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Development and implementation of a low-cost metal detector device

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ABSTRACT

Metal detectors contribute to safety, protection, and detection in a variety of disciplines by locating and identifying metal items, playing an important role in which the metal detectors appear in security, archaeology, and industrial applications respectively. The necessity for identifying different types of metals and the need for a high level of security system led to the need of affordable and sensitively metal detecting devices. In this paper, the magnetic pulse induction (PI) technology is used in the development of metal detectors. The primary control circuit is utilizing an Arduino controller which allows the input signal's to be controlled and monitored using a liquid-crystal display (LCD) and mobile application. A voltage sensor for measuring the analog output from the circuit and capturing the information to the Arduino by employing a Bluetooth module. The Arduino controller estimate the percentage of the signal's strength and display it on the LCD. Simultaneously, the signal could be sent to the mobile application through Bluetooth in order for the application to display the strength in the form of a spectrum of colors. The results of testing applied to the proposed prototype reveal that the system is running with a satisfactory accuracy and sensitivity.

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1. INTRODUCTION

Nowadays, the use of a smart and highly sensitive devices could provide and easier life as well could highly save time and efforts of end users. Detection and identification of different materials is highly required duty at which it had been carried out for different purposes. These aims could include inspection for specific material, adulteration detection, classification of matières and others. In this research the focus would be mainly on a device that could be used for metals type of materials.

Metal detectors are electronic devices that detect the presence of metal items in the surroundings. They operate by creating a magnetic field and evaluating how that field changes when it interacts with metallic things. Metal detectors are commonly employed in a variety of applications such as security screening, archaeology, treasure seeking, and industrial settings [1]. Metal detectors are frequently used in airports, government buildings, and public events for security screening to identify potentially harmful objects, such as guns or explosives, that may be concealed on a person's body or in their possessions. They contribute to improved security by alerting security personnel to the presence of metal objects. Metal detectors are useful equipment in archaeology and treasure hunting for identifying buried relics or metallic objects of historical or archaeological interest. By locating buried valuables or archaeological sites, they aid in the discovery and preservation of cultural heritage. Metal detectors are used in manufacturing and production lines in industrial settings to prevent metal contamination in products. They aid in the assurance of product quality and safety by detecting any unintentional metal objects that may have entered the manufacturing process [2].

The use of metal detectors is generally restricted to amateurs and people who are interested in obtaining minerals that are buried underground; however, this does not mean that they do not have any significant applications or uses [3]. For example, security personnel use them to conduct inspections of people entering locations that require safety and security, such as airports, tourist areas, hospitals, and government buildings. In addition to its use in prospecting and searching for the presence of minerals below at varying depths and dimensions, this tool can also be used to measure the size of an area [4].

Mineral exploration is the process of exploring through the rocks in the area for any indications that they may contain any type of mineralization. Mineral exploration is conducted with the intention of finding deposits of minerals and rocks that may be employed to fulfill the requirements placed on society in terms of its resource requirements [5]. The process of exploring for minerals can be as straightforward as prospecting, using straightforward techniques like gold panning, or it can be highly complex, requiring the use of advanced tools for data collecting and analysis [6]. A metal detector is an electrical device that can detect the presence of nearby metals. A metal detector can be used to locate anything made of metal or containing metal that is buried underground [7]. Metal detectors are typically mounted using a portable device with a sensor that may look for metals in the ground or other objects [8].

Metal detection and inspection is one of the most frequently duty aimed for metal detector devices. The basic principle based for their operation based on the reflected magnetic field from specific metal. The strength of the magnetic field that the metal object produces is used by the metal detector to assess the depth to which the metal object is buried in the earth [9]. By comparing the magnetic field strength to the depth of an item, the device is able to ascertain both its position in space and its distance from the surface of the Earth. Figure 1 displays the detection that is observable at various depths [10].

Figure 1. The detection at different depths

The magnetic field causes eddy currents in metal objects, which produce their own magnetic fields when they interacts with it. The detector’s circuit is altered as a result of these secondary magnetic fields’ interactions with the primary magnetic field the detector produces. The size, composition, strength, and frequency of the electromagnetic field, as well as the conductivity of the surrounding soil, all affect the relationship between the strength of the magnetic field and the depth of a metal.

