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Low-cost mine detector design using magnetic anomaly method

Manyetik anomali yöntemi kullanılarak düşük maliyetli mayın dedektörü tasarımı

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Low-Cost Mine Detector Design Using Magnetic Anomaly Method

Highlights

- *Magnetic anomaly based low-cost landmine detector design.*
- *Landmine detection and partial landmine type determination.*

Graphical Abstract

Land mine detection is carried out with a low-cost handheld magnetic anomaly based mine detector in three different soil types by using three types of land mines and one non-mine pheromagnetic object. First, the detector skeleton was designed, and then the electronics were designed. Measurements were made using real land mines in a real world environment.

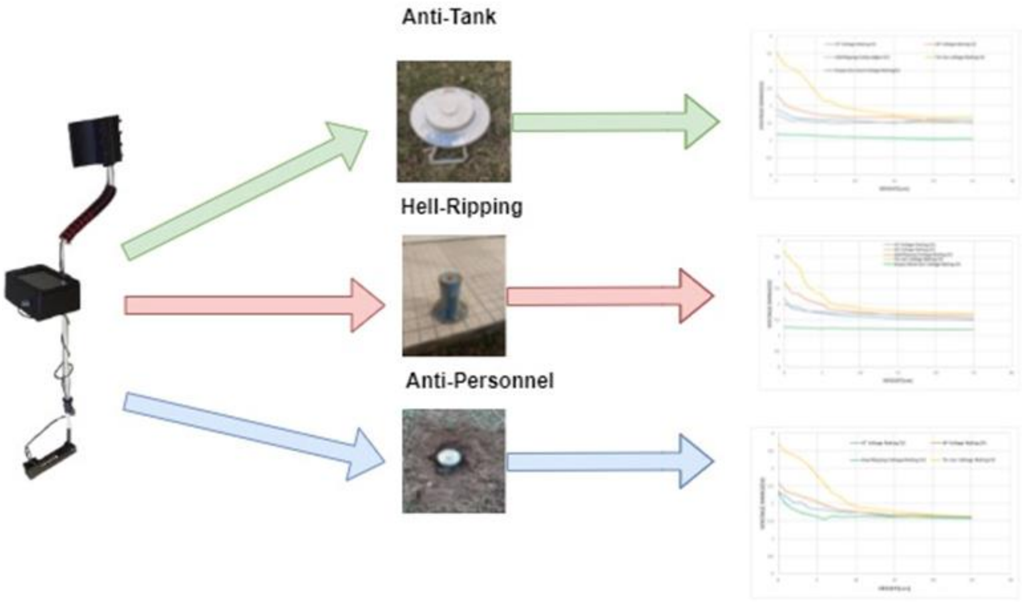

Figure. Block diagram of mine detection

Aim

The aim of this study is to detect buried and non-buried land mines.

Design & Methodology

In this study, first of all, 85% of the detector parts were produced on a three-dimensional printer using the solidwork program, then the electronics and software were made under the control of a mini computer, raspberry Pi 3, and it became one of the first handheld magnetic anomaly-based landmine detectors.

Originality

The originality of this study is that it is one of the first hand-held landmine detectors based on magnetic anomalies at low cost.

Findings

In measurements made using real world environment and real land mines, different output voltage values were measured for each land mine and ferromagnetic object at different heights. This is an indication that the working principle of the detector is designed correctly and that the detector works.

Conclusion

It has been observed that the low-cost magnetic anomaly-based detector designed as a result of this study detects landmines and can even partially determine the type of landmines.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Low-Cost Mine Detector Design Using Magnetic Anomaly Method

Araştırma Makalesi / Research Article

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ABSTRACT

Buried mines pose great dangers to humans and animals around the world, which means thousands of people die each year from buried mines. Detecting and destroying these mines without harming people is an important issue. Today, these landmines are detected using different methods such as Ground Effect Radar, Electromagnetic induction, Infrared and Nuclear Quadrupole Resonance and active sensors are generally used in most of these methods. Although active sensor-based landmine detectors are often used for performance reasons, they can cause unintentional landmine explosions because they operate with transmitted and reflected signals. On the other hand, there is no such obstacle that can perform better in passive sensor-based landmine detectors depending on the design criteria. Therefore, in this study, a prototype design including passive sensor with magnetic anomaly method has been developed and shown. For the performance analysis of this detector, real landmines are used and the designed system is tested with different distance values in different soil types. The results show that the prototype produced successfully detects different types of landmines, is assertive in its lightness and only 1750 grams with its battery, providing sensitivity as well as advantages such as ease of use and low cost. It also shows the feature of being the first handheld landmine detector based on magnetic anomaly.

Keywords: Magnetic anomaly, land-mine detector, land-mine detection, low-cost detector, hand-held detector.

Manyetik Anomali Yöntemi Kullanılarak Düşük Maliyetli Mayın Dedektörü Tasarımı

ÖZ

Gömülü mayınlar, dünyanın her yerindeki insanlar ve hayvanlar için büyük tehlikeler oluşturuyor, bu da her yıl binlerce insanın gömülü mayınlardan ölmesi anlamına geliyor. Bu mayınların insanlara zarar vermeden tespit edilip imha edilmesi önemli bir konudur. Günümüzde bu kara mayınları Yer Etkili Radar, Elektromanyetik indüksiyon, Kızılötesi ve Nükleer Dört Kutuplu Rezonans gibi farklı yöntemlerle tespit edilmekte ve bu yöntemlerin çoğunda genellikle aktif sensörler kullanılmaktadır. Aktif sensör tabanlı kara mayını dedektörleri genellikle performans nedenleriyle kullanılsa da, iletilen ve yansıyan sinyallerle çalıştıkları için kasıtsız kara mayını patlamalarına neden olabilirler. Öte yandan, tasarım kriterlerine bağlı olarak pasif sensör tabanlı kara mayını dedektörlerinde daha iyi performans gösterebilecek böyle bir engel yoktur. Bu nedenle bu çalışmada manyetik anomali yöntemi ile pasif sensör içeren bir prototip tasarımı geliştirilmiş ve gösterilmiştir. Bu dedektörün performans analizi için gerçek mayınlar kullanılmış ve tasarlanan sistem farklı toprak tiplerinde farklı mesafe değerleri ile test edilmiştir. Elde edilen sonuçlar, üretilen prototipin farklı tipteki mayınları başarıyla tespit ettiğini, hafifliğiyle iddialı olduğunu ve piliyle sadece 1750 gramlık hassasiyet sağladığını, kullanım kolaylığı ve düşük maliyet gibi avantajların yanında hassasiyet sağladığını gösteriyor. Ayrıca manyetik anomaliye dayalı ilk el mayın dedektörü olma özelliğini de göstermektedir.

