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Sensors For Landmine Detection And Techniques: A Review

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Abstract

Many of the technologies has been developed and tested across various test sites and in different Envoirment for detection of Landmines. This paper brings focus on available technologies for buried explosive detection with the help of number of available sensors. Various sensor technologies like Infrared sensors, ultrasound sensors, X-ray used to frame image subsurface at various depths. Technologies like Electrical Impedance Tomography (EIT) uses conductivity distribution underneath soil to make prediction about underlying metallic or non metallic objects. Explosives vapor detection (EVD) techniques make use of chemical composition of material for potential detection. In other way technologies like Ground penetration radar (GPR) uses very high frequency electromagnetic waves to image subsurface soils. Data gathered from precise sensors and then processed to find out anomalies by signal and image processing techniques such as feature extraction by texture mapping or by analyzing spatial conductivity distribution over the surface of interest. Processing techniques are developed in a way to enhance detection probability and to reduce false alarm rate.

1. Introduction

In warfare most of causalities are done by buried landmines. The unexploded landmines take several lives even after end of a conflict. Brutal properties of landmines is once it is active, it can be functional for a very long time. Hence there is always a risk of fatal damage and injury causing death. Landmines became effective weapon in warfare as it is cheap and easy to build. Basically, it consists of explosives along with some triggering mechanism. Triggering may be caused by weight. There are several types of landmines depending upon weight it needed to get triggered. When ready, they are buried at shallow depth in soil and hence not easily get spotted with bare eyes. Someone not aware of presence of mine can step over it causing itself fatal damage because of the explosion. [1] Landmines can be buried in certain pattern to restrict enemy movements. Zigzag pattern slows down advancing enemy; or mines can be deployed causing enemy to diverge their path and leads them in to middle of an ambush. Because of these many characteristics they are found to be very effective weapon as they can be deployed easily and they remain undetected, fully functional for very long time.

Number of nations became victim of this disaster like Cambodia, Angola, and Afghanistan etc. [2] In Cambodia one out of 236 people became handicapped and casualty ratio is even higher; one out of 140 people in countries like Angola because of mine explosion. [3] The most tragic fact is; innocent people like women and children working in farm, water canal and road construction are very high in number amongst the victims. Hence there is need of mine detection technology to remove and dispose them to prevent financial as well as loss of lives.

There are more than 350 different types available but mainly they can be classified in two categories as Anti Tank Mine (ATM) & Anti Personal Mine (APM).[1] Functional operation of both are same, only difference is ATM has more amount of explosives enough to destroy armed personnel and APM's are smaller in size and contains less amount of explosives than ATM. There is difference in pressure required for detonation also.

Technologies like metal detector [MR], Infrared detectors [IR] and Ultrasound are available for prediction of possible detection. Electromagnetic methods use RADAR signals for detection of anomaly. These devices can be mounted on hand held devices, but to prevent risk of human life they can be fix with unmanned vehicles. Some of nations developed airborne systems that can scan landscape and process available data for the prediction of mines. [4]

2. Classification of Mine

Mines can be classified in two broad areas as Anti Tank Mine (ATM) and Anti Personal Mine (APM). There are also some misfired or undetonated explosives which are named as Unexploded Ordinance (UXO). These UXO can be found on battle field. These are typically bomb shells which are fired but due to some reasons did not explode. Table 1 gives the details of all three types of mines. [5]

Table 1. Different Types of Mines

TYPE	UXO	ATM	APM
Target	Unspecified	Armed personal	Human
Weight	Various	Heavy (6-11 kg)	Light (0.1-4 kg)
Size (in diameter)	Various	Large (13-40 cm)	Small (6-15 cm)
Case material	Mostly metal	Metal, plastic	Plastic
Detonation pressure	Unpredictable	120 kg	0.5 kg

In the figure 1 shows different types of mines. Figure1 (a) and (b) shows ATMs TM-62M and TMA-2 respectively. Figure 1 (c) and (d) shows PRB-M35 and VALMARA-69 APM respectively. Triggering pressure also varies for both. Table 1 gives information about different factors like weight, size and detonating pressure. [5]