As a result of industrial development and an increase in the use of metals in numerous industries and different facets of life, there is a greater demand for metals and detecting technologies. The metal detector debuted for the first time in 1881 [11]. For medical purposes, it was used to find a bullet inside the corpse of the American President during his murder. Up until today, there have been a number of improvements made to metal detectors [12].

Modern electronic metal detectors have advanced rapidly in order to identify buried metal landmines. In the 1980s, the required theoretical foundations were developed to further the metal discrimination idea. Over the past decade, advancements in microelectronics, microcomputers, signal processing, and electromagnetic modeling have resulted in more advancements. Metal detectors for hobbyists employ modern signal processing microcomputers to analyze buried target signatures and distinguish coins and jewels from clutter. The landmine and unexploded ordnance (UXO) research community has utilized these advancements to create sophisticated detection and discrimination devices [13].

Unlike traditional metal detectors, which need people to go through them, an advanced metal detection system using a wide-area metal detection (WAMD) sensor can screen big crowds of people more effectively. This sensor system is made up of a spatially distributed metal detector and a video surveillance system that is designed to scan an area continuously rather than individually inspect each person [14]. These days, a great number of establishments have reached the point where the implementation of metal detector systems has become an absolute need. The presented system may be put into action remotely and does not require a touch metal detector to be brought into contact with the body of a suspect; rather, it relies on the wireless transmission of electromagnetic waves [15].

Robotic devices had many applications in various areas [16], [17]. The design and development of sensor technologies and robotic device for the detection of land mines is presented [18]. Presented results had shown that the proposed approach effectively operated and the system is able to detect landmines. The goal of the study is to create a conductive material detector for use in security, food, and pharmaceutical industries. According to test results, the device can identify six different conductivity materials, including tin, copper, zinc, aluminum, and stainless steel. Three seconds is the typical response time for detecting conductive material [5]. One of the fundamentals of robotics is the metal detector robot, which is efficient compared to labor-intensive, inefficient manual methods. In addition to having complete control over the robot, the proposed approach can also create rules and permissions for the robot operator, record and archive printed reports and navigated outcomes, and store all of this data in a separate database [19].

In many regions of the world, waste management has turned into a significant challenge. The majority of people are unaware of the enormous quantity of waste that is generated from the growing population, despite the fact that the population is still growing [20]. When waste management is first implemented, the metal content of the waste will most likely need to be separated, particularly if it is planned that the waste will be transformed into some sort of energy [21]. This clearly highlight how such devices could be utilized in different displumes where such duties are remarkable.

The above aforementioned application of metal detectors made high inspiration in the development of the proposed device in this research. In light of the fact that its prices are so much higher in comparison to the cost of purposed prototype, one of the most important aspects of this project idea is its creative potential, as well as its feasibility on the regional market. In addition to this, it illustrates how we can build our local industry, which will assist us in developing our local economy, adding additional industrial processes, and lowering the rate at which we import a variety of different types of products. The purpose of this study is to construct a device for detecting metal which linked up with a Bluetooth module in order to communicate with a mobile application in addition to extending the range over which objects can be detected. In the following section the details on which the developed device based on will be discussed and analyzed.

2. METHOD

Metal detectors are available in a wide variety of shapes, sizes, and configurations, ranging from portable devices to walk-through gates and conveyor belt systems [22]. They make use of a variety of technologies, such as very low-frequency (VLF), pulse induction (PI), and beat frequency oscillation (BFO), in applied to measure and distinguish between various kinds of metals [23]. These key technologies differ primarily in a range of aspects, primary among them being cost, depth, sensitivity, discrimination, frequency range, and sensitivity.

2.1. VLF technology

The technique used in VLF metal detectors most usually is the magnetic induction balancing approach. The transmitter and receiver coils are two separate coils used in this technology. The transmitter coil is an external coil through which electricity flows both clockwise and counterclockwise. The internal coil is used to capture and amplify the signal that is reflected off of metal objects, as opposed to the receiver coil, which is external [24].

The magnetic field that is generated by the alternating current that is flowing through the transmitter coil is perpendicular to the coil and the polarity of the magnetic field will change in response to changes in the direction of the electric current. When a magnetic field passes through and is exposed to conductive material, it produces a weak magnetic field, and the polarity of the magnetic field produced by the body is different from the magnetic field generated by the transmitter coil. The process is very similar to how payments and withdrawals are made [25], [26]. The interaction of the reflected magnetic field with the conductive material located beneath the surface of the ground results in the generation of an alternating electric current. This increased electric current is received by the control box, and it is then used by the central processing unit (CPU) to assess the signal and show the data [24].

