in turns generates its own magnetic field and this is done at a very high frequency. This secondary magnetic field is then monitored with a second receiver coil. However, this paper proposes a metal detector which makes use of only one coil. This can be done by making use of a microcontroller measuring the frequency of an oscillating circuit containing an inductor to generate a magnetic field. One of the theories behind the concept of detecting metals is the Colpitts oscillator of which the circuit diagram is shown in Figure 4.

Colitis Oscillator Theory

The Colpitts Oscillator was designed by an American engineer, Edwin H Colpitts in 1918 and is a linear oscillator that utilizes an inductor L and capacitor C in an LC circuit. The oscillator consists of two parts. The first is a gain device, namely an operational amplifier or transistor. The second is the LC tank circuit that acts as a band-pass filter. A bandpass filter simply allows frequencies to pass within a certain range while rejecting frequencies outside that range (Kennedy, 1994).

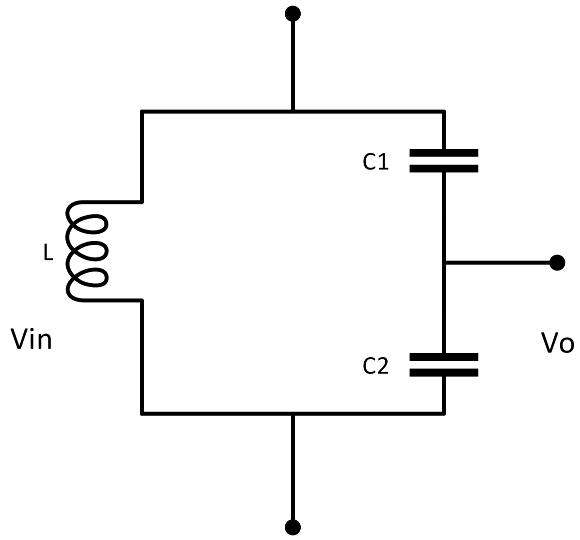

Figure 4: Capacitance Voltage Divider.

The LC tank circuit consists of an inductor L and two series capacitors C1 and C2 that forms a potential divider as seen in Figure 4 above. When power is supplied to the LC circuit the capacitors starts to charge. After being fully charged, the capacitors will begin discharging through the inductor L causing damped harmonic oscillations in the circuit. Therefore, the energy stored in the capacitors gets transferred to the inductor as magnetic flux, causing a magnetic field to build up at the inductor. After the capacitors are fully discharged, there will be a drop in the applied current to the inductor. According to Faraday, the magnetic field will then collapse and induce a current in the opposite direction, charging the capacitors. This allows us to achieve the damped harmonic oscillations, seen in Figure 5. A closed-loop control system is then used to have the un-damped harmonic oscillations by taking the voltage across capacitor C_2 as the positive feedback, as shown in

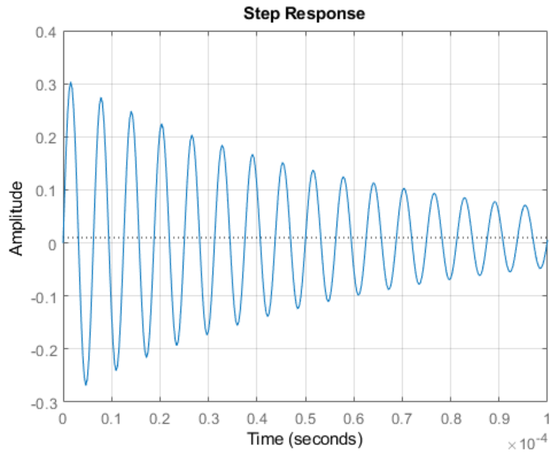

Figure 5: Damped Harmonic Oscillations.

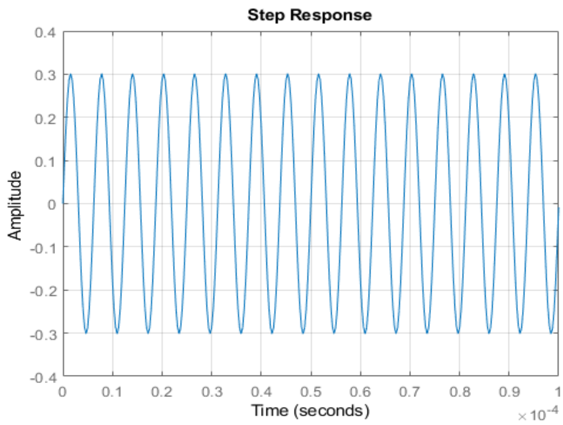

Figure 6: Undamped Harmonic Oscillations.

