AN APPROACH TO DEVELOP INFORMATION SYSTEM FOR RADAR DATA TO IDENTIFY THE SHAPE OF SHALLOW BURIED METALLIC OBJECTS

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ABSTRACT:

Present paper deals the fusion of image analysis and electromagnetic approach to predict the shape of the shallow buried metallic objects for satellite remote sensing at X-band (i.e., 10 GHz). The shape reconstruction is based on the mean of the image intensity with computed reflectivity at any depth and then deconvolution using image processing techniques. For this purpose, a monostatic scatterometer has been indigenously developed, which consists a transmitter and receiver mounted on the stand of the sand pit and when operated it moves over it. An algorithm has been proposed for shallow buried object detection system that is based on the image processing and electromagnetic theory. This algorithm is applied for square and rectangle shapes of the metallic objects and the obtained results are quite satisfactory. The shape of the buried utility is determined for any depth for which the returned echo is significant. This approach will be quite helpful to develop an automatic satellite data based information systems using image analysis and microwave remote sensing techniques to identify the shape of the various shallow buried objects.

1. INTRODUCTION

In the world, detection and shape recognition of buried objects is a challenging task because it is difficult to discern the buried objects by simply looking the signatures in the scattered power. There are several factors that create illusion or there is a greater probability of false alarm due to complexity of the terrain.

Currently, metal detectors are, by far, the predominant sensors in use for buried object detection. The most commonly used principle for the sensors is Ground penetrating radar (GPR). The GPR has a few advantages; first, it is sensitive to changes in all three electromagnetic characteristics of a medium, electric permittivity, electric conductivity, and magnetic permeability. Thus GPR is capable of detecting both metallic and non-metallic objects. Second, unlike sensors that can only survey an area directly beneath them, GPR can survey an area in front of it. Therefore, a GPR system can be used to detect dangerous objects before the system moves over and past them but these systems are currently of limited utility in this area because of the often low dielectric (i.e., complex permittivity) contrast between plastic mines and the surrounding soil. For example, the relative permittivity of most plastic materials has a very small imaginary part and a real part in the range of 2–4, while that of most dry soils is similar, making it difficult for a sensor, which relies on scattering from dielectric contrasts to distinguish these two materials. GPR has also the distance limitations. The other approach is the Radar remote sensing, which has been widely used as a non-destructive tool for the investigation of shallow subsurface, detection and mapping of subsurface utilities and solid objects. A fundamental problem in Radar remote sensing for detection of buried object detection

resides in the conflict between the need for ground penetration and the desire for tolerable resolution. The lower frequencies penetrate more effectively with fewer scattering losses. At the same time better resolution is achieved at higher frequencies, since for any system the best achievable resolution is depends upon the bandwidth of the system.

Over the years, much of the work is done in the retrieval of the buried objects and landmines. One of such autonomous system (Herman and Singh, 1994) is developed for detection of subsurface buried objects; this system automatically detects and also can remove the object. Other system include microwave imaging of multiple cylinders using local shape functions (Cho Chew et al 1992) and time domain radar system (Chew and Otto, 1994) which uses the time averaging and time gating techniques to suppress the noise level, while the time domain approach is also employed with the combination of the Finite Difference Time Domain (FDTD) and matched filter (Dogaru, and Carin, 1998) and other includes detection of buried objects equipped with neural network and Pattern recognition approach (Al-Nuaimy et al 1999) ,some systems are also based on Fuzzy logic are developed for unexploded ordinances (Collins et al 2001)and steepest descent fast multipole approach for electromagnetic scattering from penetrable/PEC objects under rough surface (El-Shenawee et al 2004) and some researchers use surface impedance concept for detection and determining the location of Buried Objects (Hulay et al 2004) and Multi-Source strategy based on a learning-by-examples technique for Buried Object Detection(Bermani et al 2005) and most recent one is a classification approach based on SVM for electromagnetic subsurface sensing in which instead of the