2.2. PI technology

Michael Faraday created electromagnetic induction in 1831, and this approach makes use of the concept of electromagnetic induction. The PI technology has numerous practical applications in the field of electrical technology, including transformers and certain other electrical devices [26]. Magnetic induction pulse technology is one of the valuable techniques for finding metal because the devices that employ it can operate in situations where other methods cannot. This makes magnetic induction pulse technology one of the useful methods for finding metal. Through the use of this method, a single coil can perform the functions of both a sending coil and a receiving coil at the same time [24].

The PI technology employs a single coil that serves as both a sending coil and a receiving coil simultaneously, is based on the delivery of electric current in the form of brief, strong pulses in a circular wire coil. The lithium-ion batteries generate an electric current. Each pulse generates a tiny magnetic field, and when the pulse concludes, the polarity of the magnetic field is reversed, causing the magnetic field to collapse and generate an electrical signal that causes the electric current to surge abruptly. This electrical signal induces an electric current to flow through the coil; the resulting electric current is known as the reflected pulse and has a duration of no more than 30 microseconds [24]. This process is repeated at a rate of 100 beats per second, but this can be increased to 250 beats per second or even up to 1,000 beats per second, the additional magnetic field produced by the metal object will lengthen the reflected pulse when the magnetic pulse collapses and results in it being elongated, and this will result in it being elongated. The VLF and PI types of metal detectors are displayed in Figure 2 [26].

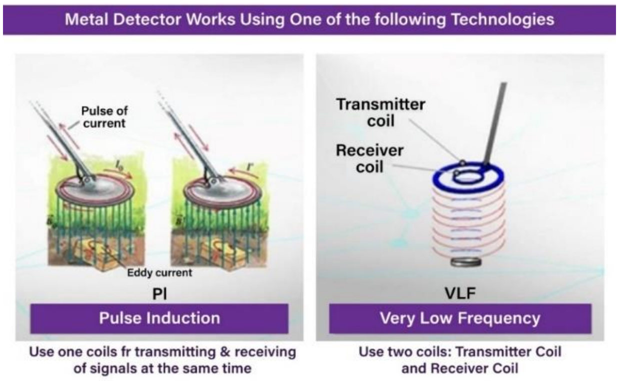

Figure 2. VLF and PI type metal detector

Figure 3 shows a simplified schematic of the basic pulsed-EMI method. A current loop transmitter is put near the metal item, and a steady current flow in the transmitter is maintained for a long enough time to allow turn-on transients in the object to dissipate. The loop current is then cut off. According to Faraday's law, the lowering magnetic field generates an electromotive force in the metal item. This force causes eddy currents to form in the metal. Because there is no energy to sustain the eddy currents, they begin to decay at a certain decay time that is controlled by the metal's size, shape, electrical and magnetic properties. The decay currents generate a secondary magnetic field, and the time rate of change of the field is monitored by a receiver coil located at the sensor. If a conductive object is shown to have a unique time-decay response, a signature library of conductive items can be constructed. When a buried metal object is discovered, it is time-decay signature can be compared to those in the library, and the object can be classified if a match is found. Classification distinguishes between potentially dangerous and nonthreatening objects [13].

2.3. BFO technology

One of the easiest approaches for metal detecting is the beat frequency technology of oscillatory pulses. At the search end, a large coil is utilized, while a smaller coil is housed within the control box. Each oscillator coils generate thousands of pulses per second [24]. The coil emits radio waves, which the receiver in the control box carries and converts into an audible signal that we perceive as pulses due to the varying frequencies of the two coils. During the process of detection, an electric current flow through the enormous coil, converting the magnetic field produced by the metal into radio waves. These radio waves have a different frequency than the waves in the control box coil and create audible-frequency pulses [24]. BFO detectors are appropriate for general-purpose metal detection tasks, such as looking for coins, jewelry, or artifacts in parks, beaches, and other low-mineralization areas. BFO is considered as the most basic and affordable type of metal detectors. BFO detectors are still capable of successfully detecting metal objects even though they do not have the powerful functions and distinguishing abilities of VLF and PI detectors.

