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A Multi - Sensor System For Land Mine Detection

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ABSTRACT

In this review article, description and discussion are given to the methods and techniques which can be used to remove the millions of landmines that are buried in the ground of more than 60 countries worldwide. These buried landmines cause very serious social and economical problems especially in countries such as Egypt with nearly 23 millions landmine contaminating very vast areas in the northern cost of the western desert, north and west of Sinai, Suez Gulf and western cost of the Red Sea. This will challenge scientists in different related disciplines to find a specific, rapid and cost effective detection techniques to remove the millions of landmines from the ground of their countries. It is worth mentioning that the real problem in demining is not defusing the mines but locating them in the ground.

At present, humanitarian demining is done using conventional methods which are mainly metal detectors, i.e., pick mines made with metal casing. However, most modern mines are made entirely of plastic. Their very small size also makes them difficult to be detected. This makes the demining of a huge number of landmine a difficult, very slow and costly process. Although some of the conventional methods such as Electro Magnetic Induction (EMI) and Ground penetrating Radar (GPR) are effective at locating metal or metal like anomalies, but they suffer from high false alarm rates because they cannot identify these anomalies as mines. However, certain nuclear techniques, capable to detect explosive materials, can be used to identify the localized anomalies and to confirm the presence or not of a landmine. Thus, a system with metal and nuclear sensors would significantly enhance the effectiveness of the demining operation.

INTRODUCTION

Landmines were first used during the first World War to stop tanks from rolling right over their battle lines. Explosive material, TNT was developed by the second World War, in 1939 and was deployed to develop much better antitank mines. However, advancing troops soon found they could remove the antitank mines by hand. This leads to the development of mines designed to explode under the pressure of a human foot. These mines were laid close to the antitank mines to protect them.

During the early 1960s, United States began using new, smaller, remotely delivered antipersonnel mines, which could be dropped by thousands from airplanes over a broad region. These mines were used to stop the flow of soldiers and supplies between North and South Vietnam . These methods of delivery means that, mine locations could not be mapped. The same method of randomly scattering mine was used by the Soviet Union during the its invasion of Afghanistan in the 1980s.

Nowadays, The use of landmines during the armed conflict is one of the most dangerous problems that facing the Human being, since they have a devastating impact on the individual lives. They kill innocent civilian people and cause a severe social and economic consequences, particularly for a country attempting to rebuild after the end of the war.

The presence of mines can leave large portions of the land unusable. Farmlands, grazing pastures and other food–producing areas my be rendered in accessible and , as a result, the ability of a community to feed itself is impaired .

Mine clearance , although essential, is slow, dangerous and an expensive process(1) . According to official figures, more than 110 million landmine have been laid in several countries, among them is Egypt, with about 23 million landmine lie buried in the Northern parts of the Western desert and Northern and Western parts of the Sinai.

Recently, mines become also a weapon of choice in smaller skirmishes and civil war, largely because they are so cheap and easy to obtain. Instead of being used to protect military positions, mines are often used to terrorize and demoralize civilians. Bosnia and Crotia now have millions to deal with many of them planted around wells, rivers, power sources, buildings and other high-traffic areas(2) .

SENSORS CURRENTLY USED FOR MINE DETECTION

Detecting of mines is the real problem before defusing them. Rarely, if ever armies leave accurate maps of locations of mines. Detectors based on metal detection pick up mines made of metal , but , most modern mines are made of plastics. Their size (some are as small 2.5 cm wide) also makes them difficult to pinpoint.

Others based on visible and infrared observation , on microwave detection and on nuclear techniques are able to detect a mines from one of its characteristics (3-5) . In this section, a brief description is given for the currently used mine detectors. However, detectors based on nuclear techniques will be given in more details in the next section.

1 Manual Detectors for Land mines :

The most common techniques for mine detection are manual, using either prodders or metal detectors.

