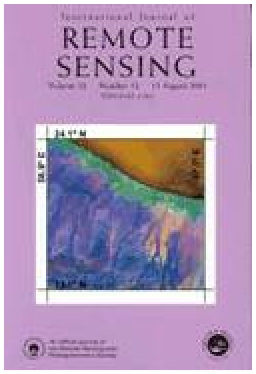

A Survey of Land Mine Detection Technology and Algorithms

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A Survey of Land Mine Detection Technology and Algorithms

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Abstract

This paper describes the state-of-the-art in Land Mine Detection Technology and Algorithms. Landmine detection is a growing concern due to the danger of buried landmines to people's lives, economic growth and development. Most of the injured people have no relation with the origin or reason why those mines were placed. There are between 50 to 100 millions landmines in more than 80 countries around the world. Deactivation is estimated at 100,000 mines per year, against the nearly 2 million mines laid annually. In this paper we describe and analyze sensor technology available including state-of-the-art technology like ground penetrating radar (GPR), electromagnetic induction (EMI) and nuclear quadrupole resonance (NQR) among others. Robotics, data processing and algorithms are mentioned considering support vectors, sensor fusion, neural networks, etc. Finally, we establish conclusions highlighting the need to improve not only the way how images are acquired, but the way how this information is processed and compared.

Keywords: landmine detection; GPR; EMI; NQR; Neural networks; Image processing.

1. Introduction

Land mine detection is a constantly growing concern due to the danger that buried land mines represent to people. Land mines affect people and civilians all over the world. Most of these people has no relation with the conflict, and most of them are children.

To begin this research, we define a land mine as a device designed to kill or injure anyone that comes in contact with it trough direct pressure or a trip-wire (Habib, 2001). The origin of antipersonnel land mines comes from World War II, where Germans and Italians improvised antipersonnel land mines with grenades and fuses in order to prevent allied soldiers from deactivating antitank mines placed on already determined defense lines (Russel, 2003). Land mines can be categorized in two types: Anti-tank (AT) mines and Anti-personnel (AP) mines. AT mines are larger and vary between 20 to 30 cms. in diameter, whereas AP mines range from approximately 5-15 cms. in diameter (Gader, 2002). Actually, there are more than 350 types of antipersonnel land mines being developed in more than 50 countries (Wen-Hsiung et al., 2007). Certain studies point out that there are around 50 to 100 million AP mines in more than 80 countries around the world. These mines kill or injure a person every 20 minutes, 70 persons a day, more than 20,000 people a year (Kowalenko, 2004). The cost of a mine is as little as $3 to produce one and as much as $1,000 to remove it.

Due to the long life of these mines, actual victims have no relation to the origin or reason why those mines were placed (Kowalenko, 2004).

The presence of landmines threatens people's lives, and also prevents much-needed economic growth and development. Long after wars are over, landmines make land unusable for farming, schools or living, preventing people from rebuilding lives torn apart by conflict.

If the actual land mine detection and deactivation rhythm of 100,000 mines per year continues, it is estimated that the time needed to remove all mines not counting new ones that will be placed, will be at least 500 years. Nieman et al. (2002) point out that this horizon will move away mainly because of new mines being constantly laid, because of the very limited use of technology for mine detection and clearance, and due to the lack of funds for detection.

It is expected that antipersonnel landmine use will decrease due to the 1997 Ottawa treaty that forbids new placement of mines. Additionally, Nobel Prize for Peace award given in 1997 to the International Campaign to Ban Landmines (ICBL) has helped people to promote a better awareness of the problem which has led to new fund assignment to develop new techniques in this area.

On the other hand, at a technical level, mine detection is a very complex problem far from being solved. Schreiner (2002) identifies two main obstacles for this:

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a) Land mines made today contain less metal and more plastic, making identification more difficult.
b) Mined areas may have metallic debris to avoid detection and identification, increasing false alarms.

Antipersonnel conventional mine detection has not evolved as much as one would like. Actually, the most widely used method for detecting and removing antipersonnel mines is directly by human beings, following the same techniques developed during World War II. Metal detectors for identification are used and a detailed and slow analysis of the affected zone is made. Every suspicious element found is meticulously checked.

