Detection of Landmines

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ABSTRACT

Detection of landmines is a problem concerning both military and peacekeeping forces. This paper reviews literature on strategic minefield layouts, modern mine clearing, and mine countermeasure techniques based on mechanical methods. Discusses hydraulic and signal processing techniques, ion-trap mobility spectrometer, subsurface probing radar and few other novel methods employed for this purpose. The specialised directions that the landmine detection methods are taking are clearly pointed out.

Keywords: Remotely deliverable mines, non-metallic mines, landmines, landmine detection, mine clearing, mine countermeasures, antitank mines, mine destroyer, antipersonnel mines, mine prodding ion-trap mobility spectrometer, minefield laying

1. INTRODUCTION

Article 2 of the Ottawa Treaty defines mine as an ammunition designed to be placed under, on or near the ground or other surface area and to be exploded by pressure, proximity or contact of a person or a vehicle. In other words, a mine is an explosive placed inside or on the ground for destroying enemy personnel or vehicles, or moored beneath or floating on or near the water surface for destroying or impeding enemy ships. Considered as force multipliers, mines are cheap weapons compared to other kinds of weapons, capable of crudely defending stretches of land and water, denying ground to the enemy, creating hindrances and barriers which must be either breached or circumvented. In either case, the enemy's movement is slowed or halted and the enemy is compelled to concentrate in areas, which can then be covered by other weapons. Mines are, however, potentially two-edged weapons in that once they have been deployed, they can be as lethal to the side that laid them as they are to the enemy. So, the landmine threat continues to be there even after the war. By one estimate, there are over 120 million landmines currently deployed in over 60 countries around the world. Each year, over 2 million new landmines are laid, while only about 1,00,000 mines are cleared. There is no easy method for removal of landmines, and with millions buried around the globe, the threat of injury and death to the civilian population is such that in every 15 min, there is a mine victim. This gigantic problem actually led to what is now called the Ottawa Treaty. While this significant disarmament treaty is a landmark achievement in many ways, it has also raised several debatable[1-3] questions.

Since their introduction in 1916, landmines have been complex pieces of equipment employing multiple sensors, including magnetic, acoustic and even infrared (IR) devices for target recognition and functioning. Mines are different from all other types of ammunitions, because they are not used for immediate effect but are primed, concealed and left as a hazard, which remains indefinitely. Either way, be it in times of war or in a land restoration

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to pay. It is now possible to control mines electronically so that they can be activated and de-activated at will, or at the very least, can be made self-sterilising. At the same time, there have been marked advances in the methods to detect landmines in their deployed and concealed state by means of mechanical probing as well as remote sensing of the subsurface by electromagnetic means. This paper reviews minefields and their nature, followed by an appraisal of various mine countermeasures (MCMs) and detection methods developed so far.

2. MINEFIELDS

Landmines, especially antitank (AT) mines, are rarely used on their own. They are most effectively employed in minefields to filter, delay and deflect enemy armoured thrusts. Thus, although a good destroyer of tanks, the most disruptive characteristic and benefit of a minefield is the fact that it channelises enemy armour into areas where such armour can be easily engaged by direct-fire weapons. Columns of tanks traversing minefields even when led by tanks fitted with mine ploughs are confined to the speed of the plough tank (about 4 km/hr–8 km/hr), and are thus easy targets for antitank fire. This, of course, pre-supposes that minefields are, in all cases, covered by aimed direct antiarmour fire.

In conventional wars, minefields are sub-divided into border, defensive, tactical, protective, phoney and nuisance. Border minefields are long and designed to prevent infiltration by hostile forces and terrorists. Defensive minefields too are long but are laid in a manner so as to prevent a major attack by enemy's armoured forces. Tactical minefields are laid in conjunction with natural obstacles to deflect the enemy into required killing areas and these deny ground to the enemy for limited periods. Protective minefields are small minefields laid by non-engineering units to give them local protection only. Phoney minefields, as the name suggests, are minefields is also used. A minimal minefield is a hastily laid minefield of a few rows, possibly surface-laid, because of lack of time or resources to lay a tactical minefield.

For obvious reasons, the laying, recording and marking of minefields is an absolute necessity and must be strictly controlled, at the highest practicable levels of command. It is essential that the site of a minefield be cleared in advance of laying to prevent jeopardising future plans and intentions. When laid, a detailed minefield record has to be maintained. This record has to be prepared in detail showing the location of the start and end of mine rows, the numbers of mines and the use of antitank mines and anti-handling devices. There is little point in clearing a path through a minefield if it is not accurately recorded. For this purpose, global positioning systems (GPSs) are being employed to provide a navigational accuracy of ± 100 m or more[4]. GPS receivers easily achieve accurate position plotting to sub-meter accuracy, which makes such receivers an almost invariable feature of minelaying and MCM exercise. Minefields are required to be marked with a perimeter fence of double strand wire, at least 1.25 m high on the rear and both sides. These fences have to be marked with red triangular minefield markers. The front or the enemy side of the minefield is also marked with a fence, but it is of single strand, knee-high and does not have marking signs. Minefield fences do not have to conform exactly to the shape of the minefields they surround, for obvious tactical reasons. However, nuisance minefields are seldom marked or laid properly and often prove very difficult to lift later. The intent of minelaying clearly has three dimensions as depicted in Fig. 1. All the three components, namely, target, obstacle effect and location together would constitute a truly successful minelaying operation. Figure 2 elucidates the second component of intent. Any one or more effects may be enforced depending upon the circumstances. In any case, before an effect is contemplated, the purpose of