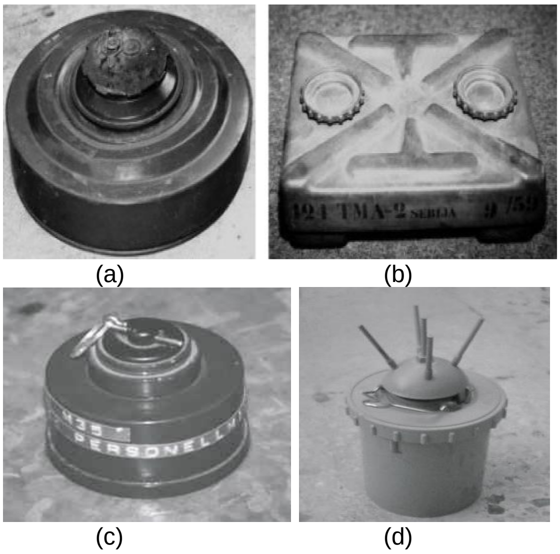

Figure 1. ATM and APM mimes

3. Sensor Technologies

To grapple with problem of mine detection various techniques are evolved and developed. Different sensors are utilized to see through thick layer of soil. It is found that these are highly dependent on surrounding Envoirment. Data available is raw in nature hence affecting performance; but it can be forestalled by some pre-processing techniques.

3.1. IR (Infra Red) Sensors

Infrared radiation consists of wavelength of $.7\mu m$ to $1mm$ in microwave regions. [6] Even all EM radiation produces heat, IR radiation detected in form of heat. Every material acts as source of infrared radiation and radiation differs with temperature. Hence IR detection is also called as thermal detection. IR detectors are available in two types i.e. Active IR systems and Passive IR systems. A passive IR system detects natural radiation from the object whereas active systems are provided with heat source and detects radiation from heated object. [7]

3.2. Ultrasound Sensor

Ultrasound frequencies are frequencies above audible range i.e. 20KHz. Sound wave travel in the form of disturbance of molecules in the medium in form of waves. [8] In a Homogeneous medium sound wave travels along the straight line as there is no change so far. But when other medium is encountered, sound waves get reflected and refracted. Behavior of propagation at boundary of two different medium is affected by speed in other medium and density of medium. Ultrasound system emanates high frequency sound waves in the ground. If other material is encountered such as metal buried in soil, speed of wave and line of propagation will change. The reflected waves are processed to make prediction about buried object as wave travel with different speed in different material. Frequency plays major role in depth of penetration. Ultrasound wave travels through humid conditions with less attenuation but gets attenuated in air.[6]

3.3. EIT (Electrical Impedance Tomography)

EIT basically adopts conductivity distribution for making prediction about presence of mines. Conductivity distribution incurred by electrical current that passes through two arrays of electrodes placed on area under consideration. Data is gathered from pair wise combination of electrodes, and is then processed to get an image of conductivity distribution profiles of subsurface media. An anomaly created in an image concludes the presence of metallic or non metallic objects. [13]

3.4. X-Ray Backscatter

X-Ray imaging can be effectively used for detection of landmines. It cannot image the subsurface view albeit wavelength of X-ray is much smaller than size of mine. But backscatters for ground surface provide ample information about objects buried in soil. Backscatters used in two ways; by aligning highly focused beams with detectors which implicitly reduces required photons for imaging. In other way; X-ray used to illuminate wide area and then spatial filters are used to deconvolve the system response. Such methodologies are adopted in hand held systems. [13]

3.5. Explosives Vapor Detection Technique

The technique is unique in its way as it does not consider any mechanical properties as shape and size nor the material of which mine is made up of for example casing. It makes use of chemical properties which are derivatives of chemical composition used in the making of explosives used in mine. When mine is buried in soil; they relinquish chemical vapor in surroundings. Contamination of surrounding by these vapour product is very low but still detected by sensors. Sensors used in such technique need to operate at low threshold levels. Natural resources such as trained dogs found very useful for detection of explosives using this technique. [13]

