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Literature Review on Landmines and Detection Methods

Rasaq Bello

Department of Physics Federal University of Agriculture, Abeokuta, Ogun State, Nigeria

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Abstract Detection of buried antipersonnel landmines (APL) is a demanding task in which one tries to obtain information about characteristics of the soil and of objects buried in it. Various methods that are used to detect buried landmines have been examined. None of these methods meets the standards that have been set by authorities such as the United Nations or the United States Army. Therefore there is an urgent need for new and improved methods to be developed, particularly in view of the threat that abandoned landmines pose to civilian populations. Various researches reviewed in this work showed thermography to be a good method to detect shallowly buried objects. Detection systems capable of quickly and accurately detecting buried landmines are the only possibility to significantly improve the demining process. Due to low signal-to-noise ratio, changing environment conditions that influence measurements and existence of other natural or man-made objects that give sensor readings similar to the landmine, interpretation of sensor data for landmine detection is a complicated task.

Keywords Landmines, Detection, Explosives, Thermography, Temperature

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1. Introduction

A land mine is a type of self-contained explosive device which is placed onto or into the ground, exploding when triggered by a vehicle, a person, or an animal. The name originates from the practice of sapping, where tunnels were dug under opposing forces or fortifications and filled with explosives. Land mines generally refer to devices specifically manufactured for this purpose, as distinguished from improvised explosive devices ("IEDs")[41]. It can also be defined as explosive charge buried just below the surface of the earth, used in military operations against troops and vehicles. It may be fired by the weight of vehicles or troops on it, the passage of time, or remote control. Though improvised land mines (buried artillery shells) were used in World War I, they only became important in warfare during World War II and have been widely used since. Most early mines had metal cases; later models were sometimes made of other materials to prevent magnetic detection.

Land mines are used to secure disputed borders and to restrict enemy movement in times of war. Tactically they serve a purpose similar to barbed wire or concrete dragon's teeth vehicle barriers, channeling the movement of attacking troops in ways that permit the defenders to engage them more easily. From a military perspective, land mines serve as force multipliers, allowing an organized force to overcome a larger enemy.

Land mines have two core uses - to create tactical barriers and as area-denial weapons. The latter use seeks to deny access to large areas, since they are often unmarked and affect civilian populations after the cessation of military operations or hostilities. When used as a tactical barrier, they serve as deterrent to direct attack from or over a well defined and marked area. Without land mines in the demilitarized zones (DMZs) of hot spots such as Cyprus and Korea it is conceivable that small raiding parties crossing though these barriers could have inflamed hostilities since all that would oppose them would be physical barriers (such as barbed wire, which can be easily penetrated) and opposition soldiers (whose use would naturally indicate open conflict). In this latter use, anti-personnel land mines keep hostile parties from fighting each other[8].

Since combat engineers with mine-clearing equipment can clear a path through a minefield relatively quickly, mines are usually considered effective only if covered by fire.

The extents of minefields are often marked with warning signs and cloth tape, to prevent friendly troops and non-combatants from entering them. Of course, sometimes terrain can be denied using dummy minefields. Most military forces carefully record the location and disposition of their own minefields, because warning signs can be destroyed or removed, and minefields should eventually be cleared. Minefields may also have marked or unmarked safe routes to allow friendly movement through them.

None of the conventional tactics and norms of mine warfare applies when they are employed in a terrorist role because the mines are not used in a defensive role (for specific position or area), mined areas are not marked, mines are usually placed singly and not in groups covering an area and mines are often left unattended to (not covered by fire).

The normal aim of terrorism - and to certain extent guerilla

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* Corresponding author:
bellomo68@yahoo.com (Rasaq Bello)

warfare is to spread fear and panic. This can be achieved by a single mine left on a civilian road to be detonated by a civilian target which is clearly quite different from the normal military application.

One example where such tactics were employed is in the various Southern African conflicts during the 1970s and 1980s, specifically Angola, Mozambique, Namibia, South Africa and Zimbabwe.

Land mines are typically used to disrupt or prevent the massed attack of tanks or infantry, but in post–World War II conflicts they have also been used to render land useless to enemy civilian populations. A treaty banning land mines — not signed by the U.S., Russia, and China — went into effect in 1997[4].

Ironically, the laying of land mines inadvertently proved a positive development in Argentina and the Falkland Islands. This is because the mine fields, laid by the sea during the Falklands War have proved favourite places for penguins. They are too light to set off the explosives and took advantage to breed in areas where humans would not dare enter. These odd sanctuaries have proven so popular and lucrative for ecotourism that there has been some efforts to avoid having the mines removed[37].

In Cambodia, Malayan viper is sometimes called the "landmine snake" because of its habit of hiding in roadside vegetation and biting people who come too near when passing by or collecting grass.

According to, MacDonald et al, 2003 landmines pose a serious threat to the society in around 90 countries in the world. It is estimated that there are from 50 to 70 million uncleared mines within at least 70 countries. About 26,000 people are killed or maimed every year by landmines. For example, in Angola one of every 334 individuals is a landmine amputee, and Cambodia has greater than 25,000 amputees due to mine blasts. The lives of over 22 million people are impeded from return to normalcy by landmines[43].

In Afghanistan there are 10-15 million mines, and there are 9 million in Angola. Cambodia has 4 -7 million mines laid and Iraqi Kurdistan has 4 million more. 2 million mines lie under the ground in Mozambique, 1 -2 million in Somalia, and 1 -2 million in Sudan. In the former Yugoslavia there are more than 3 million mines 0. 2 million in Bosnia, 1 million in Croatia, and 0.5 - 1 million in Serbia. Another 0.3 - 1 million mines lie in wait in Eritrea and Ethiopia. In Africa alone there are 18 - 30 million landmines.[73]

During the height of the war in the former Yugoslavia, 600,000 mines were being laid each week. The toll in dead and maimed that landmines produce is equally startling. There have been more than 1,000,000 casualties of landmines in the world since 1980, almost all in the Third World. Of that number, it has been estimated that approximately 800,000 were killed and 400,000 lost limbs. Every year, there are 26,000 new landmine casualties worldwide. In Afghanistan there are already 350,000 - 500,000 people dead and injured by mines, and more occur daily. More than 50% of all livestock in Afghanistan have been killed by a combination of landmines and bombs. In Angola there are approximately 26,000 amputees, and in Cambodia 30,000. In Mozambique, 6,000 people, mostly civilians, have been killed or maimed by mines since 1980[73].The worldwide trade in weapons is legal, and individuals, companies, and governments make lots of money selling arms. Landmines are no exception.