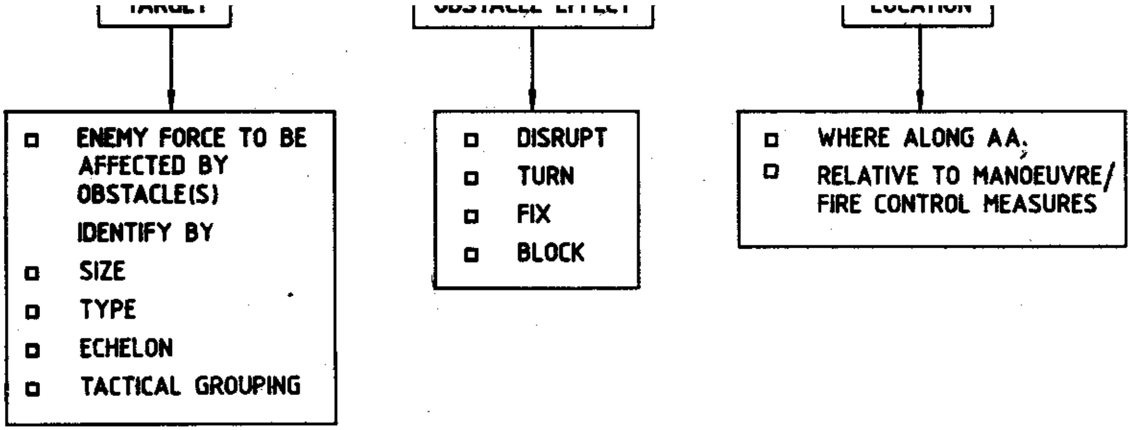


Figure 1. Minelaying operation

OBSTACLE EFFECTS AND INTEGRATION

EFFECT	PURPOSE	USE
DISRUPT	BREAKUP ENEMY'S FORMATION AND TEMPO; CAUSE A PIECEMEAL ATTACK	NORMALLY FORWARD OF THE ENGAGEMENT AREAS (RAs)
TURN	DIVERT ENEMY FORMATION OFF ONE AA TO AN ADJACENT AA OR INTO AN EA	NORMALLY ON THE FLANKS OF AN EA
FIX	SLOW AN ATTACKER, NORMALLY IN AN EA TO GIVE FRIENDLY UNIT TIME TO DESTROY THE ENEMY WITH DIRECT AND INDIRECT FIRES	NORMALLY INSIDE THE EA
BLOCK	STOP AN ATTACKER ALONG A SPECIFIC AVENUE OF APPROACH OR PREVENT THE ENEMY FROM ADVANCING THROUGH AN EA. FIRES AND OBSTACLES MUST PREVENT THE ENEMY FROM BYPASSING OR BREACHING THE OBSTACLES	FORCE THE ENEMY INTO ANOTHER AA. ASSIST IN COMPLETE DESTRUCTION WITHIN THE EA

Figure 2. Obstacle effects and integration

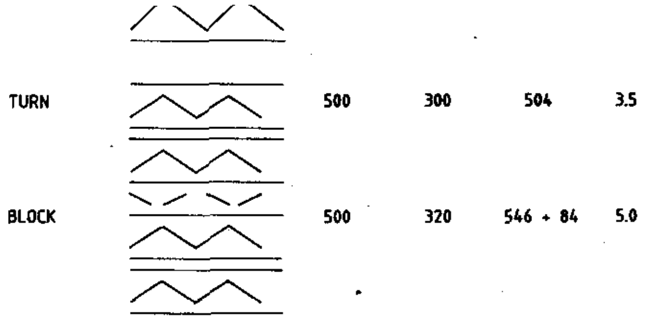


Figure 3. Mine placement with objective

the effect is carefully evaluated. In Fig. 3, typical mine placements are depicted to achieve various effects. The planting time is clearly a function of the number of mines planted and the depth at which the mines are placed. Finally, Fig. 4 depicts a scheme of mine placement whereby specific objectives are achieved in relation to advancing enemy troops along a specific area of approach. Minelaying methods range from handlaying to mechanical laying from an ordinary moving vehicle equipped with an agricultural disc to cut the surface of the soil, a double-sided plough to lift the earth, a device which arms the mine fuse (this can be a team of men), a chute to deposit the armed mine in the furrow at the required spacing, and smoothers to replace the earth. Mines can be planted both below the ground and on the surface. Alternatively, mines can be surface-laid from a helicopter. Although this method appears attractive, a helicopter has only a limited ability to carry mines. Unless the helicopter moves very slowly, there are large gaps between the mines, as they cannot be landed into the dispensing chute quickly. The helicopter, therefore, is very vulnerable when it is laying mines on the surface, as it has to travel virtually at walking pace and at ground level.

Alternatively, remotely deliverable mines are small mines delivered by aircraft, artillery shell, rocket, parachute or short range mortar bomb. Mines launched by such means have to be small, to fit into the carrier shell or rocket. They also have to

3. MINE COUNTERMEASURES

Mine countermeasures mean any action whose purpose is to neutralise, destroy or disrupt a mine or render it inactive. MCM or de-mining is normally divided into three stages: detection, removal and disposal. Before an MCM operation can commence, a detailed survey of minefields, the nature of terrain, types and number of minefields in each location (wherever known) will all need to be ascertained. Based on this information a plan of action can be realistically framed. Landmine detection methods are normally based upon two strategies: (i) when a landmine is buried beneath the ground, the surrounding and covering soil is disturbed from its original state. The change in the soil properties can then be used as a means of identification, (ii) buried landmines possess different properties (such as density, strength, thermal capacities, etc.) compared to the surrounding soil. These property changes can be detected by various means. The present mine detection methods are categorised into: hand-prodding, brute-force, hi-tech, and biological detection schemes. Metal detection is no longer a reliable method of detection since a majority of present-day mines contain very little or no metal components. In the last decade, several techniques spanning diverse areas of scientific and engineering research have been devised[5-57] for MCM.