object localization, the region of interest is divided in to free areas and UXO populated areas.(Massa et al 2005). The ground penetrating radars suffer from the limitation of 3D resolution and the ground clutter, so some of the approaches based on SAR are developed. These approaches include, the multi-static focusing from the 2-D real aperture another one is the forward looking ground penetrating synthetic aperture radar is employed in which the nature of the deflected signal is assumed to be stochastic and the parameters are estimated from the training data and the objective is to maximize the S/N ratio The most common problem with buried object detection is the return from ground or surface clutter that overrides over the return from buried utilities and subsurface boundaries. To overcome this some researchers developed polarimetric method that can distinguish the return from individual utilities, these includes Radar polarimetric Radar Interferometry (Sagues et al 2001).

Maximum approaches described here are either very complex or need a huge amount of data. Therefore, it is a current need to minimize the complexity and develop such an algorithm, which can first detect the buried objects and then determine the shape. For this purpose in this paper, an attempt has been made to fuse the electromagnetic information with image analysis approach to detect and recognize the shape or the dimension of the object of shallow buried metallic objects, which can be extended in near future for land mines.

The paper is organized in such a way that, first the methodology, which includes electromagnetic and shape recognition modelling approach has been discussed. Experimental measurements and recognition of shape with experimental data is discussed in section 3 followed by the concluding remarks in section 4.


2. METHODOLOGY

2.1 System Overview

A monostatic Radar (scatterometer, shown in fig. 1) has been assembled for the detection of buried object. In this we measure the backscattered intensity from the surface (i.e. the reflectivity pattern of the surface and the volume), since the scatterometer can be used for different incidence angles, frequencies, and polarization. In this paper we describe the plane polarized (HH polarization) at normal incidence and the frequency of 10 GHz. A pyramidal Horn is used for transmitting as well receiving the backscattered echo and the reflection are discriminated using circulator. The system is mounted on the movable platform which scans the region of interest in steps of 5cm in the two dimensional plane. The objects of different sizes are buried at different depths and the scattered power is measured and using this scattered power we construct the raw image of that region.

The observation are taken for different sizes of the aluminum sheet (30x30, 24x61, 37x61) and for the combination of the above for different depths (0.5, 1.0, 1.5 , 2.0,2.5cm) and the image is constructed from the raw data.

Fig. 1. Schematic diagram of monostatic scatterometer
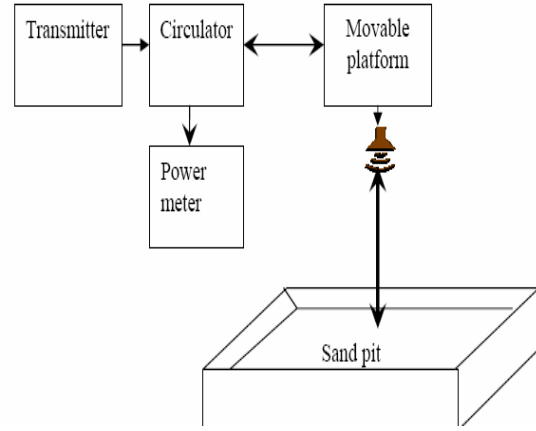
2.2 Electromagnetic Modelling Approach

In this experiment we have used the sand pit that is finite in all the three dimensions but here we can reduce the effect of reflection from the corners of the sand pit by image processing and mask generation. In general the returned field can be considered as the combination of the following

    a.   The reflection from the surface of the sand
    b.   The reflection from the buried object that is dependent on the reflection coefficient of the air-sand interface and its transmission coefficient.
    c.   The reflection from the corners of the sand-pit that is absent in real time situation

So the total reflection coefficient is given by

$$R = R_{1-2} + T_{1-2}T_{2-1} \sum_{m=1}^{m=N} R_{2-3}^{m} R_{2-1}^{m-1} \exp\left(-2\gamma_2 H\right) + R_{undesired} \qquad (1)$$

Where $R_{1-2} \rightarrow$ the reflection coefficient from the air-sand interface

$R_{2-3} \rightarrow$ The reflection coefficient from the sand-conducting plate interface

$T_{1-2} \rightarrow$ The transmission coefficient at the air-sand interface

$T_{2-1} \rightarrow$ The transmission coefficient at the sand-air interface

$R_{undesired} \rightarrow$ The reflection due to finite dimension of the sand-pit.

