2nd International Conference on Autonomous Robots and Agents
December 13-15, 2004 Palmerston North, New Zealand

A Review of Sensing Technologies for Landmine Detection: Unmanned Vehicle Based Approach

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Abstract

With the development of unmanned vehicle (**robot**) it will be possible to inspect deadly landmines by installing the smart landmine detector with it. This paper illustrates the existing and new technologies for landmine detection. There are over 100 million landmines scattered throughout 70 countries across the globe as a result of current and past warfare. Every year 26000 people are killed or maimed as a result of this. It also contributes immensely to socio-economic problems in many developing countries.

Keywords: Smart sensor, landmine inspection, electromagnetic techniques, robot based sensor.

1 Introduction

One of the most deadly legacies of this century is the use of landmines in warfare. Anti-personnel landmines continue to have tragic, unintended consequences years after a battle and even the entire war has ended. These mines continue to be functional for many decades, causing further damage, injury and death. Currently there are over 100 million landmines buried around the world. There also 10 new mines being placed for every mine that is successfully cleared. Fig. 1 shows the mine affected countries around the world, and it can be seen that the most affected areas are in the Asian and African regions.
Landmines are basically explosive devices that are designed to explode when triggered by pressure or a tripwire. These devices are typically found on or just below the surface of the ground. Landmines are easy-to-make, cheap and effective weapons that can be deployed easily over large areas to prevent enemy movements.

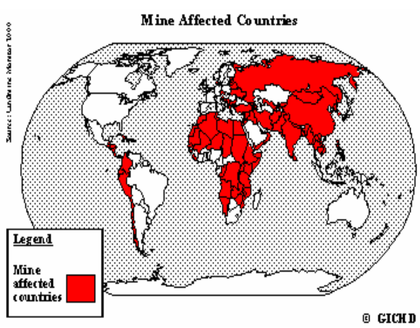


Figure 1 – Mine affected countries

Mines are typically placed in the ground by hand, but there are also mechanical minelayers that can drop and bury mines at specific intervals. While more than 350 varieties of mines exist, they can be broken into two categories: Anti-personnel (AP) mines and Anti-tank (AT) mines.
The basic function of both of these types of landmines is the same, but there are a couple of key differences between them. Anti-tank mines are typically larger and contain several times more explosive material than anti-personnel mines. There is enough explosive in an anti-tank mine to destroy a tank or truck, as well as kill people in or around the vehicle. Additionally, more pressure is usually required for an anti-tank mine to detonate. These devices are typically found on or just below the surface of the ground. In order to prevent human life during detection it is possible to employ unmanned vehicles as shown in Figs. 2 and 3 to detect landmines and to detonate it.

Fig. 2 Unmanned vehicle based landmine detection – Scheme 1

Fig. 3 Unmanned vehicle based landmine detection – Scheme 2

2 Current Technologies

Various techniques are used for the detection of landmines. There are five main areas the current technologies fall under. The five areas are:

1) Metal Detector Technologies
2) Electromagnetic Methods
3) Acoustic/Seismic Methods
4) Biological Methods
5) Mechanical Methods
6) Latest Methods

Mine action programmes have traditionally relied on manual practices, procedures and drills, which are slow and labour intensive. As shown in Fig. 4 a wide variety of conditions must be taken into account. In many situations, a manual approach may be the most appropriate and effective means of detecting and destroying landmines. However, there is a growing acceptance that a more universal application of technology may enable mine detection, ground preparation and mine clearance, as well as other elements of mine action, to be conducted more cost-effectively, quickly, and with less risk.

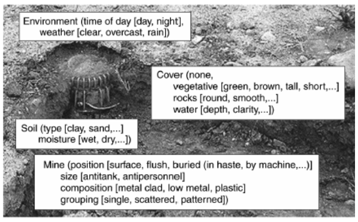


Figure 4 – Succesful Mine Detection Must Accommodate a Wide Variety of Condition

While some advances have been made in recent years, there is general consensus in the mine action community that technological developments, particularly those resulting from "high-tech" scientific Research and Development [1 – 10], have so far failed to meet field mine action needs.

3 Mine Detection Methods

3.1 Metal Detector Methods

The basic metal detector used for mine detection as shown in Fig. 5 measures the disturbance of an emitted electromagnetic field caused by the presence of metallic objects in the soil [11]. The popular, basic metal detector is easy and cheap to use and has an average success rate. However all metallic objects are identified while the problem is heightened, when using more sensitive detectors for plastic mines.