In this paper we describe Remote Sensing technology available, data processing and algorithms, and finally we present conclusions about the state-of-the-art in landmine detection.

2. Remote Sensing Technology

In this Section, we describe the most important sensor technologies used in landmine detection.

2.1. Electromagnetic Induction (EMI)

Conventional mine detection has trusted mainly metallic mine detectors based on electromagnetic induction (EMI). This method is based on two bobbins, transmission and reception. The first one allows current to flow. The second one receives the induced current modified by the presence of a metal. Its main problem is its high false alarm rate due to the large amount of metallic objects or particles spread all over the field (Collins et al., 2001). This high false alarm rate makes detection slow, expensive and dangerous. Adjusting detectors implies missing some mines, causing new victims afterwards. Metallic clutter interfering in EMI responses has been studied and analyzed through the incorporation of statistical signal processing in order to mitigate the false alarm rates (Collins et al., 2001). This statistics-based approach involves detection and classification, incorporating independent component analysis in order to separate signals from multiple objects within the field of view of the sensor. Gao et al. (2000) incorporate a wideband frequency domain EMI sensor with an algorithm that considers uncertainties regarding target-sensor orientation and a theoretical model of the response of such sensors which is mentioned to gain over 60% average improvement over traditional matched filters approach.

2.2. Ground Penetrating Radar (GPR)

Difficulty in detecting tiny amounts of metal in a plastic land mine with a metal detector has led to the development of this technique which was first used on geophysical subsurface image acquisition and applications including utility mapping and hazardous waste container location. A radar signal is sent, and its reflected signal is analyzed according to dielectric variations produced from reflections from the soil such as the presence of an object (Habib, 2001). The resolution of the image is better if the wavelength is shorter, however, the shorter the wavelength, the better the soil penetration. Digital analysis of the signals plays a very important role in this kind of technology. Several good results have been obtained combining GPR and EMI (Collins, 2003). The great advantage of GPR is that it detects dielectric changes which are useful not only for metal detection but for a large variety of mine shields. A good point is that GPR can get horizontal sections of the subsoil at different depths, which constitutes a 3D image of the ground (Gader et al., 2001). Some of the main disadvantages are that inhomogeneous subsoil may cause a great amount of false alarms, and furthermore, performance is very complex according to complex interactions produced by metal content, radar frequency, soil mixture and soil surface smoothness (moisture, etc.) (Carin, 2003; Ralston et el., 2003).

GPR is considered as one of the best techniques for subsoil research. However, mine detection using this technique becomes very complex when clutter is present, keeping good and useful results hidden. This clutter varies according to the soil surface irregularity and soil conditions, which implies adding uncertainty to the measurement. Soil moisture plays a fundamental role in the performance of GPR, therefore its results depend on the knowledge of the prevailing weather conditions, soil type, soil water content, all of them variables that will have a deep effect on GPR performance (Rhebergen, 2003). For that reason it is necessary to have a good signal process in order to keep only mine generated signals. In order to reduce false alarms and detect real mines, several techniques have been developed. Some of the most important techniques correspond to Automatic Target Recognition (ATR), methods based on 2-D and 3-D texture analysis, subspace transformation techniques, background subtraction, hidden Markov models, wavelet decomposition, and several statistical approaches. Most of these methods work with the returning signal. In weak-contrast buried objects, especially buried objects under rough soil/air interface, discrimination is always difficult. Sato et al. (2005) present a statistical approach to get image forming from buried objects through a physical model using optics for surface representation and a Born approximation for weak contrast backscattered buried objects. All of the above to capture and relate the permittivity difference between the mine material and the surrounding soil. This statistical representation leads to reconstruction algorithms for buried objects.

Two methods for mine detection are proposed by Barkat et al. (2000), which are based on time-frequency analysis of the returned GPR signal. The first use instantaneous frequency (IF) of this signal, which consist in displaying the signal's spectral components using the peak of the Wigner-Ville distribution (WVD), with apparently good results. The other method is energy based detection using another time frequency approach to detect the presence of a buried target in the soil. This method is based on a discriminator algorithm that uses the WVD difference of a pair of signals, aiming to distinguish a buried target from the GPR trace from no target (Barkat et al., 2000).

