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Performance Analysis of Techniques Used for Determining Land Mines

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Abstract

Today, remote sensing is used for different methods and different purposes. In all of the detection methods, some considerations such as low energy consumption, low cost, insensitivity to environmental changes, high accuracy, high reliability and robustness become important. Taking into account these facts, remote sensing methods are used in applications such as geological and archeological research, engineering areas, health services, preserving and controlling natural life, determination of underground sources, controlling air, sea and road traffic, military applications, etc. The method to be used is based on the object type to be detected, material to be made, and location to be found. The remote sensing methods from the past up to today can be listed as acoustic and seismic, ground penetration radar (GPR) detection, electromagnetic induction, infrared (IR) imaging, neutron quadrupole resonance (NQR), thermal neutron activation (TNA), neutron back scattering, X-ray back scattering, and magnetic anomaly detection. In these methods, detected raw images have to be processed, filtered and enhanced. In order to achieve these operations, some algorithms are needed to be developed. In this study, the methods used in detecting land mines remotely and their performance analysis have been given. In this way, the last situation on the advantages and disadvantages of methods used, application areas and detection accuracies are determined. Furthermore, the algorithms such as transmission line matrix (TLM), finite difference time-domain (FDTD), the method of moment (MoM), split step parabolic equation (SSPE) and image processing and intelligent algorithms are presented in detail.

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Keywords

Remote Sensing, Land Mine, Detection Performance, Algorithm

1. Introduction

Remote sensing methods used up to today can be listed as acoustic and seismic, ground penetration radar (GPR) detection, electromagnetic induction, infrared (IR) imaging, nuclear quadrupole resonance (NQR), thermal neutron activation (TNA), neutron backscattering, X-ray backscattering and magnetic anomaly. In recent studies on the remote sensing, instead of finding a new method, some of the issues such as low power consumption, low cost, immunity to environmental changes, high sensitivity, high reliability and robustness are considered. Therefore, it is concentrated on the studies of increasing the performance of sensors used in sensing methods and assessing the results from multiple methods together. Method(s) selected depend(s) on the type of object, material used, and the location where it is found. Today, remote sensing methods are used effectively in the areas such as geological and archeological researches, engineering fields, health services, control and protection of natural life, determination of underground sources, determination of underground sources, air, sea and land traffic control, and military applications. In military applications, these methods are normally used for the detection of buried land mines.

Land mines can be divided into two types as anti-personnel (AP) and anti-tank (AT) mines. Anti-personnel mines are used to defend strategical locations or points such as important fields or bridges, to prevent passages of military or civilian people across boundaries, while anti-tank mines are used to obstruct vehicle traffic. Estimated mine depth, date of burial and the type of mine determine the technology selection for detection. Mine detection and clearing works are highly serious problems today all over the world. To buy and use these hidden killers are very cheap but to detect and remove them are very expensive. Buying a mine costs about $3 but removing it costs about $1000 [1]. There are about 100 million unexploded mines at least in 80 countries over the world [1]. This continuously growing threat affects not only the military but also civilian people. Since the life cycle of a mine is very long, the victims are not always the target group, instead innocent people especially the children are the victims most probably [2] [3]. Around 26,000 people, of which the most are civilians, have been killed or injured by explosion of mines [1]. Existences of buried mines are a threat to living creatures, and also become a huge obstacle in front of economical growth, development and wealth of people. For example, use of buried mines under the terrains prevents them to be used for agricultural purposes and caused loss of fertile areas. Mine detection is a complicated problem that it is very difficult to solve by today's techniques. Three difficulties can be listed in this subject:

- Difficulty in the classification because of the existence of about 700 different types of mines showing large variations;
- Difficulty in the determination of mines because of the materials used that are mostly composed of plastic products and less metals;
- Difficulty in the elimination of false alarms due to environmental factors at the mine fields preventing detection and identification.

The fundamental issues for mine detection technologies are low false alarm ratio, high identification ratio of actual mine and high detection rate. In order to satisfy all these factors, different algorithms can be used. The procedural mechanisms of almost all of the algorithms can be divided into four phases such as preprocessing, feature extraction, credit assignment and decision making. The requirements of the algorithms are those of computational efficiency and memory capacity. In this study, the methods used up to today and their performances for remote sensing of land mines are analysed. Furthermore, the algorithms used for mine detection are presented in this paper.

2. Land Mine Detection Technologies

2.1. Acoustic Seismic Reflection Method

Acoustic seismic approach is based on the principle that the sound waves given by a source under the ground are reflected from the boundaries of structures and objects themselves. In this method, reflected sound waves are collected by sensors after the excitation of the soil by acoustic sound with a frequency less than 1 kHz and analysed for resulting anomalies at the round of times of the waves.

Vibration of the soil is provided by the acoustic waves carried on the air and seismic waves carried in the soil. In this case, different oscillations occur based on the different underground structures and movement of soil. Thus, the characteristic features of the ground can be determined by recording the signals received in μV levels by the sensors. In this method, non-linear distorsion is important and distinctive information for mine detection. For this reason, this method can be used for high detection probability and low false alarm ratio applications. However, it has some disadvantages that it gives false alarms in wet and high conductive areas and in the case where the mines are close to the surface [4], it is slow compared to the other methods (2 - 15 min/m^2) [2], it requires a lot of computational steps in software [5], it is unsuccessful when the mines buried in deeper levels [2] [6], it is sensitive to acoustic vibrations and noise, it has more expensive equipment than the other methods, etc.

In this study, the works on the buried mine detection using acoustic seismic method are examined and performance parameters are determined [4] [6] [7]-[9]. The principle of acoustic seismic method for mine detection is given in **Figure 1**. The following variables are selected for performance criteria parameters for each work that is examined: soil type, material tested, test height, working rate and frequency, findings under these conditions. **Table 1** gives the comparison of performance parameters for these works.

As seen from **Table 1**, the application frequency is held about at 450 Hz and the plastic metal covered land mines can be detected in soil or sand at a height of 5 cm. In case the frequency and wave speed of the sound wave are increased, the maximum height at sea level is determined as 55 m, however at lower frequencies the maximum performance is determined as 5 - 10 cm below the sea level.

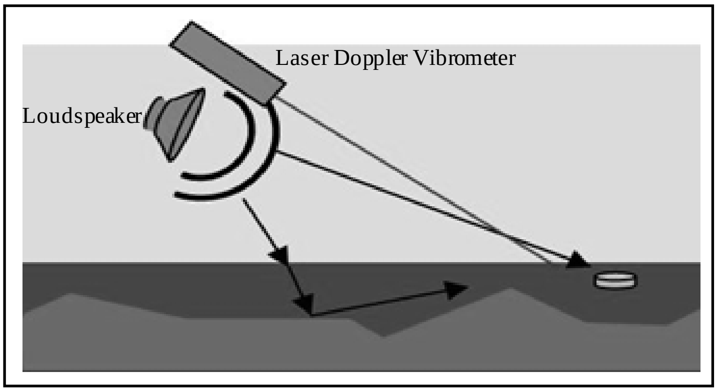

Figure 1. Principle of acoustic-seismic method.

Table 1. Performance analysis of acoustic-seismic method for land mine detection.

Soil type	Material tested	Test height	Operation speed or frequency	Operation performance	References
Soil	Land mine	40 cm	100 - 1000 Hz 80 - 140 m/s	0.5 - 2 cm	[4]
Dry sand	Ø8 cm plastic mine 30 × 30 × 10 cm anti tank mine	2 cm 5 cm	430 Hz	2 cm 5 cm	[6]
Dry sand	TS-50 anti personnel mine Ø9 cm h = 4.6 cm ρ = 1400 kg/m^3	Source height 70 cm Sensor height ground level Depth of mine 2 cm	Speed of transmitted wave 50 m/s 450 Hz	Tested only for Sadece 2 cm	[7]
Dry sand	Plastic mine ρ = 1200 kg/m^3	Source height 2 cm Source at ground level	450 Hz	Underground (not specified)	[8]
Water	AN/SQQ-32 sea mine	Below sea level	600 Hz - 100 KHz	Wave speed 1520 m/s, 35 m Wave speed 1510.5 m/s, 55 m	[9]

2.2. Ground Penetrating Radar (GPR) Method

Ground penetrating radar (GPR) method is based on determining objects buried underground using radio waves at different frequencies (1 - 1000 MHz). In this technique, electrical characteristics of the objects under the ground are observed by means of electrical and magnetic changes. It is essential that the radio waves sent by a transmitter antenna have to be reflected from the object under the ground. These reflected waves are recorded in the receiver. Since the objects have natural resonance frequencies that are different from the environment where they are found, the waves reflected from the surface of the object and the waves reflected from the environment where the object is found will show a difference depending upon the amount of absorption of the radio waves sent. But, the bandwidth of the radar signals shall be adjusted so that the natural resonance frequency of the object could be extracted [10]. Detection of reflection is not always easy because of the side effects. Variable parameters such as inhomogeneity of soil, humidity, existence of other objects, surface roughness, etc, can disturb and cover the reflections received [11] [12]. Furthermore, small cavities between the soil and object, roots of plants, the differences between soil and large stones or rocks may cause misleading reflections. This increases the false alarms that are the most important handicaps for this method [1]. During trying to detect a mine in wet sand by the GPR method, another mine that is buried in a dry sand in the vicinity of the first one cannot be detected [13]. Detecting signals from potentially varying environments and correctly interpreting them are very important. Therefore, GPR problems bring a big load to the computer that has to implement the mathematical models by appropriate algorithms and use filtering. The most important issue in GPR systems is to choose the appropriate frequency of radio wave that is sent to ground. When we work with high frequencies, we can obtain results with high resolution. However, increasing the antenna frequency may decrease the depth of study. If the required depth is d and the dielectric coefficient of the environment is ε, the appropriate frequency can be found by the expression in Equation (1) [14].

$$f = \frac{150}{d \times \sqrt{\varepsilon}} \tag{1}$$

Normally, the antenna with the lowest frequency can give an opportunity of studying deepest ground. In this case, a preference between the depth of study and the quality of the image has to be done. The tradeoff between the depth and the quality of the image depends on the factors such as environmental conditions, soil type and the position of the object.