4. MINE DETECTION METHODS

4.1 Hand-Prodding Methods

This is the traditional method of mine clearance, and is perhaps the only reliable way, even if impractical at times, of removing and neutralising non-metallic mines. It is a dangerous procedure due to the small size and easy concealment of modern non-metallic antipersonnel (AP) mines. When minefields are cleared by hand, detection is either by hand, prodding with a prodder or bayonet, or by mine detector. Mine-prodding is slow, confusing and dangerous, especially when the AT and AP mines are laid in

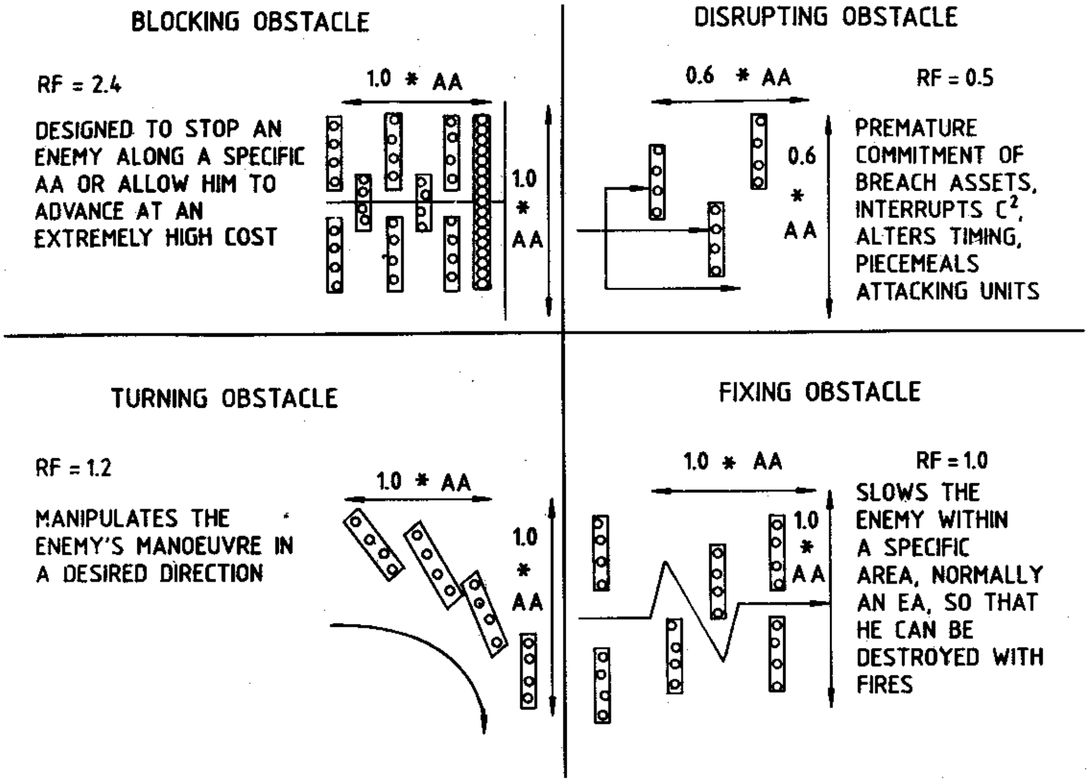


Figure 4. Minefield effects

hard-packed or stony soil, or when these are fitted with anti-disturbance fuses. Current mine detectors work on a principle of low frequency induction and electrical impedance and therefore pick up only metallic mines or mines with a high proportion of metallic components in their construction. This type of detector is useless against fully non-metallic mines and indeed can actuate some kind of influence mines. This method clears 1m² of land in approximately 4 min, which is the lowest acceptable rate. Figure 5, shows two kinds of Italian AP landmines along with a typical hand-held prodder. The properties of the two mines are listed in Table 1. However, less than 1g of metallic content is enough for some hand-held magnetic anomaly detector mine clearing equipment, such as AN-19/2 from Schiebel. Its biggest asset–its sensitivity–is also its biggest drawback since lots of objects have a metal content of 1g or more. Another example of hand-held metal detector is the German Minex 2FD, featuring a unique dual-frequency continuous wave sensor that overcomes the effect of soil composition and low inherent impedance. Minex 2FD can detect metal objects with a mass of < 0.3 g in virtually any kind of terrain.

4.2 Brute-Force Methods

Brute-force methods include ploughs, rakes, heavy rollers and flails mounted on tanks and explosive breaching methods. These methods are generally effective in clearing a path for soldiers and vehicles through a minefield in times of war, but are of little use in a peacekeeping role. The ploughs and rakes only push the mines out of the way, leaving them armed. The flails, heavy rollers and explosives are effective at destroying only simple mines, and smart mines detonate only the second or third time they are run over. Sometimes, brute-force methods cannot be used, e.g., in a neutral zone between two opposing

Table 1. Properties of Italian antipersonnel landmines

	Landmine model	
Parametres	VS-50	VS-2.2
Diameter (cm)	9.0	24.6
Height (cm)	4.5	11.7
Weight (kg)	0.185	03.6
Type	AP	AT
Burial depth (cm)	0-2	8-10
Trigger force (kg)	20	200

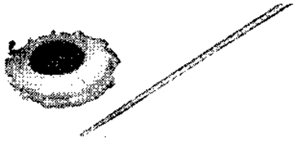


Figure 5. Antipersonnel and antitank mines with prodder

Figure 6. UNI-MULCH mine detecting vehicle

forces where detonating mines could be unsettling.