Induction Coil Imaging Sensor – create an image of the object being detected instead of producing an audio signal [12]. “In its current version it is able to detect and see metal parts of less than 1cm to a depth of 50cm”. But the system cannot be used on the newer plastic mines, and the prototype is quite heavy [12].

Fig. 5 Metal detector being used in landmine detection

Magnetic Sensors – magnetic sensors measure a magnetic field. Sending a current through a wire wrapped around a metal rod or loop produces a magnetic field that penetrates the ground. The ground significantly disrupts the magnetic field, which is measured by the magnetometer.

There are four types of magnetometers. These are namely Fluxgate magnetometers, Proton Precession Magnets, Optically Pumped Atomic Magnetometers and Meandering Winding Magnetometers. The low cost, robust and energy saving Fluxgate magnetometer measures the magnitude, and direction of a magnetic field. But they don’t discriminate well between scrap metal near the surface of the ground and mines deeper in the ground. They also usually produce an analog output that is difficult to process digitally [12]. The more sensitive but slower Proton Precession Magnet measure the movement of protons in a liquid. When these protons are polarized and subjected to an ambient magnetic field, the frequency of precession will deviate from their natural frequency in proportion to the strength of the ambient field [12]. It’s more sensitive to noise.

Optically Pumped Atomic Magnetometers use the same process as Proton Precession Magnetometers, except they use an atom of a specific gas vapour. This method is expensive yet faster and sensitive than Proton Precession Magnetometers. The Meandering Winding Magnetometer generate a varying magnetic field that excites currents in metallic objects that align primarily in one direction and can be read by a detector . It has a lower the false alarm rate by a factor of 5 to 10, costs same as a metal detector and 10 to 20 times faster. Even though it distinguishes mines from metal debris better than a metal detector, it still has a false alarm rate that could be reduced.

Conductivity Meters – use a magnetic field to produce an eddy current in the object. By establishing a baseline standard in a clean area prior to searching, changes in conductivity of the soil which may result from conducting substances such as mines can be detected [13].

Two types of conductivity meters are available.

i) Frequency Domain Conductivity Meters – induce an eddy current and read the resulting magnetic field.

ii) Time Domain Conductivity Meters – induce a transient eddy current in the ground, then observe its decay time.
Strengths: Have a reasonable penetration depth and can possibly be used for plastic landmine detection.
Limitations: Horizontal range is limited and the ground has natural variation in conductivity that must be taken into account. Image resolution is also poor, targeting individual mines is not feasible and "capability" rests more practically in establishing minefield boundaries.

3.2 Electromagnetic Methods

3.2.1 Ground Penetrating Radar (GPR)

GPR detects buried objects by emitting radio waves into the ground and then analyzing the return signals generated by reflections of the waves at the boundaries of materials with different indexes of refraction caused by differences in electrical properties. Images can be obtained as shown in Fig. 6 "The lowest frequencies offer the best penetration, but wideband techniques appear to be necessary in order to get the best detail" and the best signal-to-noise ratio.
The lightweight and easy to operate GPR systems are complimentary to conventional metal detectors. Can find mines with wide variety of types of casing and also can generate an image of the mine, or another buried object based on dielectric constant variations. However GPR performance can be highly sensitive to complex interactions among mine metal content, interrogation frequency, soil moisture profiles, and the smoothness of the ground surface boundary [14].
Very small plastic mines at shallow depths can be missed, if system is not tuned to a high frequency.

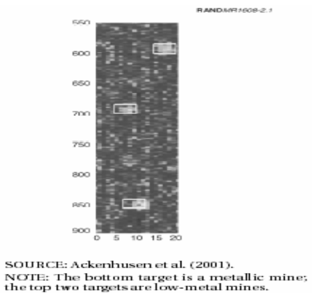


Fig. 6 – Images of landmines produced by GPR system

3.2.2 NuclearQuadrople Resonance(NQR)

An NQR device, as shown in Fig. 7, induces a RF pulse of an appropriate frequency in the subsurface via a coil suspended above ground. This RF pulse causes the explosives' nuclei to resonate and induce an electric potential in a receiver coil [15].
This type of detection claims a 90% "compound specific" detection rate and less than a 1% false alarm rate. Unlike many other technologies, NQRs false alarm rate is not driven by ground clutter but rather by its signal-to-noise ratio (SNR) so given time good results can be obtained. Another positive feature of NQR is that it is relatively robust to diverse soil conditions. The major weakness of NQR is the fact that, because of its nuclear properties, TNT, which comprises the explosive fill of most landmines, provides a substantially weaker signal than others, posing a formidable SNR problem. Another significant limitation is the susceptibility of NQR to RF interference from the environment. This is especially problematic for TNT detection because the frequencies required to induce a response from TNT (790–900 kHz) are in the AM radio band. NQR is very sensitive to the distance between the detection coil and the explosive.

