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Prediction and Optimization of Infrared Imaging used in Landmine Detection with a Suitable Numerical Modeling

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***Abstract*— Every day, all over the world millions of precious lives are in danger because of the ever alarming catastrophic destruction caused by the modern war weapons namely the landmines. As mines remain active even long after the battle ends, demining operations still remain risky, dangerous, time consuming and expensive. Due to the complex nature of the problem and lack of unique solution, various mine detection sensors exploiting the different properties of the electromagnetic spectrum are used. Infrared thermography is one such sensor technology that is used extensively for locating the mine affected areas and detecting the surface laid and shallowly buried landmines. However, the performance of IR is highly dependent on a wide range of variables in the atmosphere and on the geographical properties. So, a great consideration is to be made while declaring the potential targets as mines or clutters. The effectiveness of infrared thermography for detecting buried landmines can probably be improved if the operator of the mine detection system has some knowledge about the variables controlling the landmine signature. In this work, a three dimensional numerical model is constructed to study the infrared signature of a buried object resembling an antitank landmine in a homogenous soil. A comprehensive analysis of the thermal model that can be exploited in infrared imaging applicable to landmine detection is also reported. The spatial and time dependence of the peak thermal signature is examined. Results obtained using thermal image processing algorithms for an infrared image acquired from an outdoor test site are also presented.**

Keywords— antitank; image processing; infrared; landmine; thermal model

I. INTRODUCTION

Landmines, the so called deadly weapons which are scattered in some 78 countries all over the world kill 15,000 to 20,000 precious lives every year, maiming countless more [1]. They are usually classified as antitank (AT) and antipersonnel (AP) mines based on their potential target [2]. AT mines are designed to destroy the combat vehicles whereas the AP mines are manufactured to kill or maim humans. Identification and clearance of minefields still remains a daunting task inspite of the various efforts taken by many governmental and non-governmental organizations [3] throughout the world such as raising mine awareness programmes, supporting the victims medically and sponsoring the demining activities. New methodologies are being developed for an efficient detection of buried landmines. Among the different methods used in practice, passive infrared(IR) thermography is a widely used non-destructive evaluation tool which can detect the surface anomalies caused by the buried objects [3]. It offers a secure, non-contact, remote inspection of the minefields and can be used in night vision.

Various intelligent image processing techniques show a promising result in detecting mine like anomalies present in the infrared images acquired from a suspect area. But in order to classify the detected objects, one or more discriminating features have to be found. A wide range of variables such as the soil thermal properties, moisture content, landmine material properties and burial depth control the thermal signatures of the landmines. Several effects such as solar heating, wind and temporal climate variations also affect the performance of the infrared sensors [4] and it is very difficult to predict the occurrence of the strongest thermal signature due to the complexity involved [5]. Hence, for an efficient use of the demining IR sensors and for a better interpretation of the IR imagery, it is required to have some proper knowledge about the influence of these variables on the landmine signatures [6]. In this work, an effort is made to study the thermal behavior of a mine like object buried in a homogenous soil having properties as that of a clay soil. The considered object has material properties similar to a TNT explosive with an aluminium casing. A three dimensional numerical model is constructed and solved using finite element method. ANSYS mechanical software is used to solve the model. The objective of this contribution is therefore (1)to discuss the thermal behavior of a buried mine like object in a homogenous soil and (2)to present the image processing results of a sample infrared image acquired at an outdoor test site**.**

The rest of the paper is organized as follows: Section II gives a review of the basic principle behind an infrared thermal imager used for landmine detection. In section III, a three dimensional numerical model of the soil with a buried object is discussed. In section IV, an efficient image processing technique along with the simulated results for a representative antitank mine like object is presented. Section V presents the summary and concluding remarks.

II. INFRARED THERMAL IMAGING

Objects with different material properties exhibit different thermal behavior to a given thermal stimulus. Mines have different thermo physical properties from the surrounding medium such as soil in which they are buried. The daily heating and cooling cycle in the atmosphere causes a variation in the soil surface temperature. During daytime when the sun shines, the surface soil gets heated up and there exists a temperature difference between the hot soil in the surface and the cool soil underneath it. Heat conduction takes place as a result of the existence of a temperature gradient down into the cooler soil. The other two heat transfer mechanisms that cause a change in the surface temperature are convection and radiation. Conduction takes place in the soil and at the soil-mine interface. Convective and radiative effects take place at the soil-air interface. All the three mechanisms are time varying over a diurnal cycle [7].