3-D GPR problem has four main components. These are the ground, the air, the radar unit and the object. The ground-air interface is in the z-plane and the radar unit collects the data at a fixed altitude. When the position of the radar unit is changed linearly through x-axis and the measurements are repeated and the resulting reflections are put together, a 2-D image dependent on space and time can be obtained.

In our study, works on the detection of land mines using ground penetration radar (GPR) are investigated and again the following variables are selected for performance criteria parameters for each work that is examined: soil type, material tested, test height, working rate and frequency, findings under these conditions [1] [11] [12] [15]-[35]. **Figure 2** gives the principle of the GPR method for mine detection.

As seen from **Table 2**, the application frequency is around 1 - 5 GHz, plastic and metal covered land mines can be detected at a maximum height of 20 cm in clay soil or wet soil. It is observed that increasing the radio frequency may also increased the dept of detection.

2.3. Electromagnetic Induction (EMI) Method

When a time varying magnetic field is established at the environment where a conductive object is found, an electric field is inducted on the conductive object and this field creates a flow of charge inside the object. The inducted current on the object because of the charge flow produces a secondary magnetic field. When the secondary magnetic field produced is investigated over a wide range of the band (30 Hz - 24 kHz), a signal specific to and defining of the object has been obtained. The frequency to be selected for the object to be detected depends on the depth d (inch), relative magnetic permeability μ_r of the object and electrical resistance R (ohm) of the object as given in Equation (2) [37].

$$f = 2500 \times \frac{R}{\mu_r \times d^2} \; [\text{Hz}] \tag{2}$$

Table 2. Performanceanalysis of land mine detectionby GPR.

Soil type	Materials tested	Test height	Operational speed or frequency	Performance of work	References
Soil	VS50 Anti personnel mine	Source on the ground surface	400 MHz	10 cm	[11]
Soil	Anti tank mine (containing both high and low metal content)	Height of the source is 5 cm	200 MHz - 7 GHz	2.5 - 15.2 cm (success %87.5)	[1]
Soil	Mine resembling targets	Source is on the ground surface	300 MHz	5 cm (false alarm ratio in an area with a radius of 45 cm is 6.9%)	[15]
Soil with stone and clay covered by grass	Anti tank mine Ø20 cm h = 310 cm Anti personnel (metallic) Ø8 cm h = 15 cm	Source on the ground surface	0.7 - 2.7 GHz	20 cm	[17]
Dry sand	Ø12 cm 450 Hp power piston, 1.25 literplastic water filled cup	1.2 m	1 - 3 GHz	Image taken 2 cm No image could be taken	[18]
Soil (ε_r = 6)	M14 plastic anti personnel mine	0.5 - 2 cm	800 - 3.5 MHz	15 cm	[19]
Soil	Metallic and plastic anti personnel mine	15 cm above the ground	1300 MHz	Several cm in a depth from the surface	[20]
Dry, wet and watery soil	TS-50 and VS-50 Ø8 cm h = 3.2 cm	Source on the ground surface	4 GHz	2 cm	[21]
Clay soil (ε_r = 8)	TS-50 plastic anti personnel mine	Very close to the surface	3 GHz	2 cm	[22]
Clay soil (ε_r = 6.2)	Plastic anti personnel mine	28 cm above the ground	1 - 3 GHz	8.5 cm	[23]
Sand	Anti personnel mine, stone, brick and metallic sphere	Source is at the surface	1 GHz	1.3, 5, 10 cm	[24]
Sand	Metal cylindir, Water filled plastic, rubber, metallic sphere Ø5 cm h = 1 cm	Very close to the surface	3 MHz - 2.4 GHz	2 cm	[25]
Soil	Anti personnel mine Ø8 cm	Very close to the surface	1 GHz	15 cm	[12]
Sand (ε_r = 2.5)	Metallic sphere, aluminium folio covered sphere Ø7.5 cm	11.5 cm above the ground	100 MHz - 5 GHz	5 cm	[27]
Sand, loam	TNT and rock wit a shape of round, ellipsoid and rectangle	2.5 cm above the ground	500 MHz - 5 GHz	2.5-5-10 cm	[28]
Sand	PMN2 land mine	12 cm above the ground	0.5 - 5 GHz	5 cm	[29]
Natural stone chip, sinter, sand, soil	Steel sphere Ø5 cm	10 cm above the ground	0.5 MHz - 6 GHz	10 - 15.5 cm	[30]
Clay soil (ε_r = 3.5)	TS-50 anti personnel mine	Very close to the surface	1 - 5 GHz	2.5 cm	[31]
Soil, dry sand containing water	NR26 anti tank mine, PMN anti personnel mine	4 m above the ground	1 GHz	20 cm	[34]
Soil	Anti personnel mine (high and low metal) Anti tank mine (high and low metal content)	Close to the surface	0.2 - 7 GHz	2.5-5-7.6-10-12.7 cm	[35] [36]

The detectors used for measurements with the electromagnetic induction method are

- Image detection induction coils,
- Magnetic detectors,
- Conductivity meters both in time domain and frequency domain.

In general, the depth range is satisfactory in detecting an object but it is very difficult to identify or distinguish the objects with low metallic content [38]. For that reason, the number of false alarms is greater than the number of actual targets [38] [39]. This high ratio of false alarm may both decrease the detection rate of the mines and it gives rise to an expensive and dangerous situation [2].

In our study, electromagnetic induction (EMI) method is investigated for buried land mine detection and again the following variables are selected for performance criteria parameters for each work that is examined: soil type, material tested, test height, working rate and frequency, findings under these conditions [1] [11] [12] [15]-[35]. **Figure 3** gives the principle of the EMI method for mine detection. **Table 2** gives the comparison of performance parameters on the works of detecting land mines.

As seenfrom **Table 3** that the secondary magnetic field occured by metal covered mines in clay soil and sand areas is examined at the frequency range of 300 Hz - 2 GHz and it is found that the mines of this type can be detected at a maximum of 10 cm. It is observed that the magnetic permeability and electrical resistance of the cover affect the bandwidth and detection depth.

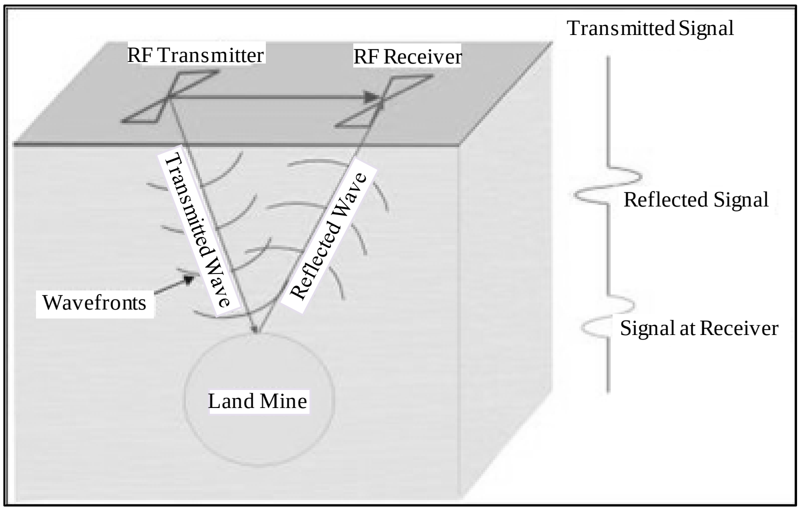

Figure 2. Principle of mine detectionburied mines by GPR.

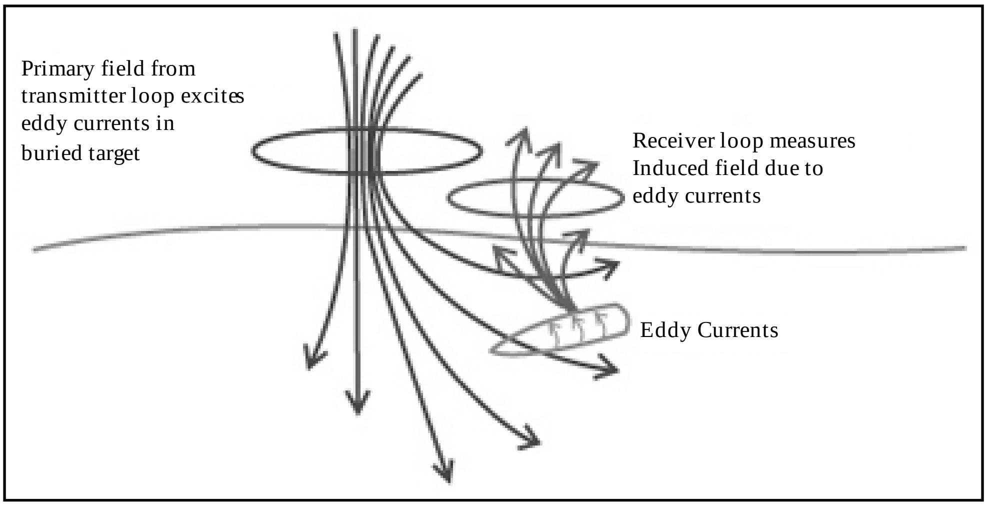

Figure 3. Principle of detecting buried mines by the EMI.