Fig. 7 – Prototype NQR Handheld Mine Detector

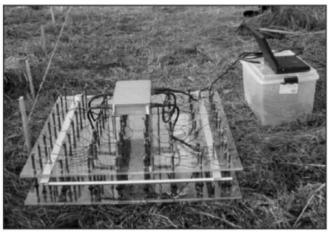
3.2.3 Microwaves

An image is constructed in the computer from the signals that bounce back when microwaves are sent into a minefield. Various prototypes are underway, and one of these in shown in Fig. 8.
Strengths: Computer constructs images of the terrain's features, such as stones, twigs, sharpnel and concealed mines.
Limitations: Ambiguous results produced by plastic mines, however, indicate that this method needs more testing.

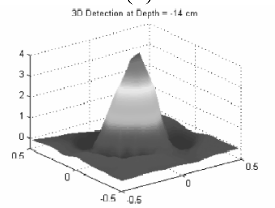
Fig. 8 – Prototype based on microwave

3.2.3 Electrical Impedance Tomography

EIT uses electrical currents to image the conductivity distribution of the medium under investigation. Prototypes are built as shown in Fig. 9a and results obtained as shown in Fig. 9b [16].



(a)



(b)

Fig. 9 EIT Landmine Detector and results

The technology is appropriate for detecting all types of mines. Moreover, it is especially well suited for mine detection in wet environments, because of the enhanced conductivity of the moist substrate. The equipment is relatively simple and inexpensive. It does have its limitations in that the required physical contact with the ground may detonate a mine and it cannot be used in dry, non conductive surfaces. The technology is also sensitive to electrical noise. Performance deteriorates substantially with the depth of the object being detected for fixed electrode array size.

3.2.4 Infrared

Infrared/hyperspectral methods detect anomalous variations in electromagnetic radiation reflected or emitted by either surface mines or the soil and vegetation immediately above buried mines. Images are obtained as shown in Fig. 10. Thermal detection methods exploit diurnal variations in temperatures of areas near mines relative to surrounding areas. Nonthermal detection methods rely on the fact that areas near mines reflect light (either natural or artificial) differently than surrounding areas.

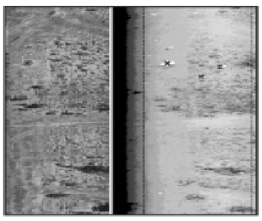


Fig. 10 Infrared image of mines

These methods are safe, lightweight and can scan large areas. When deployed from airborne platforms, they are particularly effective for detecting surface mines. However they have extreme variability in performance as a function of dynamic environmental characteristics. The algorithms to process the signals in an informative way are relatively undeveloped and are not linked to physical phenomena. Thermal signatures currently are not well understood, and a comprehensive predictive model does not exist.

3.2.5 X-Ray Backscatter

Backscattering involves sending X-rays into the ground. Objects with lower atomic numbers, such as plastics, scatter x-ray radiation better due to the electron density.

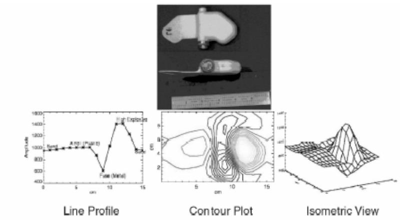
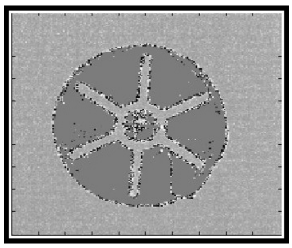


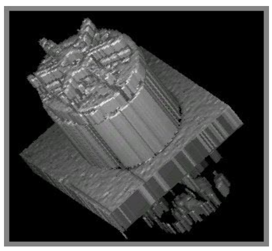
Fig. 11 High Resolution Image of a "Butterfly Antipersonnel Mine"

Cross sections are larger compared to other nuclear reactions, since low energy incident photons are used. Uncollimated systems can be made small and light due to the reduced shielding thickness. [17]. In the required energy range, soil penetrations of x-ray backscatter devices are poor. If source strengths are kept low to be safe for a person-portable system, the time required to obtain an image may be long. Also the technology is sensitive to source/detector standoff variations and ground-surface fluctuations. Further, to image antipersonnel mines, high spatial resolution (on the order of 1 cm) is required. Finally Radiation effects may cause problems in future.