Ploughs skim-off the earth in front of the tank tracks and roll it away to one side with the mines that it contains. Current ploughs employ tines, which comb through the ground and bring the mines to the surface, where an angled blade pushes them beyond the area of tank tracks. The fitting of ploughs to tanks, however, can impose a considerable strain on the steering and transmission clutches of the tank. The strain is made worse by stony soil or roots, which get tangled up in the plough tines and force the plough to the surface or stop the vehicle. Furthermore, the ploughs cannot bring deep buried mines to the surface, as the ploughs pass over them without disturbing them. Also, the ploughs cannot bring to the surface the mines fitted with anti-disturbance fuses, although these merely destroy the plough rather the tank behind them. Plough tanks can also be defeated by influence-fused belly attack mines which pass between the mine ploughs and by tilt-fuzed mines. A tilt-fused mine can be countered by fitting a chain or grid across the front of the tank to detonate the mine before the belly of the tank can pass over it.

A mine destroyer unit called UNI-MULCH and shown in Fig. 6, has been developed for clearing AP mines laid in confined areas, such as around houses, villages, industrial units, narrow-access lanes and wooded areas. It is a 1.4 m tilling drum mounted to the front of a case steer loader and designed to detonate and smash the AP mine up to 20 cm deep. The unit is both remote controlled and manually operated. The other mine destroyer unit is the UNI-DISC, which is a 1.2 m tilling drum mounted on the arm of an armoured 2.5 ton hydraulic excavator. The tilling drum rotates at 300 rpm, mulching the vegetation and soil, detonating and smashing AT and AP landmines up to 50 cm deep.

Further research has led to automation of mechanical detection and removal of landmines. A complete automated prodding system consists of two pneumatic cylinders, a steel frame to provide support and evaluate different operating conditions and various instrumentation. The instrumentation includes an accelerometer for measuring the vibrations from striking an object, two pressure transducers for recording the pressure from both the primary and secondary pneumatic cylinders, an LVDT (linear voltage differential transformer) for measuring displacement of the secondary cylinder, and a rotary potentiometer and displacement arm for measuring displacement of the primary cylinder. The control of the prodder is managed using two pneumatic cylinders. The primary cylinder provides the main thrust for soil penetration and traversing the distance from the home position to the buried object. The secondary cylinder is used as a buffer between the primary cylinder and the buried object. As the object is struck, the secondary cylinder is forced downward by the primary cylinder even though the prodder's motion stops. When this begins to happen, the LVDT connected to the prodder registers a change in voltage, and the primary cylinder is stopped. Thus, the secondary cylinder allows the primary cylinder to stop over a finite amount of time (rather than instantaneously). Also, the pressure in the secondary cylinder can be set to ensure the force applied to any location in the soil does not reach a level where the detonation of a landmine is possible.

The device created has the ability to record and analyse the signature vibrations from the prodder as it strikes various buried objects. The objects for testing included two plastic landmines, a block of wood, a rock, and a piece of steel. Although this system was able to distinguish between hard objects like rock or steel and softer objects, such as plastic or wood, the pneumatic cylinder's large internal friction and inherent back pressure did not allow for a natural return of the prodder after it had struck an object. This sometimes made the identification between plastic and wood difficult. To improve object identification, a device that decouples the prodder entirely from the insertion cylinder has been developed. Thus, when the prodder strikes an object, it freely recoils instead of being heavily damped. This evokes a stronger signal, which better represents the struck object. This is achieved using a custom-designed spring firing mechanism. Different springs and varying amounts of pre-tension are used for varying soil conditions and objects of interest. A preliminary task determines the optimal firing probe velocity to achieve a reliable signal on the prodder rebound.

This device can be altered to a simple manual reloading system for a hand-held unit, when lightweight and low cost are essential. Another preferred course is to use a solenoid recoiling and latching mechanism to automate the process. To detect trends or similarities in data generated under varying soil conditions, further intelligence has to be built into the system. In the absence of such an in-built capability, a complete set of calibration tests for each new soil condition has to be performed. The above landmine detection method has been tested successfully in the department of Mechanical Engineering at the University of Alberta, Canada. A likely means to incorporate intelligence stated above is the adaptive logic network (ALN). An ALN is a branch of neural network methods capable of learning. In using an ALN, various time and frequency domain characteristics are still determined, but the ALN procedure is able to learn a function, which correctly classifies an object. Because of the generalising ability of these networks, classification of objects is still possible when environmental conditions (buried objects, changing soil conditions, etc.) are altered. Preliminary tests with simulated and test data have shown reliable identification and an ability to classify vibration signatures in different field conditions.

Another innovative design consists of a multiple probing mechanism usually mounted in front of an armoured personnel carrier. Each of the 41 probes used to penetrate the ground is individually mounted on a hydraulic cylinder. The hydraulic fluid pressure in each cylinder is continuously monitored by a computer data acquisition system. When the probe strikes the soil or a solid object, the pressure in the cylinder rises in proportion to the force on the probe. Once this pressure rises above a threshold value, a solid object is determined to be present. A solenoid valve controlled by the computer releases the pressure in the cylinder, thus stopping the probe's further motion. The valve is quick enough to stop the cylinder to prevent accidental detonation of the landmine. A carefully chosen probe separation distance ensures that no landmine is missed by passing between the probes.

A somewhat similar arrangement with 35 rotating auger-like probes in two-staggered rows has also been used to detect rigid objects buried beneath the soil. This device, too, can be attached to the frontside of a remotely controlled all-terrain vehicle. The probe bank is lowered to the ground at a constant force using a hydraulic ram. The augers are rotated using a gearing system and a drive chain. If any auger comes in contact with a solid object, the auger is forced upwards and the force in the probe is recorded, using a piezo-resistive sensor. This sensor is located at the top of the augers and is connected to a data acquisition system. By rotating the probes, the insertion force necessary to reach the required depth is roughly 1/10th of the force required for non-rotating elements. By reducing the probe insertion force required to contact the landmines, the chances of accidentally detonating a landmine are greatly reduced. Also, the rotating auger design allows this device to function in highly compact soils.