$\boldsymbol{g}_2$ is the propagation constant of the incident wave in sand which basically depends upon the permitivity of dry sand.

For horizontal polarization

$$R_{1-2} = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1}$$

$$R_{2-3} = \frac{\eta_3 - \eta_2}{\eta_3 + \eta_2}$$

$$T_{1-2} = \frac{2\eta_2}{\eta_2 + \eta_1}$$

$$T_{2-1} = \frac{2\eta_1}{\eta_1 + \eta_2}$$

$\eta_i \rightarrow$ The characteristic impedance of the ith medium.

Using Eq. (1), we can compute the reflected power at any depth H, which will be the basic of detection of shallow buried object.

2.3. Shape Recognition Algorithm

In the experiment, it is observed that the backscattered power depends on sensor parameters (such as antenna gain, beam-width and so on the physical dimension of the antenna and operating frequency and also on polarization) thus the illumination area of the antenna system is not limited to the pixel size of the image, so there is a significant contribution from the neighbouring pixels, therefore in general, we cannot search for near field targets merely looking for bright spots in the raw image constructed from the returned echo from the surface. Following should be take care before processing the image

➢ Minimize the effect of overlap of the scattered field from neighbours.
➢ Minimize the effect of finite dimension of the sand-pit.
➢ Reduce the false alarm rate.

For this purpose, an approach based on Image processing with Electromagnetic (EM) adaptive thresholding has been proposed which is discussed in the following section.

2.3.1. Image Processing with EM Approach for Shallow Buried Metallic Object

Following process has been adopted to process the raw image (also shown in flow chart Fig. 2)

➢ Calibrate the image pixels according to the following relation

$$E_{caliberate\ d} = \frac{E_{observed}}{E_{metal}} \qquad (2)$$

Here $E_{metal} \rightarrow$ the backscattered power from the aluminium sheet covering the entire Sand-pit.

$E_{observed} \rightarrow$ The backscattered power with the buried utility.

➢ In the proposed algorithm we normalize the image by the following

$$E_{normalised} = \frac{E_{observed} - E_{min}}{E_{max} - E_{min}} \qquad (3)$$

Where E_{max} and E_{min} are the maximum and minimum values in the recorded data.

➢ Obtain the mean and standard deviation and apply the thresholding to remove the unwanted return from ground.
➢ Apply convolution operation to reduce the effect of the overlapping of the scattered field and the random noise spikes in the image with the optimised kernel. This convolution uses the extension of the size of the image by zero-padding outside the original image, and this will eliminate the effect of walls but leads to some ambiguity in the shape of the target near the walls of the sand-pit. For the outdoor experiments i.e. for infinite dimension

with respect to the imaged area this convolution is carried out with the reflected extension of the image.