Almost 100 companies and government agencies in at least 48 countries produce and export 340 types of antipersonnel landmines. Major producers have included the US, Italy, Sweden, Vietnam, Germany, Austria, Britain, France, China, the former Yugoslavia, and the former Soviet Union to mention a few. And, as of October, 1994, landmines were still being laid in Bosnia, Serbia, Angola, Cambodia, Somalia, Sudan, Rwanda, and in Tajikistan, Soviet Georgia, and Nagoro-Karabakh.

Although arms sales are accepted as legitimate commerce, most arms, including landmines, are sold by arms dealers on the black market, the sellers comfortably anonymous. Even if there were a real effort made, monitoring the worldwide sale of landmines would be impossible. The only way to try to eliminate the use of landmines is to ban their manufacture and trade[33].

There are attempts to restrict the availability of weapons systems. In 1968, the Nuclear Non-proliferation Treaty became international law. In 1972, a UN convention on the prohibition of bacteriological weapons and toxins was agreed to. In 1981, a UN convention called for a ban on chemical and biological weapons, and by 1993, the ban had been signed by 159 countries. In 1993, a UN convention on chemical weapons was passed. In 1980, a UN weapons convention called for restrictions on the use of invisible shrapnel, incendiary devices, such as napalm, and anti-personnel landmines. The main obstacle to the acceptance of this UN convention was that there are countries including the US, with a vested interest in the use, production, and trade of landmines, for political and economic reasons.

In recent years, the case for a landmine free world has become stronger, and various efforts are ongoing to develop new and improve existing technologies that can help in identifying landmine fields, and in detecting and clearing landmines. Currently, metal detectors are the only technology that is routinely used in humanitarian demining operations. However, low-metal landmines are very difficult to detect using metal detectors. Two promising techniques for the detection of low-metal landmines are ground-penetrating radar (GPR) and thermal infrared (TIR). This paper therefore reviews the status of landmine use and various detection techniques employed in the world today.

2. History of Landmines

The basic concept behind the land mine has appeared through military history. Some sources report that Zhuge Liang, of the Kingdom of Shu of China, invented a land mine type device in the third century. Forces in ancient Rome sometimes dug small foot-sized holes, covered and armed with a sharpened spike. In the Middle Ages in Europe, small, four-pronged spiked devices called caltrops or crows' feet could be scattered on the ground to delay the advance of an enemy. Around 14th century or 15th century, the Ming Dynasty started to make some *primal* modern mines with powder, which in form of stone, ceramic or pig iron[41].

The first modern mechanically fused high explosive anti-personnel land mines were created by Confederate troops of Brigadier General Gabriel J. Raines during the Battle of Yorktown in 1862. (As a Captain, Raines had earlier employed explosive booby traps during the Seminole Wars in Florida in 1840[42]. Both mechanically and electrically fuzed "land torpedoes" were employed, although by the end of the war mechanical fuzes had been found to be generally more reliable. Many of these designs were improvised in the field; especially from explosive shells by the end of the war nearly 2,000 standard patterns "Raines mines" had been deployed.

Improved designs of mines were created in Imperial Germany, circa 1912, and were copied and manufactured by all major participants in the First World War. In World War One, land mines were used notably at the start of the battle of Passchendale. Well before the war was over, the British were manufacturing land mines that contained poison gas instead of explosives. Poison gas mines were manufactured at least until the 1980s in the Soviet Union. The United States was known to have at least experimented with the concept in the 1950s (Dany, 1998).

3. Description of land mine Components and Functioning

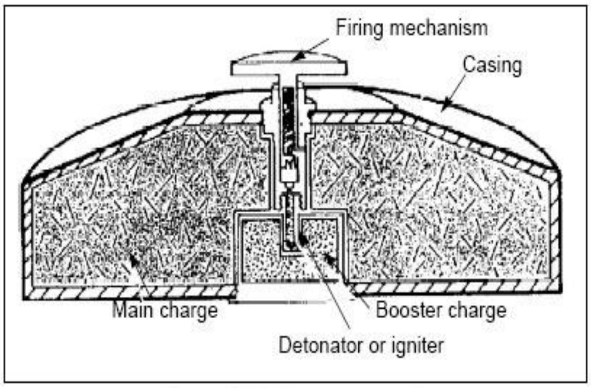

Figure 1. Mine components

The components of a typical landmine include the firing mechanism (including anti-handling devices), the detonator (to set off the booster charge), the booster charge (may be attached to the fuse, or the ignitor, or to be part of the main charge), the main charge (in a container, usually forms the body of the mine) and the casing which contains all of the above parts.

A land mine can be triggered by a number of things including pressure, movement, sound, magnetism and vibration. Anti-personnel mines commonly use the pressure of a person's foot as a trigger, but tripwires are also frequently employed. Most modern anti-vehicle mines use a magnetic trigger to enable it to detonate even if the tires or tracks did not touch it. Advanced mines are able to sense the difference between friendly and enemy types of vehicles by way of a built-in signature catalogue. This will theoretically enable friendly forces to use the mined area while denying the enemy access.

Many mines combine the main trigger with a touch or tilt trigger to prevent enemy engineers from defusing it. Land mine designs tend to use as little metal as possible to make searching with a metal detector more difficult; land mines made mostly of plastic have the added advantage of being very inexpensive.

Some types of modern mines are designed to self-destruct, or chemically render themselves inert after a period of weeks or months to reduce the likelihood of civilian casualties at the conflict's end. However, these self-destruct mechanisms are not absolutely reliable, and most land mines laid historically are not equipped in this manner.

3.1. Anti-handling Devices (AHD)

Anti-handling devices (i.e booby-traps) trigger the mine fuse if someone attempts to tamper or defuse the mine. They are intended to prevent moving or removing the mine and to prevent reduction of the minefield by enemy dismounts. An AHD usually consists of an explosive charge that is connected to, placed next to, or manufactured in the mine. The device can be attached to the mine body and activated by a wire that is attached to a firing mechanism. Some countries employ AHDs on conventional AT mines only and not on anti-personnel mines. The makes it somewhat safer to remove mines laid by these forces. Other countries may employ AHDs on both AT and AP mines, or employe AP mines in the same minefields as AT mines to prevent the removal of the AT mines.