Clutter reduction through data processing and parametric modeling is approached through an algorithm that improves signal processing techniques by incorporating an adaptive basis function for clutter representation, minimizing shallow depth objects returning image, adding the use of a matched filter to account for uncertainty in the placement of the mine (Van der Merwe and Gupta, 2000). Another approach on this subject focuses on clutter modeling using parametric modeling. A procedure called *Kalman method* reduces most of the clutter to zero while preserving the shape of the original signal (Kempen and Sahli, 2001).

2.3. Nuclear Quadrupole Resonance (NQR)

This method relies on observation of radiofrequency (RF) signals from the ^{14}N nuclei present in explosives. The frequency of these signals oscillate between 0.5 and 6 MHz, and they are characteristics of a given explosive. They provide not only a positive identification, but also an estimate of quantity or depth. Rowe et al. (1996) establish a procedure that behaves unlike the typical nuclear magnetic resonance technique as no static magnetic field is needed, so portable probes can be used. Signals are seen only as solid or solid-like materials, avoiding interference from other nitrogen-containing materials that may be present in the mine casing or surrounding areas.

This technique has been proved to be highly effective if the NQR sensor is not exposed to radio frequency interference (RFI). A robust detection method should be used, since RFI may be unavoidable (Yingyi et al., 2002).

2.4. Infra Red (IR) and Hyperespectral

These methods detect anomalous electromagnetic radiation variation reflected or emitted over the mine surface or soil immediately over the mine (Nelson, 2000; Batman and Goutsias, 2003). The idea is to get reflected energy from mined areas where its reflection differs from surrounding areas. We include thermal sensors that make use of this difference in temperature variations between the soil and the mines mainly due to the night and day thermal oscillation (Boras et al., 2002). This method has a high performance only in homogeneous soil. Laser illumination or high power microwave radiation may be used to induce these differences. They do not need to have physical contact with the surface, the equipment used is light, and image acquisition is fast. As a disadvantage we consider that its performance is variable and depends on characteristics of the environment (Ackenhusen, 2003; Baertlein, 2003). Some authors say that these sensors need to grow up a little, so for the time being it is better to "wait and see" (Boras et al., 2002).

Considering the risk in close detection, Shimoi et al. (2001), present a research in remote detection through IR cameras by peripheral temperature difference considering data between the ground and the mine. The use of infrared thermography is one of the greatest improvements for mine detection. Muscio et al. (2004) focus on the development of research tools where the chance of success can be enhanced. A two-dimensional axial-symmetrical thermal problem is obtained in order to define a procedure that would correlate field temperature measured indoors, in a test case, with reduced size and duration, and the one obtained in an outdoor mine detection campaign, enabling them to produce enough reference data for theoretical comparison and experiments.

2.5. Electric Impedance Tomography (EIT)

This system uses electricity to generate an image of the conductivity distribution. It has a bidimensional array of electrodes placed over the surface that catches signals from the distribution of the conductivity that can give information about mine presence. This system allows detection of metallic and non metallic objects due to conductivity anomalies. It behaves well in wet soil and the equipment is relatively cheap and light. A disadvantage is that sensors must be in contact with the surface, therefore increasing the risk of detonation. They do not work well in dry soil like desert or rocky surfaces because of weak conductivity. Moreover, it is useful only for objects close to the surface (Church, 2003).

2.6. X-Ray Backscatter (XBT)

This technology has the potential for low false alarm rates and high detection probability. This technique is used to obtain the image of an object through X-rays passing through matter with an attenuation consequence (i.e. absorbed or scattered) (Nieman et al., 2002). Since it is impossible to capture photons that penetrate the soil due to the impossibility of placing an X-ray detector under the mines, these system use the “Compton principle” of X-ray dispersion. This means that photons are captured from irradiation from the object. This allows having an emitter and a receiver over the surface (Grodzins,2003). The use of this technology has three main advantages (Nieman et al., 2002): scatter signal is directly proportional to the density of the material in the irradiated volume, it requires only single-sided access, and high image contrasts are achievable, meaning that XBT has a high potential for imaging purposes.