Presence of buried landmines in the soil acts as a disturbance and alters the heat transfer and mass transfer in the soil thus introducing localized temperature difference between the surface of the soil above the mine and the background [8]. A thermal infrared imaging system placed above the soil area could be used to capture this temperature difference [9].

III. NUMERICAL MODELING OF THE HEAT TRANSFER PHENOMENA IN LANDMINE DETECTION

Infrared imaging system can be used for anomaly detection only if there exists some noticeable thermal contrast between the soil above the mine and the background [10]. The variables controlling the thermal signatures are the net solar radiation, wind effect, soil thermal properties, moisture content in the soil, material properties of the landmine and the burial depth [4]. Poor understanding of this dependency confines the ability of the operator of a mine detection system in predicting the thermal signature and designing efficient image processing algorithms for landmine detection. Numerical modeling of the heat transfer phenomena is used to give an estimation of the resulting temperature contrast caused by the buried object in the soil during the analyzed period [10].

A. *Description of the Numerical Model*

A three dimensional numerical model is presented. The purpose of building such numerical model is to study the effects of the different variables that play an important role in the formation of thermal contrast in the infrared landmine images and to optimize the measurement [11].

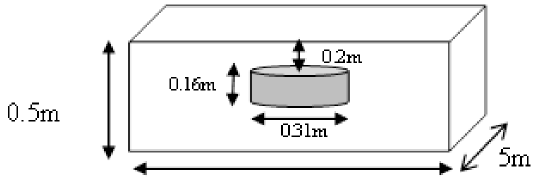


Fig. 1. Simulation setup

A soil volume is considered with a buried mine like object resembling an antitank landmine subjected to a known thermal stimulus through the soil-air interface. The simulation setup is shown in Fig. 1.

Assumptions of the real environment and boundaries are made. Balancing the energy interaction between the buried object and the surrounding is the most important concept in the analysis. The complex energy exchange between the surface of the soil, including mine like object and the atmosphere is modeled. The equation for the principle of conservation of energy [10] is given by (1).

$$\sum_{i=1}^{n} Q_i = 0 \qquad (1)$$

Where $Q(i)$ are the 'n' different energy transport processes involved such as heat transfer in the soil, convective heat transfer at the surface, absorbed radiation(<3μm and >3 μm, from sun) and the soil surface emission[10]. The soil and the mine like object are assumed as isotropic solids [12] with specific heat c(x, y, z)(J/Kg K), density ρ(x, y, z)(Kg/m^3) and thermal conductivity k(x, y, z) (W/m K). The example considered here resembles that of plane surfaces with negligible vegetation. The soil moisture content variation is also assumed negligible [12]. In such cases, the temperature distribution T(x, y, z, t) of the soil volume with the buried object satisfies the partial differential equation as written in (2).

$$c\rho \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) \qquad (2)$$

In case of homogenous solid, (2) reduces to

$$\frac{\partial T}{\partial t} = \alpha(x,y,z)\Delta T \qquad (3)$$

Where $\alpha = k/(\rho c)$ (m^2/s) is the thermal diffusivity of the soil [12].

B. *Heat Transfer Analysis using Finite ElementMethod*

The different energy transport processes involved in a finite volume including a buried mine like object are usually described by various partial differentiation equations. It is tedious to solve these mathematical equations using an analytical approach in order to get an exact solution. Hence it is desirable to find a solution that approximates the exact solution. Finite Element Analysis (FEA) is a numerical method that offers a means to find this approximate solution [13]. ANSYS is the finite element analysis tool used to examine the heat transfer problem to obtain the approximate solution.

The three main tasks involved in performing a thermal analysis using ANSYS are:

1. Preprocessing
   - Define element type and material properties
   - Create the required model
   - Mesh the area to create nodes and elements

2. Solution
   - Specify the thermal loads in thermal analysis
   - Solve

3. Postprocessing
   - Plot the temperature distribution
   - Review the results

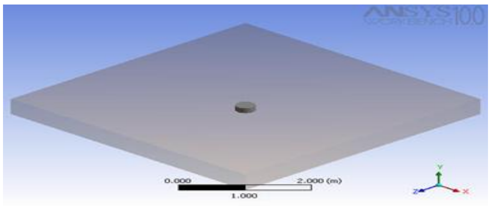
The predefined geometric shapes such as rectangles and circles are used to create the model. The global coordinate system is Cartesian, with x, y and z axes. The material properties used [10] are shown in table I. Tetrahedral elements are used for meshing the whole computational domain.

