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Review of Technologies for the Detection of Anti-Personnel Plastic Mines

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Abstract: Through this study it is present a review of the technologies for the detection of plastic mines, exposing the techniques used for locating landmines (AP) and Anti-Tank (AT), allowing for the developments that have been giving in this field in the country. The first part of the study presents the current mining situation in Colombia and in the world. The second part presents the most outstanding techniques in identification of plastic mines or with low metal content, emphasizing the implementation of Ground Penetration Radar (GPR) as the identification technique that has presented better results. Finally, it is present a study of the processing and identification techniques that are used together with the methods of detection and the conclusions obtained from the research.

Key words: Humanitarian demining, plastic mines, ground penetration radar, clutter, image processing, identification

INTRODUCTION

One of the most devastating legacies left by the 20th century is the existence of minefields in more than 60 countries around the world. Basically, landmines were buried explosive devices that are typically triggered by pressure, i.e. with the passage of persons or tanks as explained by Gooneratne *et al*. (2004). Although, this is the most common method of activation and most of the mines buried in Colombia, there are three additional activation methods as described by Roa (2002). These are by relief of pressure by tension or by relief of tension. Relief of pressure occurs when the object or person pressing on the mine is remove. In activation by tension, a wire is tie between the mine catch and a nearby object such as a tree which will result in detonation when pressure is applied to the cable. If the wire becomes cut, the mine will be activated by relieving tension on the detonator (Anonymous, 2005). Currently, according to Duran (2012), these are not the only ways to make mines explode; There is timer activation, activation defined as “Anti-manipulation” and other activation systems based on photocell systems.

Landmines are easy to build and inexpensive as the construction of a single mine can range from $3-10 but removing it could cost $300-1,000, according to data from Anonymous (2012a, b). Over time, buried mines have proven to be effective weapons that can be deployed over large areas to prevent enemy mobility. Although there are about 350 types of landmines, they can be divided into two major categories (Pardo, 2008): Anti Personnel mines (AP) and Anti-Tank mines (AT). Anti-tank mines are larger and contain more explosives than anti personnel mines and need higher pressure on the ground to activate compared to an AP mine.

Although, the use of anti-personnel mines was banned by the 1997 Ottawa convention in 158 countries, 80% of nations (Anonymous, 2011a-c), statistics show that there are currently around 100 million antipersonnel minesburied around the world and ten new mines were buried for every mine that is successfully mined. In addition, mines that were buried continue to be functional for several decades, even long after the war ended, causing future damage to outsiders. According to the UN, it takes 500 years and 50 trillion dollars to completely remove landmines (Duran, 2012). For this reason, the deactivation of minefields and therefore the detection of antipersonnel mines is one of the most important, costly and complex humanitarian tasks, bearing in mind that these explosive elements have begun to be made of plastic materials and galvanized mines which makes his location impossible with conventional detection methods such as metal detectors, so, widely used in the demining of war fields for several decades. Generally, these explosive devices were made of materials such as Poly Ethylene (PE), Poly Propylene (PP) and Poly Styrene (PS), rubber or Bakelite and his main explosive components were TNT, TETRYL, PENT, RDX and AAP (Atomized Aluminium Powder; Pino, 2009).

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Currently, there are several methods that have been used for the detection of such mines as the use of acoustic sensors or methods based on resonance systems. One of the most successful methods is known as Ground Penetration Radar or GPR which provides satisfactory results for obtaining the exact location of all types of materials within a land including mines made from materials plastics, the depth to which it is found and the size of it. Successful detection of all types of mines in a wide range of terrain under highly variable environmental conditions is one of the most important challenges for the technology and the increasing use of plastic in antipersonnel and anti-tank mines with only one small portion of metal, make his detection more difficult through conventional means. The implementation of the GPR together with a traditional Metal Detector (MD) allows the detection of any kind of mine that is buried within the land but it has certain limitations when there is a terrain with conductive characteristics such as terrain with high degrees of humidity and with high dielectric conductivity constants. Although, mine detection is only part of the minefield removal process, this is one of the most important aspects of the process. According to Sato (2009), despite many technologies for the detection of plastic mines, only GPR has demonstrated a successful detection of plastics under different conditions. Likewise, the researcher proposes a relation of the GPR signals with the physical parameters of the buried elements, starting from the fact that the dielectric properties of the objects are essential for the development of a recognition by GPR.

This article will first present an overview of the current situation of the minefields in Colombia and the world and the main efforts that have been made to deactivate them. The following will be presented the different methods that have been implemented over the last few years for the localization of these devices and lastly to speak more of the GPR whose results have shown a good performance in the location of buried mines and together with it, we will talk about the techniques of image processing that have been used in the detection of buried mines.

The humanitarian global problem generated by the presence of landmines: Today, the social and economic consequences left by the existence of minefields in countries with internal conflicts had been analysed by organizations of the world order as Lou (2012), UNICEF and UN whose reporting alarming figures about how many civilians have been affected by explosive devices. According to, the Lou (2012), the countries with the highest number of handcrafted and militaryexplosives are Bosnia, Cambodia, Croatia and Egypt as shown in Table 1.

Table 1: Countries with greater presence of buried mines. United Nations Department of Humanitarian Affairs (Anonymous, 2012)

Countries	No. of mines per mile	Estimated total number of anti-personal mines
Bosnia and Herzegovina	152	03.000.000
Cambodia	143	10.000.000
Croatia	137	03.000.000
Egypt	60	23.000.000
Iraq	59	10.000.000
Afghanistan	40	10.000.000
Angola	31	15.000.000
Iran	25	16.000.000
Rwanda	25	250.000.000

The total number of deaths from anti-personnel mines amounts to 110 million in 72 countries and seven disputed territories, representing an average of 800 deaths per month, mostly civilians and hundreds more of mutilated for life. In addition to, human losses, the problem of landmines has broad socio-economic implications as it transgresses the peace and stability of regions where mined fields exist, causing forced population displacement and preventing the use of land for agricultural purposes. Abandoned landmines have directly and indirectly affected the lives of approximately 22 million people (MAG., 2008).