The use of this technology is limited by the depth of the mines, since mines buried deeper than an average of 10 cm will not provide an adequate level of noise signal. Furthermore, it will be necessary to implement procedures to avoid exposure to irradiation by handling personnel (Jacobs and Dugan, 2003).

2.7. Acoustic and seismic

These systems emit sound waves through speakers in order to get vibration over the soil. The sensors used capture reflected waves from the soil and the mines. The difference in amplitude and frequency makes detection possible. There are special sensors that do not need to be in contact with the surface. Some experiments point out that this technique is better for antitank mine detection (Sabatier, 203). These technologies capture mechanical differences between the soil and the mines, and they can complement the information obtained from EMI sensors. This system presents a low false alarm rate, however bottles and cans may deceive the detector. Disadvantages are related to failure in detecting deeply buried mines and checking speed is extremely slow: between 2 to 15 min/m ^{2} (Donkoy, 2003). There is also some research in ultrasound use in order to characterize underground materials (Markucic, 2002; Stepanic, 2002). However, research is still needed to determine the operational framework for this technique.

2.8. Vapor sensors

A small percentage of the explosive manages to get out, as vapor, through fissures and shield structures of mines (Jenkins et al., 2003). The idea is to detect the presence of vapor from explosives. There are two research lines in this topic: biological and chemical.

Biological methods use animals (mainly dogs), insects and microorganisms to do the detection. They have the capacity to reduce false alarms since there are no similar explosives coming from rocks or debris (Burlage, 2003). Dogs have had a good performance in detection. They can detect minor vapor concentrations (Phelan, 2003). A great disadvantage however is that this method depends on dogs individually, considering a heterogeneous universe. There is some research with bees and bacteria, but with no convenient results whatsoever (Bromenshenk et al., 2003).

Chemical methods are referred mainly to vapor from TNT, RDX, and PET, therefore they may be considered as underground vapor sources. This vapor may be transported by phenomena such as molecular diffusion, adyectives and turbulence processes (Jeremic and Nehorai, 2000). The idea of this method is to build sensors capable of detecting smell using electromechanical principles, piezoelectric or espectropical (Jenkins et al., 2003; Swager, 2003). There are still some limits in this research area due to the inability to establish a minimum detection level due to the variable nature of vapors.

2.9. Robotics

The problem of detecting mines in a surface-laid minefield using autonomous robots is getting stronger because it decreases the danger and the cost involved in manual detection (Acar et al., 2001).

As path planning techniques involved in robotics, Acar et al. (2001), have investigated some methods. The first one is a sensor based coverage according to exact cellular decomposition in terms of critical points. The robot executing the coverage algorithm incrementally constructs this cellular decomposition while it is covering the space with back and forth motions. The second one considers where time is limited and there exists a priori information about the minefield. This method is called probabilistic and it works with minefield parameters extraction. Once the parameters are determined, the minefield layout is fixed, allowing opportunistic robot guidance to decrease demining time. Zhang et al. (2001) propose a probabilistic method for robot landmine search. It focuses on optimization search strategy determining location of mines and/or unexploded ordnance. They first extract the characteristics of dispersion pattern of the minefield in order to construct a probability map and then design a path for the robot searching.

The development of lightweight, low-cost, semi-autonomous robots working together with a monitoring station (Personal Mine Explorers) is a well researched approached (Nicoud and Habib, 1995). Robots search mines with such a low pressure that mine explosions are not triggered. In order to cover efficiently all mined area, robots should get used to accelerated exploration in order to get the best efficiency, especially if any surveillance team exists.

Multi-robot systems for area reduction is the next step in landmine search. Some research has been done considering a multi-agent based architecture responsible for coordinating a progressive stochastic analysis of the terrain (Santana et al., 2005). It includes a reactive obstacle avoidance method, and the development of a mission control software to plan, configure, and supervise operations. The system uses legged, wheeled, and aerial robots. Finally, a sensorial payload system is described in this research with the use of Fourier analysis (Fourier transform) as the mechanism to effectively detect mines.