4. Types of Mine

Land mines are of two basic types; antitank and antipersonnel. Antitank mines are larger and more powerful than antipersonnel mines. However, antipersonnel mines are the most common type of mine, yet the most difficult to find because they are small and often made of plastic. Antitank mines generally contain more metal than do antipersonnel mines and are thus more easily detectable by simple metal detectors. Both types are buried as close to the surface as possible and are found in a variety of soils and terrain--rocky or sandy soil, open fields, forested areas, steep terrain, jungle. For both types of mines, detonation is typically caused by pressure, although some are activated by a trip-wire or other mechanisms. Thus, a land-mine detector must do its job without having direct contact with a mine. It also must be able to locate all types of mines individually in a variety of environments[36].

4.1. Anti-tank (AT) Mines

Anti-tank mines are designed to immobilize or destroy vehicles and their occupants. Anti-tank mines can achieve either a mobility kill (m-kill) or a catastrophic kill (k-kill). A mobility kill destroys one or more of the vehicle's vital drive components (for example, breaking a track on a tank) thus immobilising the target. A mobility kill does not always destroy the weapon system or injure the crew. In a catastrophic kill, the weapon system and/or the crew are disabled[41].

Antitank or Antivehicular (AT) (figure 2) land mines often have the shape of truncated cylinders or squares with round corners, with a largest dimension from 150 to 300 mm, and a thickness of 50 to 90 mm. The explosive material is typically TNT, Comp B, or RDX. AT's are buried at various depths from flush to the surface to greater than 150 mm (Mine Facts, 1995). AT mines are usually associated with warfare, and confined to battle fields, which can be corridored thus minimizing the risk to the general public.

Figure 2. Anti-tank mine (image courtesy Wikipedia.org)

Cross section of an anti-tank mine. Note the yellow main charge wrapped around a red booster charge, and the secondary fuze well on the side of the mine.

Anti-tank mines are typically larger than anti-personnel mines and require more pressure to detonate. The high trigger pressure (normally 100 kg (220 lb.)) prevents them from being set off by infantry. More modern anti-tank mines use shaped charges to cut through armour. These were first deployed in large numbers in World War II (Maki, 2008).

4.2. Anti-personnel (AP) Mines

Anti-personal mines are normally designed to kill or injure as many enemy combatants as possible. Smaller anti-personnel mines are sometimes designed to maim rather than kill in order to increase the logistical (mostly medical) support required by such an enemy force. Some types of anti-personnel mines can also damage the tracks on armoured vehicles or the tires of wheeled vehicles (Basel, 2012).

4.3. Common anti-personnel Mines

The inherent difficulty of mine clearance is compounded by the great variety of mines in use--more than 700 types are known. Here are examples of frequently encountered mines. Pictures and descriptions are from International Committee of the Red Cross (ICRC), 1995.

4.4. PMD – 6 Antipersonnel Mines

Originally developed in World War II, the PMD-6 antipersonnel mine (figure 3) is a rudimentary pressure-activated blast device in a wooden box. It has been widely used in Cambodia. As wood rots, the mine mechanism may shift, and the device often sets itself off or becomes inoperative.

Figure 3. The PMD-6 Antipersonnel mine

4.5. MON – 50 Antipersonnel Mine

The MON-50 antipersonnel mine (figure 4) is a Soviet version of the American M-18 Claymore, a directional fragmentation mine. The curved plate is filled with pellets or projectiles in front of the explosive charge. It can be mounted against a round surface such as a tree or can be placed on a small stand-alone stake.

Figure 4. The MON Anti-personnel mine

4.6. The Soviet PFM – Scatterable Mine

Widely used in Afghanistan, the Soviet PFM-1 scatterable pressure-sensitive blast mine (figure 5) is also known as the "butterfly mine" because of its shape, which unfortunately attracts children who think it is a toy. It has been produced in various shades of brown, green, and white.

Figure 5. The Soviet PFM-Scatterable mine

4.7. The OZM – 4 Mine

The OZM-4 (figure 6), a metallic bounding fragmentation mine. A bounding fragmentation mine is designed to kill the person who sets it off and to injure anybody nearby by propelling fragments. The cylindrical mine body is initially located in a short pot or barrel assembly; activation detonates a small explosive charge, which projects the mine body upwards. (ICRC, 1995).

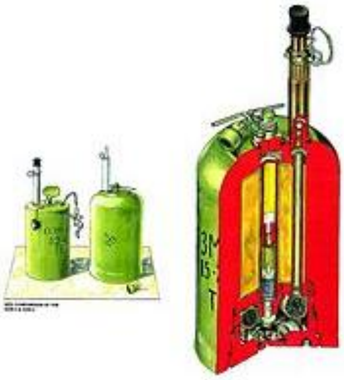

Figure 6. The OZM-4 mine

4.8. The PMN Mine

The PMN mine (figure 7) contains a large amount of explosive, and the injuries it inflicts are often fatal. It is designed in such a way that it is practically impossible to neutralize. As a safety precaution for those laying this mine, a 15- to 20- minute delay mechanism is activated when the mine is armed.

Figure 7. The PMN mine

4.9. The BPD – SB – 33 Scatterable Mine

The irregular shape and small size (about 9 cm diameter) of the BPD-SB-33 scatterable antipersonnel mine make it particularly hard to locate. A hydraulic antishock device ensures that it cannot be detonated by explosions or artificial pressure. It is also exceptionally light, and can thus be carried and deployed in extremely large numbers by helicopters (figure 8).

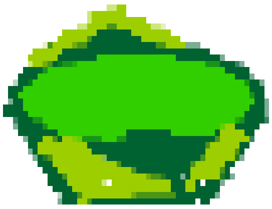

Figure 8. The BPD-SB-33 scatterable mine

4.10. The PMR – 2 A or POMZ – 2 Antipersonnel Mine

There are numerous variations of the PMR-2A or POMZ-2 antipersonnel stake mines (figure 9), which are generally planted in clusters or rows of at least four units and are set off by an intricate system of tripwires.

Figure 9. The PMR-2A or POMZ-2 antipersonnel mine

5. Laying Mines

Minefields may be laid by several means. The preferred, but most labour-intensive, way is to have engineers bury the mines, since this will make the mines practically invisible and reduce the number of mines needed to deny the enemy an area. Mines can be laid by specialized mine-laying vehicles. Mine-scattering shells may be fired by artillery from a distance of several tens of kilometres. Mines may be dropped from helicopters or airplanes, or ejected from cruise missiles.

Anti-tank minefields can be scattered with anti-personnel mines to make clearing them manually more time-consuming; and anti-personnel minefields are scattered with anti-tank mines to prevent the use of armoured vehicles to clear them quickly. Some anti-tank mine types are also able to be triggered by infantry, giving them a dual purpose even though their main and official intention is to work as anti-tank weapons.