TABLE I. MATERIAL PROPERTIES USED IN THE SIMULATION

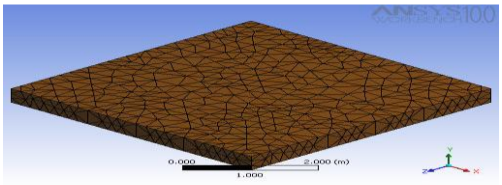
Material	**Density (Kg/m^3)**	**Thermal Conductivity (W/m K)**	**Specific Heat Capacity (J/Kg K)**
Soil_Clay	1800	1.5	1300
Shell_Aluminium	2780	204	885
Mine Filling_TNT	950	0.24	3340

The finite element solution is initiated by setting the analysis type to ‘transient thermal’. The transient end time is specified as 43200 seconds resembling a 12 hour simulation. The thermal loads are applied to the created model. Initial temperature value is set to 22.0 °C and the bottom boundary temperature is set to 17.0^{0}C. All emissivity coefficients used are set to 0.9. The initial time step is set to 432 seconds and the minimum time step is set to 43.2 seconds in this analysis.

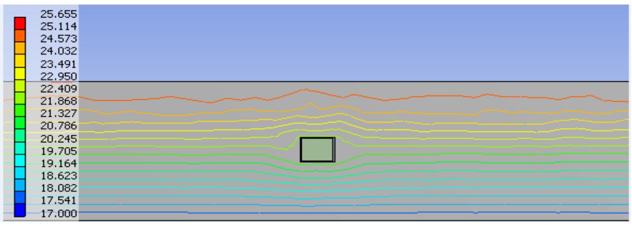
Simulation Results and Discussion



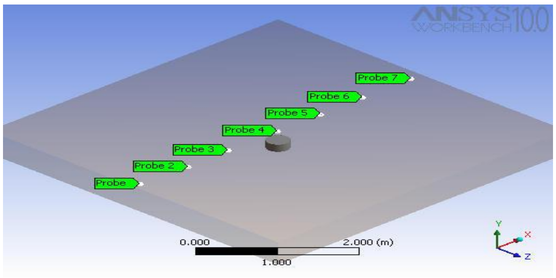
(a)Solid model of the soil with a buried mine like object



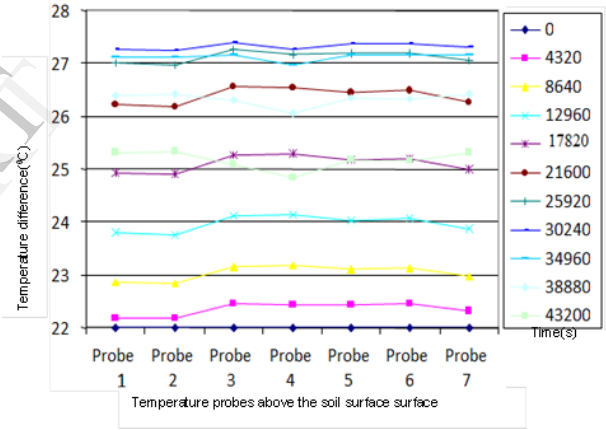
(b)Meshed model of the soil with a buried mine like object



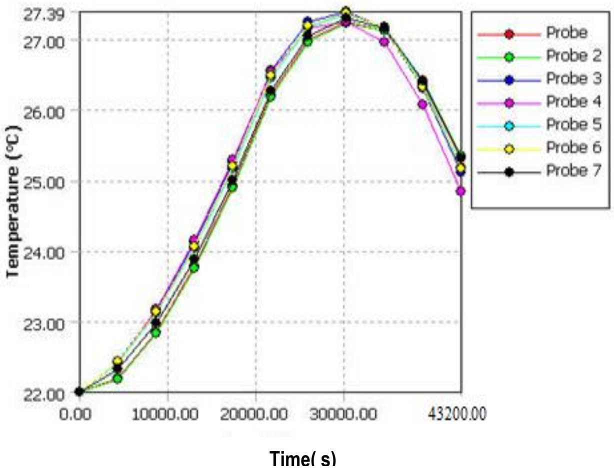
(c) Simulated isotherms in a soil containing a mine like object at 43200 seconds