3.6. Ground Penetration Radar

GPR consist of sensor or array of sensor; each sensor emits the EM wave. These waves are travelled through the medium and get reflected and refracted depending upon properties of conducting medium. [6] Reflected EM waves are received by receiver unit. Key point to detect presence of anomaly is signal strength as it tend to deviate when it encounters object with different electrical properties with reference to conducting medium. Depth of object can be found by time elapsed between transmission and reception moments of signal. Thus, GPR can provide both presence of object and location beneath soil. GPR somehow works same as ultrasonic sensors; difference is the operating frequency is from 100MHz to 100GHz. Ultrasound waves easily penetrate medium with high degree of humidity and air is resistant where as EM waves behaves in exactly opposite manner.[6] EM waves highly reliant on certain properties of soil like moisture content, homogeneity, electrical properties. Prior knowledge of these parameters alleviates further processing and heightens accurate detection. [9]

GPR A, B, C scan. Data for processing is collected by firing multiple sensors one by one and response from every sensor is collected. Hence it will form a two dimensional matrix where one of dimension represent array axis and other is depth of penetration. Depth can be changed by firing respective sensor with gradually decreasing or increasing frequency. Lower the frequency; higher will be the depth of penetration and vice versa. Response from individual sensor is being called as ‘A scan’. Aggregated response from every sensor gives ‘B scan’. Multiple B-scans when arranged in tandem produces three dimensional ‘C scan’.[9]

4. Data processing Techniques

Primary goal of this step is to make data more viable to extract feature for correct detection of presence of landmine. Generally when buried object is scanned by array of sensors throughout the length of the concerned area; it is found that hyperbolic signature immerged as one moves gradually along the length. These signatures are found in B scan image. Raw data is very arduous to process further as practical limitation of sensor leads to low resolution and highly degraded information. Dependency on nature of soil makes problem even worse. To overcome these serious problems some of the pre-processing techniques [2] like noise filtering, contrast stretching, mathematical morphological and clutter removal techniques are used.[10] Profound study of literature comes to conclusion that these pre-processing steps enhance accurate detection rate also reduces false detection.

5. Feature Extraction and Testing

Methods are commonly used in process of demining are like GPR, EIT and EVD.

5.1. GPR

GPR produce huge amount of data. Features needs to be extracted from available data which are nothing but minimum data to represent prominent information about presence of the object and suppressing redundant information. Feature set can be extracted from spatial as well as in frequency domain. Discrete Cosine Transform (DCT) popularly used in image and video compression is one of example to reduce redundant data. Texture Feature Coding Method (TFCM) is one of the methods for extracting features in spatial domain. As described [11]; intensity image is translated in to texture feature number (TFN) by taking difference in spatial domain with reference to some mapping. In this difference vectors are computed along vertical, horizontal and diagonal direction and values are quantized to {-1, 0, 1} depending upon weather difference is negative or positive or no difference respectively. Next step is to map quantized vector to gray level class number based on degree of variation.

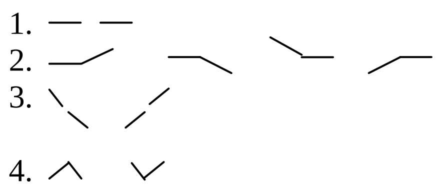

Figure 2. Graphical representation of difference vectors

Figure 2. Shows different types of gray-level graphical structure variations and corresponding gray-level class numbers (1–4).[11] Where Horizontal line indicate no difference. Lines inclined vertically upward indicate positive difference and line inclined vertically downwards indicate negative difference.

These gray level class numbers are combined to a single initial texture feature class number.