Anahtar Kelimeler: Manyetik anomali, kara mayını dedektörü, kara mayını algılama, düşük maliyetli dedektör, el dedektörü

1. INTRODUCTION

A mine is a type of war weapon frequently used in both military and terrorist activities. Mines are mostly used on land and those ones are called Landmines. They are mostly used in buried form and placed in a way that cannot be seen by people. Thus, they cause serious health problems on the people and animals. Mine detection devices are used to eliminate these problems. Especially in the devices used in the detection of buried landmines, the main factor is the detection method of the mine. Mine is detected with sensors. Sensors are separated as active and passive. The main difference between these two sensors is that active sensors detect with the reflected part of a sent signal, whereas in the passive sensor used in this study, the situation is that the world produces value due to distortions in the existing magnetic field lines, as opposed to sending signals. Among these two methods, the use of passive sensors is not very common. Because the successful performance of active sensors is higher in the studies. However, depending on the design criteria to be made, the success of passive sensors can also be very high. Besides, the biggest disadvantage of active sensors

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is that since their operating characteristics are based on signal transmission, they cause explosions when the firing mechanism unintentionally activates the buried landmines. Important researches are carried out on mine detectors both academically and commercially. It is seen that a lot of methods are used in these studies. Some of these are as follows in order; A 3D image analysis method has been proposed for the detection of land mines in the Ground Effect Radar (GPR) technique, which uses an adaptive filtering technique and image segmentation algorithm [1]. In another study, a new GPR system using an optical electric field sensor has been considered and a broadband type optical sensor with a frequency band of 100 MHz to 5 GHz has been applied to landmine detection and it was shown that buried objects could be detected [2]. Using the Ground Effect Radar (GPR) of anti-personnel landmine detection, some advanced algorithms have been presented for the obtained GPR data processing, and the distortions in the SAR image of the near area have been corrected [3]. Bistatic GPR has been developed, 3D image reconstruction has been achieved by generating the impulse with a 250 per sec pulse width, and the PMN2 mine model has clearly detected with high resolution [4]. The detector first calculated the Maximum Likelihood estimate of the prediction coefficients and then used the generalized probability method to determine whether it was a land mine [5]. The detection of anti-personnel and anti-tank mines with high resolution has been achieved with the center-band frequency of the sensor class ranging from 30 to 3000 MHz, with a central band frequency of 1300 MHz and a general-purpose pulse radar sensor up to a depth of 1 meter [6]. Landmine detection has been considered as two classification problems, and the PCA + SVM framework for the detection of landmines is presented [7]. A new, portable, ergonomic mine detector that combines electromagnetic induction and neutron backscatter has been made and it has been stated that it has become particularly suitable for the detection of plastic landmines [8]. A particle velocity-strain FD method combined with a perfectly matched layer (PML) has been developed for the simulation of propagating acoustic waves in three-dimensional poroelastic media [9]. A side-Scan sonar survey has been carried out to detect a mine-like object buried in the sediment [10]. For the analysis of elastic-wave interactions, the biorthogonal multiple resolution time-domain (Bi-MRTD) method is presented and it has been shown that buried mines can be found by the analysis of flexible waves [11]. A complete electromagnetic system consisting of a separate aperture sensor, air, soil, and buried landmines, typically tuned to 790 MHz, has been modeled using the FDTD method [12]. It is used to detect elastic waves with buried landmines [13]. By developing a signal processing technique for Ground Effect Radar (GPR) measurements, this technique has shown positive results, especially when using a Ground Effect Radar (GPR) to detect underground anti-personnel mines [14]. It has been demonstrated that these algorithms provide a significant classification performance gain by examining using a broadband frequency field EMI sensor and developing an algorithm [15]. The problem of using visual wavelength images to reduce surface clutter when detecting buried landmines using infrared imaging has been addressed [16]. It has been proposed to utilize the temperature dependencies of nuclear quadrupole resonance (NQR) signals to derive an approximate maximum likelihood (AML) detector [17]. A hybrid technique that uses both electromagnetic and elastic waves synergistically to detect buried landmines has been developed [18]. The Archimedes coiled antenna was developed to be used in a graded frequency GPR system for mine detection, and the radar image quality was improved by operating in approximately 0.5-6 GHz bandwidth [19]. By presenting an effective discretization method for the simulation of metallic objects in metal parts of metal detectors and landmines, the results for the magneto-semi-static model problem has been shown by the Lagrange multiplier method, and false alarms have been reduced [20]. By using infrared (IR) radiometers that measure the thermal radiation of objects, it has been proven that CNN is a powerful and efficient tool for various image processing applications [21]. It has been used to create images of objects by exposing various shaped objects with some significant hydrogen content to fast neutrons from a D-T generator [22]. verimini deneysel olarak incelemiştir. Çalışmasında ısıl verimin tahmini için yapay sinir ağlarını (YSA) kullanmıştır. YSA'nın güneş kollektörlerinin ısıl verimini tahmin etmede kullanılabileceğini vurgulamıştır [16]. Esen vd., güneş enerjili bir hava kollektörünün ısıl verimini deneysel olarak incelemiş ve sistemin YSA ve dalgacık sinir ağı modelini oluşturmuştur. Çalışmasında YSA'nın ısıl verimi yüksek bir hassasiyetle tahmin ettiğini belirt-mişlerdir [17]. Abuşka ve Akgül GEHK'nde yutucu plaka üzerine konik yaylar monte ederek sistemin deney-sel verilere dayalı olarak ısı transfer analizini yapmışlar landmines, the results for the magneto-semi-static model problem has been shown by the Lagrange multiplier method, and false alarms have been reduced [20]. By using infrared (IR) radiometers that measure the thermal radiation of objects, it has been proven that CNN is a powerful and efficient tool for various image processing applications [21]. It has been used to create images of objects by exposing various shaped objects with some significant hydrogen content to fast neutrons from a D-T generator [22]. These methods are among the methods frequently used in mine scanning. Magnetic anomaly detection is a good method for detecting ferromagnetic objects, especially hidden targets [23]. The study using the FLC100 type sensor in the detection of mines by magnetic anomaly method is included in the literature [24]. A weak magnetic field signal is detected due to a magnetized object in a magnetometric recording [25]. The Tc SQUID gradiometer prototype was developed and evaluated for magnetic anomaly detection of underwater targets in mobile research and thanks to this prototype, the noise amplitude is reduced by 3 times at

0.1 Hz [26]. By analyzing the magnetic anomaly data, the position of the unexploded ammunition (UXO) has been determined from the magnetic anomaly data in the air with the Self Organizing Feature Map (SOFM) Neural Network [27]. A test method has been demonstrated using a combination of eddy current techniques and classical magnetic anomaly techniques to detect defects in ferromagnetic materials [28]. In addition to these studies, another study in which magnetic anomaly signals were optimized is as follows [29].