Although, Colombia is not in the countries with the highest number of buried mines, it is one of the countries where there are more victims. According to Anonymous (2011a-c) by 2009, the number of victims in the country was <700 people, being surpassed only by Afghanistan with 1,211 victims in that year. Due to the data collection is incomplete, it is presumed that the actual number of global victims is certainly higher than that recorded by Landmine Monitor, both in Colombia and the rest of the world. Anonymous (2011a-c) identified the placement of anti-personnel mines by three governments: Israel, Libya and Myanmar as well as the use of these devices by non-state armed groups in countries such as Afghanistan, Colombia, Myanmar and Pakistan for the period 2010-2011. Among the 12 countries currently producing AP and AT mines, Landmine Monitor identified Cuba, China, the United States and Russia among others.

Among the humanitarian demining field worldwide, the monitor records for 2010 cleaning approximately 200 km^2 of mined areas through 45 programs related to mining activities. This is the highest portion of land cleared within one year which has been recorded so far. During this removal, more than 388,000 AP mines and 27,000 AT mines were destroyed.

In Colombia, the numbers of people affected by landmines have been registered for more than 18 years by Anonymous (2012a, b) (Campaign “No more antipersonnel mines”, 2012), along with the vice presidency of the republic.

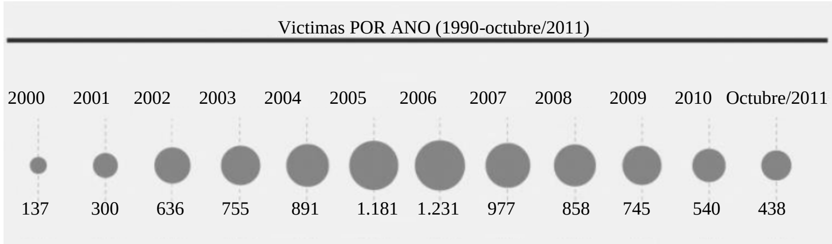

Fig. 1: National number of people affected by anti-personnel mines (Anonymous, 2012)

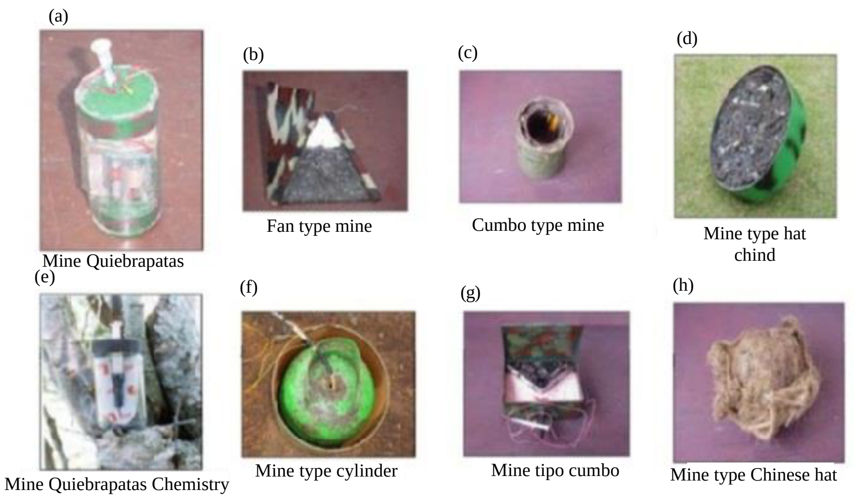

Fig. 2: a-h) Improvised explosive artefacts produced in Colombia (Anonymous, 2012)"

Since, 1990, a detailed record of the number of victims affected per year has been made. According to Roa (2002), the presence of this type of explosive devices in the Colombian territory has caused irreparable sequels in approximately 7,500 people and death to more than 2,000 from 1990 to the present. These victims are mostly soldiers in charge of the demining of camps or civilians outside the armed conflict. According to statistics, since, 2002 the number of peoplein the country has been affected by anti-personnel mines has increased considerably, as shown in Fig. 1. This shows the high risk in which the population is constantly of being a victim of this type of weaponry.

The national government had created the Presidential program for Integral Action against Antipersonnel Mines (PAICMA., 2012) which researches together with the international community to reduce the risk caused by anti -personnel mines in Colombian territory and ensure the assistance to victims of these artefacts. Among the most important activities of the program are the humanitarian demining, the victim assistance and the education in the risk of landmines. Despite the research done by the government and international entities, the Colombian state does not know what and how many areas should be cleared as well as their extent and level of contamination (PAICMA., 2012). The lack of knowledge of the location of anti-personnel mines in the national territory makes it indispensable to implement devices capable of locating mines of any material and size and in any type of territory without risking the lives of military and civilians in charge of the research of demining.

The presence of antipersonnel mines and anti-tank mines in Colombian territory may add to the proliferation of non-conventional mimes or also known as improvised explosive devices (AEIs) such as those shown in Fig. 2.