(d)Various probe locations on the soil surface with a buried object



(e) Soil surface temperature at various probe locations



(f) Spatial distribution of temperature contrast at various time instants
Fig. 2(a) to (f). ANSYS simulation results

It is difficult to understand the formation of the thermal contrast on the soil surface at each instant in time due to the complex combination of variables involved in the process. Nevertheless, some inference is gained from the above simulation results by considering the process with a minimum number of variables. The effects of the presence of the buried mine like object at a depth of 0.2m from the soil surface is clearly shown in Fig. 2e and Fig. 2f for a homogeneous soil condition. Fig. 2f shows that the soil surface temperature above the buried object is warmer than the surrounding soil for the duration from 4320 seconds after the simulation started till 21600 seconds which resembles the noon condition. This can be attributed to the fact that the aluminum cased object conducts heat faster than the surrounding soil as a result of its higher thermal conductivity as compared to the soil thermal conductivity.

The result gets altered for the time duration starting form 25920 seconds to 43200 seconds. This is again due to the fact the aluminium cased object releases heat quickly compared to the surrounding soil and so the soil surface above the buried object tends to be somewhat cooler than the surrounding soil in this duration. The position of probe 4 exactly right above the buried object as shown in Fig. 2d confirms this fact. The above effect is also perceived from the shape of the isotherms in Fig. 2c. The soil surface mine signature repeats itself for a similar semidiurnal cycle.

It is also inferred from the Fig. 2e and Fig. 2f that the maximum temperature contrast occurs during the period varying from 30240 seconds to 43200 seconds from the start of simulation. This time duration is estimated as the predicted or expected time for an efficient use of a thermal imager in order to see this temperature contrast in the acquired infrared image from such a scenario as considered in the above example.

IV. IMAGE PROCESSING TECHNIQUE FOR LANDMINE DETECTION

A temperature variation between the soil containing mine like object and the surrounding soil produces a thermal contrast on the soil surface that can be detected in the acquired infrared images of the surveyed area. Various two dimensional image processing techniques are available for anomaly detection in infrared images. The proposed framework is given in Fig. 3.

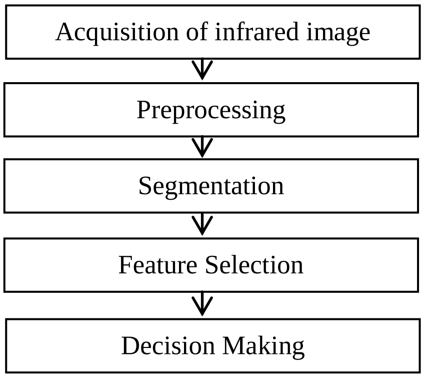


Fig. 3. Proposed framework for detection of mine like object

A. *Preprocessing*

It is always desirable to preprocess the acquired infrared images using image enhancement and noise reduction techniques before carrying out further processing to detect mine like objects from the images. The acquired sample infrared image containing mine like object undergoes some of the preprocessing operations as follows: (i) The true color infrared image is transformed to a gray tone image and it is resized to a spatial resolution of 256 X 256 pixels.(ii) A linear averaging filter which is otherwise known as mean filter is used to smooth the pixel intensity values of the image and remove the impulse noise. It makes use of a convolution mask or window of size 3. The square mask slides over the input image, pixel by pixel from left to right and the value of the output pixel is the 'average' of the corresponding input pixels in the neighborhood of the processed pixel. Thus the output is a blurred version of the original image. Fig. 4 shows the 3X3 average filter mask used.

$$(1/9)\begin{array}{|c|c|c|}\hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline\end{array}$$

Fig. 4. Average filter mask

B. *Segmentation*

It is the process of identifying regions of interest that share some similar characteristic features in a scene. A semiautomatic segmentation technique namely deformable contour segmentation which is also known as deformable snake segmentation is implemented to segment the smoothed version of the infrared image. A rectangular mask is initialized using the spatial coordinate values close to the object of interest in the image. Then, this initial shape of the mask is deformed iteratively so as to fit onto the contour of the object of interest by the deformable active contour algorithm [14, 15]. The deformable model is matched to the image by minimizing the energy function [16] as in (4).

$$E_{snake} = \int_{0}^{1} [E_{int}(u(s)) + E_{ext}(u(s))]ds \qquad (4)$$

Where E_{int} and E_{ext} are the internal and external energy of the snake, respectively. The number of iterations is chosen as 100 and the localization radius is 32 pixels in the algorithm.