As can be seen in the studies, most of them are active detector-based using active sensors. The solution to eliminate explosion risk of active based detectors is the use of passive detectors.

The passive sensors used in this study are TE100 type sensors. These sensors produce value according to the distortions caused by the earth's magnetic field. Depending on the values obtained, it is possible to detect and determine the type of landmine. Although there are information and studies about this method in the literature, all of them were carried out in the form of laboratory studies. In this study, the method used and the results obtained were tested in the field with different soil types, heights, and real landmines. Besides, this study presents a prototype product that uses this method for the first time. All parts of the prototype product created were obtained from 3D printers with original designs.

The detector designed and manufactured as a prototype has been subjected to many tests to determine its performance analysis. The results obtained demonstrated the success of the prototype product

Our study consists of three parts. The first part includes the determination of design criteria and the design and production of mechanical parts accordingly, while the second part includes the electrical design and software development stages. The last part includes the tests for performance analysis. Conclusion part includes the interpretation of the analysis and results.

2. MATERIAL and METHOD

Earth's magnetic field extends from the south pole to the north pole in the form of lines. Magnetic anomaly is expressed in the form of distortions in these magnetic field lines of the earth. For the magnetic anomaly to be detected, the objects forming this anomaly must be made of ferromagnetic materials and positioned perpendicular to the earth's magnetic field. However, today's sensors can detect objects in different positions [31]. In the presence of magnetic material, the decrease in flux density in the area where the sensor is located causes an electrical charge in the sensor and changes the output voltage. By interpreting these changes, information about the location, dimensions, and, if detectable, characteristics of the magnetic object can be obtained. Magnetic anomaly detection is a good method for detecting ferromagnetic objects, especially hidden targets [23]. The study is designed with a method based on the magnetic anomaly method and which enables the determination of land mines buried in the soil with this method. The basic idea in this method is to determine the object that constitutes the magnetic anomaly, that is, the magnetic distortion in the lines of the earth, with the necessary sensor systems. If this method can be applied correctly, it is possible to detect metallic, semi-metallic landmines buried in the soil and even handmade explosives.

Since the distance between the landmine to be measured and the detector is much greater than the size of the landmine, the measured landmine can be considered a magnetic dipole. Fig. 1 shows the magnetic dipole model of the sensor placed in the middle of the coordinate plane. The magnetic induction distribution of the magnetic dipole in space is expressed as:

$$B(M,R) = \frac{\mu_0}{4\pi}\left[\frac{3(M.R).R}{|R|^5} - \frac{M}{|R|^3}\right] \tag{1}$$

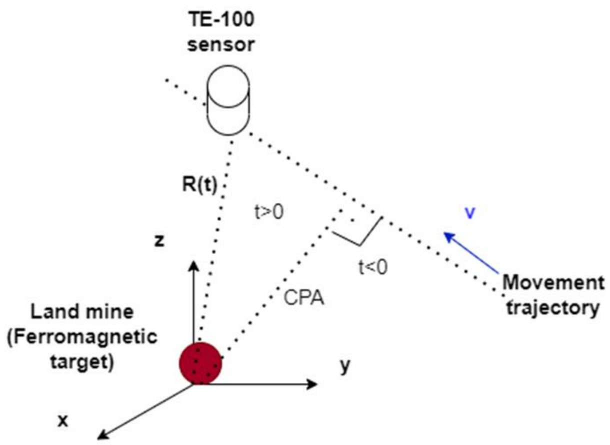


Figure 1. Diagram of magnetic anomaly detection

Here, μ_0 is the permeability coefficient of the air, and M is the magnetic moment of the target expressed as $M = (m_x, m_y, m_z)$. The distance between the sensor and the landmine as a function of time is expressed as $R(t) = (x + v_x t,\ y + v_y t,\ z + v_z t)$. In this equation, (x, y, z) is the cartesian coordinates and v_x, v_y, v_z is the component of the velocity vector in cartesian coordinates. In other words, the closest direction between the target land mine and the sensor is the motion trajectory and is defined as the closest proximity approach (CPA). The closest proximity approach is shown as $CPA = (x_0, y_0, z_0)$. Here, when the detector sensor moved at time $t = 0$, CPA passes, the expression of the components of magnetic induction B in the Cartesian coordinate system by changing the expression given in the Eq. 2 is shown as the equations below. Since the TE-100 sensor used in this study has no effect on the direct current (DC) magnetic field, the geomagnetic field is not taken into account. Here, the sensor of the moving detector is expressed as magnetic moment vector $M = (m_x + m_y + m_z)$, velocity vector $V = (v_x + v_y + v_z)$, CPA vector $CPA = (x_0, y_0, z_0)$.

$$B_x(t) = \frac{\mu_0}{4\pi}\left\{\frac{[2(x+v_xt)^2-(y+yt)^2-(z+v_zt)^2]m_x+3(x+v_xt)(y+v_yt)m_y+3(x+v_xt)(z+v_zt)m_z}{[(x+v_xt)^2+(y+v_yt)^2+(z+v_zt)^2]^{\frac{5}{2}}}\right\} \tag{2}$$

$$B_y(t) = \frac{\mu_0}{4\pi}\left\{\frac{3(x+v_xt)(y+v_yt)m_x+[2(x+v_xt)^2-(y+yt)^2-(z+v_zt)^2]m_y+3(y+v_yt)(z+v_zt)m_z}{[(x+v_xt)^2+(y+v_yt)^2+(z+v_zt)^2]^{\frac{5}{2}}}\right\} \tag{3}$$

$$B_z(t) = \frac{\mu_0}{4\pi}\left\{\frac{3(x+v_xt)(z+v_zt)m_x+3(y+v_yt)(z+v_zt)m_y+[2(x+v_xt)^2-(y+yt)^2-(z+v_zt)^2]m_z}{[(x+v_xt)^2+(y+v_yt)^2+(z+v_zt)^2]^{\frac{5}{2}}}\right\} \tag{4}$$

In order to measure magnetic anomaly, this study uses the TE-100 sensor which is a Fluxgate type. Fig. 2 illustrates the operating principle of the sensor.