Probes have also been reportedly used in other ingeneous designs. One such design is based on the fact that the plastic used to make some of the landmines becomes soft and viscous when heated above 180 °C. When a probe contacts a landmine, the strain in the probe is recorded using a strain is heated. Using this idea, the false alarms are generally reduced.

Another design utilises an ion-trap mobility spectrometer to detect explosive gases produced by landmines. This design consists of 44 rotating probes mounted on a 3 m frame. Each probe is fitted with its own electric motor and an accelerometer for controlling the depth of penetration and detecting if a solid has been hit. To obtain samples for the spectrometer, holes are drilled into the probes to facilitate the sampling of gases. Through these holes, gas samples are taken after determining that the probes have hit a solid object. Along with the gas analysis system, there is also a method for determining the depth of penetration of the probe. This particular design allows the probe to rotate into the soil as well as drive forward in controlled increments. These probes are mounted at 45 °C from the horizontal to allow some protection against the effects of an accidental detonation of the landmines. A double-row prodder consists of two rows of probes. One row typically consists of 78 probes searching for AP mines, while the other consists of 32 probes searching for AT mines. These probes are powered into the ground by hydraulics. By using hydraulics, fine control of the position and forces can be ascertained. When an object is hit, there is a steep rise in the line pressure of the hydraulic fluid and the cylinder is stopped. A computer is then used to determine the depth of insertion and stores this value for further processing. The array moves forward while leaving the main drive vehicle stationary and the probing process is repeated. When the array has reached the end of its range, computer mapping is used to locate possible landmines. An area with more than six probes raised is a possible AP mine and similarly for AT mines. To determine different objects that may be hit under the ground, dense packing of the probes is required.

Somewhat similar to the double-row prodder is the air-spring prodder array which consists of 64 probes mounted to scan a width of 3 m. The probes incorporate the use of an air spring in conjunction with a hydraulic drive system to measure the depth of penetration. The pneumatic cylinders are used to provide a controlled insertion pressure because as the depth of penetration increases, the force required also increases. LVDTs are mounted inside the pneumatic cylinders to prevent contamination from dust and other such particles. All the information from LVDTs is recorded and analysed by an onboard computer. This information is then used to plot a sub-surface map of the scanned area and locate possible landmines with the help of pattern recognition techniques.

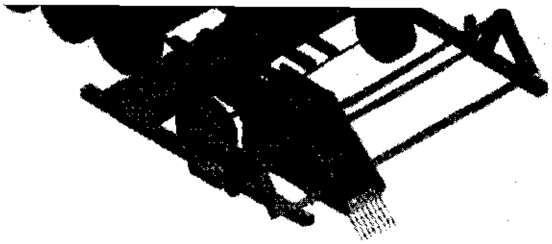


Figure 7. Overview of multiple prodding system

There have been other multiple prodding devices designed keeping in mind the objective of landmine detection. An overall view of one such design is shown schematically in Fig. 7. The detection unit consists of a frame, a traversing rack, and multiple probes. The frame is the largest part of the device. It has two wheels attached to the front clevis pins on the vehicle and supports the rack. The rack contains the prodders. The rack is mounted on three transverse support rods at the front of the frame. A motor mounted on the frame slides the rack along the width of the frame through a chain drive. In the rack, there are two large probes, 20 cm apart, and 8 small probes 5 cm apart. The large probes are designed to detect AT mines which are normally buried 8 cm–10 cm, while the smaller probes are designed to find the relatively smaller AP mines, which are normally buried between