C. *Feature Selection*

Once the region of interest is obtained from the segmented image, characteristic features of the region are measured for the purpose of decision making. Some of the structural and statistical features of the mine like blob in the segmented image are calculated. The computed geometrical features describing the shape of the mine like blob are area(2881 pixels), eccentricity(0.68) and perimeter(175 pixels) and the intensity based features are correlation(0.8844), energy(0.9374) and homogeneity(0.9964) respectively.

D. Decision Making

Interpretation is made by comparing the numerical values of the extracted features of the detected anomaly in the infrared image with the known physical properties of the landmine.

E. Simulation Results

The proposed algorithm was implemented using MATLAB 7.6 and the application of the proposed algorithm to a sample infrared image containing a mine like blob resembling an antitank mine is shown in Fig. 5.

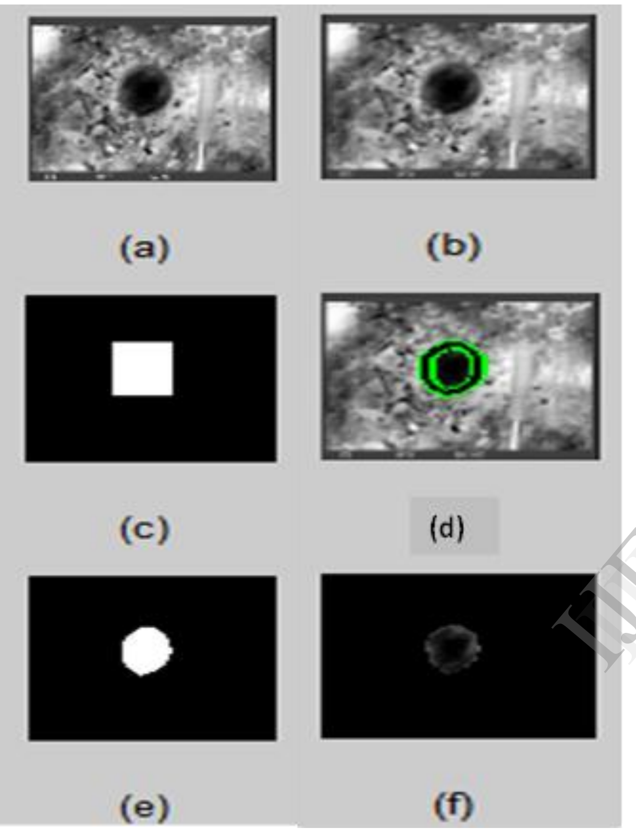


Fig. 5. Image processing results: (a) original image (b) filtered image (c) initialization mask (d) active contour segmentation after 100 iterations (e) segmented image (f) region of interest

V. SUMMARY AND CONCLUDING REMARKS

There must exist some sufficient thermal contrast between the soil above the buried object and the background in order to use an infrared camera for anomaly detection such as landmine detection. Various parameters of the landmine, the atmosphere and the soil affect the formation of thermal contrast in the infrared landmine images. The effect of each variable differs in different situation and there exists no unique solution to this problem. In this contribution, we have presented a thermodynamic model for a particular landmine problem and simulated it using the finite element method. Simulation of the numerical model presented gives an estimate of the temperatures at all nodes for every time step. The time of occurrence of the maximum thermal contrast or detectable thermal contrast between the soil surface above the mine and the background is the interesting information that is acquired from the simulation results.

Inspection of the movement of the isotherms in the soil volume with a buried mine at various time intervals also gives us useful information regarding the various levels of contrast formation on the soil surface above the mine. Hence with this predicted information, the infrared measurement process can be optimized by selecting suitable time of flights for a similar scenario. It also enhances the detection probability in feature extraction and reduces the false alarm rate. The material properties and the geological parameters used in the model can be varied just by changing the numerical values in order to make a different model for a different landmine set up.

Hence we conclude that a relevant numerical modeling of the landmine scenario should be carried out in a parallel manner along with the infrared imaging in order to make an efficient use of the thermal imager in landmine detection applications. However, the result obtained from image processing techniques has to be interpreted along with the relevant information also such as combat history and geographical properties of the surveyed area.

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