The changing nature of this type of homemade artefacts and materials with easy acquisition, makes that the infrastructure necessary for detection in the national territory must be chosen very carefully (Pino, 2009). According to Duran (2012), there are already 12 types of AEIs that currently exist in the country Table 2. It presents some characteristics of this type of artefacts found in the Colombian territory. Studies carried out in the Colombian territory with GPR allow to conclude that this technique can contribute to the identification of conventional land mines (AP and AT) as well as AEIs, ideally being complemented with additional techniques such as the traditional metal detector (Lopera and Milisavljevic, 2007). The following is a review of the

Table 2: Characteristics of some AEIs evaluated by Lopera and Milisavljevic (2007)

AEIs form	Material	Geometry (cm)	Inground depth (cm)	Dielectric relative permittivity
Cylindrical	Metal	High: 10-40	0-50	-
		Diameter: 6-30		
	PVC	High: 10-17	0- 10	3.6
		Diameter: 8-14		
	Wood	High: 20-30	0-3	3.6/8.9
		Diameter: 7-10		
Rectangular	Wood	High: 15-20		
		Length: 20-25	0-20	3.6/8.9
		Width: 20-25		
Irregular	Textile fibber	Diameter: 15-25	0-20	3.3

methods that have been implemented for the detection of landmines, both metallic and those made in other materials in different types of terrain.

MATERIALS AND METHODS

Methods of identification of plastic mines: Two types of demining of a field can be recognized: military demining and humanitarian demining. Military demining aims to clean up the minefield as quickly as possible to mobilize troops without ensuring that the land is completely free of mines with a clearance rate varying between 80 and 90%. While humanitarian demining is more difficult, costly and dangerous as it aims to ensure the return of the civilian population to what was once a minefield, so, all mines must be eliminated in it (PAICMA., 2012; Rosengard *et al*., 2001). There are many techniques that have been used to carry out the humanitarian demining of a field, avoiding first of all putting human lives at risk and considering aspects such as time, cost and effectiveness. Many of these technologies are not yet known or used in Colombia. Gooneratne *et al*. (2004), classifies in 5 major areas the methods of detection: Metal detectors, electromagnetic methods, acoustic methods, biological methods, mechanisms and the most recent methods. The choice of a method will depend on the type of terrain to be analysed as each method has characteristics that will provide better performance in certain types of terrain. It will also depend on the kind of explosive you want to deactivate. The variety of mine forms, the materials of which were composed and the hostile nature of some terrain prevent a single method of detection from operating effectively on all terrains and for all types of mines. The combination and integration of different techniques increases the detection range and decreases false alarms. In this study, we will discuss the current methods that best perform in the detection of antipersonnel mines and antitank and the advantages and deficiencies of each one.

Metal detectors: His operating principle is electromagnetic induction. It consists of one or more inductor coils that were used to generate a magnetic field that fluctuates around the coil. This field was emitted toward the ground and interacts with the metal elements buried inducing the magnetic field of these and generating an opposing coil current which in turn generates a signal indicating the presence of metallic elements (Brown *et al*., 2002). Metal detectors have evolved from the earliest models to the most modern techniques involving intelligent robotic systems. This is perhaps the most classical method of detection and is still used in many of the world's minefields. Since, it is a metal detector his disadvantage is that it ignores explosive devices that are made from other materials such as plastic or wood or contain almost irrelevant amounts of metal. However, it is usually combine with modern methods for the detection of mines made with a wide range of materials (Pardo, 2008). Another disadvantage is if increase the sensitivity of the sensor to be able to detect mines with very little metal content, the device will fail to distinguish between a mine or a piece of buried metal (debris or cans) which generates a large number of errors or better known as false alarms. One way to reduce these shortcomings was presented by Guzman and Roa (2004) in what was known as metal discrimination which refers to the classification of metals detected within a group of metals previously established to rule out false alarms and subsequently by electromagnetic image of the terrain, the electromagnetic response of the buried material can be analysed. The implementation of these improvements in metal detectors was translated into savings of time, effort, money and more importantly, human lives.

Acoustic sensors: They are sensors that send acoustic waves into the earth. These acoustic waves are reflected in the boundaries between materials with different acoustic properties and the reflected waves were used to locate and identify the object. This type of detection depends on soil density, being more effective on wet and heavy soil than on sandy soils (Anonymous, 2011a-c). MIT's Lincoln Laboratory (Haupt and Rolt, 2005) had developed a high-powered sound transmitter that emits a powerful and narrow ultrasonic frequency acoustic beam which detects both metal and plastic mines. The low-frequency sound penetrates the earth and produces detectable vibrations in the plungers and membranes of the mines that rise to the surface and were measured with a Doppler vibrometer. The type of mine, the materials of which it was composed and the size of the mine were characteristics that can be determined by the way in which the vibrations that were reflected by the buried object were presented.

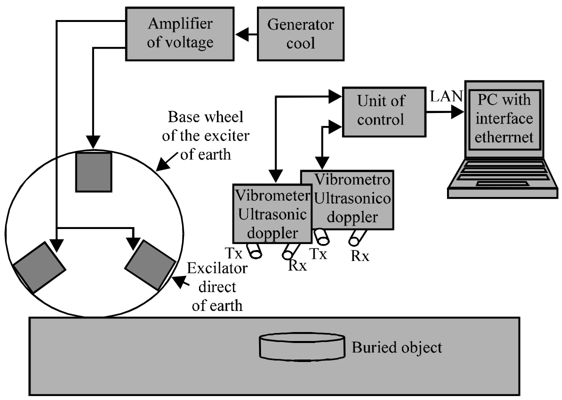

Fig. 3: Schematic block of the ALMD (Acousto-ultrasonic Landmine Detector; Rajesh *et al*., 2012)

Another development in detectors of buried mines using this technique was the acousto-ultrasonic sensor presented by Rajesh *et al*. (2012), a system of acoustic scanning for locating land mines and antitank incorporated in a vehicle, using an Innovative non-contact ultrasound technology that allows detecting both plastic and metallic mines in different soil, wet or dry conditions. Acoustic resonance images allow discrimination mines buried in the ground other objects, it had a scanning capability of 700 m^2/sec. The Acoustic-Ultrasonic Landmine Detector (ALMD) was based on the resonant vibration of soil and buried objects when the ground was excited by mechanical vibrations. The scheme of this detection method was shown in Fig. 3.