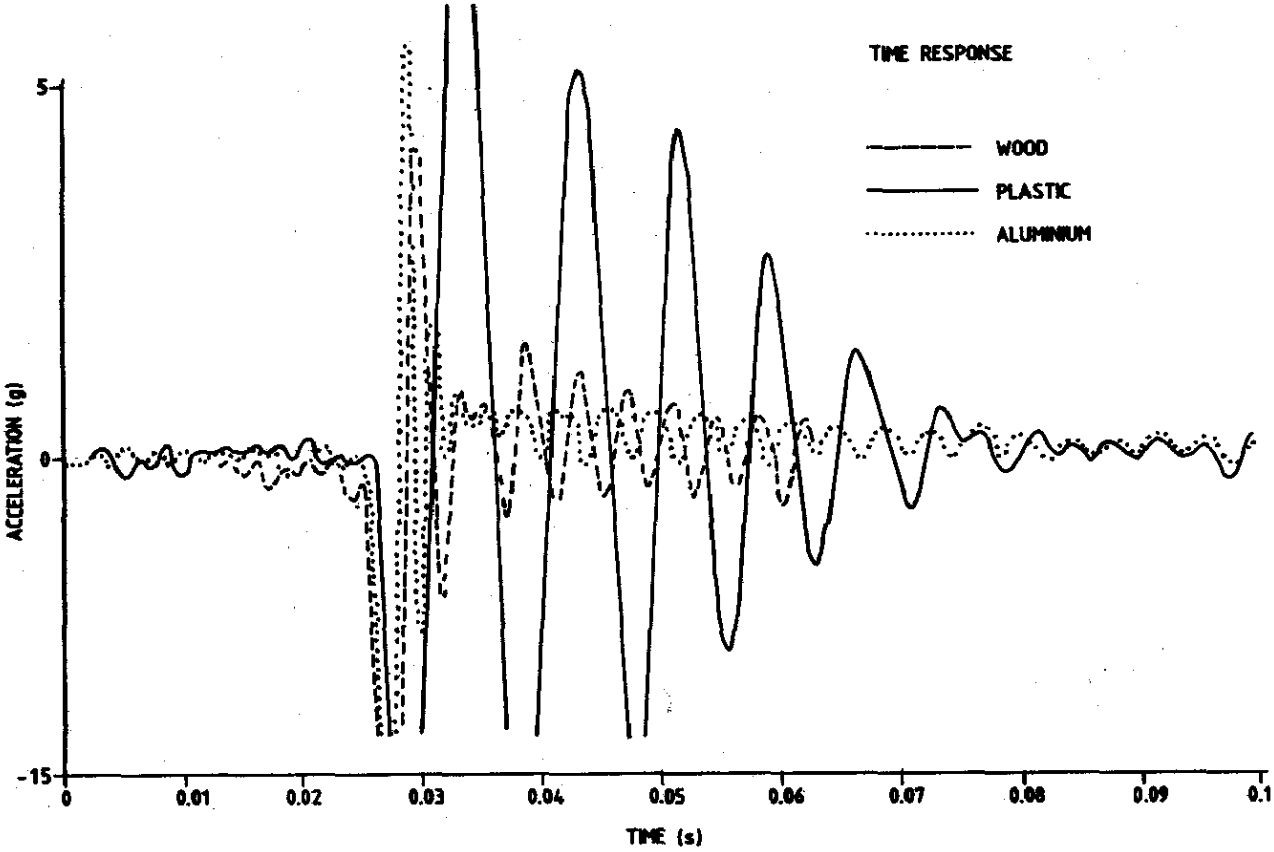


Figure 8. Time-domain output signals

0 cm–2 cm. A slider-crank mechanism is used to provide the motion to the probes. A motor on the rack drives two parallel crankshafts (one for AP probes and the other for AT probes). Connecting rods convert motion of the crankshafts into a reciprocating motion of the probes. The crankshafts make one revolution during which the probes enter the ground simultaneously and then retract. If no object is struck by a probe, the rack moves 40 cm sideways, and the probing action repeats itself. About 1m^2 is cleared in 2 min if no mines are detected. If a mine is detected, the machine shuts down so that an explosive ordnance disposal team can neutralise the mine.

The probes are mounted by springs to sliders attached to the connecting rods. At the back of each probe is an accelerometer to measure vibration signals from the probe striking an object. When the probe strikes an object, different vibrational signals are generated, depending on the composition of the object. Examples of vibration signal from a probe hitting a piece of wood, metal, rock and a plastic mine shell are shown in Fig. 8. The plot shows the amplitude of acceleration as a function of time. A distinct difference can be observed between the signals generated by the impact from the plastic mine and other objects. Another way of looking at this data is to observe the Fourier transform of these signals; i.e., to convert the above time domain representation to a frequency domain view. These results are shown in frequency domain in Fig. 9. It is again observed that distinct differences arise between various signals. Automated analysis procedures have been developed to determine what type of object, if any, has been struck, from the probing action. Experimental results have shown that this method of landmine detection works. A total of 40 such tests were performed, 10 on plastic mine casings and 30 on different types of benign objects (rock, wood and metal). All 10 mines were correctly identified, and there were no false alarms.

A distinct trend in mines is toward sophisticated fusing. Mines that are actuated by the magnetic