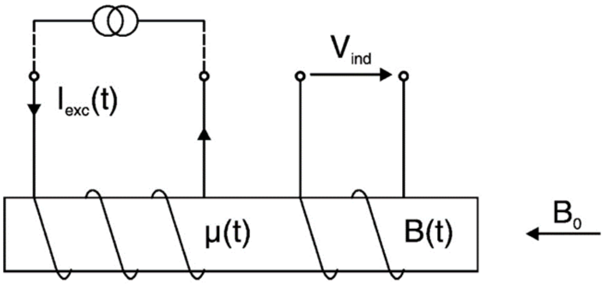


Figure 2. Fluxgate operating principle [31]

This sensor is a single-axis, feedback, orthogonal magnetic field magnetometer that can operate without an external driver circuit. In this orthogonal perpendicular magnetometer, the excitation area and the measured area are perpendicular to each other and are therefore named orthogonal. Excitation and measurement fields of a primitive type orthogonal type magnetometer are shown in Fig. 3.

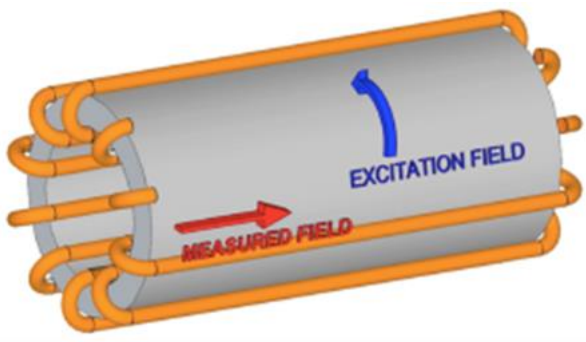


Figure 3. Simple structure of orthogonal fluxgate [32]

It has the best sensitivity among the vectorial field sensors. The excitation current through the excitation coil produces a field (in both directions) that periodically saturates the soft magnetic material of the sensor core as shown in Fig. 1. At saturation the core permeability decreases and the DC flux associated with the measured DC magnetic field B0 decreases. Fig. 4 shows the analog structure of the common feedback type magnetic field magnetometer.

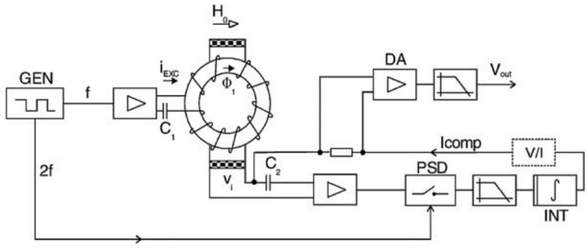


Figure 4. Analog fluxgate magnetometer [31]

When the measured field is present, the voltage is induced into the sensing (collecting) coil at the second (or even higher) harmonics of the excitation frequency. The measured area is returned to DC or zero frequency value by the well sensitive detector and generates the second harmonic voltage at the output. Integrator provides feedback gain. The feedback current is detected by the differential amplifier on the resistor and acts as the magnetometer output. This voltage, which is proportional to the measured area, is usually the sensor output [30]. In this method substantially provides, low power consumption, low cost, not being affected by environmental changes, high sensitivity, high detection speed, reliability, and durability. In this sense, this study mainly purposes to determine ferromagnetic materials that create magnetic distortion with remote sensing systems using magnetic anomalies. Detectors used to detect buried landmines are of two types; active and passive detectors. The biggest handicap of active detectors is that they detect buried landmines through transmitted and reflected signals. These transmitted signals can trigger the firing mechanism of the landmine and cause it to explode. Such a handicap has not been encountered in passive detectors. Passive detectors are therefore considered to be safer. In this study, independent variables were determined for the test procedures of the prototype designed with the magnetic anomaly method. These are soil type, elevation, and type of object buried in the ground. In our study, the measurements were determined according to these variables and the characteristic voltage outputs of the object to be detected were obtained. In the content of the test, it is seen that the variables that affect the magnetic anomaly measurement caused by the objects are the soil type, the height, and the type of the object that creates the anomaly. Three different situations have been considered. These; measurement of moist soil, dry sand, and objects without being buried in any soil and four different object types; AP mine, AT mine, Heel Breaker mine, and a full canister were measured at heights of 0-25 cm and the characteristic voltage outputs of the objects are presented with graphics. When determining the height, the distance between the points of buried mines and the contact surface is adjusted as approximately 4 cm. This adjustment is made because of the required activation altitude of the mine. The mine as well as its firing mechanism cannot be activated below 10 cm.

3. DESIGNED SYSTEM

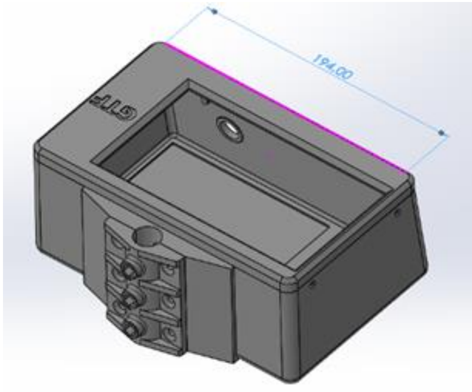
3.1. Mechanical Design

In light of the information given in the statement of the problem, the production phase of the required mechanical system has started. In order to use the product comfortably in the mechanical system design, production has been made for the placement of the sensors, armrests, and the areas where the detector box is located. The view of the produced mechanical design is presented in Fig. 5. Mechanical system design has been made with 3D printers. Additive PLA is used, as it makes the mechanical system both flexible and durable. The armrest occupancy rate is 40%, and the number of layers is four. The occupancy rate of other produced materials is 30%, and the number of layers is three.