3.2.6 Sound and Ultrasound

Ultrasound is a "technology that uses high-pitched sound waves to create images of hidden internal anatomy" [18] as shown in Figs. 13 a and b. 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 materials with different acoustical properties.





(a) 2D image (b) 3D image

Fig. 12 AP mine in water

A strong enough ultrasound signal could penetrate the ground and detect otherwise unobtainable signatures of buried mines. It is also capable of operating in wet ground. Ultrasound systems encounter problems at the interface of air and ground.

3.2.7 Neutron Methods

Are based on the excitation of elements – from the soil, and any explosives - by gamma rays or neutrons, and on the detection of emitted gamma rays and neutrons. The physical properties of neutron moderation allow the technology to use low-strength source radiation, which reduces shielding required to protect workers from radiation exposure.
However they cannot determine what molecular structure is present. Ground-surface fluctuations and sensor height variation also contribute to false alarms in nonimaging systems. The nature of the shielding required in the detector is, however, a major concern and it is anticipated that in a remotely-controlled vehicle, the head weight would be 300 to 400kg, while a manned vehicle as shown in Fig. 13, would have to weigh almost twice as much in order to offer the operator sufficient protection.

Fig. 13 – Thermal Neutron Activation Sensor

3.3 Acoustic/Seismic Methods

Acoustic/seismic methods look for mines by "vibrating" them with sound or seismic waves that are introduced into the ground. Materials with different properties vibrate differently when exposed to sound waves [18] as shown below in Fig. 14.

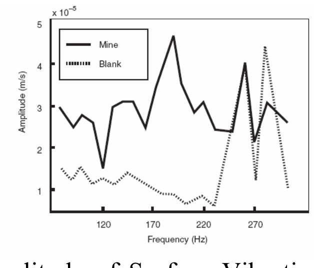


Fig. 14 Amplitude of Surface Vibration of Ground over a Mine(solid line) and a Blank(dashed line) in Response to Sound Waves.

These methods are complementary to existing sensors with low false alarm rates and are unaffected by moisture and weather [18]. Existing systems are slow and they do not detect mines at depth, because the resonant response attenuates significantly with depth. An additional limitation of existing systems is that moderate to heavy vegetation can interfere with the laser Doppler vibrometers that are commonly used to sense the vibrations at the ground surface.

3.4 Biological Methods

3.4.1 Dogs and Rats

Trained dogs (Fig. 15) can detect the smell of explosives in a landmine buried in the ground up to 60cm [19]. As an alternative to using dogs or in conjunction with using dogs, researchers at the University of Antwerp have trained African giant pouch rats to detect mines. The rats are trained using food rewards to signal the presence of explosives by scratching the ground surface with their feet.

Fig. 15 Mine Detecting Dog and Rat

Canines are proven to work exceptionally well in many scenarios and under many environmental conditions. Rats are light and can be deployed in large numbers. Dog performance varies widely depending on the individual dog, how, when and how often it was trained, and the capabilities of the handler. An additional limitation is that when trained to detect high levels of explosives, dogs may not automatically detect much lower levels and may need to be specially trained for this purpose. Rats likely would have similar limitations.

3.4.2 Bees

Entomologists have trained bees to detect a variety of explosives and have been researching ways to use trained bees in humanitarian demining.
Trained bees detect explosives and therefore are not limited by the same types of false alarms that plague metal detectors. They also potentially could search a relatively large area in a short time. As for chemical and bacterial detection systems, more needs to be understood about the fate and transport of explosives in the subsurface before the full potential of trained bees to detect landmines can be understood.

3.4.3 Bacteria

In principle, a bacterial mine detection process would involve spraying bacteria on the mine-affected area, possibly using an airborne system. The bacteria would be allowed to grow for several hours. Then, a survey team would return to search for fluorescent signals.

Bacteria can be engineered to be highly specific to the explosive of concern hence reducing false alarms. Can also cover a large area in a short time. However the potential for false alarms is unknown and has possible environmental limitations. Finally, the fate and transport of explosives in the subsurface will limit the performance potential of this method.

