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Metal detecting robotic vehicle

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***Abstract*---**Today's need for workers in mines is to detect the metals in the path. The previously used metal detector uses BFO (Beat Frequency Oscillation) and RFO (Resonant Frequency Oscillation) techniques which has a drawback of frequency instability. The depth further can be increased by Pulse Induction Method. It uses a single coil as both transmitter and receiver. When current is sent through the coil each pulse generates a magnetic field. When the pulse ends it reflects and it is called the reflected pulse. An electrical spark is generated when both the pulses collapse. Now when a metal comes in the range of the magnetic field, there is a change in the amplitude and phase of the pulse in the received coil. Planar square spiral coil is the geometry best suited for increasing depth sensitivity. It depends on the parameters such as fill ratio and spacing to width ratio. A coil with a higher fill ratio is shown to have higher size sensitivity and a coil with a smaller wire spacing-to-width ratio is shown to have higher depth sensitivity. Using this Pulse Induction Metal Detector we build a robotic vehicle.

***Keywords*---**metal detector, sensitivity, geometry, depth, square planar spiral coil, robotic vehicle, ferrous, range, magnetic field.

Introduction

A metal detector is an electronic device that detects the presence of metal nearby. They are used in various fields such as archaeology and surveillance. In archaeology, they are used for finding metal inclusions hidden within objects, or metal objects buried underground. In surveillance fields such as military surveillance, they are used to find the chips inserted inside the body and in airports for concealed weapon detection. Thus, they are used in security screening. They are also used in searching objects such as jewelry, mobile

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phones, cameras and other devices which are buried under dirt, sand, grass and even in bodies of water. Waterproof metal detectors are used in searching submerged objects in areas of shallow water[1]. The basic working of a metal detector is, when an electrical current is passed through the search coil, a magnetic field will be created around the coil. The magnetic field will spread out to a particular depth. The area covered by the magnetic field will be considered as the detector's range of detection. When a conductive material comes within that range, the electromagnetic property of the material will disturb the magnetic field produced by the coil. Then by using the visual/audio alerts in our system, we can know that some metal is being detected. By monitoring the frequency change or by listening to the tone change, we can analyze the depth of the metal.

Wouter et.al [2] proposed that it has a higher order of magnitude of the soil response when compared to that of the minimum metal landmines at an average depth. A detection algorithm is used to detect the object present. Magnetic Induction Spectroscopy is a methodology used to obtain the soil types and depth of the metals based on the magnitude and phase response. Even in challenging soil conditions, MIS(Magnetic Induction Spectroscopy) is used to detect buried metallic objects. It is inferred from this paper that there is a large soil response when compared to the response of the buried objects. It has a drawback of less sensitivity and has a lower detecting distance. Omar Siddiqui [3] proposed a method based on highly dispersive Lorentz resonators for sensitive metal detection which have a distinctive phase signature. It is inferred that metal presence and conductivity were detected by analysing the phase and amplitude of the response. By the broadening of the amplitude response, it is used to detect the presence of resistive losses which results in the decrease of the resonator's Q-factor. It has a drawback of very little sensitivity in that, it cannot detect a very small target and there is a frequency instability.

Bobae Kim [4] proposed that the Pulse Induction method with a spiral coil of specified fill ratio and spacing to width ratio is used for better depth. Planar square spiral coil is the geometry best suited for increasing depth sensitivity. It depends on the parameters such as fill ratio and spacing to width ratio. Several coils with various fill ratios and wire spacing-to-width ratios are analyzed and the size and depth sensitivities of coils with different ratios are investigated based on a numerical simulation. A coil with a higher fill ratio is shown to have higher size sensitivity and a coil with a smaller wire spacing-to-width ratio is shown to have a higher depth sensitivity. Hakan Citak proposed [5] that metal detection is based on Pulse Induction. BFO oscillation is a method in which it has two coils, primary and secondary coil. When a target metal is intruded into the primary coil there is a change in the emf in the secondary coil. With the change in the emf in the coil, we can detect metal detection. RFO oscillation is a method in which a single frequency is given to a coil and the resonant frequency is noted and when the metal target is intruded there is a change in the resonant frequency. With the change in the resonant frequency, the metal can be detected. The BFO(Beat Frequency Oscillation) and RFO (Resonant Frequency Oscillation) techniques are said have a drawback of frequency instability. The depth further can be increased by Pulse Induction Method. It uses a single coil as both transmitter and receiver. When current is sent through the coil, each pulse generates a magnetic field. When the pulse ends it reflects and it is called the reflected pulse. An electrical spark is generated when both the pulses collapse. Now when a metal comes in the range of the magnetic field, there is a change in the amplitude and phase of the pulse in the received coil. There are various methodologies used in metal detection. Among them, the most common methods are as follows:

- Beat Frequency Oscillation (BFO) method
  Here, a single frequency will be fed to the primary coil. When a metal intrudes, some electromagnetic force will be induced in the secondary coil. Based on its strength, we can find the metal depth.[6]
- Resonant Frequency Oscillation (RFO) method
  This method uses a single coil. A response is obtained with metal placed very close to it and another response is taken without any metal presence. When a metal intrudes, the amount of deviation from the reference responses will indicate the depth[7].
- Induction Balance (IB) method
  Here, a single frequency is fed to both the coils. When a metal intrudes, the change in magnitude and phase will indicate the metal depth[8].
- Pulse Induction (PI) method
  Here, small pulses are passed through the coil. Spikes will be created when the reversed pulses meet the incoming pulse. The peak of this spike will be disturbed by the metal. This is then analyzed to find the depth. PI detectors are best suited for searching in beaches, rivers, or underwater. I detectors will have a single coil only. That single coil will act as both transmitter and receiver. The coil will transmit a magnetic field and will detect the conductive materials. They are more expensive and cannot be used in city sides because they cannot discriminate between iron trash like nails and treasures like gold and coins[9]. Among them, the Pulse Induction method is used in this work.

Proposed Methodology

Pulse induction is a method preferred for our metal detector. The coil which we used here acts both as a transmitter and a receiver. When current flows through the coil there is a generation of pulses in the coil. Each pulse in turn generates a brief magnetic field. When the coil ends the pulse generated reverses its path and this current is called the reflected pulse. When both these pulses collapse there results in an electrical spike. The change in magnitude and amplitude of the received signal is detected by the receiver coil. By which we can detect the size and depth of the target metal. Here we concentrate on the depth of the target metal. To increase the depth sensitivities of the coil, we change the geometry of the coil. Planar spiral square coil gives better depth sensitivity when compared to circular coil. It depends on the parameters such as fill ratio and spacing to width ratio. Several coils with various fill ratios and wire spacing-to-width ratios are analysed and the size and depth sensitivities of coils with different ratios are investigated based on a numerical simulation. A coil with a higher fill ratio is shown to have higher size sensitivity and a coil with a smaller wire spacing-to-width ratio is shown to have higher depth sensitivity. The proposed methodology is shown in fig.1

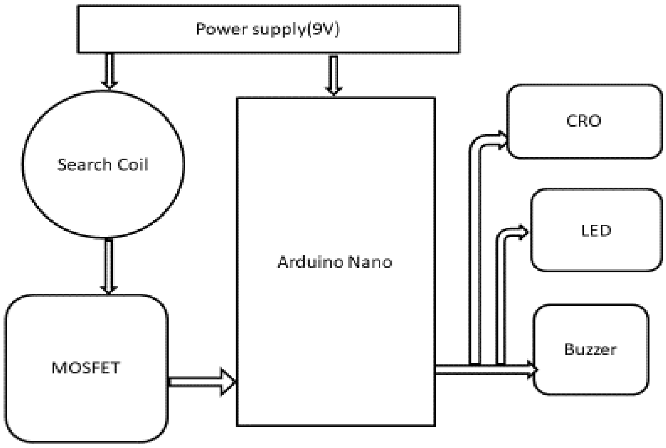

Figure 1. Proposed block diagram

Working Principle

A Pulse Induction metal detector is mounted on a robotic vehicle, which has an ArduinoNano, metal detector circuit, coil, and RF module. A serial data is received by the RF transmitter and it is transmitted wirelessly through its antenna through RF. The data which is transmitted by the transmitter is received by the RF receiver which is operating at the same frequency as that of the transmitter. A metal detector which is mounted on the robotic vehicle detects the target metal for a certain depth. Based on the serial data received from the transmitter, robotic vehicle motion is controlled. Now when the vehicle moves and if it detects the target metal, there is an indication of the detected target metal using a buzzer and Led. And also the vehicle stops its motion when the target metal is detected.