Table 3. Performance analysis for land mine detection by electromagnetic induction (EMI).

Type of soil	Materials tested	Height of test	Operating speed or frequency	Performance	Reference
Clay and air	Valmarave VS50 anti personnel mine	17-19-20-21-23 cm above the ground	3990 - 23,970 Hz	On the surface, just under the ground	[40] [42]
Sand	TS-50 and MAI-75 anti personnel mine	Several cm above the ground	300 Hz - 90 KHz	5 cm	[39] [41]
Sand	Anti personnel mine (high and low metal content) Anti tank mine (high and low metal content)	Just above the ground	330 Hz - 90.03 KHz	0 - 7 cm 2.5 - 12.5 cm	[43]-[45]
Sand	Bakalit PT Mi-Ba III anti tank mine	Just above the ground	1 - 2 GHz	10 cm	[46]

2.4. Infrared Imaging Method (IR)

All of the hot objects emit infrared radiation. This method is based on the determination of infrared radiations at different wavelengths because of the heat difference between the object and the environment. The infrared radiations from the object and the environment can be detected by thermal sensors which are sensitive to heat and visualized as a colored images.

Infrared imaging technique can be used in different applications such as in the control of electrical process equipment, in medical devices, in defence and indoor identifications. It has to be noted that the success of infrared techniques is related to the conditions of operation environment and surface heat changes [47] [48]. In experiments, it was observed that because of roughness of surface, uneven sunshine, continuous change in environmental conditions and difference in oscilation powers of objects, it is difficult to obtain accurate temperature measurements and depending on it interpretation of images correctly [3] [48].

In areas where the type of soil is non-homogeneous and having vegetations formed in time the performance and the depth are not enough [46]. In this technique, it is believed that because of the frequency of the infrared wave used during determining buried objects, it cannot pass the surface of the soil and therefore for detecting buried objects by this technology can only be achieved at special conditions and short time intervals [46] [47].

In our study, infrared imaging (IR) method is investigated for buried land mine detection and again the following variables are selected for performance criteria parameters for each work that is examined: soil type, material tested, test height, working rate and frequency, findings under these conditions [3] [46]-[48] [49]-[52]. **Figure 4** gives the principle of the IR method for mine detection. **Table 4** gives the comparison of performance parameters on the works of detecting land mines

As seen from **Table 4** that the infrared wave frequency is held at a bandwidth of 3 MHz - 140 GHz. Plastic and metal covered land mines in sandy soil can be detected at maximum 20 cm. They can be detected in a soil with grass at about 5 mm. If the operating badwidth is increased, then the detection height increases. Some layers such as grass covering the soil may decrease the detection depth.

2.5. Nuclear Method

In this method, existence of explosives such as nitrogen based RDX, HMX, PETN and also nitrogen-hydrogen based TNT (**Figure 5**), but not the outer covers of mines is tried to determine.

2.5.1. Nuclear Quadrupole Resonance (NQR) Method

Nuclear quadrupole resonance is a special radio frequency (RF) technique based on detecting nitrogen isotope (^{14}N) found in the structure of many explosives and drugs.

Observed NQR frequencies are obtained with the interaction between the electrical quadrupole of the nucleus and electrical field changes formed from outside around the nucleus. The NQR sign that the nitrogen based explosives such as TNT, HMX, RDX and PETN create can be used to detect and identify the amount of explosive and estimate the depth.

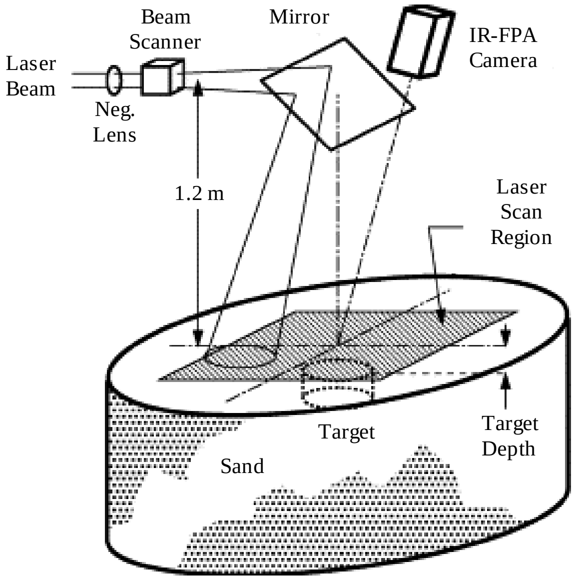

Figure 4. Principle of mine detection by infrared method.

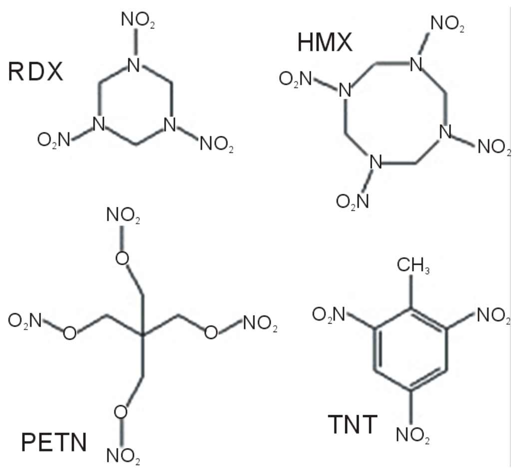

Figure 5. Molecular structure of nitrogen and nitrogen-hydrogen based explosives.

Table 4. Performance analysis of land mine detection by infrared imaging method.

Soil type	Materials tested	Height of test	Speed or frequency	Performance of study	Reference
Sand	Cola can, Bakalit PT Mi-Ba III anti tank mine PPM-2 anti personnel mine	Just above the ground	Wave length 3 - 5 μm 8 - 12 μm	10 cm 10 cm Just under the surface (best image)	[46]
Sand and surface with vegetation	Anti personnel plastic mine	Above the ground	8 - 12 μm	1 cm	[47]
Sand, grass and leaves and asphalt surface	Plastic anti personnel Metal anti personnel Plastic/metal anti personnel Metal antitank mine	2 m 5 - 50 m 200 m	94 GHz ve 140 GHz	Very close to surface (2 - 5 mm)	[52]
Sand	Land mine Ø10 cm h = 3.5 cm	1m	8 - 14 μm	1.5 cm	[3]

As in the metal detectors, when a RF signal that has a frequency (about in between 0.5 and 6 MHz) closing to the NQR frequency of the explosive which is found just under the ground is sent through a planar antenna, the energy level of nitrogene changes. When the RF excitation is removed, the nuclei return to their original energy levels and some characteristic radio waves that are specific to the expolosive appear. By using a second antenna designed specifically, the weak radio waves returning from the excited explosive object can be received. The strength of these weak induction currents obtained from the sensor coils determines the amount of explosive. In addition, the frequency of the induction currents gives the type of explosive [53] [54]. Because of the nature of the NQR method, low sensitivity that is a result of low resonant frequencies (0.5 - 6 MHz) is a big problem [55]. For that reason, powerful detection systems have to be used by this method. Otherwise, it can be easily affected by RF interference. To increase the sensitivity of nitrogene is costly. For example, the price of a Lanthanum detector (7.62 × 7.62 cm) is about $35,000 and a germanium detector with the same dimensions which is more sensitive than the former is about $100,000 [56]. In order to receive a signal from the sensor from a potential explosive, the antenna must be placed directly on the explosive and it has to be close to the ground. Otherwise the information collected for the place and depth of the buried mine will be inaccurate [54]. Therefore, the applications where the buried AP mines are tied to be determined by the NQR method have given bad results [54]. For this reason, this method more practical and fast for the cases where the mine are not buried and found on surfaces. Furthermore, in order to increase the signal to noise ration, it is required to measure the average value of the temperature of the explosive in the mine by using appropriate techniques before scanning and determine it as an input from the sensor. This means that new detectors and algorithms to be developed [54]. In recent studies, non-linear least-means-square detector and maximum likelihood detector that can also read the dependencies of the NQR frequencies to the temperature have been developed in order to increase the low signal to noise ratio. It is also possible to avoid from the disturbing effect of fertilizers with nitrogene content in the ground that can give rise to false alarms [44] [57].

In our study, NQR method is investigated for buried land mine detection and again the following variables are selected for performance criteria parameters for each work that is examined: soil type, material tested, test height, working rate and frequency, findings under these conditions [54] [55] [57]. **Figure 6** gives the principle of the NQR method for mine detection. **Table 5** gives the comparison of performance parameters on the works of detecting land mines.

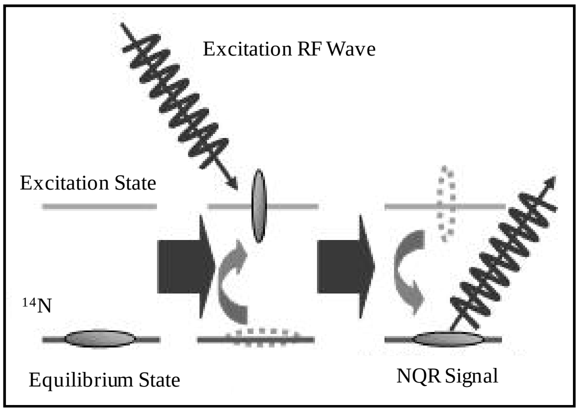

Figure 6. Principle of mine detection by NQR method.