1-1 Prodders:

Prodders are the most basic method which is used for mine detection . A Prodder is a rigid metal stick about 25 cm long , the deminer scans the soil at a shallow angle of typically 30^0. The method is effective but is slow and dangerous. In many case, deminers lie flat on their stomachs, often wearing only protective headgear and a flak jacket, and probe the ground at five centimeter intervals with a long metal rod. The work is necessarily slow and painstaking proceeding at a rate about a meter every 12 or 15 minutes .

1-2 Metal Detectors:

Metal detectors measure the disturbance of an emitted electromagnetic field caused by the presence of metallic objects in soil. Magnetometers which do not radiating energy also are used. They measure only the disturbance of the earth’s natural electromagnetic field(5).

- Metal detectors pose problems for mine detection , these include :
- Identification all metallic object ,
- Incapability for differentiating a mine from other debris. This leads to false alarms : 100:1000 false alarms for each real mine detected one ,
- Waste time and disrupt the deminer’s concentration ,
- By increasing the detector sensitivity to detect mines with little metal , does not solve the problem where such sensitivity detect more metal debris and increases considerably the rate of false alarms.

NEW DETECTORS

To increase the speed , safety and maintain the accuracy of mine detection , the following developed detectors are used;

1- Advanced Metal Detectors

A series of studies are performed to improve metal detectors capability to discriminate mines and UXO from metallic debris, reducing the false alarm rate. The most significant innovations in this area include;

- Impulse metal detector with a characteristic decay curve. It is effective only with objects whose decay curves are known already.
- Eddy current metal detector with large frequency range. It gives interesting results for objects with some metallic content.
- Non conducting targets or cavities detectors which rely on the principle that a large non-conducting target locally alters the natural ground conductivity .
- Array of metal detectors , can be used to scan a large area quickly .

The above technologies are so new and under investigation.

2- Ground Penetrating Radar (GPR):

GPR emits in to the ground through a wide band antenna, an electromagnetic wave covering a large frequency band. Reflections from the soil caused by dielectric variations (such as the presence of an object) are measured. Moving the antenna reconstructs an image that represents a vertical slice of the soil; further data processing allows the display of horizontal slices or three- dimensional representations [6].

Although promising , but it has the following limitations.

- The resolution needed to detect small objects involves GHZ frequencies, which decreases soil penetration and increases image clutter.
- High cost compared with other methods, GPR systems are expensive beyond the budget of most demining operations.

To decrease the size and price of GPR the Lawrence Livermore National Laboratory (LLNL) developed a Micro power Impulse Radar (MIR) with antennas less than 50 cms which allows a faster and more simplified scan of a minefield.

3- Infrared Imaging (IR):

IR imaging method depends on the fact that mines retain or release heat at a rate different from their surroundings. IR cameras create images that reveal the thermal contrast between the soil immediately surrounding a buried mine and the top layer of soil. When this contrast results from the presence of the buried mine (alteration of the heat flow), it is a volume effect when the contrast results from the disturbed soil layer above and around the mine (because of burial) it is a surface effect. The surface effect is detectable for weeks after burial and enhances the mines signature [7]

IR techniques have been recognized in certain cases, there is a large thermal contrast between mines and soil just after dawn and after dusk. One approach, originated by Roder, essentially used a large heater to heat the soil followed by an infrared imaging camera to detect mines . For this to be more practical, better methods of heating the ground and cheaper infrared imaging techniques must be developed.

The application of imaging to mine detection presents these problems :

- Requires very sensitive cameras with sufficient spatial resolution .

- Measures mines at a maximum burial depth of 10-15 cm .
- The results of passive infrared images depend heavily on environmental conditions .
- During cross- over periods (morning and evening) the thermal contrast is negligible, rendering mines undetectable through IR.
- Presence of foliage also impedes accurate IR imaging.

4- Trace Explosive Detection:

Well trained dogs are used to identify mines through the explosive material within them. This is a common method of detecting explosives. Exactly how dogs detect explosives remain a mystery. No one knows whether dogs use senses other than the olfactory sense. Also unclear is the substance that dogs detect, vapors or trace particles and the concentration of the substance they detect [(8)].