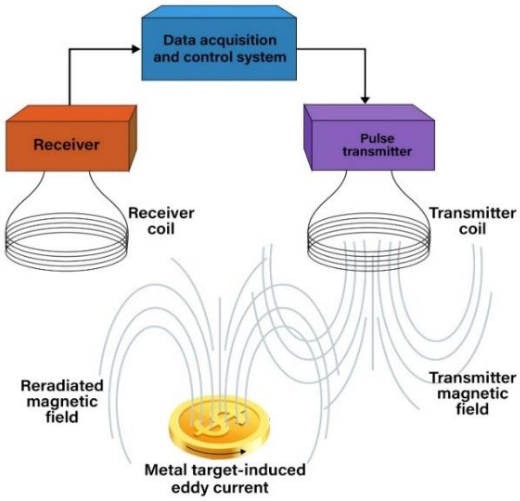

Figure 3. Basic PI metal detection scheme

2.4. Metal detector operation

The transmitting coil is located in the center of a standard metal detector, while the two receiving coils are placed on either side. A differential amplifier is attached to the receiving coils. The presence of foreign metal fragments is discovered when the magnetic field produced in the transmitting coil is perturbed by metal objects by altering the amplitude and phase of the differential amplifier’s output voltage.

A reference study was used to investigate the link between output amplitude and phase and the electromagnetic properties of metal objects [27]. A simultaneous resistivity and permeability measurement (SRPM) technique was created to assess the electrical and magnetic properties of a spherical sample by vectorially measuring the impedance difference between two circular solenoid coils, one with and one without the sample. Using a spherical sample to estimate the vector voltage induced in the receiving coil by the metal object simplifies the research. Experiments with brass, aluminum, copper, and iron objects demonstrated the correctness of the new formula. The unique formula described in this study is regarded as a useful guide for the construction of metal detectors, which previously relied on the analytical experimental technique [27]. Figure 4 displays the block diagram of a typical metal detector.

Metal-detector performance depends heavily on the sensor head. Errors in coil arrangement within the head might lead to detector performance reduction. The effect of coil placement errors on detector sensitivity is demonstrated using electromagnetic modeling of typical very-low-frequency detector heads. As long as the bucking coil ‘tracks’ the receive coil, the required error corrections can be kept to a minimum [13]. The two-channel metal detector, comprised of two sets of perpendicularly oriented sensor antennae, is proposed to increase metal sensor’s detectable size from mm to cm scale, whereas conventional metal detector is only designed for mm or cm scale detection. In the cited study, the relative properties of the two metal detecting sensor channels were investigated, and the interference impact of two sensor channels operating simultaneously was detailed [28].

The metal detection channel’s detectable sensitivity to moving ferrous spheres with diameters as small as 0.7 mm was shown by its sensitivity scale, which is measured in millimeters. Excitation frequency of 50 kHz and improved sensitivity distribution. The metal detecting channel with its sensitivity measured in centimeters demonstrated a more even distribution of sensitivity together with the flexibility required for future modular assembly. The interference caused by the simultaneous operation of two sensors led to a lower output response, but the detection range was still useful despite the interference. As a result, it was possible to run two sensors, each of which had a distinct sensitivity range, simultaneously. Furthermore, it was possible to extend the detection range from mm scale to cm scale while still being within the bounds of what was practically acceptable. Figure 5 shows the conventional antenna set of metal detection sensor [28].