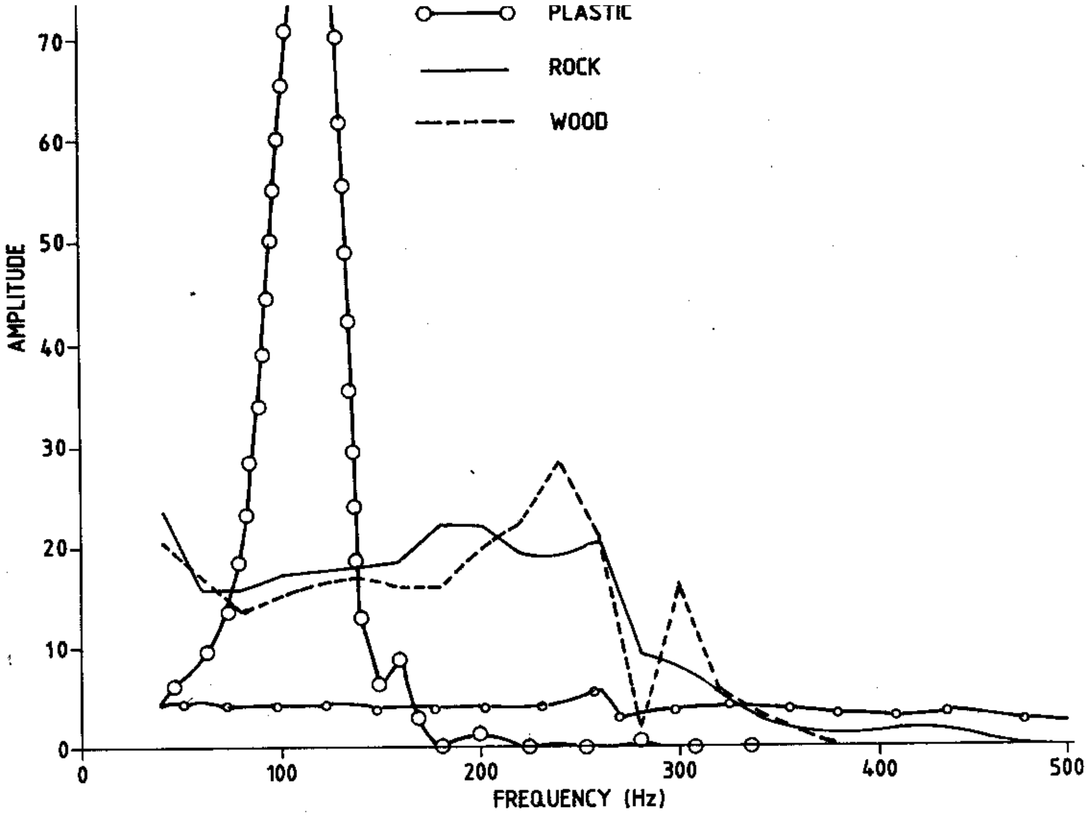


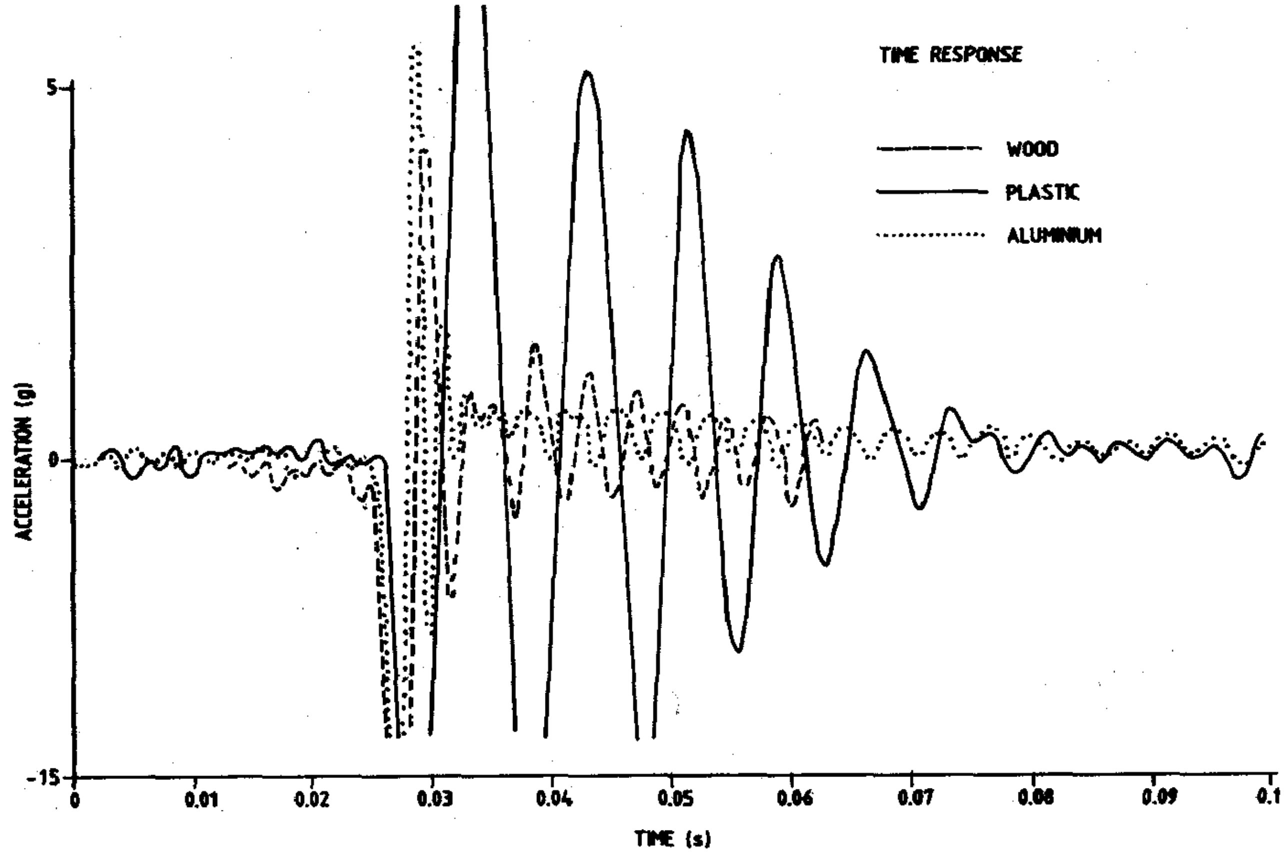
Figure 9. Frequency domain output signals

disturbance of a passing vehicle are not only more lethal but also possess a full vehicle-width attack capability. Most of these mines have a self-forming fragment warhead that defeats all belly armours. A countermeasure for defeating these mines is the antimagnetic mine actuating device (AMMAD), also known as improved dogbone assembly (IDA). The IDA detonates magnetically-fused mines by projecting a magnetic field ahead of the host vehicle that duplicates the magnetic signature of the host vehicle. Designed and produced by Israeli Aircraft Industries (IAI), the IDA is able to pre-detonate tilt-actuated mines and can be fitted on both the mine clearing blade (MCB) and mine clearing roller (MCR). Further improvements in the form of add-on kit, which has the capability for not only forward projection of the magnetic field, but for side projection as well are being carried out[58-61].

4.3 Hi-Tech Methods

Hi-tech methods[62] of landmine detection include methods based on passive IR, millimeter/microwave, electro-optical, ground penetrating radar (GPR) and sub-nuclear particles. GPR studies were initiated in the late 1960s to extend the state-of-the-art. As a consequence, there have been several attempts to detect and identify buried targets including AP mines and other unexploded ordnance that had not been previously achieved using GPR. GPR techniques were extended and applied successfully by the British in the Falkland war. A substantial need for improvement of the GPR requires expertise in such areas as signal processing. GPR has been identified as one of the promising technologies for the detection of non-metallic landmines.

Two GPR techniques developed are: pulse or



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Sweden[65,66] has been at the forefront of designing the impulse radar for sub-surface mine detection. The radar employs a transmitted pulse 1 ns wide with a prf of 250 KHz and a peak power of 50 W. A broadband crossed dipole antenna is optimised for operation in the 0.2 GHz–2 GHz. Data are sampled and preprocessed by a digital signal analyser with an amplitude resolution of 8-bits, a real-time sampling rate of 2 G sample/s, while the equivalent time sampling rate can be as high as 1 T sample/s.