Although dogs effectively detect the presence of mines , but,

- They cannot determine a mines precise location. The odor of an explosive penetrates the ground and the vegetation up to 10 meters from the actual mine.
- Another hindrance to locating mines with dogs is the scattering of trace explosive particles far from the actual mine.
- Finally a mines vapor- release rate changes significantly over time.
- Although somewhat effective , mine detection with dogs poses obstacles such as time and money costs for training dogs. In addition, the dogs quickness too tire and their sensitivity to environmental conditions.

An-alternative to training dogs is the artificial odor or vapor sensors. These sensors, however, are not practical for mine detection . They lack sensitivity, speed and portability .

5- Passive Millimeter Wave (MMW) Detectors:

In the millimeter wave band , soil has a high emissivity and low reflectivity, while metal has a low emissivity and strong reflectivity . Soil radiation depends, therefore, almost entirely on its temperature, and metal reflections relies mostly on the low - level radiation from the sky . It is possible to detect mines by measuring this contrast with a millimeter wave (MMW) radiometer. Passive MMW radiometers are relatively simple , less complicated than GPR. They also can generate clear two dimensional images of surface or shallowly buried (few centimeters deep) metallic objects, yielding best results in dry environments and for metal mines[(9)].

The main disadvantages of MMW detectors are;

- Small percentage of water causes poor penetration of the soil so it is ineffective in wet environments.
- plastic mines have much lower reflectivity and transparency to radiation from below them.

6- Ultrasound Detectors:

Conventional ultrasound detection involves the emission of a sound wave with a frequency higher than 20 KHZ into a medium. This sound wave reflects on boundaries between material with different acoustical properties. Therefore, ultrasound systems effectively penetrate very wet and heavy ground such as clay, rendering them complementary to CPR. However, ultrasound system counter problems at interface of air and ground[(10)]. Ultrasound detectors are used to detect AP mines submerged in water, a simulation of mines thrown into rice fields.

The above mentioned techniques are mainly used for detecting trace explosives, interest is growing in techniques for detecting bulk explosives. These techniques are used in security or non-destructive testing . Applying these techniques to mine detection, which requires:

- One- sided sensor configuration ,
- Operator security ,
- Equipment portability , and
- Extensive soil penetration .

However, some techniques such as nuclear methods and NQR (Nuclear Quadruple Resonance) appear promising. A detailed description and discussion of these methods are given in the next section.

NUCLEAR TECHNIQUES

Explosive materials contain different concentrations of H , ^{12}C , ^{14}N and ^{16}O compared with soil. This makes the nuclear techniques the only possible methods and precise way which could be used to identify the explosive charge of landmines and therefore, distinguish between mines and other scattered debris. The identification of explosive material can be achieved by applying the neutrons or nuclear quadruple resonance analysis to determine the constituent elements and their concentration in soil and explosive material. The nuclear techniques by neutron analysis are performed via thermal neutron analysis, fast neutron analysis, and with combination of thermal and fast neutron analysis. It could be also performed using the quadruple moment of nitrogen to detect the presence of compounds such as TNT [(11)]. These methods are the most promising at the current stage of development, especially in the aviation security. A brief description of the main features the nuclear reactions used for mine detection and the proposed integrated system is given below.

1- Main Features of Neutron Interaction with Matters:

When the nucleus of a medium-weight or heavy element absorbs a neutron it gains excitation energy equal to the binding energy of the neutron plus its kinetic energy. The compound nucleus so formed may lose this excitation energy in various ways. The de-excitation most often occurs by the prompt emission γ-rays, leaving the nucleus in its ground state. The process is most properly described as neutron capture and is symbolized as the (n, γ) reaction. The total energy of the emitted photons for each capture must clearly added-up to the neutron binding energy plus whatever kinetic energy the neutron brings into the nucleus. The neutron binding energies are usually in the neighborhood of 6 to 7 MeV for capture in hydrogen to about 11 MeV in nitrogen-14 and silicon-28. The cross-section for radiative capture becomes quite small for neutron kinetic energies above 10 to 20 KeV; the reaction then no longer provides a significant source of γ-radiation [(12)] .