Figure 5. Mechanical parts view of mine detector prototype

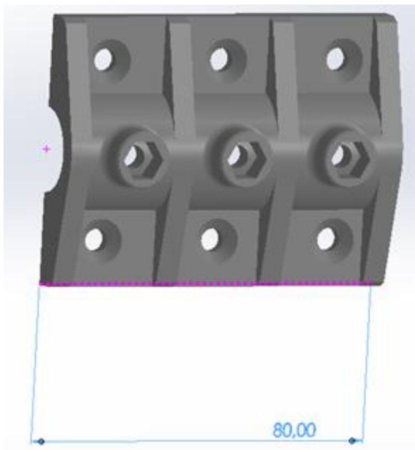
The detector component box, ergonomic armrest, and sensor carrier part, which are the parts of the prototype, were designed in SolidWorks 2013 program and produced using PLA filament with additive in a 3D printer. During the mechanical design phase, a metric 19 aluminum pipe was used to form the mainframe of the mine detector prototype. The reason for choosing aluminum is that it is not a ferromagnetic material and does not create magnetic anomalies, thus allowing a clean measurement. Besides, the weight of the produced prototype with its battery is only 1750 grams and is much lighter than other detectors, which provides a great advantage in terms of ease of use.

Together with the wall thickness of the box, its total footprint in space is 380 cm3 and it is made up of three parts in total; the detector box, the detector box cover that will protect the parts inside the detector box from external factors, and the fixing part of the box to the aluminum pipe.



a) Detector box

b) Detector screen cover



c) Detector box fixer

Figure 6. Component box parts of mine detector prototype

The length of the main armrest piece shown in Fig. 7 is 12 cm, arm grip diameter is 115.73mm and depth is 52.33 mm, and it is designed to hold a 19 mm aluminum pipe, suitable for human ergonomics and not creating extra weight for the detector.

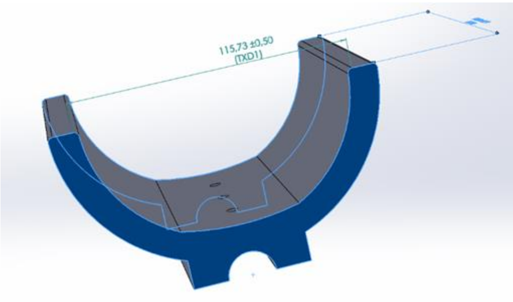


Figure 7. Armrest part of mine detector prototype

The place where Fluxgate TE-100 sensors with 200mm length and 33mm width can enter, shown in Fig. 8, is designed by cutting by extrusion and emptied to reduce the weight, and is shown in Fig. 8.

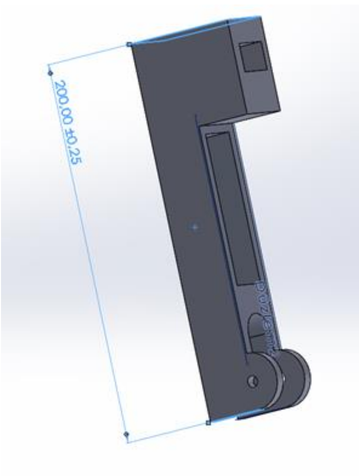


Figure 8. Sensor carrier part of mine detector prototype

For the designed prototype, Raspberry PI, whose electronic design is a processor card, waveshare capacitive touch screen compatible with the processor card, a 4-channel ADS 1115 soldered on a pretax and a buzzer to receive an audio warning, 11.1V 3400mAh 35C ' It consists of a battery and LM9526 voltage regulator to keep this battery at 5V required by the system. Finally, it consists of a Fluxgate type TE-100 sensor that will detect the Magnetic Anomaly connected to the system. A simple model of the system is given in Fig. 9. and the table of the components used in the prototype circuit is given in table 1.

Table 1. Table of the components used in the prototype circuit

#	Components Used In The Prototype Circuit
1	Raspberry Pi 3 B+
2	ADC Converter
3	Voltage Regulator
4	Buzzer
5	Battery
6	TE-100(Magnetic anomaly sensor)

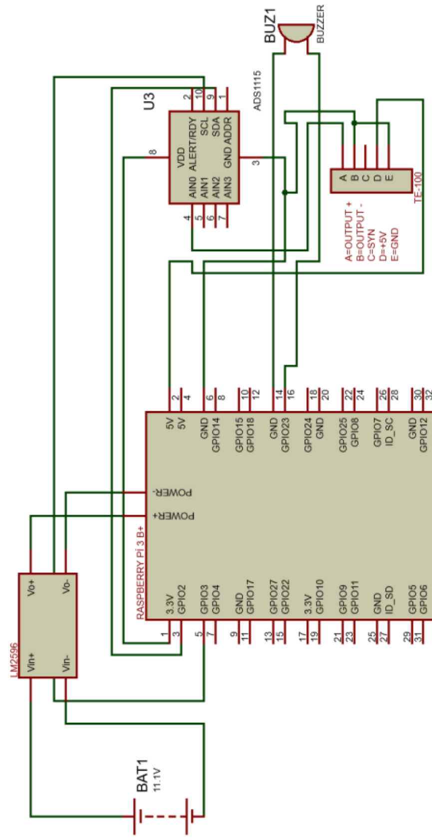


Figure 9. Simple electronic circuit diagram of mine detector prototype

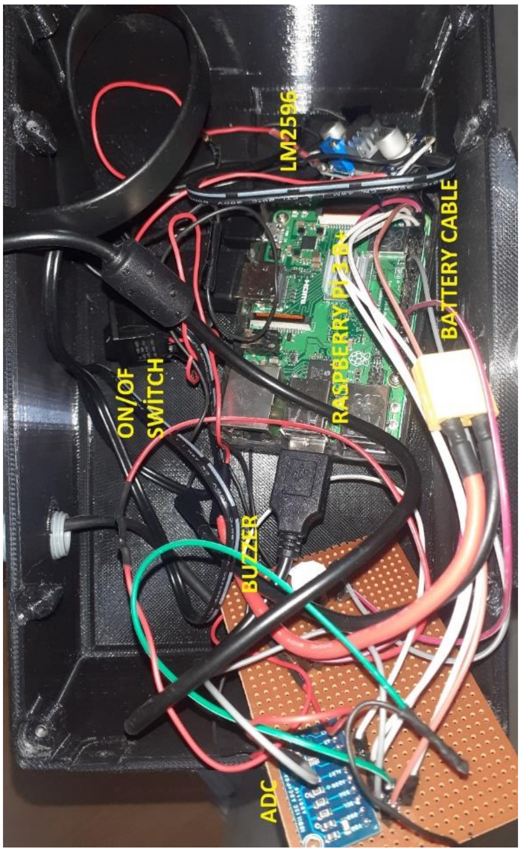


Figure 10. Circuit image inside the box of the detector prototype

The main operation flow chart of the designed mine detector prototype is given in Fig. 11. According to this scheme, the voltage value to be read first and the anomaly value are assigned to zero and a function is created and inserted into the loop and the reading process is performed with a frequency of 4 Hz. The voltage values of each value obtained are printed on the screen and the buzzer placed according to these values is provided to output at different period intervals. These outputs given are parallel to the anomaly severity caused by the buried object.