Table 5. Performanceanalysis of mine detection by NQR method.

Soil type	Materials tested	Height of test	Operating speed or frequency	Performance of operation	Reference
Garden soil	Anti tankr (19 × 19 × 7 cm) and anti personnel (14 × 14 × 7 cm) minen (sodium nitrade filled)	Above mine, close to surface	0.5 - 6 MHz	3-5-7-8-10 cm	[55]
Soil	TNT	Above mine, close to surface	0.5 - 6 MHz	20 cm (explosive can be determined. Boundaries and depth are problematic)	[57]

As seen from **Table 5** that the radio frequency badwith is held at 0.5 MHz - 6 MHz. The nitrogen radiation within plastic and metal covered land mines is detected at a height of 20 cm above the ground. It is observed that soil type may affect the detection depth.

2.5.2. Thermal Neutron Activation—TNA Method

This is a method based on the detection of special gamma rays radiated from the nitrogene nucleus found in the structure of many explosives activated by neutron bombardment on the surface of the soil.

Since the explosives have more nitrogene content than the soil (18% to 38%), the probability of making an error to detect them is very low. As the content of explosive in AT mine is greater than the content of AP mines, this method is advantageous in detecting AT mines than AP mines. The disadvantages of this system are that it has a complicated structure and weight (180 kg), in addition the detection time with it is long [56] [58] [59]. The TNA method is mostly used in confirming the misgiving or refusing results obtained by faster methods. By this way, false alarm ratios may be reduced to acceptable levels. However, it has to be remembered that the gamma rays are dangerous for living creatures in case they exposed to them, therefore during detection process the distance between a user and the detection system must be at least 4 m [60].

In our study, thermal neutron activation (TNA) method is investigated for buried land mine detection and again the following variablesareselectedforperformancecriteriaparametersforeachworkthat is examined: soil type, material tested, test height, working rate and frequency, findings under these conditions [56] [59]-[66]. **Figure 7** gives the principle of the EMI method for mine detection. **Table 6** gives the comparison of performance parameters on the works of detecting land mines.

As seen from **Table 6** that in the works, electrons with an energy of about 10 - 14 MeV are used. The nitrogen based gamma radiation is detected for plastic and metal covered mines at a level of 20 cm above the sand area. The detection depth may change with the amount of explosive and cover of the mine.

2.5.3. Neutron Back Scattering Method

Neutron back scattering method is based on a process in that the electrons of hydrogen present in the structure of the object to be detected are breaked by activating them with the kinetic energy of accelerated electrons by means of a cyclotron and then detecting the electrons with low energy that are backscattered and counting them.

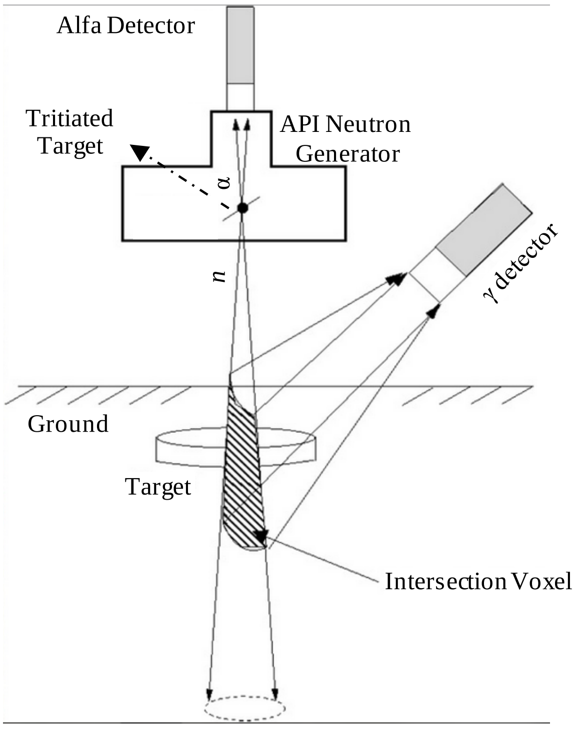

Figure 7. Principle of mine detection by the TNA method.

Table 6. Performance analysis of land mine detection by thermal neutron activation.

Soil type	Materials tested	Height of testing	Operation speed or frequency	Performance of study	Reference
Sand	Land mine	12 cm	10.8 MeV gamma ray	3 cm	[60]
Sand	Anti tank mine (with 1 - 3 kg nitrogene) 100 g nitrogene	On the mine, close to surface	9.5 - 11 MeV gamma ray	10 cm (1 dakika) 20 cm (5 dakika) Yüzeyeserili (5 dakika)	[56]
Dry soil	Anti tank mine (5.6 kg) Anti personnel mine (200 g)	Close to surface	14 MeV gamma ray	7.5 cm 5 cm	[62] [63]
Sand	M15 (steel) (3.1 kg) M15 (steel) (3.1 kg) TMA3 (resin) (1.2 kg) TMA3 (resin) (1.2 kg) TMA3 (resin) (1.2 kg) M21 (metal) (0.9 kg) TMA5A (plastic) (1 kg)	On the mine, close to surface	10.835 MeV gamma ray	0 cm (2 s) 10 cm (24 s) 0 cm (2 s) 10 cm (28 s) 20 cm (954 s) 10 cm (40 s) 10 cm (69 s)	[59]
Space	Teflon buttle (TP and NB filled) Ø6 cm h = 2 cm	25 cm	8 MeV gamma ray	25 cm	[65]
Sand	Disc Ø6 cm h = 2 cm ($C_3H_6N_6$, NH_4NO_3, H_2O) Plastic mine Ø10.2 cm h = 1 cm (222 g Al, 576 g Fe,686 g Cu,863 g Pb)	10 cm	14 MeV gamma ray	0.2 - 4 cm	[66]

In this method, the particle to be sent may be a neutron. In this case, it is based on the detection of scattered thermal neutrons with low energy (0.08 eV) as a result of the interaction between the fast neutrons radiated from a neutron generator with active source and the hydrogen nucleus of the explosive.

Since the neutron backscattering is a method based on the determination of hydrogen within an explosive, the special condition is that the soil must be dry. Otherwise, it is difficult to make detection because in a soil with a humidity content of 12% the hydrogen concentration in soil and hydrogen concentration in mine becomes equal [67]. As a result, the change in humidity and irregularities of surface may give rise to high false alarm ratios. As the source-detector system is heavy, there is a need to install it together with the required electronic equipment on a vehicle [67]. By using this method, the AT mines can easily be detected, however the small mines can be noticed [68] [69]. This method is mostly successful in shallow depths. Therefore, as the detector to be very close to the surface, this method can be used in applications in which there is a reliable base surface [67].

In our study, neutron backscattering method is investigated for buried land mine detection and again the following variables are selected for performance criteria parameters for each work that is examined: soil type, material tested, test height, working rate and frequency, findings under these conditions [67]-[69] [70]-[72]. **Figure 8** gives the principle of the EMI method for mine detection. **Table 7** gives the comparison of performance parameters on the works of detecting land mines.

As seen from **Table 7** that a neutron generator producing neutron with an energy of about 14 MeV is used in the works. Low energy thermal neutrons scattering as a result of interaction with the produced neutrons and explosive can be detected at a height of maximum 20 cm for sand and wet soil areas. The amount of explosive and cover depth may affect the detection depth.

2.5.4. X-Ray Back Scattering Method

This method is based on a process that an X-ray is passed through the object under consideration and the image on a light sensitive film ay the back side of the object is interpreted. However, the image at the back side of a mine is impossible to obtain physically. In this case, an X-ray focused by passing it through an accelerator is sent to the mine buried and the outer cover or the explosive is stimulated. The cover or explosive returns to a base and gives the energy that it received back. The X-ray is passed again through another accelerator and arrived at the detector where the related image is formed. As a matter of fact, the X-rays from regions where the densities are different will vary in strength. Depending on the strength, a two-dimensional image of the region

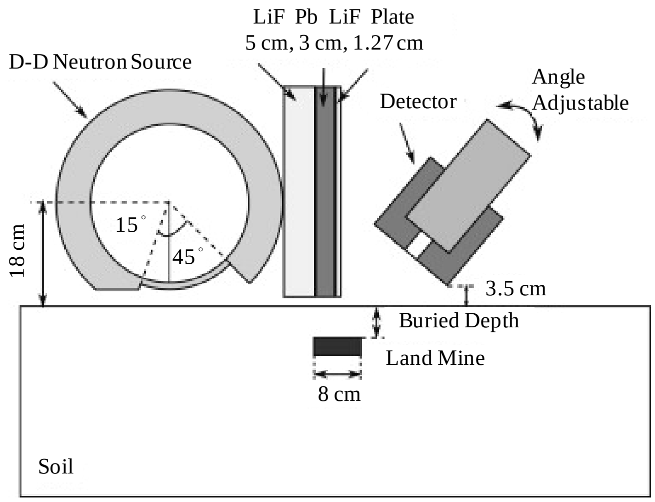

Figure 8. Principle of neutron back scattering method.

Table 7. Performance analysis of land mine detection by neutron back scattering method.