Some minefields are specifically booby-trapped to make clearing them more dangerous. Mixed anti-personnel and anti-tank minefields, double-stacked anti-tank mines, anti-personnel mines *under* anti-tank mines, and fuses separated from mines have all been used for this purpose [41].

6. Landmine Detection and Detection standard

6.1. Landmine Detection

While placing and arming landmines is relatively inexpensive and simple, the reverse of detecting and removing them is typically expensive, slow, and dangerous. This is especially true of irregular warfare where mines were used on an ad hoc basis in unmarked areas. Anti-personnel mines are most difficult to find, because of their small size and the fact that many are made almost entirely of non-metallic materials specifically to avoid detection. New detection systems however are being developed by making use of rats. Because these rats have a high sense of smelling and are light, they are suited to detect landmines without being blown-up (Gooneratne, 2004).

The requirements of civilian demining (mine clearance) are quite different from those of military demining; and this affects the detection problem. During a military countermine operation, the objective is to breach a minefield as fast as possible, often using brute force. The demining operation then involves identifying a minefield and breaching it using explosive charges, flails, rollers, plows or rakes. The objective is clearing a path for crossing, typically one vehicle wide and as long as required, with limited casualties. Plows and rakes leave berms containing unexploded mines that are often ignored and left as a problem for others. In battles, a minefield can also be marked and avoided altogether by going around it. Simply put, in military demining one is not concerned with problems that can be addressed at a later time.[29]

Civilian demining, on the other hand, is more difficult and dangerous than military demining, as it requires complete removal of all mines. Normal traffic and use of land must be re-established and therefore absolutely no explosive material can be left un-removed. This is also necessary to restore public confidence, since even rumours can lend an entire field or road useless.

Post-cleaning of cleared roads or fields, also called proofing, is essential to rebuild the public's confidence. This process involves the detection and removal of any mines that may remain undetected. Mines left undetected in the first phase of demining are likely those that were more deeply buried and can cause future problems if left undetected. These aspects make the detection process even more challenging, and may require special proofing detection technology.

A landmine detection system should be able to detect mines regardless of the type of explosives used, since mines are made of a variety of explosive materials. Mines come in a variety of shapes and in various types of casings, and therefore a detection system should be either insensitive to the geometrical shape of the mine and the type of casing material, or preferably provide imaging information. This latter feature will enable the system to better distinguish mines from background clutter, such as rocks, metal shreds, etc. This, in turn, will reduce the false-positive alarm rate and the time wasted in trying to clear an innocuous object thought to be a mine. On the other hand, it is vital that the detection system find a genuine mine; that is, near zero false-negative alarms need to be achieved. Since mines can be buried at different depths under the ground surface, the detection system should not be overly sensitive to the depth of burial. The operator of a detection system should be able to avoid close proximity to the position of the mine to minimize the possibility of inadvertent triggering of the mine. Detection should also be performed at a reasonable operational speed, and at not too prohibitive a cost. In summary, the ideal system must be accurate, not too slow and not too expensive[29].

In addition to the detection requirements, practical considerations dictate that a detection system should be easily deployable in the field and be usable by technically unsophisticated people. In other words, the system should not represent a logistical burden by requiring complex machines and operation.

In summary, mine detection involves dealing with wide variety of mine material and shapes, different soil types and terrain, and non-uniformity of clutter. It is expected that the characteristic signature for the presence of a mine may vary widely depending on local circumstances. It may, therefore, be difficult to apply any one technique unless the nature of the mine, soil and background clutter is well known. It also is desirable to have a technique that is specific in its identification of landmines, so that it is not affected by the surrounding conditions. It is inconceivable, however, that a single detection technology will be able to meet all needs.

Since the 1940s, many countries have worked on the solution to the problem of detecting nonmetallic landmines. The research has encompassed an extremely wide range of technologies and hundreds of millions of dollars have been spent. Despite these efforts, there is still no operational satisfactory detection solution. This lack of success is attributable only to the extreme difficulty of the problem. In Canadian, for example, research in unexploded ordnance (UXO) detection was initiated in the mid-70s, but research into detection of landmines specifically, started about 10 years later. Although focus has been on "niches" of the problem relevant to Canada, the research considered a large number of technologies for possible application to the landmine detection problem. This research was carried out in-house by the Defence Research and Development Canada (DRDC) as well as participation of a number of Canadian universities and companies[18].

6.1.1. Backscattered x-ray Radiography

The use of backscattered x-rays for the detection of landmines is done by using a collimated x-ray beam and a system of collimated and uncollimated detectors, images of buried and surface objects can be created when the x-ray beam is rastered across the surface. The uncollimated detectors receive most of their energy deposition from photons that have had only one scattering event and therefore respond primarily to surface features while the collimated detectors respond to buried features as well as surface features. Because the images generated have one set that predominantly contains surface features (uncollimated) and another set that responds to both surface and buried objects (collimated), it is possible to first analyze and then remove any surface features before examining the buried objects.

The work of Wehlburg et al, 2007 reveals that the images of the real landmines can not only show the location of the landmine but also the features of specific landmines can be identified. It can work in areas with ground cover, surface irregularities, snow, surface and buried objects, and can image both plastic and metal landmines. The backscatter x-ray imaging system can also function under a variety of weather conditions.

6.1.2. Penetrating Radiation

Penetrating radiation (neutron and photon) offers some attractive features that can be utilized in landmine detection, particularly for material characterization. However, unlike conventional radiographic or tomographic methods, one cannot rely on the radiation transmission modality, as it requires access to two opposing sides of an object; a situation not attainable with landmines. Therefore, one has to rely on secondary radiation emissions (activation) or radiation scattering. The main reason penetrating radiation would be used in landmine detection, in spite of its radiological shielding requirements, is to provide material characterizati on information. It is therefore useful to closely scrutinize the composition of explosive materials[29].

6.1.3. Ultrasound Technique

Among the applications of the non-destructive testing methods there is a materials characterisation using ultrasound. In this method, mechanical characteristics of a material are determined through measurements of properties of an ultrasonic pulse that can propagate through the material. In order for the registered ultrasonic pulse to be intense enough, transfer losses in the system should be relatively low. Additionally, in order for information about the tested material to be fully extractable from the registered ultrasonic pulse, changes in the pulse occurring during propagation through various objects should be known.