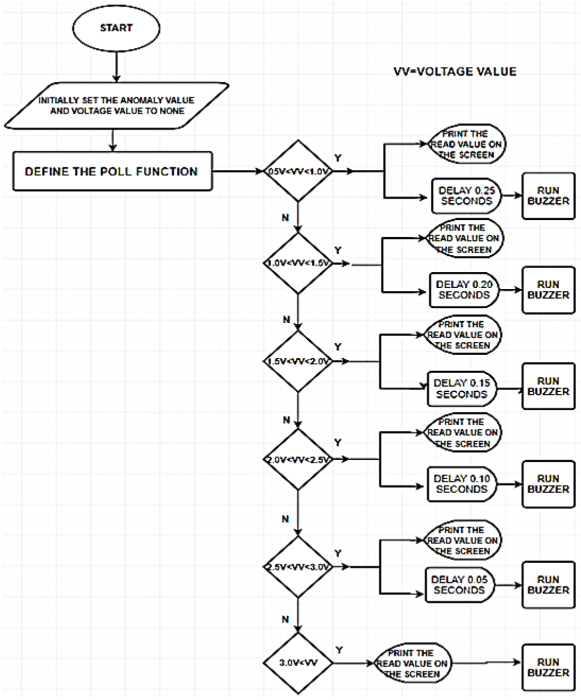


Figure 11. Flow chart of the main operating program

4. EXPERIMENTAL RESULTS

After the mine detector prototype was produced, tests were carried out to perform performance analysis. The measurements obtained were carried out in environments that exactly match the real conditions, that is, in environments where tree roots, rocks, and metal residues that may cause noise to the magnetic anomaly signals are located at different height levels of the soil. In the measurements, a full canister was used to simulate real hollow mines and handmade explosives, which are free of explosive materials shown in Fig. 12.

a) Anti-personnel mine

b) Anti-tank mine

c) Heel-ripping mine

Figure 12. Different types of mine images

Table 2. Measurements on dry sandy ground

Height (cm)	AT Voltage Rating (V)	AP Voltage Rating (V)	BTAP Voltage Rating (V)	CAN Voltage Rating (V)	Empty Dry Sand Voltage rating (V)
0	1,89E+00	2,32E+00	1,73E+00	3,55E+00	1,18E+00
1	1,79E+00	2,05E+00	1,65E+00	3,18E+00	1,17E+00
2	1,67E+00	1,92E+00	1,55E+00	3,07E+00	1,16E+00
3	1,63E+00	1,87E+00	1,59E+00	2,94E+00	1,16E+00
4	1,62E+00	1,81E+00	1,55E+00	2,69E+00	1,15E+00
5	1,61E+00	1,76E+00	1,51E+00	2,40E+00	1,14E+00
6	1,59E+00	1,72E+00	1,53E+00	2,13E+00	1,12E+00
7	1,60E+00	1,71E+00	1,49E+00	2,12E+00	1,11E+00
8	1,58E+00	1,69E+00	1,49E+00	1,99E+00	1,10E+00
9	1,57E+00	1,66E+00	1,49E+00	1,92E+00	1,10E+00
10	1,55E+00	1,67E+00	1,51E+00	1,89E+00	1,09E+00
15	1,50E+00	1,67E+00	1,52E+00	1,73E+00	1,06E+00
20	1,61E+00	1,55E+00	1,51E+00	1,67E+00	1,04E+00
25	1,58E+00	1,50E+00	1,51E+00	1,68E+00	1,05E+00

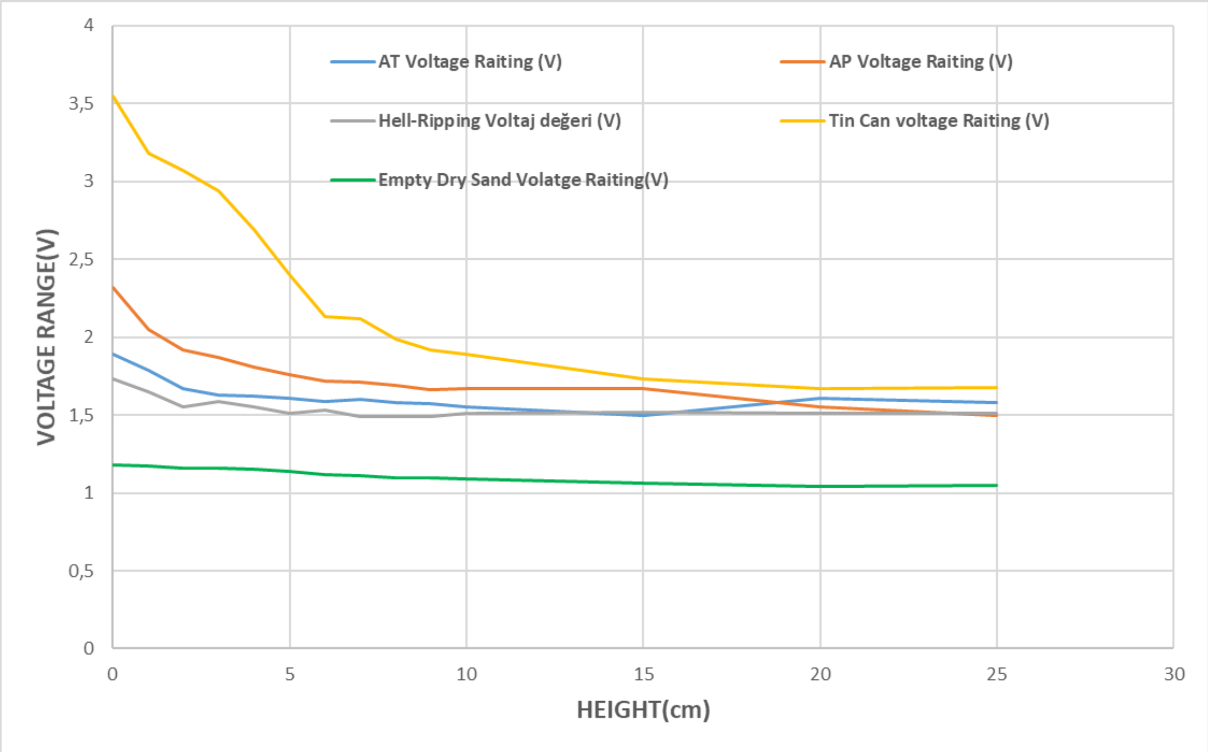


Figure 13. Measurements on dry sandy ground

When Table 2 and Fig. 13 are examined, the anomaly values created by empty dry sand at 0-25 cm heights were between 1.18V-1.05V, while the anomaly values of each buried object were higher than that of empty dry sand and different values for each measured object. This shows that the designed prototype can detect mines and objects that can create anomalies in dry sand.