Soil type	Materials tested	Height of testing	Operation speed or frequency	Performance of study	Reference
Space	Cylinder Ø10 cm h = 10 cm	1 m	14 MeV neutron generator	1.5 cm	[70]
Sand	Anti personnel mine (MN-AP-NR-22) Ø6.2 cm h = 3 cm Anti tank mine (MN-AT-NR-26) Ø30 cm h = 15 cm	5 cm	14 MeV neutron generator	3 - 5 cm	[69]
Sand	Anti tank mine Ø20 cm h = 4 cm Anti personnel mine DLM2.2 Ø8 cm h = 3.4 cm	On the mine, close to surface	0.33 - 3.33 KHz neutron generator	20 cm 10 cm	[67]
Soil	Anti personnel mine (200 g) Anti tank mine(5.6 kg)	On the mine, close to surface	10.8 MeV neutron generator	5 cm 7.5 cm	[72]
Soil %2-%10-%18.5 wet	RDX (29 g, 100 g) TNT (100 g, 240 g)	3.5 cm	14.1 MeV neutron generator	5-10-15 cm (confidence level %68)	[73]

can be obtained. However, detection accuracy, low penetration depth, multiple targets, slope of area and height of the detection cap may cause some problems to be encountered [74] [75]. Metal covered land mines have lower absorbtion-scattering ratio than the plastic mines and soil, their detection by this method is much more difficult [2]. Because of the long determination time (about 22 min), the recent studies have been concentrated on obtaining a good quality of images in a shorter time [75]. Speeding up the process may increase the system weight and volume, but decrease X-ray density. A system detecting an explosive by back scattering is shown schematicallyin **Figure 10**.

In our study, X-ray backscattering method is investigated for buried land mine detection and again the following variables are selected for performance criteria parameters for each work that is examined: soil type, material tested, test height, working rate and frequency, findings under these conditions [74] [75] [76]-[83]. **Figure 9** gives the principle of the X-ray method for mine detection. **Table 8** gives the comparison of performance parameters on the works of detecting landmines

As seen in **Table 8** that X-rays with an energy of about 150 keV is used in the works. In dry soil, X rays radiated from the explosive within the mine can be detected at a height of maximum 3 cm. The amount of explosive and cover may change the detection depth.

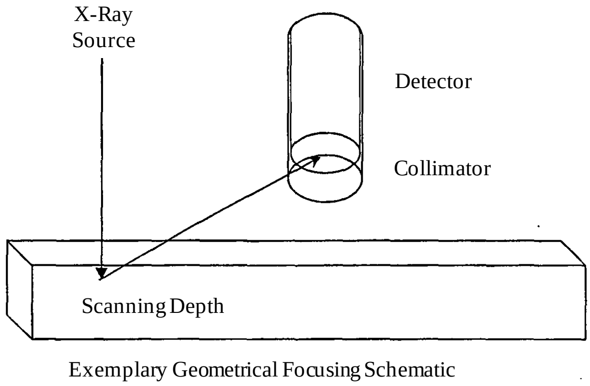

Figure 9. Explosive detection by back scattering method.

Table 8. Performance analysis of şand mine detection by X-ray backscattering method.

Soil type	Materials tested	Height of testing	Operation speed or frequency	Performance of study	Reference
Dry loose soil	PMA-2 Ø6.8 cm (70 g TNT strengthen with steel balls)	4 cm	20 - 120 KeV photon energy	1 cm	[74]
Soil	Cylindirical metal Ø8 cm h = 0.5 cm	60 cm	0 - 300 KeV photon energy (source 120 kV_p 3 mA)	1 cm	[76]
Soil	TS-50 anti personnel mine TMA-4 ve M-19 anti tank mine	30.5 cm	Source 150 kV_p 140 W	Laid down on surface 3 cm	[75]

2.6. Magnetic Anomaly Method (MAD)

Research on magnetic sensors with medium sensitivity appears as the studies for determining magnetic anomaly. Magnetic anomaly method is based on the detection of changes in magnetic field by an object with ferromagnetic characteristics exposed to an external magnetic field. Any decrease in flux density at the region where a magnetic object exists can give rise to an electrical change in the sensor. As a result, the output voltage of the sensor will change. By interpreting these changes, it is possible to have information on the place, dimensions and, if applicable, the other characteristics of an object with magnetic characteristics. Ferromagnetic materials can be divided into two classes as being hard and soft materials. Hard magnetic materials can preserve their magneticity after the magnetic field is removed. However, soft materials may lose their magneticities after the removal of the magnetic field. Therefore, magnetic permeability of soft materials is greater than the hard ferromagnetic materials. When an external magnetic field is applied, the magnetic flux will be denser in regions where magnetic permeability is high. In **Figure 10**, it is seen how a submarine within a magnetic field of the earth may change the flux lines by collecting them towards it.

In MAD method, different sensors such as MR, SQUID, Hall and coil can be used to detect magnetic anomaly [84]. In this method, low energy consumption, low cost, insensitivity to environmental changes, high sensitivity, fast sensing, reliability and robustness are essential factors. Taking into account these facts, the main purpose of the research in this area is the identification of the ferromagnetic materials creating magnetic anomaly. The system required is composed of a moving platform, a sensing mechanism and an electronic unit converting the data into electrical signals. Since the silicon based sensors cost about several cents, this method may be the most cost effective solutions among the other methods. In addition, as the moving platform carries only the small sensors, it is very small in size and portable (1 - 2 kg). All the data can be processed by simple PICs, hence the system can be implemented as simple unit. Since it is a lightweight system, it can be moved easily and faster. In most of the applications, a 24 bit ADC is more than enough (500 nV). Power requirement of such a system is very low (3, 12 W). In addition to the advantages mentioned above, interoperability of it with the other sensing systems is its invaluable property.

In military area, magnetic anomaly method is used in detecting of land and naval mines, unexploded munitions, detecting submarines [85]-[90]. In our study, the works done in this area are investigated and the performance parameters are evaluated. In **Table 9**, performance analysis of this method can be seen.

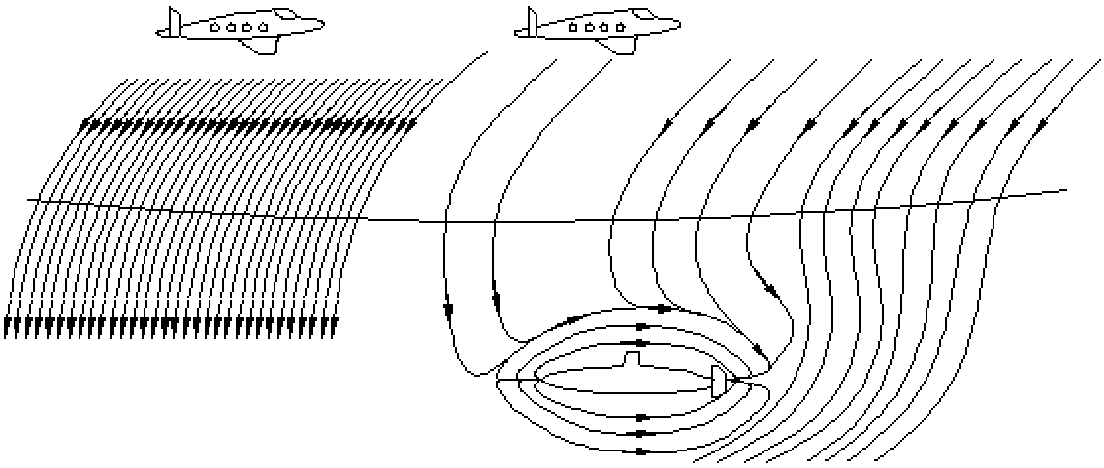

Figure 10. The change of earth's magnetic field by a submarine.

Table 9. Performance analysis of mine detection by magnetic anomaly method.

Soil type	Materials tested	Height of testing	Operation speed or frequency	Performance of study	Reference
Water	Pipe	12 m	3 - 25 kHz	One food buried in sand	[85]
Space	M2, M16 anti personnel mine	1 - 13 cm	-	13 cm	[88]
Space	Aluminum 5 × 5 × 0.15 cm Iron nail 3 × 0.3 cm	20 cm 10 cm	1 kHz	20 cm 10 cm	[89] [90]

As seen in **Table 9** that the AC current frequency supplying magnetic field is chosen as 1 - 25 kHz. The magnetic anomaly created by the covers of land mined can be detected from a height of maximum 20 cm for water and air. The magnetic permeability of may change the test depth.

3. Algorithms Used for Mine Classification

In subsurface mine detection problems, there are several numerical methods based on the solution of electromagnetic (EM) field problems to analyze the scattering by homogeneous bodies. Among them the most efficient numerical techniques may be the transmission line matrix (TLM), the finite difference time-domain (FDTD), the method of momentum (MoM), and the split step parabolic equation (SSPE) methods.

One of the most efficient numerical techniques to analyze the scattering by homogeneous bodies is the surface integral equation numerically evaluated by the method of momentum (MoM) [91]. As a special case, the minimum number of basis functions for convergence of the method of moments (MoM) analysis of EM scattering by bodies of revolution is investigated in [92]-[94]. Although EM scattering from conducting, dielectric, and composite bodies have been successfully studied using MoM [95]-[97], they are often limited to small geometries and small relative permittivities (ε_r), and the optimal number of basis functions has not been addressed. The method of moment (MoM) is one of the methods for the analysis of the array antennas [98]. In that paper, when the array antenna has Nantenna elements and each element is divided into M segments for the subdomain MoM analysis, $N_T \times N_T$ matrix equation has to be solved to obtain the unknown current vector, where $N_T = M \times N$. Iterative methods [99] in computational EMs has led to the publication of a variety of papers on the available iterative algorithms. One iterative algorithm, the conjugate gradient method (CGM) [100], is currently a focal point for much work in the area. The study in [99] attempts to complement the method in [100] by characterizing the typical numerical convergence rates of the CGM when applied to equations representing a wide variety of EM scattering problems.