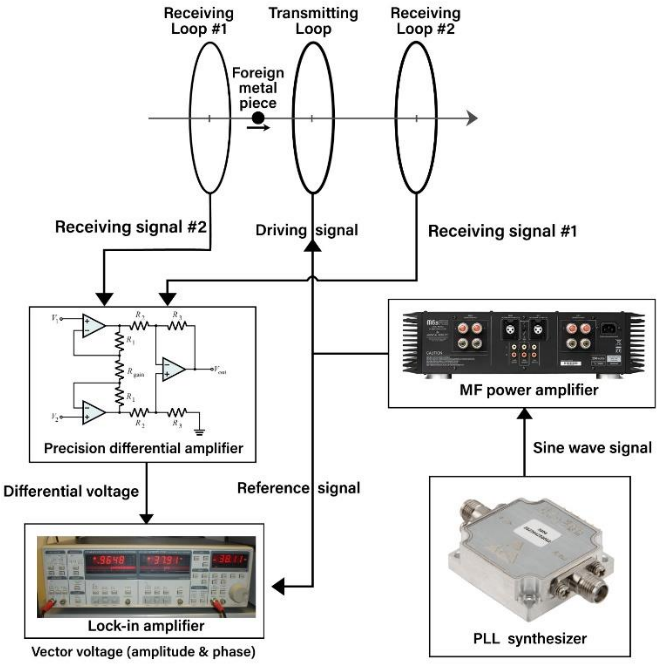

Figure 4. Block diagram of a typical metal detector

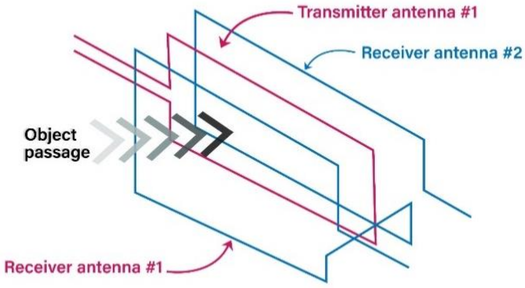

Figure 5. Conventional antenna set of metal detection sensor

The VLF, PI, and BFO are three common technologies used in metal detectors. Each has unique qualities and benefits. These approaches differed in concept, sensitivity and accuracy of detection, classification of distinct mentals, and cost of various instruments [29]. The VLF employs two coils-a transmitter and a receiver-to send and receive radio waves. The transmitter creates a continuous electromagnetic field with a low frequency, while the receiver detects interruptions in this field induced by metal objects nearby. The PI detectors generate a magnetic field by sending short pulses of high-voltage current through a coil or antenna. The detector detects the decay duration of the generated magnetic field when the pulse ceases. Metal objects disrupt this field, producing a signal for detection. BFO detectors use two coils, one for emitting and the other for receiving a continuous radio frequency (RF) signal. When the RF signal contacts a metal item, a “beat” or audible change in frequency is produced, which can be sensed by the user [30].

In conclusion, the decision amongst VLF, PI, and BFO metal detectors is contingent upon the particular needs of the metal detecting task. VLF detectors are renowned for their discrimination powers, whereas PI detectors excel at penetrating deep into the earth. BFO detectors are frequently chosen due to their cost and ease of use, making them ideal for beginners and enthusiasts. Environmental circumstances and budget concerns also play a crucial influence in selecting the most suited technology. Table 1 summarized the main differences between each technique.

Table 1. Metal detections techniques

Technology	Application	Depth and sensitivity	Classification capabilities	Price	False alarms
VLF	Discrimination	Moderate	Superior	Affordable	Moderate
PI	Detection	Excellent	Moderate	Expensive	Low
BFO	Detection	Limited	Limited	Low-cost	High

3. SYSTEM IMPLEMENTATION

Even as metal detectors differ in appearance, their operation is largely similar. Some metal detectors may have minor differences, such as having additional headphones or having the control device installed at the bottom of the shaft and the monitor screen installed at the top, so that the metal detector consists of four basic components that work identically, which are the shaft, stabilizer, control box, and search coil [24]. The shaft of the device It is the part to which the rest of the components are attached. It also connects the control box and the detector, and its length is typically adjustable so that it can be tailored to the height and comfort level of the individual who will be using it. The stabilizer is the component of the device that makes it simple to operate, performs the function of an auxiliary shaft, stabilizes and balances the device, and eliminates vibrations when the gadget is being used in the search process.

The control box, sometimes known as the device's "brain", is where the electronic circuit, control keys, settings, CPU, and internal speakers can all be found. The system is made up of its components, which are separated into the main board, the operating board, and the monitoring board. The operating board is where all of the electronic components that are required to run the system and determine whether or not metals are present simply by listening to the sound coming from the speaker are located. In terms of the monitoring board, it is comprised of the Arduino, the liquid-crystal display (LCD) screen, and the Bluetooth module. Figure 6 shows the main designed board which contains a group of major electronic parts.