➢ Again apply the normalization and thresholding (based on the mean and the standard deviation with inclusion of computed reflectivity from Eq. 1) to generate the mask. This mask represents the shape of the object/objects. The thresholding is generally function of the type or the
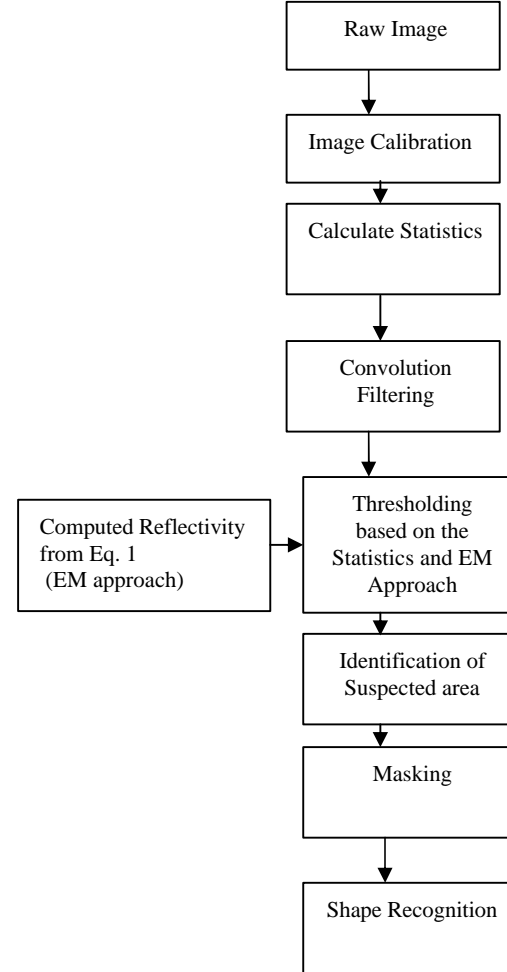
characteristics of the buried utility.

Fig. 2. Flow chart of proposed algorithm to recognize the shape of shallow buried metallic objects.

3. EXPERIMENTAL MEASURMENTS AND RECOGNITION OF SHAPE

3.1. Experimental Measurements

To study the detection and identification of the buried objects, we took the object of aluminium sheet of size of 30x30, 24x61, 37x61, and 61x61 cm^2 as target. Object was buried into sand pit at different depths (0.5, 1.0, 1.5, 2.0, 2.5, 5, 6cm). The microwave reflection/scattering phenomenon from buried objects basically depends upon its conductivity, dielectric constant, and the target characteristic (size, shape, thickness, depth as well as medium of the burying object). The objects/materials having high conductivity and large dielectric constant give higher reflection/scattering and those having low conductivity give lesser reflection/scattering while studying microwave signature. This phenomenon mainly depends upon the frequency of operation, look angle and the sensitivity of the system due to which the depth of penetration of microwave is governed. Since the dielectric constant, conductivity as well as permittivity of the aluminium sheet and the sand is different, so the received power would be different for both and thus the buried object can be detected easily by the electromagnetic radar technique, in which the above mentioned three factors are affected highly and the signal reflected/back-scattered from the object give nearly true extent of the target. The observations were taken for following objects

- Aluminium Sheet to cover the entire sand-pit(for calibration purpose)
- For sand-pit only (to see land clutter distribution).
- Aluminium sheet of different sizes (24x61, 37x61, 61x16, and 30x30) at different depths (0.5cm, 1.0cm, 1.5cm, 2.0cm, 2.5cm) and in individual and different combinations (two sheets of 30cm X 30cm, four sheets of 30cm X 30cm).
- Aluminium sheet of dimension 30x30(cm x cm) at six cm depth.

3.2 Recognition of Shape with Experimental data

The proposed algorithm as shown in fig 2 has been applied for different combinations and depths. Some of them are discussed below

(a) For Aluminium sheet buried at the depth of 6cm

Raw image is generated from the scatterometer data and normalized as eq. 3 (max=9.7724, min=2.4547). After that statistics of image has been calculated (mean=0.2833, standard deviation =0.2181). Apply the convolution filtering into the normalized image. Again normalize and identify the suspected region then apply the threshold approach based on the statistics (mean = 0.0653, standard deviation = 0.1510) and Electromagnetic approach (i.e., reflectivity calculated by eq. 1). Find the bounding surface and the number of objects (one in this case).