System based on infrared images: It was based on the fact that all bodies emit infrared radiation that was related to body temperature. At an appropriate temperature and spatial resolution, it was possible to detect anomalies in the earth generated by the presence of mines. Because each material had a characteristic response to a thermal stimulus, called Footprint Thermal, the process of cooling/heating affect differently the buried objects and soil as anti-personnel or anti-tank mines which generally have higher characteristics of insulating than the soil itself (Pardo, 2008). This first part of the infrared thermography which was based on the submission of the inspection area to a natural or artificial process of heating and cooling and the study of the ground response by analysis of the thermal evolution given by a temporal sequence of infrared images (Pardo *et al*., 2011).

The representation of the thermal spectrum of the terrain results in an unmistakable characterization of the latter. An efficient method for extracting information about

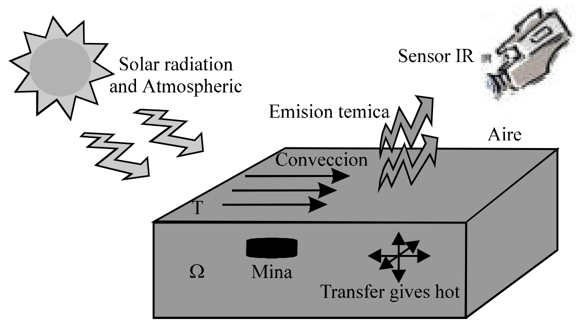

Fig. 4: Infrared Thermography for mine detection process (Pardo *et al*., 2011)

the presence of landmines was by thermal modelling 3D terrain based on the solution of the heat equation which was presented by Lopez. The major limitations of this technique were, firstly, that temperature differences were strongly influenced by atmospheric conditions and secondly, 3D modelling requires a very large computational load which leads to time and high costs. The influence of atmospheric conditions can be overcome using artificial radiation sources such as the laser in what was known as active thermography. The computational cost of this method was explained further in Pardo *et al*. (2009) as well asobtaining the thermal model of the land to explore. The general process that was considered in this technique was summarized in Fig. 4.

Nuclear techniques: The nuclear techniques shown below have been developed for the detection of explosive elements possessed by both conventional and non-conventional buried mines, regardless what they were composed of metal or plastic. These methods were based on penetrating radiation that was achieved through a portable electrostatic electron generator. It seeks to achieve the detection of gamma rays with very short wavelengths that were emitted by nucleus excited because of neutron irradiation. Subsequently, by means of specialized spectral analysis software, the constitutional elements of explosives such as nitrogen, carbon or oxygen can be determined. Thermal Neutron Analysis (TNA). All explosive materials contain a large amount of nitrogen that cause the emission of a gamma ray with 10.8 MeV of energy. In the presence of an induced neutron which gives a very clear signal of the presence of nitrogen in a buried artefact (Rosengard *et al*., 2001). Nuclear Quadruple Resonance (NQP). It allows the detection of explosive materials such as TNT or RDX due to their atomic properties. The signals to detect were very weak and the electronic requirements to generate the appropriate frequency conditions are still in development.

Backscatter X-ray: This was based on the passage of phot ons through the object and back-scattering of the X-ray which was used to provide information about irradiated buried objects. It was possible to produce high resolution images of buried mines since the bandwidth of the X-rays varies in comparison with the size of the mines. In contrast to other methods, this technique was a direct image as the dispersion of the signal was directly proportional to the material density of the irradiated volume (Niemann *et al*., 2002).

Techniques based on microwaves: His principle of operation was the microwave radiation inside the earth to analyse the waves that were returned. Signal feedback occurs when the sent waves meet a discontinuous surface. Higher frequencies provide a high resolution but they were also highly attenuated by the ground, making this method suitable for the detection of small and shallow objects (Suess *et al*., 2001). Some developments and results obtained with this technique have been presented by Peichl *et al*. (2003) and Bassey (2009).

Electrical Resistivity Images (ErxI): Detection of land mines using ERI was based on the detection of disturbances in subsurface continuity caused by the presence of shallow land mines. It has proven to be a fast and effective tool for the detection of non-metallicmines especially in conductive environments such as wet soils, beaches and marshy areas where the behaviour of other techniques shows great limitations. Like other geophysical methods, there were limitations when the surface was extremely dry or there was electrical noise near the mined area. Used in conjunction with ground penetration radar, it allows the detection of a wide range of both metallic and non-metallic land mines (Metwaly, 2007).

RESULTS AND DISCUSSION

Ground Penetration Radar (GPR): As mentioned above, GPR was the technique that currently has the highest development and best results for the location of landmines. Ground penetration radars have been used for sensing and non-destructive exploration of the subsoil for decades and among his many applications were fields as varied as agriculture, archaeology, sedimentology, hydrology, geology, mining, detection, mapping, among many others. Being a tool with such varied applications, it presents a great development in the acquisition, processing and interpretation of the data as well as numerical modelling of the signals (14th International Conference on GPR, 2012). This technique offers the highest resolution in subsoil images than any other method for geophysical applications. His depth exploration ranges from less than one meter to 3 km depending on the soil properties and the operating frequency range (Crocco *et al*., 2011). The following study will present an overview of the latest advances that have been made with this technique including the developments that have been developed in Colombia for humanitarian demining.