Process involved

- Serial data is transmitted by the RF module.
- Vehicle motion gets controlled by the RF module.
- With the help of the coil interfaced with the metal detector, the target metal is detected.
- If target metal is detected, it is indicated using a buzzer and led.
- And if the metal is detected the vehicle stops its motion

Equivalent circuit parameters for the coils when they are modeled as the series inductance (l) and resistance can be calculated as:

$$R=\rho_c \, {}^{l_c}/_{w.t_c} \qquad (1)$$

$$L = k_1 \mu_0 \frac{N^2(D_{out}+D_{in})}{2(1+k_2\rho)} \qquad (2)$$

Where the coefficients k_1 and K2 are 2.34 and 2.75 for square coil, lc is the total wire length. The basic setup in a metal detector consists of three main units:

- **Sensor probe unit/Search coil**
  As the name suggests, the sensor probe unit is the unit that senses the presence of metal. When a metal intrudes in the path of the robot, the magnetic field created by the electrical pulses will be disturbed. This results in a decrease of the current flowing through the coil, at most care, must be given while choosing the coil. Their type, thickness, conductivity, permeability will contribute to the results.
- **Controlling unit**
  Here, embedded **s**ystems are used for controlling the process. This unit decides the time interval between the successive pulses i.e. the pulse generation rate. The MOSFETS will decide the switching frequency. This part will do the Decision-making task. This unit will decide for which value from the receiver does the buzzer/LED has to be ON.
- ***Display unit***
  This unit will display the results either in audio form (buzzer) or as an LED signal.

Coil Geometry
Circular coil

An insulated copper coil with a diameter of 20 cm and windings of 25 turns with a wire thickness of 0.04 mm can detect a depth of 4 cm. To increase the depth sensitivities of the coil we move onto a better geometry which is a square planar spiral coil.

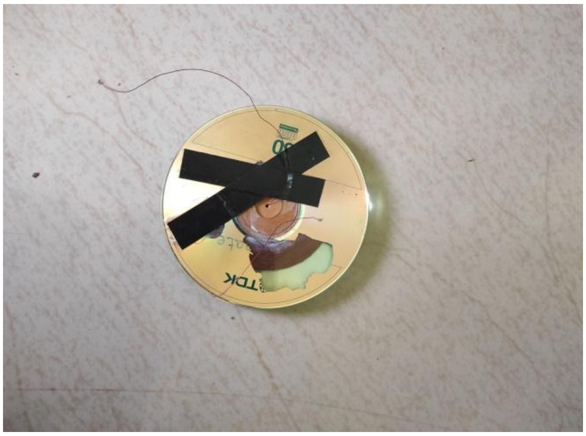

Figure 2. Circular coil

Square planar spiral coil

Square planar spiral coil mainly depends on two parameters: fill ratio and spacing to width ratio. To increase the depth of the coil we mainly focus on spacing to width ratio. The smaller the spacing to width ratio it has the stronger the magnetic field for the entire distance observed. By keeping other parameters constant and decreasing the spacing to width ratio results in an increase in the number of turns. By doing so there results in an increase in a magnetic field as an equal amount of current is carried in each turn of the loop of the coil. Thus it is found that smaller the spacing to width ratio has a higher depth sensitivity.

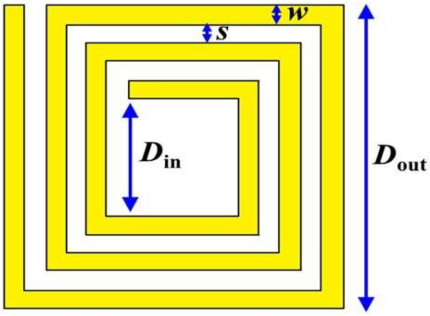

Figure 3. Square planar spiral coil

The geometry of the planar square spiral coil can be described by the outer side length (D_{out}), the inner side length (D_{in}), the number of turns of the planar spiral square coil (N), the wire width (w), and the wire spacing (s).

Results and Discussions

Various factors such as thickness, number of turns, the geometry of the search coil were changed and their results were analysed.

Results for stage I

To check the basic performance of a metal detector, a simple circuit is designed by using 555 Timer IC and some basic components such as resistors and capacitors. A power supply of 9V is used to energize the circuit. The number of turns in the coil is chosen as 300 turns. By using this setup, we achieved a detection depth of about 0.1 mm to 0.5 mm. block diagram for stage 1 is shown in figure 4.