3. Data Processing and Algorithms

Data processing and algorithms will determine finally if the object's image corresponds to a landmine or not. This aspect is probably the most important in landmine detection because technology is not currently showing big changes, however detection algorithms will probably play a significant role in improving performance.

Support vector is an interesting method where anomaly detection in hyperespectral images is identified, therefore improving detection of the spectral signatures of unknown targets (Banerjee et al., 2006). The support vector data description is a technique that has been used in other domains such as faulty-machine-part detection and image retrieval.

Fusion is a growing technique in which getting information from several detection system becomes relevant. Output information from different modules (systems) is grouped and compared, getting full potential from every available method, avoiding the weaknesses of each.

Sensor fusion in landmine detection states the difference between data fusion and data integration. With respect to data fusion, a multi system includes three main levels: raw data level, vector level, and decision level (Rennie and Inggs, 1997). In the raw data level each sensor's data is combined. In the second level, each sensor analyzes the raw data and produces a feature vector where its further coordinates will be combined to obtain a fused vector. Finally, in the third level, each sensor analyzes the data, produces a feature vector, and then makes a decision of what feature vector is being described.

Neural networks is another approach with a natural skill for automatic target detection. In this topic, automatic target detection using entropy optimized shared-weight neural networks is an interesting research that compares standard shared-weight neural network performance (which is stated as inferior) with a morphological shared-weight neural network for automatic target detection (Khabou and Gader, 2000). The first algorithm is improved by an entropy maximization term added to the method, and the results are compared between entropy trained and non-entropy trained data sets, concluding that the proposed optimization increases performance in detection.

Hidden Markov models (HMM) are used with some success through two and three dimensional vector sequences (Gader, 2002). Gader et al. (2001) show a method for detecting signatures through HMM. This method is evaluated in real data with a principle of transforming a GPR signal in a sequence of time dependent observation.

Bayesian network (BN) representation of a sensor's measurement process is developed so the problems of sensor fusion and management can be approached from a unified point of view (Ferrari and Vaghi, 2006). This method uses a priori expert knowledge of the sensor's operating principle and available databases of actual sensor data to build a probabilistic model of the measurement process. This system works with GPR, EMI, and IR sensors. It shows that BN models are capable of inferring target features by considering single or fused sensor measurement and known environmental conditions.

Decision fusion considers numerous detection algorithms and sensor modalities where detection algorithms are combined and fused into a common database. Liao et al. (2007) exploit the strengths of existing multisensor algorithms in order to achieve the required performance, exceeding those of isolation operating sensor algorithms. This approach is based on signal detection theory using the likelihood ratio. It considers a GPR and a metal detector.

Digital filtering for GPR signal enhancement is presented by Potin et al. (2006), aiming to reduce clutter noise in dielectric transmissions, which constitute a mayor problem in shallow depth buried mine detection.

Several other methods look for improvement in landmine detection like fuzzy clustering (Frigui et al., 1998), inductive learning as a fusion engine (Kercel and Dress, 1997), ROC optimization (Wen-Hsiung et al., 2007), etc.

4. Conclusions

Humanitarian demining continues to be a world problem far from being solved. We have described some of the new technologies of landmine detection, some methods of process and identification of landmines and algorithms. There is no single method for efficient landmine detection. Several technologies can be found, but their direct results can not be generalized. There is work to be done in fusion of landmine detection technology in order to enhance its performance, since every approach has good results within limited conditions.

Due to the aforementioned limitations, a multi-sensor system based on signal and algorithm fusion should be developed (Collins, 2003; Russel, 2003). There is lack of information on image processing techniques, especially segmentation, feature extraction, classification and post processing of characteristics, edge detection, texture, multiple view, and digital image processing techniques including image restoration, enhancement, image processing and compression, wavelet transform, and object recognition. All these aspects should help in discriminating useful data, a critical point where great amounts of false alarms help to increase uncertainty, causing limitation in future research.

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