Table 3. Measurements in moist soil

Height (cm)	AT Voltage Rating (V)	AP Voltage Rating (V)	BTAP Voltage Rating (V)	CAN Voltage Rating (V)	Empty Humid Soil Voltage Rating (V)
0	2,00E+00	2,69E+00	2,18E+00	3,70E+00	1,26E+00
1	1,93E+00	2,36E+00	1,86E+00	3,36E+00	1,26E+00
2	1,89E+00	2,30E+00	1,80E+00	3,16E+00	1,25E+00
3	1,78E+00	2,13E+00	1,77E+00	2,60E+00	1,24E+00
4	1,74E+00	2,06E+00	1,76E+00	2,39E+00	1,23E+00
5	1,71E+00	1,99E+00	1,75E+00	2,30E+00	1,22E+00
6	1,68E+00	1,84E+00	1,73E+00	2,05E+00	1,24E+00
7	1,65E+00	1,81E+00	1,71E+00	1,95E+00	1,23E+00
8	1,62E+00	1,80E+00	1,71E+00	1,94E+00	1,22E+00
9	1,61E+00	1,76E+00	1,70E+00	1,92E+00	1,22E+00
10	1,60E+00	1,74E+00	1,69E+00	1,86E+00	1,22E+00
15	1,54E+00	1,65E+00	1,67E+00	1,76E+00	1,20E+00
20	1,51E+00	1,60E+00	1,65E+00	1,72E+00	1,19E+00
25	1,49E+00	1,55E+00	1,64E+00	1,70E+00	1,19E+00

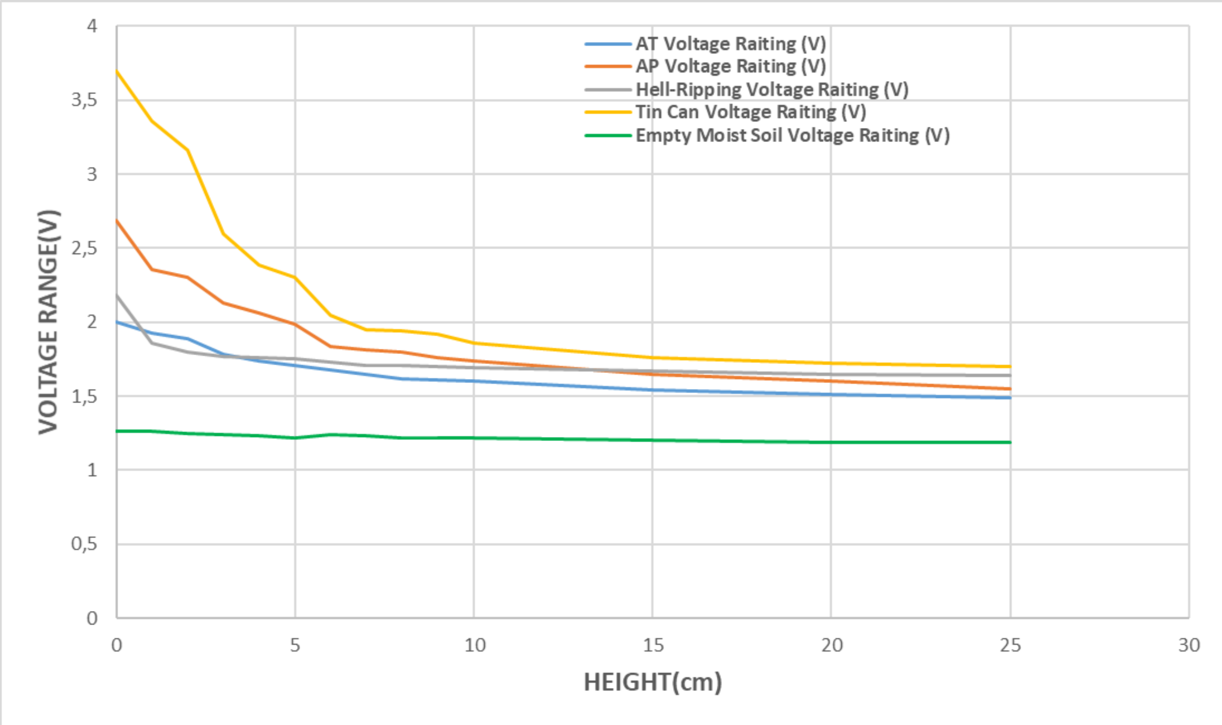


Figure 14. Measurements in moist soil

4.2. Measurements In Moist Soil

When Table 3 and Fig. 14 are examined, the anomaly values created by empty dry sand at 0-25 cm heights were between 1.26V-1.19V, while the anomaly values of each buried object were more than empty moist soil and different for each object measured. This shows us that the designed prototype can detect objects that can create mines and anomalies in moist soil. When compared to the previous environment, dry wax, it has been observed that the detection ability of the detector increases because the moist soil is a better conductor. In the ranking of only anomaly values, there were small displacements in anti-tank mine measurements and heel-breaking mines in some values, which is thought to be due to the different shapes of the two mines and the fact that the measurement was not 100% stable.