As Agarwal (2018) stated, continuous undamped oscillations can be achieved by using the Barkhausen stability criterion. Barkhausen criterion states that for sustained oscillations we need to achieve a phase shift of 360º or 0º at resonant frequency. In the circuit shown in Figure 4, the voltage at C1 is at a 180º phase shift with the voltage at C2. Therefore, when a using a transistor as a feedback device we get a 180º phase shift between its input and output voltage.

Calculation for the Colitis Oscillator's Components

The main components of the CO are the inductor L and capacitors C1 and C2 as per Figure 4. The knowledge of the oscillation frequency we require will lead to the knowledge of the value of a component given, the values of the others. The resonance frequency relates to the inductance and capacitance as described by equation (1) that in turn. To determine the total capacitance of that in turn can be manipulated used to obtain the values of the two capacitors in series, which is expressed by equation (2). At resonance, the reactance of a capacitor and inductor in an LC circuit are equal as seen in equation (3). Therefore, by substituting the equations for the capacitive and inductive reactance in equations (4) and (5) respectively into equation (3) we can determine the total capacitance using equations (6) and (7).

$$f_r = \frac{1}{2\pi\sqrt{LC_T}} \tag{1}$$

$$C_T = \frac{C_1 C_2}{C_1 + C_2} \tag{2}$$

$$X_L = X_C \tag{3}$$

$$X_L = 2\pi f_r L \tag{4}$$

$$X_C = \frac{1}{2\pi f_r C} \tag{5}$$

$$2\pi f_r L = \frac{1}{2\pi f_r C} \tag{6}$$

$$C_T = \frac{1}{2\pi f_r^2 L} \tag{7}$$

SYSTEM DESIGN AND OPERATION OVERVIEW

The system design consists of three main parts, namely the metal detector, the vehicle and the webpage. When power is applied to the system, the vehicle waits for a start signal sent from the webpage operated by the user. Once a start signal is received, the vehicle starts to move forward looking for any objects within thirty centimeters in front of the vehicle. If an object is detected the vehicle will be brought to a stop, turn one hundred and eighty degrees then proceed by moving in forward direction once again. During the vehicle's operation it is also constantly looking for any metal-based object. When an object is detected, the vehicle is brought to a stop after which its GPS coordinates are sent to the webpage for the user to read. After the metal-based object is removed the user can start the vehicle operation from the webpage. At any given point, the user can use the webpage to stop or run the vehicle.

Microcontrollers

Choosing a microcontroller is an essential part of the design process of the remotely controlled vehicle. The microcontrollers' function needs first to be established, then the minimum specifications determined. Following this process helps choosing a microcontroller that is neither over nor under qualified for its intended purpose. For this project, two microcontrollers were required. One for the metal detecting circuit and the other for the vehicle control circuit. Each of these circuits had their own requirements when it came to the choice of microcontroller.

Vehicle Control Design

To accommodate all the components of the vehicle control circuit, a minimum of twelve I/O pins were required on the microcontroller. Due to the anticipated size of the vehicle control program, a minimum microcontroller unit (MCU) flash memory with 10kB was adopted. The third specification required the microcontroller to have at least one UART. Although this design requires a separate UART for both the Wi-Fi module and GPS, we only require a single UART on the microcontroller, as we can create a second software serial UART within the firmware.

Metal Detecting Circuit

In most cases, the deciding factor for the choice of a microcontroller is the number of I/O pins the system requires. However, the metal detecting circuit requires only two I/O pins. The firmware makes use of both a 16-bit as well as an 8-bit timer. Therefore, the second specification required the microcontroller to have at least one of each of these timers. Due to the firmware monitoring a change in frequency, it is essential to have some form of debugging system while designing the program. Therefore, the microcontroller requires at least one UART to allow for serial printing. The decision was made on a minimum MCU flash memory of 4kB as the size of the program will be considerably smaller than the vehicle control program.