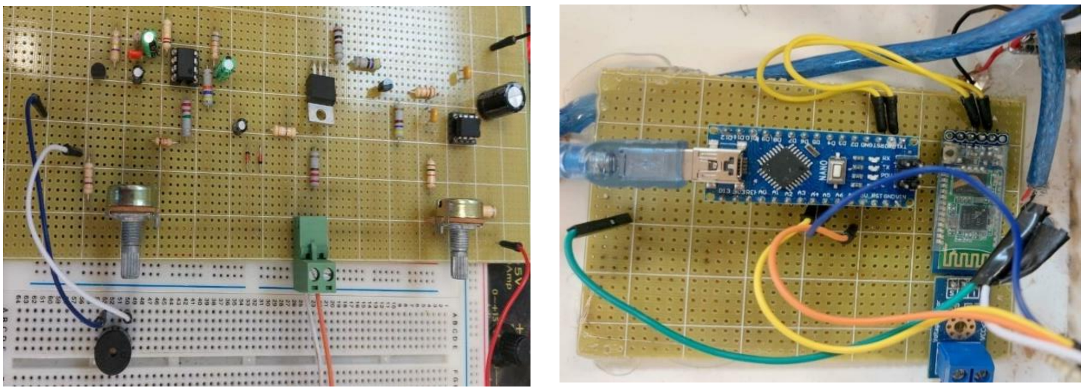

Figure 6. The main and monitoring boards

Microcontrollers are finding more and more applications, not just in manufacturing processes but also in a wide variety of other fields and aspects of daily life. This advancement of microcomputers in smart remote monitoring and controlling applications through the use of wireless and wired techniques, which are frequently utilized these days [31]. The ATmega328 serves as the brains behind the little, all-inclusive, and breadboard-friendly microcontroller known as the Arduino Nano (Arduino Nano 3.x).

A voltage sensor device is utilized for the purpose of carrying out the task of voltage measurement. In addition, voltage sensors are capable of measuring the voltage in a variety of different methods. The LCD is a device that both displays information about the system and receives data from the microcontroller. A Bluetooth module is a piece of hardware that serves as an interface between two electronic devices. It facilitates the wireless connection of any two electronic gadgets using Bluetooth low energy and creates a standard for the exchange of data between the devices. Utilizing this equipment allows for the successful establishment of a link between the mobile device and the system. While the application that was developed is called “metal detector” and the application itself is programmed by making use of the code, respectively.

The search coil is designed in the form of a flat circular coil and it is positioned at the base of the constructed gadget that is moved above the ground. In addition to this, it functions similarly to an antenna in that it creates a magnetic field in order to detect nearby metal objects. As a general rule, the diameter of the search coil is directly proportional to the amount of depth it can detect. Because the field generated by the large coil is larger and deeper than the field generated by the small search coil, it is the best choice when searching for large and deeply buried metals such as antiquities. The field generated by the large coil also increases as the diameter of the coil increases.

The proposed design of the prototype had been built to realize the metal detector. Several considerations had been taken in to account in terms on the hardware design and end user requirements. The system components successfully assembled and found to be satisfactory operated. In the following section the results of testing and operating of the proposed design is presented.

4. RESULTS AND DISCUSSION

The final results of the developed and implemented prototype of metal detector device is shown as in Figure 7. The control box of the developed device which considered as the brain of the device. The control box includes: the electronic circuit, control keys, settings, processor, and internal speakers as disputed in Figure 8.

Figure 7. The search coil

Figure 8. Metal detector machine and control box

The shaft that it is the part to which the rest of the parts are connects the control box and the detector. Furthermore, it is usually adjustable in length to suit the length and comfort of the person when using it. The stabilizer of the device. This part of the device, which makes it convenient to use and acts as an auxiliary shaft. In addition, the stabilizes acts as a balancer of the developed device and reduces the vibrations during the search process.

Figure 7 shows the search coil which is located at the tip of the developed device. This part is move on the surface of the ground. Therefore, it is act as an antenna that generates a magnetic field to senses the different type of metal objects.

This technology uses a single coil that acts as a sending and receiving coil at the same time as. The idea of this technique is to send an electric current in the form of short and strong pulses in a coil consisting of circular wire. Each pulse generates a small magnetic field and when the pulse ends, the polarity of this field is reversed, and the magnetic field collapsed, forming an electrical signal, for a period of time, which leads to a large rise in the electric current [26].