Table 4. Measurements of non-buried mines and objects

Height (cm)	AT Voltage Rating (V)	AP Voltage Rating (V)	BTAP Voltage Rating (V)	CAN Voltage Rating (V)
0	2,34E+00	2,58E+00	2,30E+00	3,70E+00
1	2,20E+00	2,34E+00	1,98E+00	3,46E+00
2	2,03E+00	2,28E+00	1,83E+00	3,38E+00
3	2,02E+00	2,20E+00	1,73E+00	3,25E+00
4	1,86E+00	2,13E+00	1,69E+00	3,07E+00
5	1,84E+00	2,06E+00	1,63E+00	2,80E+00
6	1,82E+00	1,94E+00	1,55E+00	2,56E+00
7	1,78E+00	1,88E+00	1,65E+00	2,29E+00
8	1,77E+00	1,80E+00	1,61E+00	2,19E+00
9	1,74E+00	1,79E+00	1,62E+00	2,00E+00
10	1,76E+00	1,75E+00	1,63E+00	1,91E+00
15	1,63E+00	1,67E+00	1,61E+00	1,77E+00
20	1,60E+00	1,66E+00	1,61E+00	1,67E+00
25	1,58E+00	1,63E+00	1,60E+00	1,63E+00

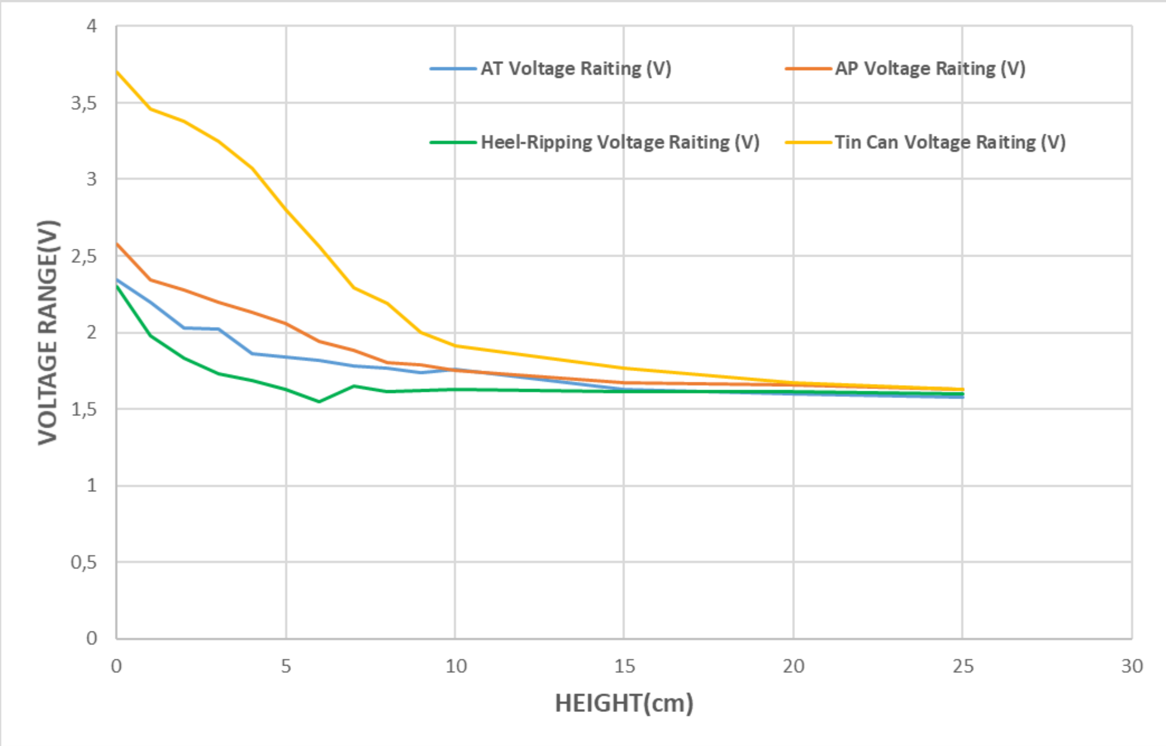


Figure 15. Measurements of non-buried mines and objects

4.3. Measurements of Non-Buried Mines and Objects

When the relationship of the magnetic anomaly values of the non-buried mines and the object with the height is examined, it is observed that the anomaly values created by the mines and objects are the same or more than the measurements made in moist soil. Although moist soil is advantageous in terms of conductivity, measurements made without burial showed more anomaly values, which is expected. The reason for this is that the detection capacity increases when there is no obstructive environment between the designed prototype and mines and objects.

5. CONCLUSION

In this study, a detector prototype is designed to detect underground buried objects that create magnetic anomalies and various types of mines. The basis of this detector prototype is based on magnetic anomaly. Although similar studies have been carried out in the literature before and the variables that make up the magnetic anomaly depend on the soil type, height and object type that creates the anomaly, the mechanisms in all these studies are not hand-held size, but fixed devices that can move in certain axes. This study presents a new type of handheld magnetic anomaly-based mine detector prototype that makes the study different from previous studies in the literature. Another difference is that although the sensors used in mine detectors are active, the TE-100 magnetic anomaly sensor used in this study is passive. In other words, it can detect the location of mines without sending signals to the mines and triggering the firing mechanisms. The additional advantage of our study compared to the study in the literature [24] is that the prototype is portable and can be used in all terrain conditions. With the prototype produced in our study, measurements were made in different soil types, different types of mines and environments that exactly match the real environments. The mines used in the measurements are hollow and do not contain explosives. One of the measurements was made with a full box. This is because it simulates landmines filled with liquid or non-liquid explosives and embedded improvised explosives. As can be seen from the measurement results and the graphs of these results, it is this solid metal box that creates the highest anomaly. The magnetic anomaly created by the materials used in the measurement occurred in the form of cans, anti-personnel mines, anti-tank mines and heel crusher mines, respectively. This is because the conductivity of liquids is higher. It is also known that the shapes of the materials that make up the anomaly contribute to the anomaly. Considering that our study is compatible with the literature. As a result, it was determined that the prototype designed in the study detected anomaly materials buried or not buried in the ground. When compared with the results in the literature, the results were found to be successful. However, the prototype we have developed has its shortcomings. To mention these, the number of sensors and the precision in determining the mine type can be counted. If the method used is supported by artificial intelligence, much better results will be obtained. In our future studies, which will be the basis of this study, these limitations will be removed by adding artificial intelligence algorithms. It is thought that the landmine detector prototype we have produced can be used effectively in regions where terrorist activities are common and that it will inspire landmine detectors to be developed.

DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Mehmet Fatih IŞIK: Performed the experiments and analyse the results.

Çağrı SUİÇMEZ: Performed the experiments and analyse the results. Wrote the manuscript.

Cemal YILMAZ: Performed the experiments and analyse the results.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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