Detection of mines or subsurface objects by for example GPR, which are mostly used within multi-area, multi-sensor, land-based, maritime and/or air-based integrated complex systems requires the modelling of EM wave propagation over realistic earth's surface through a radially inhomogeneous atmosphere. Ground wave propagation changes due to the ground effects. The variability of the ground characteristics and terrain profiles as well as those of the overlying atmospheric layers render the problem non-tractable via exact analytical methods. In [101], it is claimed that the only analytical approximate solutions, such as ray and mode theories [102] exist. However, a full-wave, observable based and numerically computable solution has not appeared yet. L. Sevgi, *et al*. introduced a two-dimensional, parabolic equation (PE) technique, which is called split step parabolic equation (SSPE) [103]. It is an alternative to ray-mode methods. In that paper, SSPE method is explained with the necessary modifications required for modelling propagation over irregular terrain and applied for typical as well as complex propagation scenarios. Other propagation models capable of accounting for horizontal refractive gradients may be found in the literature, but they are restricted to simplistic refractive conditions, lower frequencies and/or certain regions of space. The use of parabolic equation (PE) for EM wave propagation in a vertically inhomogeneous medium was described by Leontovich and Fock [104]. However, their approach has not been famous until after the introduction of the Fourier Spit Step algorithm by Tappert [105] [106], who solved the acoustic parabolic wave equation with this method numerically, because the scalar parabolic equation associated with EM propagation in troposphere is, within a good approximation, the same as the one used to describe acoustic wave propagation in the ocean.

Transmissions line matrix (TLM) are finite difference time domain (FDTD) are the other efficient techniques for the solution of scattering problems. TLM is a space and time-domain method. It is based on the analogy between the EM field and a mesh of transmission lines. Modeling the EM field problems using electrical networks were established long time ago [107]-[109]. They were analytical solutions. Some numerical solutions had been developed with the introduction of digital computers [110]-[115]. In TLM method, voltage pulses are used to calculate EM field components. It is based on electrical network theory. In the TLM, each node is represented by a scattering matrix. However, in FDTD, EM components are calculated directly. It is based on field theory. The field components are located at different positions in the cell [116]. In recent years, developed image processing techniques and intelligent algorithms and systems such as neural networks have also been widely used in identifying objects effectively [117]-[119]. In the following, we summarize the above mentioned methods shortly.

3.1. Transmission Line Matrix (TLM)

Transmission line matrix (TLM) is a numerical time-domain technique that is widely used to analyse GPR concept. TLM is normally a space and time discretization method for computing EM field scattering. It uses the analogy between the EM field and an electrical network namely a transmission line equations. A transmission line (TL) ended with a load is shown in **Figure 11(a)**.

The characteristic impedance of the TL is Z_0. The reflection coefficient Γ_L can be defined as in Equation (3)

$$\Gamma_L = \frac{V^-(x=0)}{V^+(x=0)} = \rho_L e^{j\varphi_L} \tag{3}$$

where $V^+(x=0)$ is the incident voltage wave at $x = 0$, and
$V^-(x=0)$ is the reflected voltage wave at $x = 0$,
Γ_L is a complex quantity with a magnitude of ρ_L and an angle of φ_L.

Γ_L can easily be represented by the impedances as in Equation (4):

$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} \tag{4}$$

When three equal loads are connected in parallel with each other to the TL as in **Figure 11(b)**, the equivalent impedance becomes

$$Z_{eq} = \frac{Z_L}{3} \tag{5}$$

If we consider that the load impedances are $Z_L = Z_0$, then the equivalent impedance becomes

$$Z_{eq} = \frac{Z_0}{3} \tag{6}$$

In this case, the reflection coefficient is

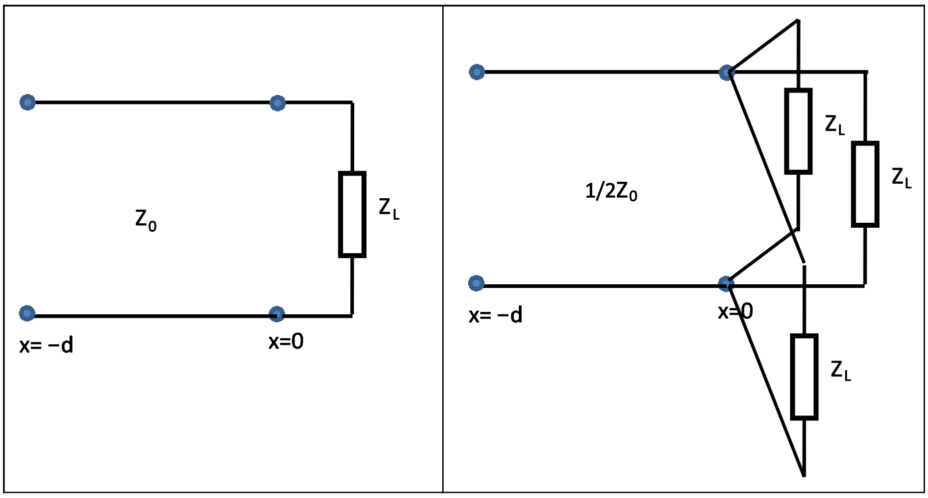

Figure 11. (a) A transmission line with a load; (b) Parallel connection of three identical loads.

$$\Gamma_L = \frac{Z_0/3 - Z_0}{Z_0/3 + Z_0} = \frac{-2Z_0}{4Z_0} = -\frac{1}{2} \tag{7}$$

We can say from Equation (7) that the half of the energy is reflected from the load. By using this analysis, we can make an analogy between the EM field and the network of the TL. We can model the three parallel impedances (each of which is of Z_0) as in Figure 12. In this model, V^+ is the incident voltage pulse. Half of it is reflected at the nodal point.

A plane TEM wave of infinite extend may be represented by a rectangular matrix with boundaries of the form shown in Figure 13.

If the voltage impulses $V_j^+(k)$, on lines $j = 1, \cdots, 4$ are incident on any junction node in the transmission line at time *k*, then the combined voltage reflected in line 1 at time $(k+1)$ will be [110]

$$V_1^-(k+1) = \frac{1}{2}\left[\sum\nolimits_{j=2}^{4} V_j^+(k) - V_1^+(k)\right] \tag{8}$$

If this pulse is reflected from a node at position (z, x) in the matrix, then it becomes an incident pulse on node $(z, x-1)$, that is

$$V_1^-(k+1, z, x) = V_3^+(k+1, z, x-1) \tag{9}$$

Similarly, the other lines can be written. For the boundaries, for example at node (*p*, *q*):

$$V_j^-(k, p, q) = V_j^-(k, p, q \pm 1) \tag{10}$$

where ± indicates upper boundary for (−) and lower boundary for (+).

3.2. Finite Difference Time-Domain (FDTD)

The finite difference method is based on the replacement of Maxwell's equations into a set of finite difference equations [115]. Because of the huge processing and memory capacity of today's computers, it is now possible to solve these difference equations more easily than the early day's approaches.

The famous Maxwell's equations in an isotropic medium are

$$\frac{\partial B}{\partial t} + \nabla \times E = 0 \tag{11}$$

$$\frac{\partial D}{\partial t} - \nabla \times H = J \tag{12}$$

$$B = \mu H \tag{13}$$

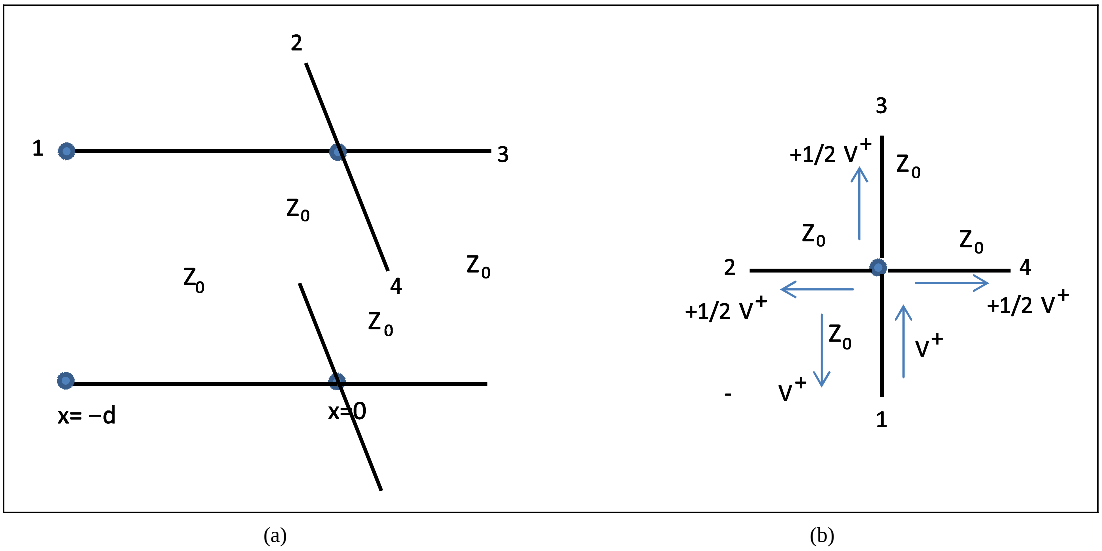

Figure 12. (a) Model of the transmission line with three parallel impedances; (b) Upper view.