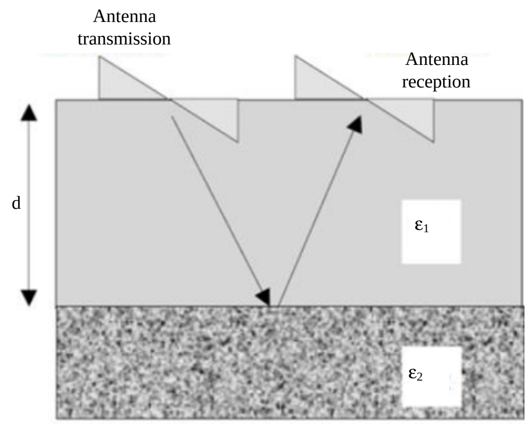

Fig. 5: Electromagnetic wave reflected by a geological boundary (Sato, 2009)

Ground penetration radar for humanitarian demining: The Ground Penetration Radar (GPR) was an electromagnetic technique that uses high resolutions to evaluate the location and depth of buried objects such as mines and pipettes, among other explosive devices. It operates by transmitting the electromagnetic wave that was sent inside the earth, by a transmitting antenna located close to the surface. The electromagnetic wave was reflected by several buried objects or the contact that exists between different types of materials (Sun and Li, 2003). The reflection was created by the abrupt change in the dielectric properties of the terrain such as relative permissiveness, relative permeability and conductivity. Additionally, the bandwidth of the electromagnetic wave had the possibility of providing the correct distance from the antenna to the buried object and the structural characteristics of the object (Wang *et al*., 2008). In Fig. 5, it was shown as the wave was reflected to find a material with different permeability ($\varepsilon 2 \neq \varepsilon 1$) at a distance d from the surface.

Once the reflected wave was generated and returned to the surface, it was captured by a receiving antenna. The other units that make up the system as the control unit which transmits synchronized pulses to the transmitting and receiving antennas and a computer or embedded system which was responsible for signal

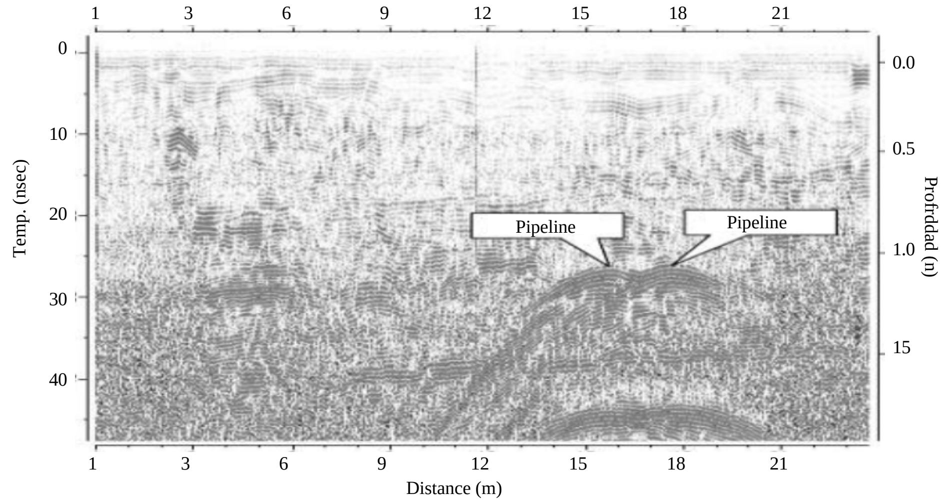

Fig. 6: Profile obtained by the GPR (Anonymous, 2011a-c)

processing. The ability of the GPR to detect objects depends on the bandwidth of the input signal, there was an inversely proportional relationship between the quality of the image that was obtained (the image quality was higher if the bandwidth decreases) and the depth of penetration of the signal (Abujarad, 2007).

This method was also known as Geo-radar and the main advantages that it presents were his versatility and speed for investigations of subsoil to depths of high rank. His main characteristic was to delineate the interfaces between the different materials that were in the place where the scan was to be carried out, this was achieved, if it was provided a considerable difference between the dielectric properties of the materials involved (Anonymous, 2011a-c). Figure 6 shows a typical image obtained from a GPR scan.

Despite the good performance presented by GPR, the use of high frequency waves in the detection process induces the presence of a group of factors known under the term "clutter" which may partially or totally hide or distort the response from landmines. These factors include (Soldovieri *et al*., 2011):

- The effects of antennas that produce multiple reflections and the distortion in the signal
- The electromagnetic properties of the terrain and the spatial distribution that determine the wave propagation rate, his attenuation and dispersion
- The electromagnetic contrast between the ground and the mine which was the propagation force of the signal from the mine to the receiving antenna
- The roughness of the soil and the heterogeneities inherent in it which can produce a diffuse dispersion