In most practical situations the total emitted energy is given simply by the neutron binding energy. For a few elements, the energy is radiated by a single photon to the ground state, as many as four photons being radiated on the average per capture. The emitted γ-photon takes place within 10^{-12} to 10^{-13} sec after capture

Fast neutron analysis uses the gamma-rays which are produced by inelastic neutron interaction whose energy is determined by the element in which the incident neutron interacted. In this process, the energy lost by the neutron goes to excite the target nucleus to some level above the ground state. Within a very short time after the scattering (10^{-14} sec) the nucleus loses its energy of excitation by emitting one or more γ-rays. Inelastic scattering cannot take place unless the incident neutron energy in the CMS is at least equal to the first excited level. The maximum energy of the emitted photon is less than or equal to the incident neutron energy. If more than a few excited levels are involved, the photon emission often proceeds by cascade process to ground state, and there will not be a 1 : 1 correspondence between the photon and scattered neutron energies. The inelastic scattering γ-ray spectrum is complicated even for neutrons of energies below 4 MeV. As the neutron energy increases, many more nuclear level can be excited or participated in cascade γ-ray emission. In case of ^{12}C and ^{16}O, the γ-ray spectrum due to inelastic collisions of neutrons above 4 MeV is continuos.

Fast neutrons especially those with energies above a few MeV, are capable of penetrating materials depth sufficient for identification of mines at depths up to 50 cm in ground. While limited by the mean free path of neutron and gamma-rays and by the noises coming from equipment and from the soil around the mine. Other distinct factors make fast neutron detecting technique very promising are [13],

- The interactions of neutron with materials are very sensitive to the neutron energy and the nuclides in the material , and this makes it possible to determine these nuclides (and have the corresponding chemical elements) by monitoring the neutron interactions in various ways.
- In case of explosive materials are the elements, hydrogen, carbon, nitrogen and oxygen which differ strongly from one - another in their interactions with neutrons and can thus be characterized via the different reactions.
- Different elements are identified via their characteristic gamma spectra resulting from the interaction of neutrons of different energies.

The inelastic scattering process is singular in that the residual nucleus is the same as the target nucleus. But other neutron reactions can also lead to excited residual nuclei which lose their energy of excitation by photon emission. Although this reaction, is not important for the elemental analysis of the explosive materials during the field operation, it is of prime important for the chemical analysis of the soil.

2- Elemental Analysis by Neutrons:

Thermal neutron analysis relies on the activation via neutrons emitted by a radio-isotopic source of the nitrogen nuclei, abundantly contained in most explosives. The activated nitrogen nuclei emit specific gamma-rays which can be detected quickly .Sensors based on TNA yield good results for antitank mines but not for antipersonnel mines which contain a smaller explosive volume[12]. Another drawbacks of TNT include system complexity and limited depth at soil penetration (10 -20 cm).

When a thermal neutron is captured by a ^{14}N nucleus, the following reactions take place ;

$$^{1}_{0}n + ^{14}_{7}N \longrightarrow ^{15}_{7}N^{*} \longrightarrow ^{15}N + \gamma$$

The $^{15}N^{*}$ de-excites to its ground state by the emission of one or more gamma-rays of energies up to 10.82 MeV. This reaction has a capture cross section of about 80 millibarn; the hydrogen cross section is four times more and the capture reaction rate is almost 400 times larger for hydrogen than for nitrogen.

The neutron techniques with fast neutrons can be used to identify elements such as carbon and oxygen. This is achieved through the reactions (n, nγ) and (n, pγ) with nuclei of C and O. Neutrons of energy higher than 9 MeV, or 14 MeV neutrons emitted in pulsed mode allow to separate the different reactions by the time at the microsecond scale.

3- Elemental Analysis by Fast Neutron (FNA):

Fast neutron analysis uses the gamma - rays which are produced by inelastic neutron interaction whose energy is determined by the element in which the incident neutron interacted . Thus, measuring the energy and origin point of the gamma- ray determines the element presence and its location within the ground . The measured gamma-rays give a three dimensional image of the source by separating out the gamma-rays from each element.