Table 2. Initial texture feature class number

Gray level class 1 (columns); Gray level Class 2 (rows)

	1	2	3	4
1	1	2	3	4
2	2	5	6	7
3	3	6	8	9
4	4	7	9	10

Table 2. Describes the mapping of gray level class numbers to obtain initial texture feature number (IFN).[11]

Table 2. Gives pair of initial texture feature numbers which are further mapped to texture feature number (TFN) by using mapping shown in table 3. [11]

Table 3. Mapping of IFN

Initial Feature Number (IFN)1											
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
I	**1**	0	1	2	3	4	5	6	7	8	9
F	**2**	1	10	11	12	13	14	15	16	17	18
N	**3**	2	11	19	20	21	22	23	24	25	26
	4	3	12	20	27	28	29	30	31	32	33
2	**5**	4	13	21	28	34	35	36	37	38	39
	6	5	14	22	29	35	40	41	42	43	44
	7	6	15	23	30	36	41	45	46	47	48
	8	7	16	24	31	37	42	46	49	50	51
	9	8	17	25	32	38	43	47	50	52	53
	10	9	18	26	33	39	44	48	51	53	54

Table 3. describes mapping of initial texture feature number to texture feature number. This mapping gives a matrix where every element of matrix indicates degree of level of variation.

At this point concepts like gray level histogram and co occurrence matrix are applied to extract features like variance, convergence, uniformity, entropy and energy distribution which gives feature vector. This feature vectors can be classified using pattern recognition tools like RVM based on a sparse Jeffrey's prior for feature Classification. Results conclude that about 90% of success rate achieved [11] without rigours attempt to pre-processing techniques.

Alternatives for feature extraction and recognition process further described by considering hyperbolic curvature properties. As described [12]; maxima in each time sequence of B scan is found and the process is repeated for forthcoming time sequence until all end of an all scans. Then next step is to find out polynomial equations that fits the maxima point. Amongst the maxima; maximum value of a point itself serves as one of the feature and named as strength of the curve. Hence; strength of a curve and coefficient of the polynomial forms feature vector. Hidden Markov Model (HMM) is discriminates between the feature vectors for making decisions like mine or no mine.

5.2. EIT

EIT basically consist of array of electrodes. A pair of electrodes is fired and all other remaining electrodes are used to measure potential difference. Data gathering is completed after every combination of pair. Processing techniques are then applied to reconstruct the image of electrical conductivity distribution. Anomalies in an image can be concluded as presence of mines. EIT is basically impedance (Z) measurement device which uses four electrodes to accomplish impedance measurement. Two electrodes are stimulated by current that initiate electrode flow (I) and other two electrodes measures potential difference (V). Impedance can be measured by Z= V/I. [15]
Once data is available; it can be reconstructed by the process which is characterized by sensitivity matrix approach. Flow of current in region V can be standardized by electromagnetic wave equations.[15]

$$\nabla\,(\sigma\,\nabla\varphi) = 0\ in\ V. \qquad (1)$$

$$\sigma\,\partial_n\,\varphi = i\ in\ \partial V. \qquad (2)$$

Equation 1. and equation 2. Represents parameters as σ the electrical conductivity, φ *is* the potential, and i is a surface current density on the boundary ∂V of V. Solving above equations results value of σ with priory knowledge of current source i and φ. By rearranging above equations one can get [14] equation 3. As

$$\delta Z = S\ \delta\sigma \qquad (3)$$

In equation 3. δZ is an *n* element difference vector that highlights difference between transfer impedance for pair of electrodes under consideration and transfer impedance proclaimed by homogeneous semi infinite model for same electrodes [15]. S is sensitivity matrix. Solution of equation 3 needs inverse of S. But it is not a square matrix. Various methods utilized by many group to find pseudo inverse; one of them is probabilistic maximum a posteriori (MAP) method. In this method initially S is exemplify by product of three matrices by making use of singular value decomposition (SVD) as in equation 4.

$$S = U \Lambda V^T \quad (4)$$

In equation 4. U And V are square orthogonal matrices of dimensions $n \times n$ and $m \times m$, respectively. Λ is a no square $m \times n$ diagonal matrix. The superscript T denotes the transpose of the matrix. The pseudo-inverse of S can be written by following equation 5.