This approach can be developed for the purpose of unknown, buried objects' material type determination. The very presence of the object is obtained through the mechanical contact. In the realisation of the ultrasound characterisation for unknown, buried objects the ultrasonic pulse is brought from an ultrasonic transducer to a border of the tested material through the auxiliary object of known characteristics. The reflection in the region influenced by the tested material takes place, followed with the reflected pulse propagation through the material of known properties to the transducer. The possible applications of the method include application in the humanitarian demining [35].

6.1.4. Acoustic Technique

Acoustics technique is a non-destructive testing method regularly used with two main scopes: *flaw detection* and *material characterization*. Special area of application of this physical principle is landmine detection. Regarding the nature of soil structure with many different macro constituents, the landmine detection by means of elastic waves is quite different than flaw detection in homogeneous materials.

Air and soil in comparison with homogeneous metals, are not so "suitable" media for elastic wave propagation. To avoid this, elastic waves should be emitted close to or during physical contact with the buried object. So, there are two possible set-ups to transfer pulses from transducer to buried object: non-contact and contact. Both set-ups comprise many impact factors, advantages and disadvantages, but to get any response from the object the crucial factor is entry surface. Starting from the character of the surface of buried objects, the surface topography and roughness are notable and common for both set-ups[15].

Acoustic-to-seismic coupling (using linear acoustic techniques) has proven to be an extremely accurate technology for locating buried land mines. Donskoy (1998); and (1999) has suggested a nonlinear technique that can detect an acoustically compliant buried mine that is insensitive to relatively noncompliant targets.

6.1.5. Thermography

The use of thermography for land mine detection has become a topic of great interest in recent years. The underlying principle of all dynamic-thermography-based techniques is the idea that the thermal signature of the soil is altered by the presence of shallowly buried objects. This fact makes this approach very well suited for land mine (including Buried Objects and Unexploded Ordinances) detection since their different thermal properties will result in perturbations of the expected thermal pattern that can be measured by sensors (infrared and thermocouple). Moreover, this holds for every type of mine and other buried objects, despite the amount of metal content, if any, making possible the detection of small plastic antipersonnel mines.[38]

Infrared (IR) thermography is a technique that uses an imaging system to measure the electromagnetic energy emitted from a surface in the IR radiation band. This kind of energy is also known as thermal radiation. Applications of IR thermography have been found in various fields from science, civil and military industries to medical diagnostics, fire rescuer and maintenance, etc.

The difference in the thermal capacitance between soil and mine affects their heating/cooling rates and therefore their associated infrared emissions. Infrared cameras are used to map heat leakage patterns from the ground which, nevertheless, makes this thermography method an anomaly identification technique [5, 79].

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Thermography detects differences in infrared radiation intensity emitted from the surface of an object. The differences are caused by the different heat content of the object or its various parts, additionally influenced by the surface emissivity characteristics. When a non- homogeneous structure, having different thermal characteristics, initially being in thermal equilibrium with its surrounding, is exposed to heat stimulation, the temperature difference occurs in the structure as well as on their visible surfaces [30].

6.1.6. Neutron Back-Scattering Method

Neutron Back-Scattering (NBS) technique is a well established method to find hydrogen in objects. It can be applied in landmine detection taking advantage of the fact that landmines are abundant in hydrogen. The NBS technique is suitable for landmine scanning e.g., seeking for landmines with a moving detector system[72]. The unique feature of this method is that it is mainly sensitive to the amount of hydrogen atom in its surrounding[17].

The neutron back-scattering method is based on the moderation of high energy neutrons produced by either a radio-isotopic source or neutron generator. The amount of low (thermal) energy neutrons that is reflected from the soil is a direct indication of the amount of hydrogen[34].

6.1.7. Gamma Rays Method

Neutron-induced reactions that produced radioactive products can also lead to the delayed emission of characteristic gamma rays. Gamma rays are detected by a bismuth germinate scintillator. The pulse height spectrum from the bismuth germinate is analysed to identify the nuclei and hence the elemental constituents that produced the gamma rays and to determine their relative proportions. It is thus possible to identify explosives from their chemical composition which is indicated by the elemental concentration ratios (H: C: N: O) determined from the analysis of the pulse height spectrum. This provides a signature for identifying Anti-Personnel Landmine or other explosive objects, with excellent discrimination against metallic debris and other artefacts[11]

6.1.8. Metal Detection Method

Metal detectors attempt to obtain information on buried mines by emitting into the soil a time-varying magnetic field to induce an eddy current in metallic objects; which in turn generates a detectable magnetic field. However, landmines typically contain a small amount of metal in the firing pin while many others contain no metal at all. Increasing the sensitivity of a metal detector to detect a smaller amount of metal makes it also very susceptible to metal shreds that are often found in mine infected areas. Although the use of pulsed waveform and monitoring of multi-frequency emissions may improve the capabilities of electromagnetic induction probes, they will remain unsuited for use in magnetic and heavily mineralized soil. Metal detectors, even when successful, can only succeed in identifying the presence of an anomaly, without providing information on whether explosive material is present or not.

Mine prodders enable subsurface inspection by employing bayonets or hand-held probes (about 250 mm long) to poke the ground, inch by inch, to sense the presence of a hard (solid) object in the soil. It is, therefore, another anomaly identification technique that provides no material characterization information. Prodding is done at an angle to avoid causing detonation if the mine is pushed from the top, where the primary trigger usually is. Aside from the inability of this primitive method distinguish between a landmine and any other solid object that can be present in the soil, such as a rock, it is a dangerous operation.[29].

6.1.9. Biological Method

The odour discriminating skills of dogs considerably exceed the abilities of laboratory machines used in attemps to investigate the skills, limiting the ability of the researchers to study the skills and limitations of dogs for detection of mines (Ann et al, 2012). Dogs have greater olfactory senses compared to humans, especially for trace quantities, and can be trained to detect the presence of explosives. This is, in effect, a material characterization process as dogs are sniffing the vapours emitted from the explosive material. This technique requires, however, extensive training, and the dogs' limited attention span makes it difficult to maintain continuous operation. Electronic chemical sniffers can also be used, though they are not as sophisticated as dogs in terms of their detection abilities. Moreover, minefields are usually saturated with residual vapour emissions from recently detonated explosives, which may add to the chemical clutter of the area, thereby confusing the dogs' senses[29].