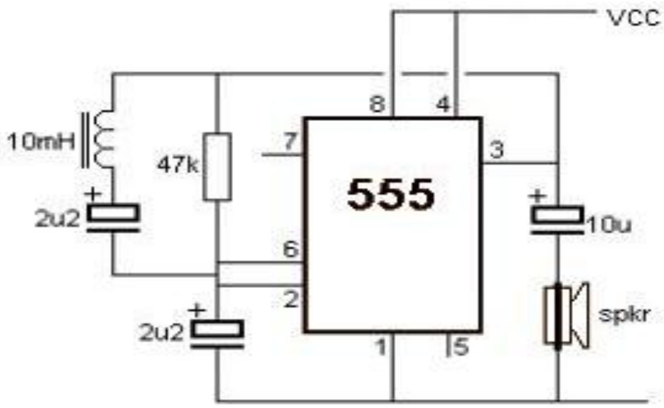

Fig 4. Metal detector block using 555 Timer IC

Table 1
Specifications for Stage I

Supply voltage	9V
Number of turns in the coil	300
IC used	555 Timer
Principle used	Edge triggering
Search coil diameter	5 cm
Diameter of the insulated copper coil	0.02 mm

Detection depth

By using this setup of 555 timers and the edge triggering principle, the metals at a distance between 0.1mm and 0.5 mm are detected successfully. The presence of the metal is indicated by a change in the tone of the buzzer and the output tone is visualized by a CRO. There the presence of metal is indicated by a decrease in the frequency of the output wave.

Results for stage II

The detection is very less for the above-said setup. To increase the detecting depth, two parameters were changed.

- The number of turns in the search coil was increased from 300 to 450 turns
- The thickness of the coil is changed from 0.2mm to 0.4 mm.

Table 2
Specifications for Stage II

Supply voltage	9V
Number of turns in the coil	450
IC used	555 Timer
Principle used	Edge Triggering
Search coil winding diameter	5 cm
Diameter of the insulated copper coil	0.4mm

Detection depth

When the number of turns in the coil is increased from 300 to 450 turns and the thickness of the coil is changed from 0.2 mm to 0.4 mm, the detection depth is obtained as 3.5 cm below the ground.

Results for stage III

Here, instead of using 555 Timer IC, a microcontroller called ArduinoNano is used for controlling purposes. Some modifications are made in the circuit also. The components like power MOSFET, amplifiers are used along with the basic components (resistors and capacitors). And the block diagram for stage III is shown in figure 5.

Table 3
Specifications for Stage III

Supply voltage	9V
Number of turns in the coil	25 turns
Controller used	Arduino nano
Principle used	Pulse Induction
Search coil winding diameter	20 cm
Diameter of the insulated copper coil	0.4mm

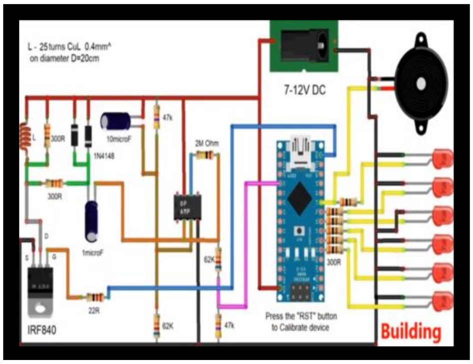

Figure 5. Metal detector block using microcontroller

Detection depth

By using the above setup, the metal detection depth achieved is up to 5 cm below the ground.

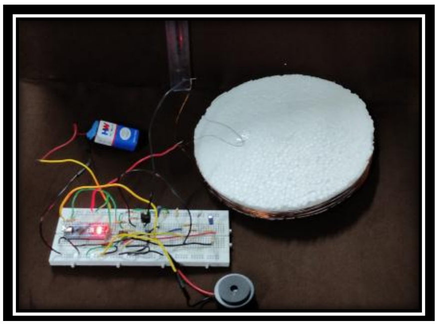
Figure 6. Metal detector using a coil with width as 0.4 mm and winding diameter as 20 cm

Results for stage IV

Two modifications are done in this stage. 1) Thickness of the coil is changed from 0.4 mm to 2.5 mm. 2) Geometry of the coil is changed from circular to planar concentric squares.