Due to the factors listed above, a common approach was the combined use of GPR with a metal detector in what was known as "Dual Sensor" for humanitarian demining. One of these was the dual sensors developed by Tohoku University (Sato, 2010a), known as ALIS for his acronym (Advanced Landmine Imaging System). ALIS provides 3D images that allow high efficiency in detecting buried mines. In addition to the implementation of the dual sensor, also it was necessary to develop appropriate techniques to reduce clutter and improve the detection and processing of the signals obtained. Some of these techniques were named in the following study. Depending on his principle of operation, the GPR method can be divided into four subcategories (Abujarad, 2007); Pulse Radar which researches in the time domain; Frequency radar of step, frequency radar of pulse step and frequency radar of continuous wave (in which uses the sequence of harmonic signals of the desired frequency with an exact fixed step) in the last one the data were measured in the frequency domain (Ivashov *et al*., 2011; Kabourek and Cerny, 2010). ALIS can select from frequency radar of step using a vector network analyser VNA and pulse radar, since, both methods use the same tracking system sensor. VNA was a combination of synthesizer and receiver synchronized. This was controlled by a CPU and can store data collected in his memory. The VNA adjusts the operating frequency of the GPR system depending on ground conditions (Sato and Takahashi, 2008). The radar pulse can generate a short pulse of approximately 200 ps covering a frequency range from CD to a few GHz. This type of sensor cannot change the operating frequency but had important advantages as low weight and high-ranking acquisition of data. ALIS uses rear cavity spiral antennas to transmit and receive data. The antennas

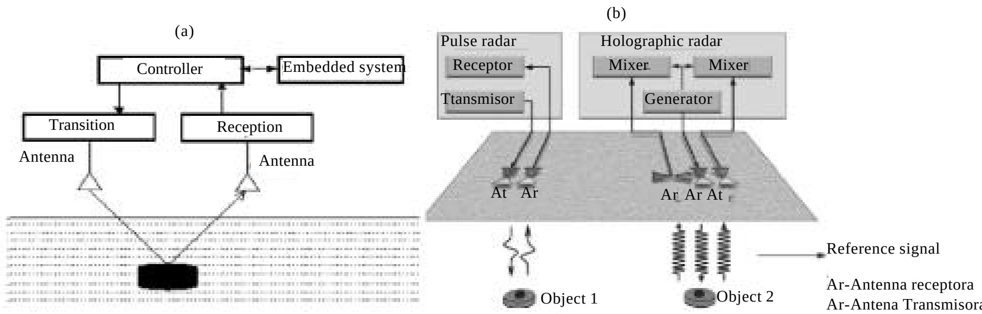

Fig. 7: General outline of GPR: a) Usual outline for the GPR system (Abujarad, 2007); b) Comparison between Pulse radar and the holographic radar (Ivashov *et al*., 2011)

were combined with a sensor coil for the metal detector. The location of the antennas as both the coils was optimized to avoid interference (Sato, 2010b).

Among the techniques developed in recent years, it was the use of the subsurface radar holographic (Ivashov *et al*., 2011) which although not as popular as the radar pulse or frequency step his use for the study objects and anomalies in the subsurface was an application area increasingly proven experimentally in exploration in heterogeneous soils with relatively high levels of attenuation and dispersion. It can replace or supplement radar pulse when it was necessary to obtain high resolution and accuracy for objects that were located at shallow depths where other models of GPR tend to have more difficulties (Razevig *et al*., 2010). The easiest way to design a holographic radar using a surface was coupled between the transmitting antenna and the receiving antenna signal as a reference signal. The antenna should guarantee the independence of the phase of the reference signal, the roughness of the surface resonance and heterogeneities of the terrain. Figure 7a shows an overview of basic operation of a conventional GPR system while Fig. 7b shows a comparison between the radar and the radar pulse subsurface holographic (Ivashov *et al*., 2012).

Although, the GPR was a known technique for several years, it was relatively recent his used in the recognition of buried mines. It has been widely used to investigate underground structures and buried in geology, civil engineering and environmental sciences objects. One of the first papers on the use of GPR in location of mine was published by Chignell (1996). In it proved possible the location of antitank mines plastic with a simple and classic radar detection techniques. Similarly, Craib and Chignell (1988), presented the results of the project for his time was the largest demonstration of the use of digital signals processed to analyse data from the scanned field and the use of GPR to find both plastic mines as metal.

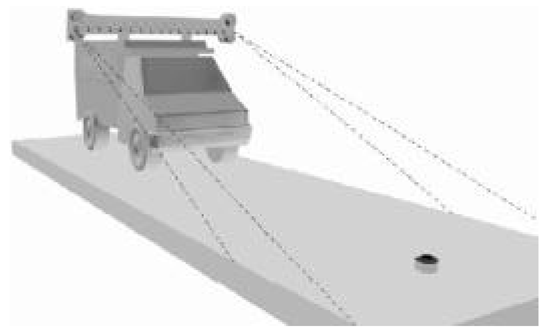

Fig. 8: The detection system FLGPVAR (Shi *et al*., 2011)

One of the main advantages of GPR was his easy implementation and operation, providing results in real time his ability to locate and characterize both metallic and non-metallic elements; The possibility of generating images of these based on the dielectric characteristics of the materials and their versatility in that it could be combined with other techniques such as EMI or ERI (Electrical Resistivity Imaging) elements. According to Chignell (1996) and Metwaly (2007), it was possible to combine the use of the GPR technique along with the incursion of Resistivity Electrical Images (ERI) for the detection of small non-metallic mines in conductive environments such as example gritty environments.

Among the latest developments in the GPR was exposed by Jin *et al.* (2012) for real-time detection of plastic mines and low metal content, known as Forward-Looking Ground Penetrating Virtual Aperture Radar or FLGPVAR for his acronym. It was a safe and reliable mine detection technique which forms 2D high-resolution images of the area to be demined. Had a long-range reconnaissance, it allows a wide detection area and provides high-speed performance. His implementation was shown in Fig. 8. Based on this same development Shi *et al.* (2011), presented a new classification algorithm of the signals obtained that seeks to minimize the range of false alarms that occur during the detection process mines, mine detection pose as a problem if the object reconnaissance FLGPVAR used and thus improving the detection capability of the system. Jin *et al.* (2012), use this same technique for draw-characteristics of mines buried with an array of multiple inputs and multiple outputs, obtaining high-resolution images of the area ahead of the vehicle where the minefield. Once again it seeks to reduce false alarms that were more frequent when working with a high probability of detection. As a result, an efficient vector of features for discrimination mine, seeking an increase in the detection behaviour was obtained.