6.1.10. Ground Penetrating Radars

Ground-penetrating radars (GPRs) are short pulse, wide-band low-energy radars intended for probing into the earth. One of the major problems with GPRs is that dielectric discontinuities occur at places other than the mine. Reflections are therefore also found at the air/ground interface and at roots, rocks and hollows within the sub-surface. These reflections can hide the existence of a mine by cluttering the return signal and provide false alarms (Waschl, 1994). The transmitted pulse is usually only one radio-frequency cycle in duration; hence these radars are also called "impulse radars." The transmitted pulse is usually generated by discharging an avalanche transistor into a resistively-loaded dipole antenna which is placed in contact with the earth. The radiation pattern is ordinarily that of a simple dipole radiating into half-space.

It is difficult for GPR to discriminate between natural variations and those for mine. The performance of these radars is limited by attenuation of the signals in moist soils, especially soils having high clay content.

The transmitted pulse is very short-which allows for accurate measurement of distances from the antennas on the surface to the sub-surface targets. However antennas having narrow beams cannot in practice be built for such radars.

A more serious problem limiting the usefulness of GPR's at many locations in the world is the attenuation of the radar signals in the sub-surface medium. To minimize these losses a low radar frequency is desired.

Ground-penetrating radars in principle are capable of locating plastic pipes as easily as metallic pipes since the radar signal reflection from the pipe depends on contrasting dielectric properties of the soil and pipe, not just a high electrical conductivity for the pipe.

6.2. Detection Standard

Effective solution to the problem posed by land mines means that close to 100% of the mines in any area must be detected at the fastest rate possible and with few false alarms (i.e., mistaking a buried object, such as a rock, for a mine). The United Nations, for example, has set the detection goal at 99.6%, and the U.S. Army's allowable false-alarm rate is one false alarm in every 1.25 square meters. No existing land-mine detection system meets these criteria. And the reasons for this failure have as much to do with the mines themselves and the variety of environments in which they are buried as with the limits or flaws in the current technology[36].

Humane demining is done in various climates as well as geographical environment, using various technologies and equipment for detection and protection. It is important to mention that in accordance with the existing laws on Humanitarian Mine Clearance Operations: " an area is cleared when all mines and munitions have been removed and/or destroyed". Also, "the area should be cleared of mines and unexploded ordinances (UXOs) to depth which is agreed to be appropriate to the residual/planned use of land, and which is achievable in terms of the resources and time available. The contractor must achieve at least 99.6 % of the agreed standard of clearance. The target for all UN sponsored clearance programmes is the removal of all mines and UXO to a depth of 200 mm"[21].

7. Recent Researches into Detection of Landmine, Buried Object and Unexploded Ordinances

7.1. Backscattered x-ray Radiography

The use of backscattered x-rays for the detection of landmines is done by using a collimated x-ray beam and a system of collimated and uncollimated detectors, images of buried and surface

7.2. Landmine Detection Using Backscattered x-ray Radiography

The use of backscattered x-rays for the detection of landmines has been demonstrated in the laboratory by both Sandia National Laboratories (SNL) and the University of Florida (UF.) Using a collimated x-ray beam and a system of collimated and uncollimated detectors, images of buried and surface objects can be created when the x-ray beam is rastered across the surface. The uncollimated detectors receive most of their energy deposition from photons that have had only one scattering event and therefore respond primarily to surface features while the collimated detectors respond to buried features as well as surface features. Because the images generated have one set that predominately contains surface features (uncollimated) and another set that responds to both surface and buried objects (collimated), it is possible to first analyze and then remove any surface features before examining the buried objects. Previous work has demonstrated the backscattered x-ray imaging system’s ability to work with surface clutter i.e., rocks, branches, vegetation, with varying surface-to-detector heights, and ‘with surface irregularities i.e., potholes and soil mounds. The research focused on the configuration of the system for imaging the Iandmines under field conditions and image performance with real landmines.[76]

7.3. Landmine Detection: Radiation Methods

Hussein and Waller,[29] explores the role of radiation methods in addressing the problem of detecting landmines. The application of neutron activation analysis, with an isotopic source or a pulsed neutron generator, is discussed. The use of neutron moderation as an indicator of the presence of a landmine was also explored. In addition, information provided by measuring scattered photons (gamma- and x-rays) was examined.

7.4. Material Characterization by Mechanical Point Contact Impact Emitted Ultrasound

Among the applications of the non-destructive testing methods there is a materials characterisation using ultrasound. In this method, mechanical characteristics of a material are determined through measurements of properties of an ultrasonic pulse that can propagate through the material. In order for the registered ultrasonic pulse to be intense enough, transfer losses in the system should be relatively low. Additionally, in order for information about the tested material to be fully extractable from the registered ultrasonic pulse, changes in the pulse occurring during propagation through various objects should be known.[30]

7.5 Method for Determining Classification Significant Features from Acoustic Signature of Mine-like Buried Objects

Good feature selection method is an essential step in a classification system. That is especially true for detection systems that have to deal with low signal-to-noise ratio, and varying background conditions, which is the case for landmine detection systems. Proposed method analyzes spectrum of a signal collected from the microphone placed inside the deminers prodder and extracts set of features with best discrimination ability. Feature selection is performed in two stages. First, huge initial set of near $2x10^4$ features is reduced to approximately 100 features and from reduced set best feature subset is selected. Algorithm was successfully applied to the set of unified samples from different materials, as well as on the real landmines and harmless objects.

The paper proposed the hybrid feature extraction method applied to the buried landmine detection problem. Method is based on the Best individual features selection algorithm, used to reduce the complexity of initial large feature set, followed by Complete and Sequential search algorithms for determining feature subset with highest discrimination ability. This approach gives good results on test samples from different materials, as well as on the real-world samples. It could be applied to various sensor configurations not restricted to the landmine detection.[3]

7.6. Possibilities of Material Classification by Means of Ultrasound

Ultrasonics and acoustics as non-destructive testing methods are regularly used with two main scopes: *flaw detection* and *material characterization*. Special area of application of these physical principles is landmine detection. Regarding the nature of soil structure with many different macro constituents, the landmine detection by means of elastic waves is quite different than flaw detection in homogeneous materials. The problematic is more wisely combination of *detection* and *characterization* - therefore called here *classification*, because between many responses the proper one should be distinguished, recognized and evaluated.

Air and soil in comparison with homogeneous metals, are not so "suitable" media for elastic wave propagation. To avoid this, elastic waves should be emitted close to or during physical contact with the buried object. So, there are two possible set-ups to transfer pulses from transducer to buried object: non-contact and contact. Both set-ups comprise many impact factors, advantages and disadvantages, but to get any response from the object the crucial factor is entry surface. Starting from the character of the surface of buried objects, the surface topography and roughness are notable and common for both set-ups.