Microcontroller Selected

After determining the requirements for the microcontrollers for each circuit, the datasheets for multiple microcontrollers to find the suitable ones sere referred to. ATmega328P and ATmega48 for the vehicle control and metal detector respectively were selected. The ATmega328P has 32 pins of which 23 are I/O. The microcontroller also has 1-Universal Asynchronous Receiver and Transmitter (UART) port and 32kB of flash memory, which satisfies the requirements for the design. The ATmega48 has 32 pins of which 23 are I/O, 4kB flash memory, 1-UART port and both an 8-bit and 16-bit timer. Although the number of I/O pins on the ATmega48 is much larger than the required amount of variables, all the specifications are perfectly met by this microcontroller.

Motors

The design required four geared dc motors for the vehicle movement as well as a servo motor to rotate the ultrasonic sensor used for collision detection. Motors that operated with a voltage of 5V-9V were found out to comply with the circuit requirements.

For the vehicle movement, a geared 6V DC motor with a 1:120 ratio was used, which allowed an RPM of 100. This allowed the vehicle to move at a steady pace without affecting the operation of the metal detector.

For the ultrasonic sensor rotation, the servo motor is required to rotate 180º allowing it to check the right, left and front of the vehicle for a collision. Therefore, a Tower Pro MG995 Stepper Motor with 180º rotation and 13Kg Torque which satisfies the angle requirement as well as providing enough torque to rotate the sensor was selected.

Collision Sensor

For the collision detection the selection falls on HC-SR05 ultrasonic sensor which has a detecting distance of 2cm – 450cm. The sensor is activated when a pulse of 10us is sent to the TRIG input on the sensor. Once activated the sensor sends out eight 40 kHz square waves. A timer will then be started and the ECHO pin on the sensor will output a HIGH value. The timer stops once the ECHO pin outputs a low. The distance is then calculated using this recorded time.

Wi-Fi

For the Wi-Fi communication the decision was made on ESP8266-01 module. It is a cheap module with integrated Transmission Control Protocol (TCP)/ Internet Protocol (IP). The onboard processing and storage capabilities are also powerful enough to allow it to be integrated with sensors and other applications using the tow GPIO pins. However, for this application, it will be used to host a local webpage.

Motor Driver

To drive the geared DC motors, a L298N Dual H-Bridge Motor driver was used. The driver is able to drive two DC motor while controlling the speed and direction of each one independently. Therefore, both the left and right motors of the vehicle can be controlled using the L298N driver.

GLOBAL POSITIONING SYSTEM (GPS)

When the metal detector detects a landmine, it is necessary to record the vehicles position at the time of detection. Therefore, a Neo-6m GPS module that has an external antenna and built-in Electrically Erasable Programmable Read Only Memory (EEPROM) is used to record the vehicles GPS coordinates. These coordinates are then sent to the vehicle control microcontroller using serial communication.

Inductor (Metal Detector)

For the metal detector, an inductor to act as a coil was used. For my prototype, an old TV antenna was used; such an antenna was the perfect size for the vehicle prototype.

FIGURE 6 SHOWS THE PICTURE OF THE DEVELOPED PROTOTYPE

THE REMOTELY CONTROLLED LANDMINE DETECTOR VEHICLE DEVELOPED IS SHOWN IN VARIOUS VIEWS IN FIGURES 7, 8 AND 9.

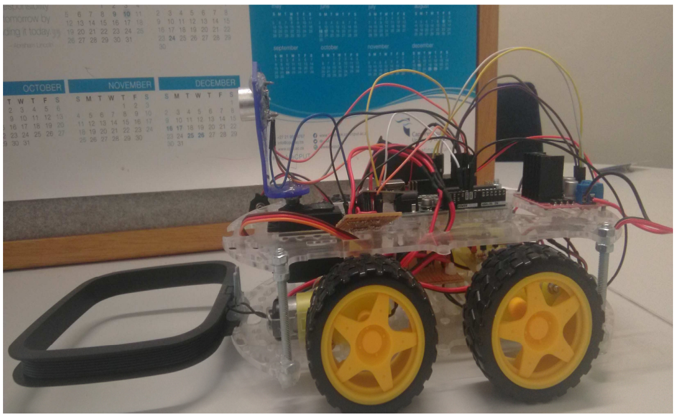

Figure 7: The Vehicle's Side View.