Another study presents the influence of soil heterogeneity on the behaviour of a dual sensor. As it was shown above, the detectors consist of a GPR system mines that generally employ relatively high frequencies to detect small objects buried shallowly which increases system sensitivity to soil heterogeneity, decreasing the effectiveness of detection (Takahashi *et al*., 2012). The researchers propose a method which model the conditions of dielectric permeability of three different types of soil (laterite, sand and humus), evaluate the behaviour of landmine detection where the "Clutter" that can be seen in the detection process plays an important role in locating small objects in heterogeneous soils. This was because the performance of the GPR was not ideal when there was significant contrast between the dielectric properties of landmines and the environment in which they were so, you can present major faults on land drivers, inhomogeneous and presence of "Clutters".

In the case of Colombia, the behaviour of GPR to detect land mines and improvised explosive devices was studied by Lopera and Milisavljevic (2007), among other researches. The authors propose the use of a GPR system Ultra-Wide Band (UWB) for detecting mines of different materials in the environmental conditions of the country and further study the influence of soil characteristics and objects to detect for predict the performance of detection in Colombian minefields present specifically into two departments, Antioquia and Santander. Other applications of GPR in humanitarian mine clearance in Colombia was the methodology presented by Hernandez *et al*. (2011) for the implementation of a robotic development demining, it was based on the use of GPR and MD in order to recognize discard plastic and metal and metal objects that were not mine explosive devices. Similarly, another of the advances in this field was presented by Infodefensa which deals with the implementation of a portable detector system dual mines which integrates penetrating radar soil (GPR) and a metal detector, conducted by the University of the Andes in association with INDUMIL. The following section describes the main methods used for processing the signals collected by a detection system based on GPR, progress in the process of extracting the required signal characteristics and treatment that should be done to features that were extracted.

Signal processing: The detection methods described in the previous section allow obtaining signals of a different nature which were equivalent to the location, size and composition of landmines. Once generated the equivalent signal should implement signal processing algorithms and subsequently control algorithms for the correct identification of anti-personnel and anti-tank mines. This section present and provides an overview of the current state of the processing steps and identification have been implemented with location technologies landmine. Note that the main purpose of signal processing in the case of GPR was the reduction and eventual elimination of unwanted signals or clutter which was a complex task when taking into account that factors unwanted signals obtained vary in relation to the type of terrain, the type of mine and weather conditions which makes necessary a priori knowledge of the area to be scanned for proper disposal of own clutter in this area.

Many studies have been developed towards improving the quality of the images obtained from the radar to facilitate detection of landmines and to minimize economic costs and invested in the demining process time. As the GPR tool with multiple applications, some of the developments that have been made in recent years mainly have applications in fields other than mine detection. However, they have all contributed to improving the performance of GPR detection system and the quality of the images obtained from underground. Detecting plastic mines with GPR often have a difficulty: the weak response given by small mines low contrast that was often obscured by undesirable effects (clutter) as the coupling of the antenna and reflections given by the inhomogeneous surface of the floor. In order to reduce these setbacks that generate false alarms in the detection process and increase the efficiency and sensitivity of the GPR, Gonzalez-Huici (2012), presented a method of signal processing that compares responses simulated with real answers to improve the quality of detection. This method consists of two stages, the first in which the tracks were filter derived from model of the object model which reduces the volume of relevant data and eliminates unwanted echoes. In the second phase, before performing the detection, the pixels were removed whose magnitude was less than estimated through simulation for noise or "Clutters" in order to not take into account contributions that may be associated with signals unwanted. Nakano

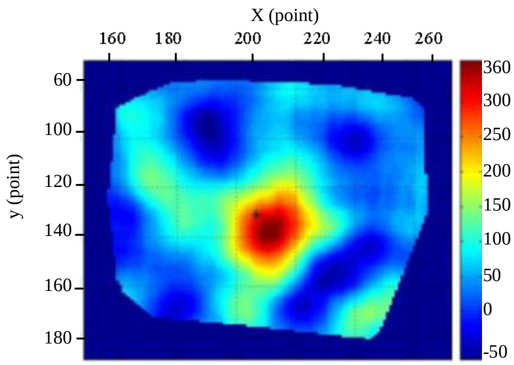

Fig. 9: Acquired image by ALIS, a minefield of Afghanistan (Sato and Takahashi, 2008)

and Hirose have developed two techniques based on frequency GPR staggered to improve the performance of the display system GPR plastic mines. The first, uses a Self-Organized Maps topology space (SOM-space) to stabilize the sorting process signals (Yukimasa and Akira, 2010). The other technique uses local correlations as the feature vector components in the frequency domain which allows better extraction of information. Sengodan and Cockshott (2012), presented algorithm simulated correlation (SIMCA), a technique that performs correlations between real traces given by the GPR system were taken in the scanning minefield and ideal traces that were obtained through simulations. To perform simulations, SIMCA calculates a GPR spread function based on the properties of radar and soil characteristics. Subsequently, filter unwanted components or "Clutter" from the signal to increase the detection quality, providing the operator of the detection system, an image that was much easier to interpret.