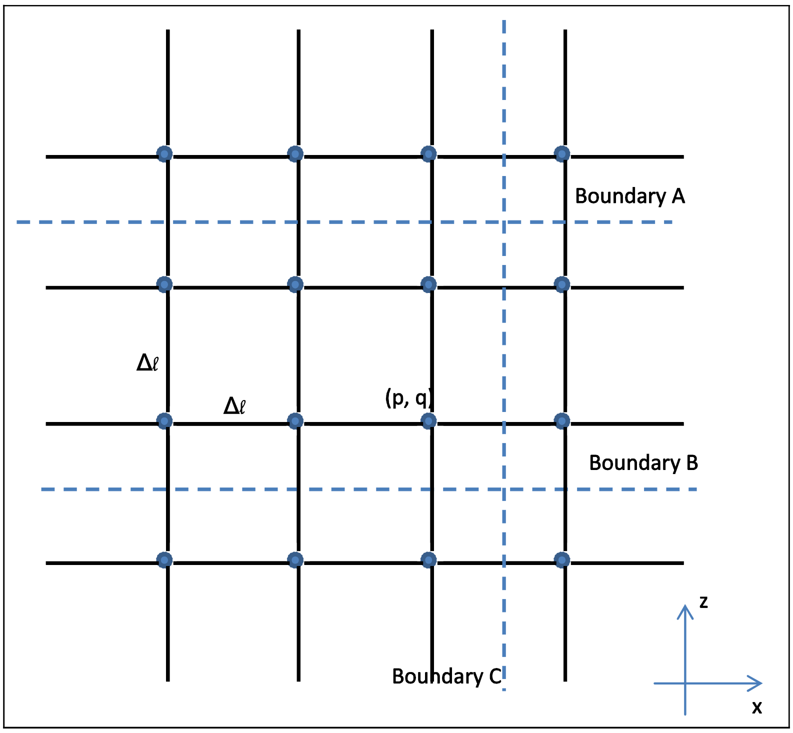

Figure 13. Transmission line matrix and boundaries.

$$D = \varepsilon E \tag{14}$$

where boldface letters represent vector quantities in 3-dimension. These vector quantities are functions of space and time. We can use the following notation for the scalar rows of them:

$$F(n\Delta t, i\Delta x, j\Delta y, k\Delta z) = F(n, i, j, k) \tag{15}$$

where n is discrete time and (i, j, k) are orthogonal unit vectors. Using this notation we can write, for example, the finite difference equation for the scalar equation of x component of Equation (11) for perfectly conducting boundary condition as follows:

$$\frac{1}{\Delta t}\left[B_x\left(n+\frac{1}{2},i,j+\frac{1}{2},k+\frac{1}{2}\right)-B_x\left(n-\frac{1}{2},i,j+\frac{1}{2},k+\frac{1}{2}\right)\right]=\frac{1}{\Delta z}\left[E_y\left(n,i,j+\frac{1}{2},k+1\right)-E_y\left(n,i,j+\frac{1}{2},k\right)\right] -\frac{1}{\Delta y}\left[E_z\left(n,i,j+1,k+\frac{1}{2}\right)-E_z\left(n,i,j,k+\frac{1}{2}\right)\right]. \quad (16)$$

The other finite difference scalar equations for components B_y and B_z cab be written in the similar manner. The finite difference equations for scalar rows of Equation (12)

$$\frac{1}{\Delta t}\left[D_x\left(n,i+\frac{1}{2},j,k\right)-D_x\left(n-1,i+\frac{1}{2},j,k\right)\right]=-\frac{1}{\Delta z}\left[H_y\left(n-\frac{1}{2},i+\frac{1}{2},j,k+\frac{1}{2}\right)-H_y\left(n-\frac{1}{2},i+\frac{1}{2},j-\frac{1}{2},k\right)\right] +\frac{1}{\Delta y}\left[H_z\left(n-\frac{1}{2},i+\frac{1}{2},j+\frac{1}{2},k\right)-H_z\left(n-\frac{1}{2},i+\frac{1}{2},j,k+\frac{1}{2}\right)\right] +J_x\left(n-\frac{1}{2},i+\frac{1}{2},j,k\right). \quad (17)$$

The other scalar difference equations can be written similarly.

The grid points for E-field and H-field are shown in **Figure 14**.

3.3. Method of Momentum (MoM)

The method of moment (MoM) is another efficient method for the analysis of electromagnetic problems such as the arrays of antennas. Nice iterative algorithms have been developed and can be applied to scattering problems [91]. In this analysis, groups of several neighboring array elements are constituted. For each group, the sub matrices are decomposed from the impedance matrix. The diagonal submatrices and off-diagonal submatrices represent the self and mutual impedance of the same group, and different groups respectively. The submatrices are the basic iteration units. If each group consists of K elements, and the total array elements are divided into N/K groups completely, the iterating procedure can be expressed as

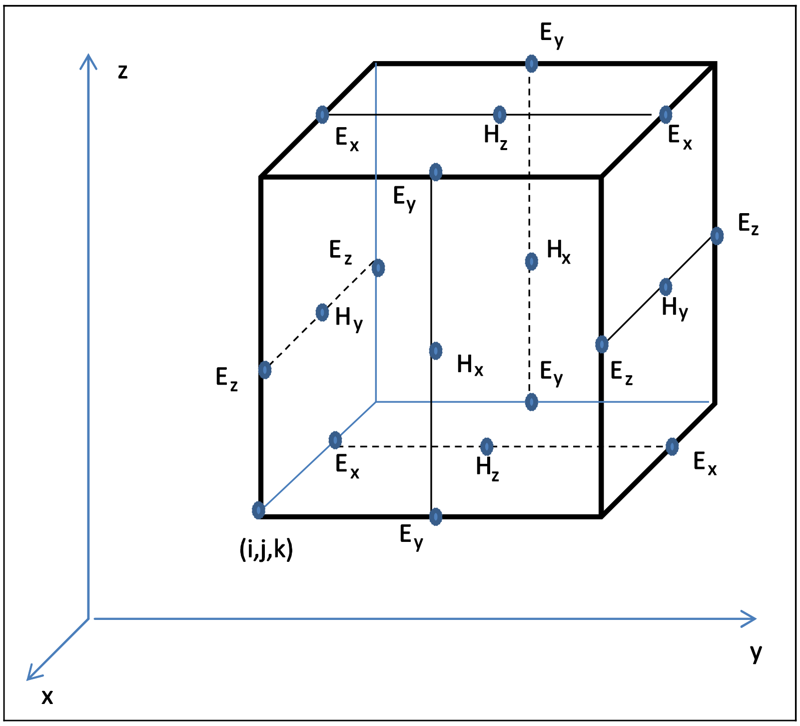

Figure 14. Positions of various field components.

$$\left[\overline{I}\right]_i^{(l_s+1)} = \left[\overline{Z}\right]_{ii}^{-1}\left[\left[\overline{V}\right]_i - \sum_{j=1}^{i-1}\left[\overline{Z}\right]_{ij}\left[\overline{I}\right]_j^{(l_s+1)} - \sum_{j=1}^{N/K}\left[\overline{Z}\right]_{ij}{}_j^{(l_s)}\right]^{\mathrm{T}} \quad i=1 \text{ to } N/K \text{ and } l_s=1 \text{ to } L_s \tag{18}$$

where, $\left[\overline{I}\right]_i$ is a $\frac{N}{K}$ current vector of the group i, $\left[\overline{V}\right]_i$ is voltage vector of the group i, $[Z]_{ij}$ is a $\frac{N}{K}\times\frac{N}{K}$ matrix whose elements are the self and mutual impedance between the segments of two groups *i* and *j*. $\left[\overline{Z}\right]_{ii}^{-1}$ can be calculated using a direct method.

3.4. Split Step Parabolic Equation (SSPE)

Parabolic equation methods are applied to model propagation over terrain. The equation that must be solved is

$$\frac{\partial^2\psi}{\partial z^2} + 2ik_0\frac{\partial\psi}{\partial x} + k_0^2\left(n^2-1\right)\psi = 0 \tag{19}$$

where k_0 is the free-space wavenumber, n is the index of refraction, ψ represents a scalar component of the electric field, and x and z are the spatial Cartesian coordinates corresponding to range and height, respectively [104]. The boundary condition is

$$\psi\left(x, z = f\left(x\right)\right) = 0 \tag{20}$$

where $f\left(x\right)$ describes the terrain. Let's simplify the issue by mapping range-dependent terrain coordinate system to a flat earth coordinate system. Now, we have a modified parabolic equation subject to a simpler boundary condition. The field is then vanishes at the surface and it is range independent in the new coordinate system. We can solve the problem now by using the split-step method [120]. Let's change the variables to make the coordinate transformation

$$\overline{x} = x,$$
$$\overline{z} = z - f(x),$$
$$f\left(x\right) = t\left(x\right) - \frac{x^2}{2a}.$$

Scalar component of the field in new coordinate system

$$\psi\left(x,z\right) = \overline{\psi}\left(\overline{x},\overline{z}\right)\mathrm{e}^{i\overline{\varphi}(\overline{x},\overline{z})}$$

The function $t\left(x\right)$ is the actual terrain and can be any digitized set of height/range points.

$\frac{x^2}{2a}$ takes into account the earth's curvature where a is the radius of the earth.