While the reliability of pyrotechnicians (personnel) is out of the extent of the paper the capability of detection method is in the focus. It is also presumed that inherent characteristics of the equipment e.g. sensitivity, resolution, reliability, signal to noise ratio etc., are suited for the purpose and are satisfactory[16].

7.7. Buried Mine and Soil Temperature Prediction by Numerical Model

In recent years, many world-wide institutions have started the work to improve mine disposal effectiveness. Among about 20 technologies being presently developed, IR imaging is one of essential ones - although strong dependence of results on both measuring conditions and operator skills, is a weakness of this method. Thermal detection can be effective only when high enough difference in radiant signal exists at the surface above the mine, compared to region free of this target. Due to very high thermal inertia of the soil, usually it is assumed, that underground mines manifest themselves only as result of changes in solar activity. Because of that, the ability to predict proper time and detection procedure, plays particularly important role. Much deeper understanding of the buried mine's signature, proved to be indispensable. To describe mine's image in the output of thermal imager, a few different models have to be combined. Models to describe the influence of the IR camera features and models to predict the radiometric aspects of incoming signals, almost similar for land and buried mines, appeared to be relatively well developed. Study of the physics-related papers showed considered, here, problem as not developed enough. It is probably due to high complexity and variability of the soil physics processes. Models presented here were elaborated as the base to the next ones, more specialised and simplified, through links with various bases of the reference data. [50]

Temperature measurement is an important phenomenon in almost all industrial and agricultural sectors. Several instruments and methods have been developed to measure the temperature of objects. Temperature measurements in the agricultural and food industries have mostly relied on conventional contact methods such as thermocouples, thermometers, and thermistors, which provide limited information[80]. Several techniques such as x-ray tomography, infrared thermography, electrical impedance tomography, ultrasound imaging, microwave radiometry, and magnetic resonance imaging (MRI) are available to map the temperatures of biological materials [81, 82]. However, infrared thermal imaging has great potential for both pre-harvest and post-harvest operations in agriculture due to the portability of the equipment and simple operational procedure.

7.8. Detection of Underground Objects Using Thermography

Detection of buried antipersonnel landmines (APL) is a demandable task in which one tries to obtain the information about the soil and buried objects characteristics using various methods. In this paper the possibility of the active thermography application in APL detection is considered. The analysis is based on the mutual influence of the system scanning capacity and the quality of thermograms. The data are obtained by modelling and measuring for set-ups of several types of various objects buried in various soils.

Using the active thermography, on a given set of objects put in homogeneous, dry and vegetationless soil, the non-stationary thermal field was realised. This field is rather sensitive on the physical properties of objects that represent soil non-homogeneities. The difference in physical properties means that in the relatively large time interval of heating and subsequent cooling of heated region large enough temperature differences are obtained. Differences in temperature enables buried object detection and their differentiation. However, in non-homogeneous soils the possibility of buried objects detection and differentiation becomes questionable.[30]

7.9. Detection of Perturbations in Thermal IR Signatures: an Inverse Problem for Buried Land Mine Detection

The analysis, from infrared images, of perturbations on the thermal signature of the soil is a powerful tool for the detection of the presence of buried objects, but, by itself, gives little insight in the nature of the detected targets. Lopez *et al*,[38] presented a method for the detection of surface and shallowly buried land mines in infrared images based on a 3D thermal model of the soil. This model is been used to detect perturbations on the expected behavior that will lead to the assumption of the presence of unknown buried objects.[38].

7.10. Nonlinear Acoustic Techniques for Land Mine Detection

When airborne sound couples into the ground seismic waves can interact with a target buried in the soil and effect the vibration velocity of the surface. Acoustic-to-seismic coupling (using linear acoustic techniques) has proven to be an extremely accurate technology for locating buried land mines. Donskoy 1998 and 1999 has suggested a nonlinear technique that can detect an acoustically compliant buried mine that is insensitive to relatively noncompliant targets. (Utilizing both techniques could eliminate certain types of false alarms.) Airborne sound at two primary frequencies f_1 and f_2 undergo acoustic-to-seismic coupling and a superimposed seismic wave interacts with the compliant mine and soil to generate a difference frequency component that can affect the vibration velocity at the surface. Geophone measurements scanning the soil's surface at the difference frequency (chosen at a resonance) profile the mine with more relative sensitivity than the linear profiles - but off the mine some non-linearity exists. Amplitude dependent frequency response curves for a harmonically driven mass-soil oscillator are used to find the non-linearity of the soil acting as a "soft" spring. Donskoy's nonlinear mechanism (over the mine) involves a simple model of the top surface of the mine-soil planar surface separating two elastic surfaces. During the compression phase of the wave, the surfaces stay together and then separate under the tensile phase due to a relatively high compliance of the mine. This "bouncing" soil-mine interface is thought to be a bi-modular oscillator that is inherently nonlinear.

Acoustic-to-seismic (A/S) coupling has been demonstrated to be an effective and extremely accurate technique for the detection of buried land mines in soils and in particular, roadways. A/S coupling requires that airborne sound induce vibrations in the soil, below the surface where a land mine might be buried. It is the porous nature of the ground (up to about 1 meter below the surface) that plays an important role for A/S coupling to be used successfully in the detection of buried land mines. The experimental technique requires that loudspeakers insonify broadband acoustical noise (or a swept tone) over the soil and a laser Doppler velocimeter (LDV) system (equipped with X-Y scanning mirrors) detect increased soil vibration across a scan region over the mine on the soil's surface[45].

7.11. Soil Effects on Thermal Signatures of Buried Nonmetallic Landmines

Thermal sensors hold much promise for the detection of non-metallic landmines. However, the prediction of their thermal signatures depends on a large number of factors. Remke *et al*,[57] used an analytical solution for temperature propagation through homogeneous and layered soils is presented to predict surface temperatures as a function of soil heat flux amplitude, soil texture, soil water content, and thermal properties and burial depth of the landmine. Comparison with the numerical model HYDRUS-2D shows that the relatively simple analytical solution proposed here is reasonably accurate. The results show that an increase in soil water content has a significant effect on the thermal signature, as well as on the phase shift of the maximum temperature difference. Different soil textures have relatively little effect on the temperature at the surface. The thermal properties of the mine itself can play a significant role. It is shown that for most soils 10 cm is the maximum burial depth to produce a significant thermal signature at the surface[57].