The electrical signal causes an electric current to pass through the coil, this current generated by an electric signal is called as the reflected pulse, and its duration is very short, not exceeding 30 microseconds. This process is repeated at a rate of 100 beats per second, and this number can be increased to reach 250 beats per second or increases to 1,000 beats per second according to the manufacturer [26]. When the detector is above a metal object, the electric pulse produces a magnetic field towards the object.

The coil receives a pulsing current, which then creates a magnetic field, which is depicted in blue as shown in Figure 9. Eddy currents are electric currents that are caused by the induction of a magnetic field into a metal by the movement of a coil's magnetic field across the surface of the metal. The magnetic field is induced into the coin as shown in Figure 9. As a result, the eddy currents form their own magnetic field, which is depicted in red. This produces an opposite current in the coil, which in turn triggers a signal indicating the presence of metal [26].

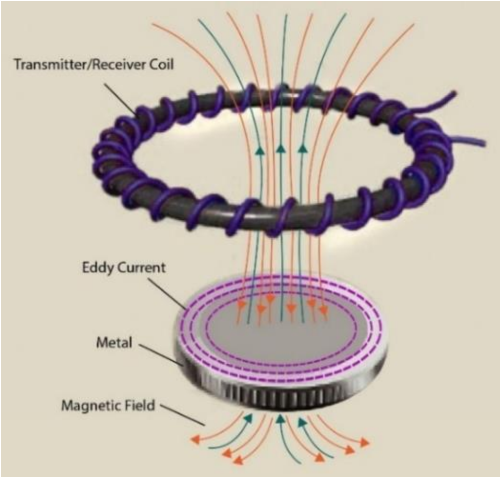

Figure 9. The direction of the magnetic field of coil and of eddy current

When the magnetic pulse collapse and causes the reflected pulse, the additional magnetic field generated by the metal object will increase the duration of the reflected pulse. The functionality of the proposed design is clarified as in the block diagram which can be seen in Figure 10. The relationship between the distance in centimeters and the voltage levels is depicted in Figure 11. In addition, when the detecting distance rises, the voltage decreases, as depicted in Figure 11. Moreover, the curve exhibits a high degree of linearity of R^2=0.96.