Fast neutrons especially those with energies above a few MeV are capable of penetrating materials depth sufficient for identification of mines at depths up to 50 cm in ground . While limited by the mean free path of neutron and gamma-rays and by the noises coming from equipment and from the soil around the mine . Other distinct factors make fast neutron detecting technique very promising are.

- The interactions of neutron with materials are very sensitive to the neutron energy and the nuclides in the material , and this makes it possible to determine these nuclides (and have the corresponding chemical elements) by monitoring the neutron interactions in various ways.
- In case of explosive materials , hydrogen , carbon , nitrogen and oxygen differ strongly from one-another in their interactions with neutrons and can thus be characteristic via the different ratios .
- The energy spectrum and time of arrival of prompt gamma-rays which are excited by inelastic neutron scattering in the interrogated material can by measured .
- Different elements are identified via their characteristic gamma spectra and the time measurement is used to locate the position of different scatter.

The neutron techniques utilize either fast neutrons for the identification of elements such as carbon and oxygen or thermal neutrons for the measurement of elements such as nitrogen. Detection of all elements from mines is only possible using neutrons of energy higher than 9MeV. 14 MeV neutrons emitted in pulsed mode allow to separate the different reactions by the time at the microsecond scale. A SODERN small size sealed neutron tubes are best used in pulsed mode and is turned off after used. The neutron tube produces in the pulsed mode a train of 14 MeV neutrons pulses a few μs wide (10-15 μs) .

The fast neutrons incident on the object to be interrogated and a series of nuclear reactions such as (n . nγ) and (n, pγ) with nuclei of C and O , which have a large cross section for these reactions. Slowed -down neutrons to energies about 1eV (through the collision with soil and explosive nuclei) interact with the H, N, S, Cl, Fe nuclei and emit prompt gamma-rays through (n, γ) reactions. The same set of gamma-ray detectors will be used to measure the gamma-rays produced from fast and thermal neutron interactions as well as the gamma-rays emitted from elements such as Si and P that have become activated after a predetermined number of neutron pulses. Different modes of gamma-rays produced during different sequences of operation mode , are stored at different sections of the acquisition system and are used by the analyzing codes to give information for ratios and concentration . Therefore, by utilizing gamma-rays produced, a large number of elements contained in the object can be identified .

NUCLEAR QUADRUPLE RESONANCE (NQR)

This technique relies on the resonant response of certain nuclei possessing electric quadruple moments. In case of mine detection, NQR technique uses the quadruple moment of nitrogen nuclei to detect the presence of compounds such as TNT. The NQR detects RDX material well but it does not efficiently detect TNT, the chief substance in mine explosives . To achieve a better detection efficiency of TNT by NQR , the signal to noise ratio for TNT has to be increased. This is a priority in current NQR research (16) .

NQR has the advantage that there are essentially no false positives , but the techniques possesses these problem ;

- It cannot detect explosives within conductive materials and thus will be useless against metal mines .
- Sensitivity is limited for TNT and in particular, it is necessary to use a non optimum probe coil arrangement to detect mines from the surface.
- The method works even if the mine is surrounded by materials found in soil .

CONCLUSIONS

- None of the well know landmine detection techniques has the capability to detect mine in various environments. Therefore, a combination of techniques is required.

- Explosive materials are rich in nitrogen which serves as a bonding agent as well as with oxygen which is the oxidizer . Therefore, the mine identification technique must detect the nitrogen content together with the oxygen content.
- Detection techniques with high energy neutrons from pulsed neutron generator can offer a viable solution to the problem of landmine detection and removal in terms of safety, and efficiency. They can offer the unique feature of unambiguous identification of the hidden object through either partial or complete chemical characterization .
- A nuclear sensor based on TNA and FNA could be used with other currently used techniques to increase the detection efficiency ,and greatly enhance the level of safety and reduce the demining cost.
- Removal of all landmines already in the ground is very costly, but the only thing more costly will be to leave them in the ground.

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