3.5. Image Processing and Intelligent Algorithms

Recently, image processing method is very suitable for analyzing magnetic anomalies created by buried objects [119]. The measurement process can be modeled as a 2-D fictitious sampler for mathematical convenience. The discrete 2-D data obtained by the sensor network can be written as

$$r^*\left(x,y\right) = \sum_{k=0}^{n}\sum_{l=0}^{m} r_{k,l}\delta_{k,l}\left[\left(x-kT_1\right),\left(y-lT_2\right)\right] \tag{21}$$

where n is the number of impulses in the *x*-direction and m is the number of impulses in the *y*-direction, respectively. Normally, the summations go to infinity, but the terrain of measurement has finite dimensions. The input in (11) is applied to the computer that functions as a 2-D ZOH, and a staircase 2-D continuous spatial function can be obtained

$$c\left(x,y\right) = \sum_{k=0}^{n}\sum_{l=0}^{m} r_{k,l}\left\{u\left[\left(x-kT_1\right),\left(y-lT_2\right)\right] - u\left[\left(x-kT_1-T_1\right),\left(y-lT_2-T_2\right)\right]\right\} \tag{22}$$

Note that a general nth-order holder could be used for the accuracy of the application. However, in the context of this paper, the use of a ZOH is well enough and shows the basic approach. After obtaining the measured data in continuous form at the output of a 2-D ZOH, it can be smoothed further in order to process in later stages. The smoothing process is a 2-D enhancement with a 3 × 3 convolution mask operation applied to $c(x,y)$. The smoothing can be achieved by a "neighborhood averaging" procedure. The output of the smoothing operation is a magnetic distribution having well highlighted objects inside it. Then object identification algorithm is applied.

4. Discussion

In this study, application principles of remote detection techniques are given, the academic works carried out using these techniques are investigated and performance achieved for detecting mines by these techniques are determined. In our study, the following variables are selected for performance criteria parameters for each work that is examined: soil type, material tested, test height, working rate and frequency, findings under these conditions.

The methods such as acoustic seismic, GPR, EMI, IR and MAD are used mainly for detecting mine cover, on the other hand the neutron based methods such as NQR, TNA, Neutron Backscattering and X-ray Backscattering are focused on detecting explosives foundwithinthemines. Taking into account the previous academic works as well, all the results for maximum performances are listed in **Table 10**. The equipment and costs for the methods are given in **Table 11**.

Table 10. Maximum performances reached by remote detection techniques.

Method	Place	Detected object	Application frequency	Maksimum detection height
Acoustic-sesimic	Sand or soil	Plastic or mine cover	450 Hz sound wave	5 cm
GPR	Sand, clay and wet soil	Plastic or mine cover	1 - 5 GHz radio wave	20 cm
EMI	Sandy and clay soil	Metal mine cover	300 Hz - 2 GHz bandwidth secondary magnetic field	10 cm
IR	Sandy and soil with grass	Plastic or metal mine cover	3 MHz - 140 GHz band range infrared wave	5 mm - 20 cm
NQR	Mixed soil	Plastic or metal mine cover	0.5 MHz - 6 MHz band range radio wave	20 cm
TNA	Sandy soil	Plastic or metal mine cover with its explosive	10 - 14 MeV energy electronsr	20 cm
Neutron backscattering	Sandy and wet soil	Plastic or metal mine cover with its explosive	10 - 14 MeV energy neutrons	20 cm
X-ray backscattering	Dry soila	Plastic or metal mine cover with its explosive	150 keV energy X-raysı	3 cm
MAD	Soil, water and air	Plastic or metal mine cover	1 - 25 kHz band AC source	20 cm

Table 11. Cost of the equipment for each technique.

Method	Equipments	Unit price
Acoustical seismic	Laser-doppler vibration transdusers	21,000$
Ground penetration radar	GPR system, transmitter antennas	25,000$
Electromagnetic ınduction	Induxtion coil, magnetometer, conduction meter	10,000$
Infrared imaging	Thermal camera	15,000$
Neutral quadruple resonance	RF exciter, detector	14,000$
Thermal neutron activation	Electron accelerator, gamma detector	20,000$
Neutron backscattering	Electron accelerator, electron detector	23,000$
X-ray backscattering	X-ray source, backscattering detector	14,000$
Magnetic anomaly	External magnetic field source, magnetic detectors, mechanical system	10,000$
Magnetic anomaly (without using any external magnetic)	Sensors, mechanical system	3000$

As seen from **Table 10**, the maximum detection height for each method is about 20 cm. Under appropriate environmental conditions (such as soil type, burrying depth, soil without grass) this value may be increased somehow like 5 - 10 cm. But it can be said that the height cannot be changed by changing the method. As a matter of fact, the last studies are focused on the improvement of the mothod rather than inventing a new method. In this respect, the MAD method for example may be the method that use minimum power consumption (**Table 10**). If we look at **Table 11**, the MAD method is also the most cost effective one among the others. The reason for it is that instead of using external magnetic field, very accurate magnetic sensors are used to detect the Earth's magnetic field. As seen, the MAD method may be preferred taken into account its power consumption, accuracy, portability and cost. However, the disadvantage of this method is the use of it to detect only metal covered mines. This method may be used to detect the metal pins of plastic mines by lowering the detection range and increasing sensor sensitivity. It may be understood that only one method cannot be used for an application looking at its cost, power consumption and sensitivity. Every method has advantages and disadvantages. In order not to depend on only one type of sensor, more than one method has to be used for good results in an application.

5. Conclusions

As a conclusion, we may offer the MAD and GPR together for academic studies, because the first criteria for us is the transportability and the time of detection. The cost may be a secondary criterion. Especially, the equipment for determining the explosives within the mines is heavy systems and cannot be transported by a single person. The weight of IR, EMI and acoustic-seismic systems are heavier than that of GPR.

An academician who wants to use a MAD system and a GPR system may carry only a magnetic sensor card and a radio frequency receiver. These systems are enough for her/him. If this academician has aslo a wireless communication medium between herself/himself and a decision and storage center, she/he will not need to have an electronic storing device. In addition, the decision center may evaluate the sensor information and can give a reduced number of alarms to that academician. She/he may choose one of the classification algorithms depending upon her/his requirmennts and available computing capabilities.

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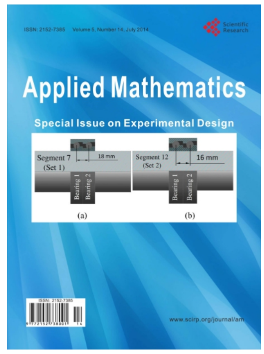
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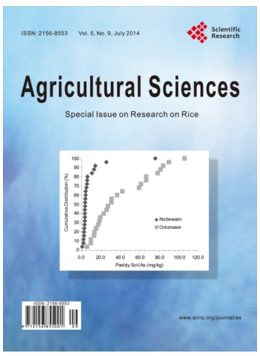
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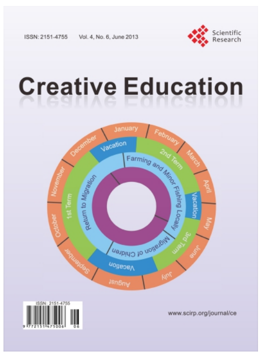
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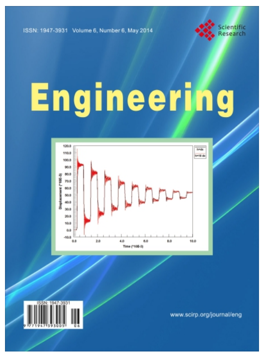
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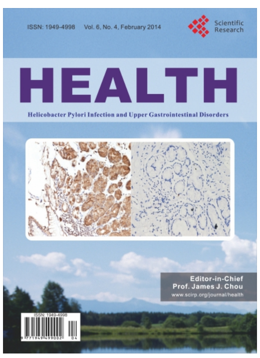
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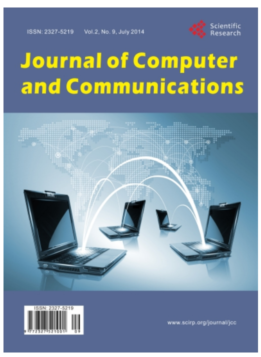
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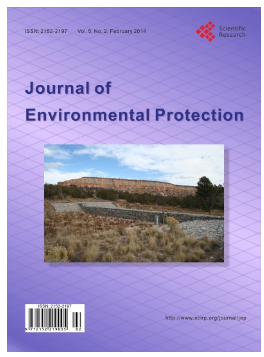
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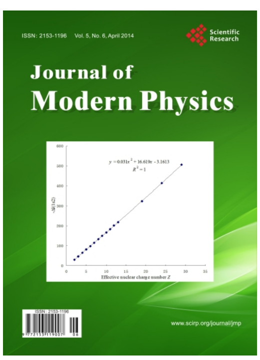
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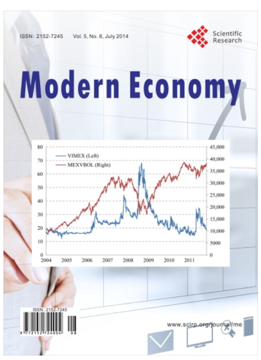
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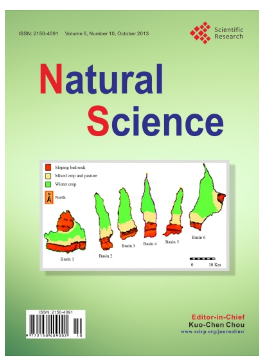
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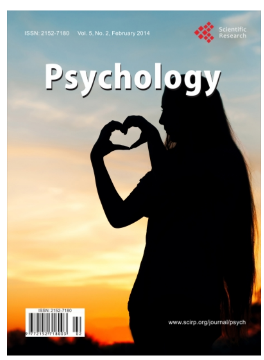
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