3.4.4 Antibodies

An area where mines are suspected is liquefied, and then passed over a crystal oscillating at a certain frequency and containing antibodies to TNT or another explosive. The liquefied vapor will cause antibodies to detach themselves from the crystal and attack. The release of the antibodies results in a change in the mass of the crystal, which causes a change in the frequency. An analysis of the change in frequency can tell the operator if the antibody-specific vapor is present. Has good efficiency and detection rate. But reacted antibodies are not reusable. The presence of these already reacted antibodies could also change the sensitivity of the sensor. Another problem is that .it is very hard to refresh used antibodies.

3.4.5 Chemical Methods

A variety of possible nonbiological mechanisms for detecting low concentrations of explosives in air or in soil samples have been investigated in recent years. Most of these investigations resulted from DARPA's "Dog's Nose" program, which sponsored R&D leading to the development of highly sensitive odor detection devices. Some of the techniques were patterned after the mammalian nose. For example, one approach uses arrays of polymer-based sensors that detect explosive vapors (and other volatile chemicals) based on the amount of swelling in the polymers caused by exposure to the analyte of concern.

Of the various vapor sensors, a system using novel fluorescent polymers is closest to being deployable and currently has the lowest detection. The sensor consists of two glass slides, each covered by a thin film of the fluorescent polymer. When a sample of air containing explosives passes between the slides, some of the explosive binds to the polymer and in the process temporarily reduces the amount of fluorescent light that the slides emit. A small photomultiplier device detects the reduced light emission, and electronics signal the operator that explosives are present. The system developed by Nomadics Inc can detect explosive vapor concentrations as low as 10^{-15} g per milliliter.

Complementary to the detection devices that rely on physical features of the mine. In addition, most of the methods have the potential to be engineered as small, lightweight, easily transportable, and simple-to-operate systems with relatively low power requirements. The Nomadics prototype already available is comparable in size to a typical metal detector and, like a metal detector, can operate at a walking pace. It has an extremely low detection threshold (10^{-15} g per milliliter).

However a probability of detection of one is needed, if they are to replace manual prodders for confirming the presence of mines. The detection sensitivity of fluorescent polymer approach may not perform well in very dry environments. Another problem is that the presence of explosive residues in soil from sources other than landmines will trigger false alarms. Naturally occurring chemicals that react with the polymers also may cause false alarms.

3.5 Mechanical Methods

3.5.1 Prodders and Probes

The most basic approach to mine detection is prodding. Using prodders, rigid sticks of metal about 25 cm long, the deminer scans the soil at a shallow angle of typically 30°. Each time he detects an unusual object, he assesses the contour, which indicates whether the object is a mine. The probe operator learns through experience to feel or hear the difference between a mine casing and other buried objects.

Probing is an established step in manual demining. Improved probes could decrease the risks to deminers by providing feedback about the nature of the object being investigated. In addition, theoretically, a probe could deliver any of a number of different detection methods (acoustic, electromagnetic, thermal, chemical, etc.), and the proximity of the probe to the landmine could improve performance. But probing is dangerous. The deminer might encounter mines that have been moved or have been placed so that they are triggered by prodding.

3.5.2 Mine Clearing Machines

When there is not a lot of time for an army to clear a minefield, it will often employ the use of certain machines to roll through and clear a safe path. Military forces employ several kinds of mine-clearing machines to clear out or detonate mines. Some machines are specifically designed for the task of mine clearance, while tanks can also be fitted with certain mine-clearing devices.

There are several types of mine-clearing machines. New machines are remote controlled, which minimizes the risk to personnel. Mine-clearing machines as shown in Fig. 16 use one of three techniques, including flailing chains to beat the ground, rollers to roll over and detonate mines, and rakes or blades to plow through the minefields, pushing the mines to the side.

These methods are quick and efficient and there is less chance of people getting injured during demining. However this leaves the area virtually destroyed. Plush land for farmers etc will be destroyed. The machines can easily miss mines.

Fig. 16 Panther armoured mine clearing vehicle

4 Conclusions

This paper has described different methods used to detect landmines. It is an old problem and still a lot of new researches are carried out. Most of the technology can be installed on robot or unmanned vehicle to prevent loss of human life. Robots in landmine detection range from kamikaze, the kind that roll around a field and blow up all the mines, to more sophisticated ones that may someday take the place of human deminers. The latter type of robots have probes, which, like the mechanical method of mine detection, are spring loaded and will retract if they hit an object harder than ground. The use of these robots is safe for the deminer, and often quicker. A robot with several probes can simulate several deminers walking side by side. The only problem of robot based system is that if the strength of the landmine is very strong the robot might blow up and it is expensive to repair or replace.

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