According to Sato and Takahashi (2008), the data acquired by the ALIS system were relocated in a regular grid of points by interpolation algorithms. Thereafter, the metal detector signal could be displayed directly on a horizontal image. The GPR 3-D images were reconstructed by means of Kirchhoff migration algorithm which gives each output signal a corresponding point of dispersion in the subsoil. One of the images acquired by ALIS shown in Fig. 9. Other researchers, like Feng and Sato (2005), using migration technique for image processing. This technique was now commonly used in the processing of GPR data has been used for nearly 5 decades in seismic reflection surveys. Essentially, this technique builds reflected by the target surface from the recorded surface.

Similarly, Soldovieri *et al*. (2011), presents a new approach for detection of all types of landmines based on advanced techniques of signal inversion of GPR and determining the dielectric permittivity of the medium, along with a strategy to remove reflections caused enter ground and air. Additionally, the use of microwave tomography to achieve better results in terms of the location and determining the geometry of the object when compared with common techniques migration occurs. According to the researchers, screening techniques were employed in an image of the subsurface constructed only with the GPR scanning before removing the clutter. These techniques include advanced algorithms hyperbolic detection, convolution models, migration techniques, among others. According to Kabourek and Cerny (2010), the data received from the detection of plastic through GPR mines were evaluated based on the method of Synthetic Aperture Radar (SAR) of two and three dimensions and the method known as Stolt Migration. The technique known as migration was generally used to move objects in a GPR image from where they were apparently where actually were located in real life (Sengodan and Cockshott, 2012). The GPR data were poorly represented due to the structure of the pulse transmitted and spread of the GPR signal. Stolt migration uses the wave equation to propagate back to the source the received signal and obtain an image of the reflection high structures in the subsoil. In order to classify the reflected waves that were useful, a threshold value was defined for proper identification of plastic materials. According to Kabourek and Cerny (2010), the data were below the threshold were discarded and those who were above the threshold were used to generate an image of the buried element. Thus, the threshold for the metal was 0.029 whereas the plastic was 0.12 because the reflection from the mine was less plastic. Other current methods for extracting features of landmines was known as UWB radar artificial opening. This method operates at low frequencies and had pervasiveness of land. It was a safe and efficient way to detect landmines because you can obtain high resolution images of objects in the ground over large areas. The classic framework of automatic detection of buried targets by UWB SAR was composed of the following three states: Formation of the image, preselection and discrimination. After the image formation, the present state running computationally efficient mask features on the image to determine localized regions of interest or ROIs. Each region of interest was extracted from the images from the SAR contains a suspicious object. A high probability of detection was desired for the preselection stage. The stage of discrimination classifies suspicious objects between objectives (landmines) and clutter, using computationally demanding algorithms, since, only be applied in the few ROIs that were identified in the preselection.

CONCLUSION

Throughout this study several existing techniques for the detection of anti-tank and anti-personnel landmines made of different materials such as metal, plastic and non-conventional explosive devices were presented. The current state of the global problem associated with the presence of landmines was presented, displaying the social and economic consequences of it and concluding that although they had passed several years, since, the official ban on such weapons, they continue representing a great danger for the civilian population in more than 60 countries. This was perhaps the greatest motivation to continue researching how to develop a detector capable of overcoming the difficulties of the process of locating mines and reduce time to allow clearance of certain area, ensuring the integrity of his operators.

Data on the current situation of minefields submitted by Landmine Monitor warn that emergency education was needed about the risks posed by mines in Colombia, Myanmar, Pakistan and Somalia as were the territories with most victims. The civilian population living in nearby fields to fields of war or where his presumed buried mines must know the methods of activating such devices as well as the danger to both children and adults represents were trying to defuse or detonate such devices without the proper equipment and training. To address this reality, the national government had provided various entities to contribute to the tasks of humanitarian demining, victim assistance and education on the danger of such artefacts. However, ignorance of the number of anti-personnel mines and unconventional explosive devices and their location within the country notes that there was still more development and research in the field before transforming back to Colombia in a free field of landmines.

Acoustic sensors, infrared imaging systems based and ground penetrating radar were the most development approaches presented so far in recent years. The principle of operation of these three methods allows imaging of subsurface that provide the necessary information on size, material manufacturing, deep and almost exact location of landmines. Depending on the type of terrain which count can choose either method. Despite this and development had been conducted in acoustic and infrared detectors, the Ground Penetrating Radar (GPR) was positioned as the most mature and most developed technique today, mainly because it allows use in areas with different electrical characteristics and allows the detection of small objects and buried at a shallow depth, as was the general case of landmines. The fact that it had many other geological applications other than the detection of buried mines contributed to the development of more and better techniques, data processing, extraction and classification of information from the GPR from subsurface images and it had improved the response time of the system, making it more efficient and quick scanning of large areas of land, increasing his functionality, accuracy and detection capability in multiple scenarios, reducing the false alarms and increasing the chance of detection at very advanced levels. Another of the great advantages of GPR was the ability to implement together with any additional technique such as the classic metal detector or images of electrical resistivity, delivering 3-D images of the subsoil and the location and depth of the target detected.

The main disadvantage of identifying mines buried by GPR was related to the presence of factors that can affect the performance of detection, better known as clutter, aspects of the terrain, the electromagnetic contrast between the field and the mine, among others. Clutter removal requires the implementation of signal processing techniques such as the use of SOM-space for classifying the features extracted from the signals or stolt migration which allows a real image of the subsoil, eliminating unwanted effects. Despite the good performance of GPR shown in real experimentation, it was not possible to ensure that it had a universal method to present a successful performance forall types of mines in all types of environment, although, developments in processing signals detected by GPR they try to approach this goal. The main reason for this was that there were many variables involved in the screening process and must be taken into consideration in each particular case before starting a process of mine detection. This demonstrates the need for a priori knowledge of the environmental properties where the mine to be located before carrying out any detection method described before.

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