The above radar was designed with an objective of assessing the ability of GPR to classify detected buried objects. The design is based on the concept that targets, depending on their geometrical shape and material content, exhibit different radar-back scattering signatures. Object classification proved to be especially formidable for objects buried in a lossy medium. For this reason, intensive studies have been conducted into field measurements and landmine detection, both plastic and metallic, under various soil conditions. For normal soil conditions the detectability seems to be reasonably good. Two methods have been tried to classify objects. The first is based on complex poles modelling of electromagnetic scattering, which is related to the singularity expansion method developed by Baum[67,68]. This technique has been applied successfully to data from free-space objects, but it needs further clarification when applied to subsurface-object classification. The second method is based on the application of pseudo-Wigner distribution[69] to data from free-space objects. Disparate object signatures are obtained in the combined time/frequency domain in cases where spectral features are almost indistinguishable.

The display of the GPR exhibits a depth view of the scanned ground with representations of the amplitude from a subsurface object. A smaller antenna (0.3 GHz–3 GHz) and a pulse transmitter (0.3 ns) have improved system performance considerably.

Similar mine-detection studies have been conducted in UK. A high performance, high resolution GPR has been used to generate images of the internal composition of many structures. Detection of buried landmines requires that signals be radiated without distortion over a wide band of frequencies from a suitable antenna. The antenna is the key factor in determining successful system operation. It has been found that the antenna must mechanically scan over the ground area suspected to have mines buried. Alternatively, frequency scanning can be resorted to with an antenna array.

A plan-image presentation offers the operator the best means of recognising the images generated by scanning over the mines in a regular manner although the importance of accurate registration cannot be emphasised too strongly. An alternative option is to employ a remotely controlled crawler which carries the scanning antenna and radar head. This helps in overcoming the risk of operator fatigue generating irregular scan profiles.

The German company Eltro has pioneered a microwave method for detection of buried mines by essentially analysing the dependence of backscatter from objects of different dielectric constants. The backscattered signals are processed electronically, evaluated and represented in 3-D on a monitor. The display shows the boundary surfaces between materials with different relative dielectric constants. In this way, it becomes possible to estimate the structure of soil and the form and size of the objects (mines, stones, etc.). The complete equipment can be vehicle-mounted and is remotely controlled. To assist in the remote-control and observation of the sensor head, the detection vehicle is equipped with three television cameras. The sensor-head observation camera is fitted at the bottom of the vehicle and trained to the lower part of the sensor head and terrain below. Each of the two other cameras look in one of the two possible directions. The video images and sensor data are transmitted the bacteria, from crop-dusting aircraft to trucks that can spray the areas on either side. On a large scale, an area seeded by a plane during the day could be photographed again at night and a topographical map created. With night-vision goggles to take away the glare, one could even see the bacteria in full daylight.

Other biological methods of landmine detection are being looked into. For example, through genetic manipulations, mutants, such as bees or insects can be created that will search out explosives. In another study, researchers from the US Dept. of Energy plan to equip 50 bees with miniature radiofrequency tags. These hi-tech devices allow scientists to track the bees' movement and their ability to detect minute amounts of explosive powder. Scientists are betting on the honeybees' propensity to attract dust and garner all kinds of particles as they buzz around. The tagged bees will be released to conduct their honey-gathering activities as their movements are tracked from a distance. Once they return to their hives, a device developed by Sandia National Laboratories in New Mexico, USA, will detect any trace of munition powder picked up by the insects during their pollen hunt.

5. A RE-APPRAISAL OF STRATEGIES

The case of landmine detection provides an example of interface between military compulsions and humanitarian imperatives. The deadly nature of landmines is likely to increase with future advances in their design. The fundamental advances will come from: (i) continued miniaturisation of computers and solid state electronics and (ii) new explosive compounds with increased energy yield per unit volume.

Next generation landmines are likely to be old ideas made more feasible and reliable by modern technology, such as:

for irregular channels and delivery routes, and with reserve power for attacking any target within detection range

- Mines capable of shifting their positions into adjoining swept paths
- Mines capable of timed, fail-safe explosive sterilisation.

All this will, in turn, necessitate the design and development of more advanced MCM techniques. However, none of the mine detection technologies, now or later, will find every type of landmine in every situation, and for this reason, mine-clearing experts would prefer to have a modular, multisensor system which is portable, and whose various sensors will share a single processor that compares returns in real-time to overcome false alarms.

Notwithstanding the parallel development of landmines and their countermeasures, it must be borne in mind that mines once planted are weapons that wait. No other weapon has had an effect in this century so utterly inhuman. The real challenge is to find an alternate defensive system that does not have the same indiscriminate nature of a landmine, especially, the AP landmine. Technology today provides enormous options, one such option being nonlethal weapons[71,72].

6. CONCLUSION

In this paper, some of the recent mine clearing techniques and equipment have been reviewed. It is seen that landmine clearing techniques vary widely in nature: Ploughs, flails, rollers, electromagnetic signature duplicators and pyrotechnic chords, to name a few. Of these, at present, the GPR offers maximum possibilities of accurately detecting deployed landmines under various ground conditions. The problem, however, is far from having been solved satisfactorily. The reasons are not hard to find. Detection and recognition of buried objects mine-detecting radars have been designed and tested in very few numbers and that too in rather idealised conditions. The present state-of-the art is such that isolated designs and prototypes are still to prove their battleworthiness, and hence, have not been inducted into full-time service by any of the world's armies. Most armies do not like to invest funds in building up an assortment of such sophisticated mine detecting radar until their efficiency is proved beyond doubt under actual battle conditions. A beginning has been made, however, and interesting designs are sure to emerge in near future.

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