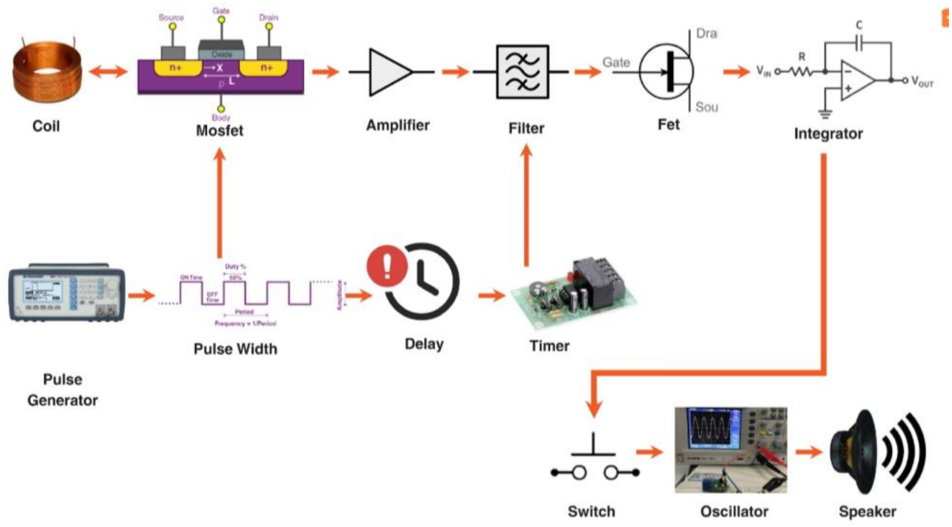

Figure 10. Block diagram of PI metal detector

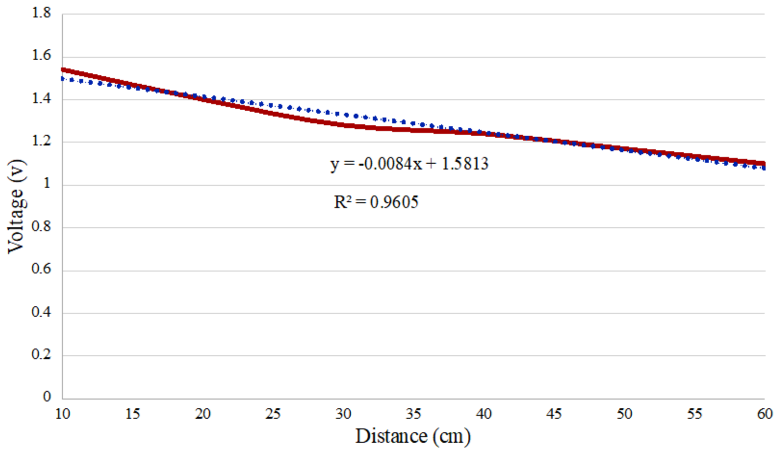

Figure 11. Distance verses voltage

Figure 12 proves the relationship between the distance in centimeters and the values appears on the LCD screen. Besides, as the detection distance increases the value of the degrees out of 100 is decreased as shown in Figure 12. Likewise, this prove that the developed detection machine is able to sense up to 65 cm for different type of metal.

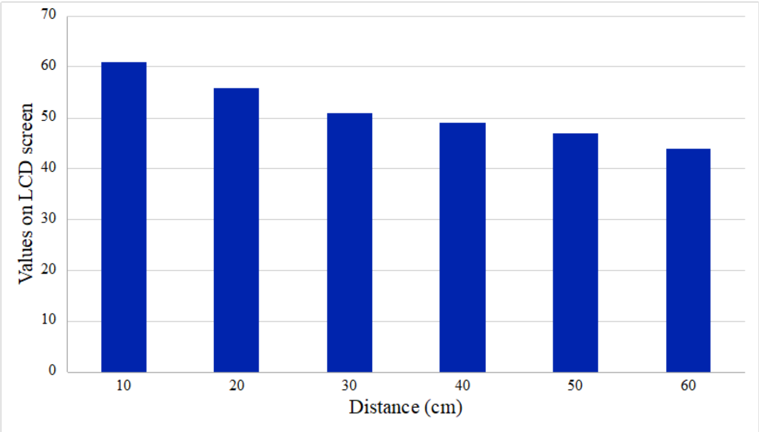

Figure 12. The relationship between detection distance and values on LCD screen

Table 2 shows a comparison with other metal detectors, as clarified in the table, the proposed design had shown a good and satisfactory distance detection compared to other devices. Furthermore, the developed device was able to detect objects effectively through the air and soil medium. The key constraint associated with the produced suggested device is primarily the detectable distance, which can be considered an advantage when compared to other devices, as shown in Table 2.

Table 2. Comparison with other metal detectors

Reference	Coil parameters	Operation frequency (Hz)	Detectable distance (cm)	Objects detected	Medium	Technology
[32]	a 35×35 cm ~180 μH 1.5 Ω	1 k	69-89	Mines	Air	PI
[33]	ϕ 11.5, 50 cm, 0.6 mm	80 k	40	Tin Can	Air	PI
[30]	ϕ 7 cm, 42 μH, 0.056 Ω	175.4 k	20	small piece of metal	Air	BFO
Proposed device	27,0.5 mm	140	65	piece of metals	Air Soil	PI

5. CONCLUSION

By locating and identifying various metal objects, metal detectors play an important role in the fields of security, archaeology, and industrial applications, respectively. This enables metal detectors to contribute to increased safety and protection while also facilitating the discovery of previously unknown objects. In this research, an Arduino controller is used to link the main control circuit for the purposes of this investigation. The input of the signal controlled and monitored through an LCD and a mobile application. The analog output of the circuit measured by a voltage sensor, and this information then be transmitted to the Arduino through the utilization of a Bluetooth module. The detector’s electric pulse creates a magnetic field that targets the metallic object above it. The metal object’s magnetic field lengthens the reflected pulse as the magnetic pulse collapses. Pulsing electricity creates a magnetic field in the coil. Eddy currents form in metal as the coil’s magnetic field passes across it. The developed metal detector device estimates the metal’s depth using the metal object’s magnetic field. The device calibrates magnetic field strength with depth to locate and distance the object from Earth. The device can be utilized in various applications, including detecting land mines, firearms, airport security, archaeology, and treasure hunting. The findings of the evaluations carried out on the prototype indicated that the system operates with an accuracy and sensitivity that are up to the standards expected.

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