Fig. (3a, 3b, 3c) shows the unprocessed and processed image. It is clearly seen that after applying the proposed algorithm target is reasonably detectable and shape can also be determined.
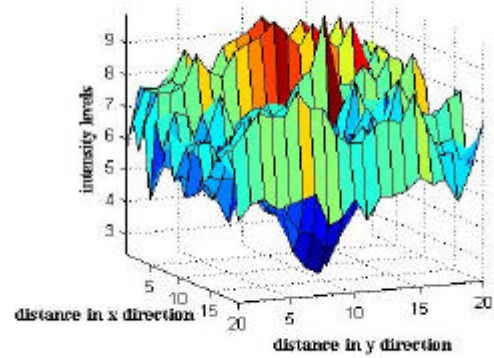

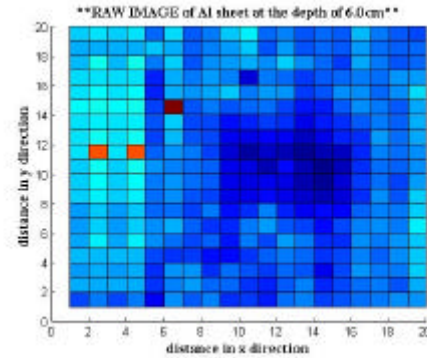Fig. 3.a. Raw 3D-graph of Al sheet at the depth of 6.0 cm

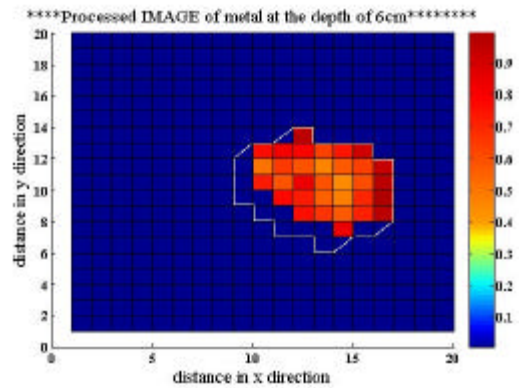Fig. 3.b. Raw image of Al sheet at the depth of 6.0 cm

Fig. 3.c. Image after applying the proposed algorithm

(b) For two Al sheets buried at the depth of 0.5 cm

Similar procedure has been adopted for processing the image, which has two objects buried at the depth 0.5 cm. Raw image is shown in fig 4a, while as processed image as proposed algorithm is shown in fig 4b. In both figures the utility of proposed algorithm is clearly evident.
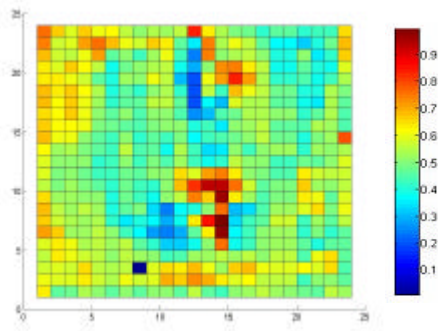
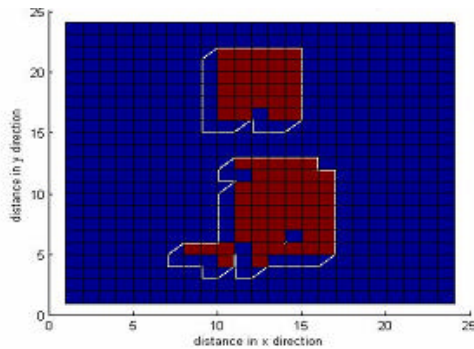Fig. 4.a. Raw image with two buried objects at 0.5 cm depth

Fig. 4.b. Image after application of algorithm

4. CONCLUDING REMARKS

An algorithm based on EM and image analysis approach has been proposed for detecting and identifying the shape of shallow buried objects. The algorithm were analysed with experimental data and obtained results are quite encouraging. More work has to be done in near future for different shape and terrain conditions.

This type of work will be quite helpful in near future to develop information system for radar data to identify the shape of shallow buried objects, which can also be applied to satellite remote sensing.

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