$$S^{-1} = V \Lambda^{-1} U^{-1} \quad (5)$$

Equation 5. serves as basis to compute conductivity reconstruction can be formulated by

$$\delta\sigma \approx S^{\#} \delta Z \quad (6)$$

In equation 6. $S^{\#}$ Represents Moore-Penrose pseudo inverse. [15]

Anomaly detection algorithm uses equation 6 as a base that can be characterized by size as well as shape of mine. Detection algorithm utilizes matched filter approach. Detector response of replica is calculated for various grid locations below the surface. Next; correlation is computed between detector response for replica and actual detector response for all positions of replica. A position that contributes to largest value of correlation treated as most likely position of mine.[15]

5.3. X-ray Backscatter

Principle of X-ray backscatter imaging is whenever photon with energy less than twice the mass of electron encounters an object; two main consequences appears are Compton scattering and Photoelectric effect. Compton scattering found proportional to the material density [17] and serves as foundation for backscatter imaging as it shows density variation for the area under consideration. Photoelectric effect brings out different energy dependence. Hence both of the process used simultaneously to find out target density. Main goal remain in front of backscatter imaging technique is to ascertain vertex of scattered photon to customize spatial distribution of scattering material that potentially help in target identification. Focusing by ray optics could be a potential solution but still challenging as photons scatters multiple times and each time reduce the information from previous scatter [16]; such problems can be overcome with proper collimation technique. One of them is Coded aperture technique used in many applications including medical nuclear imaging. In this technique accurately design collimator known as mask that consist of pixels or plates which are either transparent or opaque; placed in between source of photon radiation and position sensitive planner detector. As design of mask is known; photon distribution can be obtained by [16] convolving detector response with the response caused by mask.

Planner detector gives a 2D representation; matrix D; of response in which each matrix element is a detected value. The mask is then represented as matrix A where each element has value 1 if pixel is transparent and 0 otherwise. Now if area under scanning is partitioned in subareas then every segment represents source distribution matrix S in which every value represents number of photon emanated from respective segments. Hence detector response can be found out by [16] equation 7.

$$D=S*A+B \quad (7)$$

In equation 7; * represents correlation operator and B is for noise components.

Let G is the matrix which satisfies equation 8.

$$A * G = \sigma \quad (8)$$

In equation 8; σ is Kronecker delta function; then approximate source distribution $S^{\wedge}$ can be obtained as [16]

$$S^{\wedge} = S + B * G \quad (9)$$

Equation 9. is the basis of imaging technique as provided detector response D and knowing G which is mathematical representation of mask one can get approximation of source distribution in interested segments which is further processed for target detection.

6. Summary

All available technologies that contribute to the target detection buried in soil have been influenced by near field Envoirment. But options available for detection bring down the tampering of the success rate.

In case of Ground penetration radar (GPR) it is found very effective in finding variety of targets as its response is influenced by electrical properties of material. Some facts that limits the effective use of GPR is subsurface inhomogeneities; moister content of soil and smoothness of ground surface.[18] Along with this; GPR tuned to high frequencies therefore probability of missing mines in shallow depth is very high as well as high frequencies causes low resolution images. Electrical impedance tomography (EIT) found suitable for soils with high moister content; like near beach landscapes. But it needs physical contact with land hence there is always risk of detonation of mine. EIT has comparatively low resolution as that of GPR.[18] X-ray backscatter found potentially accurate in detecting mines but still land with some serious problems as required energy range gives poor soil penetration. If source strength is kept low then time required for obtaining images is impractically long. Infrared (IR) detection systems are much easier and can be used for long distance scanning instead keeping detectors close to ground.[18] But these systems are highly dependent on dynamic changes in Envoirment. Ultrasound or Acoustic systems has an advantages over others is these are independent on mechanical or chemical composition of material and moister content is not big issue as waves can pass through water easily. Hence underwater buried mines can also be detected with potentially low false alarm rate.[18] Most of the acoustic system operates at low rate as compared to other available techniques. Apart from manmade precise response sensors trained dogs found very useful in identifying and tracing explosives.

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