7.12. Field Implementation of the Surface Waves for Obstacle Detection (SWOD) Method

The SWOD method is an extension of the Spectral-Analysis-of-Surface-Waves (SASW) technique, used in detection of anomalies in layered systems. It is a result of experimental and numerical studies, where it was demonstrated that underground obstacles/buried objects and soil heterogeneity significantly effect surface (Rayleigh) wave dispersion. Obstacles denser than the surrounding soil cause an increase in the phase velocity of the dispersion curve in some frequency ranges for larger receiver spacings, comparing to cases without obstacles. Cavities and obstacles looser than the surrounding soil cause a decrease in the phase velocity. An important observation is that for a small receiver spacing obstacles cause strong fluctuations in the dispersion curve. The phenomenon is especially pronounced as receivers move from the source towards the obstacle. The fluctuations vanish as receivers move behind the obstacle, thus enabling identification of the obstacle position. The SWOD technique was implemented in the field for the purpose of detection of a cavity under a highway. Some of the phenomena identified in numerical simulations are observed in the field results. The theoretical background and field implementation procedures are explained and illustrated[24].

7.13. Effect of Depth on the Thermal Signature of Buried Metallic Object

The use of thermography for land mine detection has become a topic of great interest in recent years. The thermal properties and burial depth of the buried object also play a role in the thermal signature at the surface. The work of olowofela *et al* (2010) determined the effect of burial depth on thermal signature of buried metallic object. The objects used in the work were steel materials buried at depth ranging from 1cm to 50cm. The two buried objects used in the work were steel of 12cm x 12cm surface area with thicknesses of 0.5cm and 3cm respectively. The soil where the objects were buried was mainly sandy. Soil above the buried objects and below it was assumed to be the same type of soil. The work was carried out in Abeokuta, Ogun State, Nigeria. There was a remarkable phase shift which increased with burial depth. A change in burial depth from 1cm to 10cm caused the maximum positive peak to shift from 46.5^0C to 38.0^0C and a change in burial depth from 40cm to 50cm, caused the maximum peak to shift from 30.0^0C to 29.0^0C. The burial depth of the buried objects has effect on the amplitude of the temperature at the surface and thus its thermal signature. It was also observed that the thickness of the buried objects has a significant effect on its thermal signature.

7.14. Mathematical Modelling of Effect of Ambient Temperature and Relative Humidity on Soil Surface Temperature during Dry Season in Abeokuta, South – Western Nigeria

Temperature distributions on the soil surface strongly depend on the state of the processes of mass and energy exchanges (radiation and convection, evaporation and water condensation, supply of water through precipitation and gaseous exchange). It was assumed that soil medium is homogeneous and parameters describing this medium are changeless in the whole of its volume except that they depend on soil temperature and humidity. The work of Bello, 2011 examined the effect of Ambient Temperature and Relative Humidity on Soil Surface Temperature during Dry Season. The experimental data obtained from experiment were used to generate a model which can be used to predict the soil surface temperature during the dry season in Abeokuta, South – Western Nigeria once the ambient temperature and the relative humidity are known. The chi-square test showed that there was no significant difference ($p>0.05$) between the expected and observed data. The coefficient of determination (r^2) showed that 92.89% of the experimental data were predicted by the model. The model developed in the work enabled the use of simulation prediction as the basis for temperature determination, which otherwise would be difficult or impossible to perform.

7.15. Evaluating Thermal Properties of Rock

Application of thermography in material identification and characterization was applied in the work of Bello, 2011. Nigeria geological set up comprises broadly sedimentary formation and crystalline basement complex, which occur more or less in equal proportion all over the country. The models generated in his work can be used to identify/characterise rock types. The coefficients of the generalized model give the thermal properties of each rock type. The chi-square test showed that there was no significant difference ($p>0.05$) between the expected and observed data for all the models. The model developed in the work enabled the use simulation prediction as the basis for rock identification, which otherwise would be difficult or impossible to perform.

8. Efforts to Ban Anti-personnel Mines (Party States to the Ottawa Treaty)

The Ottawa Treaty (*Convention on the Prohibition of the Use, Stockpiling, Production and Transfer of Anti-Personnel Mines and on their Destruction*) came into force on March 1, 1999. The treaty was the result of the *International Campaign to Ban land mines*, launched in 1992. The campaign and its leader, Jody Williams, won the Nobel Peace Prize in 1997 for its efforts[60].

The treaty does not include anti-tank mines, cluster bombs or claymore-type mines operated in command mode and focuses specifically on anti-personnel mines, because these pose the greatest long term (post-conflict) risk to humans and animals since they are typically designed to be triggered by any movement or pressure of only a few kilograms, whereas anti-tank mines require much more weight (or a combination of factors that would exclude humans). Existing stocks must be destroyed within four years of signing the treaty.

Signatories of the Ottawa Treaty agree that they will not use, develop, manufacture, stockpile or trade in anti-personnel land mines. There were originally 122 signatories in 1997; as of November 2006, it has been signed by 155 countries and ratified by 152. Another 40 have yet to sign on. The convention requested, among other things, that "Each State Party in a position to do so shall provide assistance for mine clearance and related activities". In recognition of the inabilities of some countries to do so, the Convention also stated that "States Parties may request the United Nations, regional organizations, other States Parties or other competent intergovernmental or non-governmental fora to assist its authorities in the elaboration of a national demining program".[29].

There is a clause in the treaty, Article 3, which permits countries to retain land mines for use in training or development of countermeasures. 64 countries have taken this option.As an alternative to an outright ban, 10 countries follow regulations that are contained in a 1996 amendment of Protocol II of the Convention on Conventional Weapons (CCW). The countries are China, Finland, India, Israel, Latvia, Morocco, Pakistan, South Korea, Sri Lanka, and the United States.

9. Conclusions

Classical demining technologies have number of drawbacks, including risk for the deminer, low speed and high unit cost. Detection systems capable of quickly and accurately detecting buried landmines are the only possibility to significantly improve the demining process. Due to low signal-to-noise ratio, changing environment conditions that influence measurements (humidity, temperature, composition of soil, etc.), and existence of other natural or man-made objects that give sensor readings similar to the landmine, interpretation of sensor data for landmine detection is a complicated task.

None of these methods has actually met the acceptable standard that mines in any area must be detected at the fastest rate possible and with few false alarms (i.e. mistaking a buried object, such as rock, for a mine). The UN, for example, has set the detection goal at 99.6%, and the US Army's allowable false-alarm rate is one false alarm in every 1.25 square meters. No existing landmine detection system meets these criteria. Therefore, there is urgent need for detection technique(s) that will meet these detection criteria, bearing in mind the treat pose by landmines to civilian population. The experiment conducted shows thermography to be a good method to detect shallowly buried objects.

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