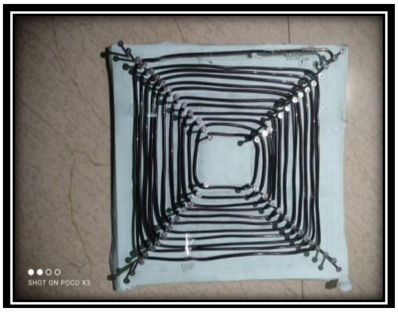

Fig 7. Planar square spiral coil

Table 4
Specifications for Stage IV

Supply voltage	9V for circuit and 30V for coil
Number of turns in the coil	13 turns
Controller used	Arduino nano
Principle used	Pulse Induction
D_{in}	4.6 cm
Diameter of the insulated copper coil	2.5 cm

Thus, by designing the square planar coil, the detection depth obtained is 9 cm below the ground.

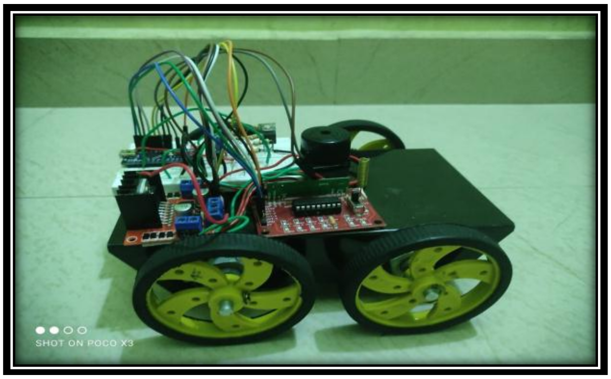

Figure 8. The robot setup

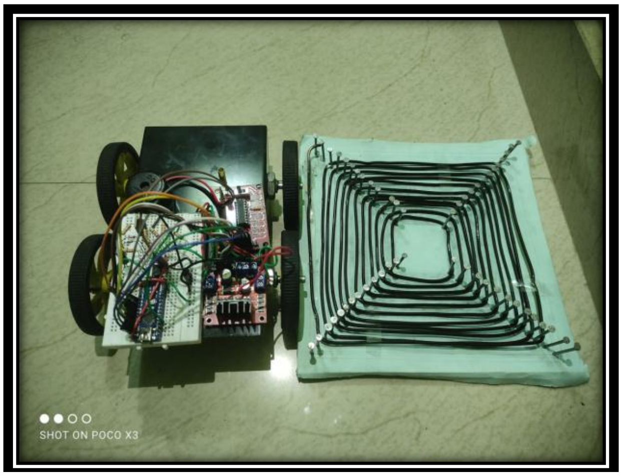

Figure 9. The complete setup of the metal detecting robotic vehicle

Table 5
Performance measures

Parameters	Timer IC	PI method
IC/Controller used	555 timer IC	Arduino Nano
Detecting distance	3 cm	Upto 5 cm
Principle used	Edge Triggering	Pulse Induction
SC diameter	5 cm	20 cm
No. Of turns in SC	300 turns	25 turns
Diameter of insulated copper wire	0.02 mm	0.04 mm
Applied voltage	9V	9V

Various factors such as thickness, number of turns, the geometry of the search coil were changed and their results were analysed. By using this setup of 555 timers and the edge triggering principle, the metals at a distance between 0.1mm and 0.5 mm are detected successfully. The presence of the metal is indicated by a change in the tone of the buzzer and the output tone is visualized by a CRO. There the presence of metal is indicated by a decrease in the frequency of the output wave. When the number of turns in the coil is increased from 300 to 450 turns and the thickness of the coil is changed from 0.2 mm to 0.4 mm, the detection depth is obtained as 3.5 cm below the ground. By using the microcontroller set up, the metal detection depth achieved is up to 5 cm below the ground. By designing the square planar coil, the detection depth obtained is 9 cm below the ground.

Conclusion and Future work

Thus, by changing the coil parameters such as the number of turns, width of the coil used, winding diameter and geometry, we have achieved a maximum detection depth of up to 9 cm under the ground. The controlling part is taken care of by the microcontroller ArduinoNano and the movement of the vehicle is controlled by the RF transmitter and receiver module. We can further increase the number of windings in the coil to increase the depth sensitivity of the coil. When the robot is interfaced with a camera, we can have a live metal detecting environment. We can also incorporate some gas sensors with the robot so that it can sense any harmful gases present in that surrounding and will alert the miners.

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