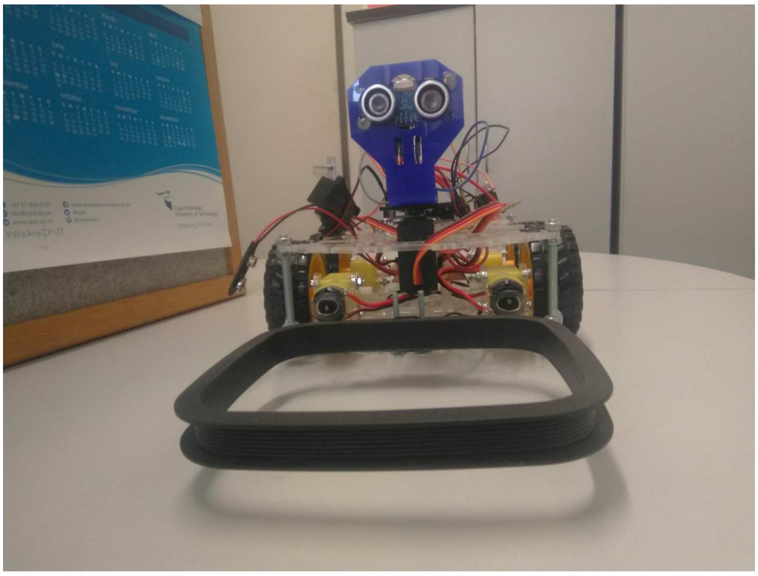

Figure 8: The Vehicle's Front View.

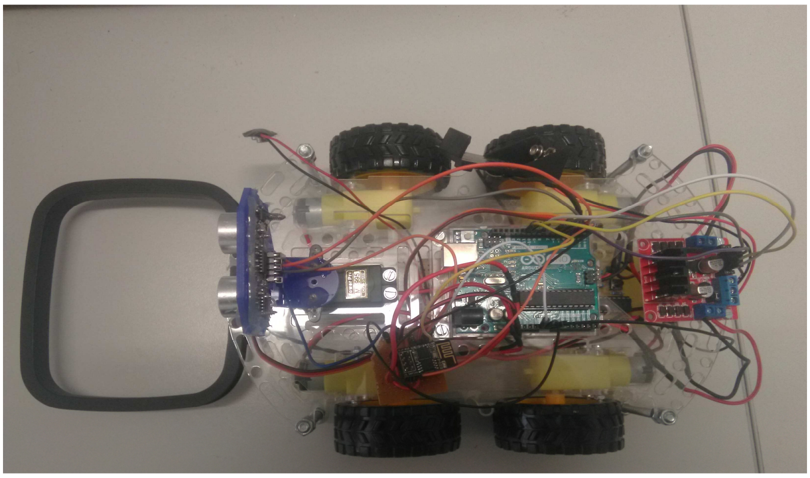

Figure 9: The Vehicle's Top View.

BUDGET

The cost of the components used to build the mine detecting vehicle amounts to R1402.31 as shown in Table 1.

Table 1: Budget

Component Name	Quantity	Unit Cost	Total Cost
Ultrasonic Sensor	1	R45.00	R45.00
Servo Motor	1	R151.32	R151.32
L298n Dual H-Bridge DC Motor Driver	1	R119.99	R119.99
Atmega328P	1	R56.00	R56.00
Atmega48	1	R35.00	R35.00
Wheel	4	R50.00	R200.00
ESP8266-01	1	R85.00	R85.00
Battery + Holder	1	R25.00	R25.00
28-pin Socket	2	R7.50	R15.00
Neo-6M-GPS	1	R220.00	R220.00
Geared DC motor 1:128 ratio	4	R75.00	R300
Sundries	-	R150	R150
Total	**-**	**-**	**R1402.31**

RECOMMENDATIONS

Although the webpage serves its current purpose of displaying where metal-based objects were detected and allowing the vehicle to be remotely controlled, it can still be improved to provide a map of the vehicles movements and display, not only the location of metal-based object but also the location of any avoided obstacle. For future prototype, a localized GPS system can be designed, to more accurately determine the location of the vehicle at any given point. The current GPS module does not always give an accurate position within 2 meters.

CONCLUSIONS

The purpose behind this thesis was to design a landmine detecting device that can detect a metal-based landmine remotely without putting a person's life in danger. At the end of the project, a vehicle with a built-in metal detector and obstacle detection was designed. The vehicle makes use of a webpage to monitor the location of the vehicle when a metal-based object is detected as well as give the user the ability to stop and start the vehicle remotely.

Therefore, it can be concluded that the project has achieved its aim at providing a metal detecting vehicle that can be remotely accessed through a webpage on a user's handheld device or personal computer.

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