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THE EFFECT OF VIEWING ANGLE ON DETECTION OF LANDMINES FROM THERMAL TIME SERIES IMAGES USING ACTIVE THERMOGRAPHY

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Abstract

Use of landmines in soils is a significant international threat facing the world today. There are no safe and highly reliable methods or inspection systems capable of detecting landmines in all situations. The use of infrared thermography is one of the promising methods for mine detection tasks. In infrared thermography, the investigation is done in either way: actively or passively. In this study, thermal signatures of the active infrared time difference images of buried mines and sand are investigated for different camera angles. It is aimed to find the effects of shot angles of the thermal camera on the performance of landmine detection. The experiments are performed at a sandbox emplaced in an indoor laboratory environment. A metal and a plastic antipersonnel mine are buried at 2 cm depth in sandbox. The sand surface is initially heated homogeneously by an infrared heater (2400 W) for 10 minutes on different days. During the cooling phase of the surface, a sequence of images are captured with an LWIR (8-12 μm band) camera (FLIR T 650 SC), which is 280 cm away from the detection area at different angles (90°, 60° and -60°). Images of the size of 480×640 pixels are taken at 15 seconds intervals during one hour. "Thermal signatures" of the buried mines and soil in three viewing angles are compared in MATLAB® environment. The results show that the locations of landmines are easily detected from the captured images during the cooling phase of the surface since observable differences develop between temperature signatures of landmines and sand, but the observation angle of camera has little effects on the detection performance. In addition, it is found that one hour measurement period is adequate for the detection of landmines at 2 cm depth in active thermography.

Key words: *Landmine detection, Thermal infrared imagery, Active thermography.*

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1. Introduction

Infrared (IR) thermal imaging, also often briefly called thermography, is a very rapidly evolving field in science as well as industry owing to the enormous progress made in the last two decades in micro system technologies of IR detector design, electronics, and computer science. Thermography nowadays is applied in research and development as well as in a variety of different fields in industry such as non – destructive testing, condition monitoring, and predictive maintenance, reducing energy costs of processes and buildings, detection of gaseous species, and many more [1]. IR thermal imaging has also been widely used for landmine detection.

The detection of landmines and clearance is still a time consuming and unsafe task. Additionally, efficient and accurate detection of buried mines is still a challenging problem [2].

There is no universal technique capable of detecting landmines in all conditions. Infrared thermography is a promising technique in the detection and discrimination of the landmines. The detection principle is based on the variation of the ground temperature due to the presence of buried or surface landmines.

Sand and mines have different thermal properties and this difference can be observed on the surface through the thermal sensors. Since thermal property is a dynamic behavior driven by radiation from the external heating system, it can change with the temperature in a few minutes and it can be observed better in thermal image time series than a single image.

Active thermography technique can be applied to enhance the contrast between the possible targets and the background. This contrast stems from the difference in radiant characteristics between the landmines and the background soil.

Emissivity value, which is one of these characteristics, plays a significant role in the determination of correct temperature of an object surface [3]. The source of uncertainty in temperature measurement with the infrared camera can be listed as followings: emissivity ($\mathcal{E}$) of objects, infrared detector-to-surface angle and distance. Those are mainstream technical factors for an accurate infrared thermo graphic measurement.

Some authors [4-6] have used analytical, numerical and experimental methods to model the thermal signatures of land mines. But, in our humble opinion, how angle of observation influences the results has not been investigated in detail yet.

Therefore, the main objective of this paper is to evaluate the effect of change in camera angle on detection performance of buried landmines.

2. Background

2.1. Mine Problem

Landmines are explosive devices hidden just below the surface designed to be detonated by contact of people or vehicles, as they pass over or near them. Still some 60 countries around the world are contaminated by landmines and thousands of people continue living with a risk of losing their life or limb. In addition, emplaced landmines hinder the cultivation of large productive areas. Besides, they maintain a sense of insecurity long after conflicts end, delay peace processes and impede countries' development for years [7].

Because of these horrendous effects, a lot of research and technological developments are needed to solve the detection and clearing of landmines problem. One widely searched solution for this problem is IR thermal imaging.

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2.2. Thermal imaging

Each material shows a characteristic thermal response to a given stimulus, also known as the thermal signature. Thus, the cooling or heating process affects buried objects and the surrounding soil in a different way. This difference is due to the fact that the mines are better insulators than the soil. The general concept of using infrared thermography for mine detection is based on the fact that mines may have different thermal properties from the surrounding material [8]. Thermal imaging devices measure the emissivity of surfaces in an area at various temperature ranges.

Uniquely, IR can work in either way, actively or passively. It can work by accepting only the natural radiation from the object called as passive thermography, or it can provide an extra heat source and receive the artificial radiation created by that heat source dubbed as active thermography [9].

Most thermal detection concepts involve single snapshot of the region of interest. The soil over a mine has different thermal dynamics than homogeneous soil and, as a result, a time sequence of images can often produce better detection than a single image [10].

Consequently, the soil temperature on the ground above the mines is often different from that of the background. This temperature can be measured by an IR imaging system placed above the soil area.

3. Experiments

The equipment required for the experiments consists of model anti-personal landmines (plastic and metal), thermal camera, a tripod of camera stand or framework, sandbox and a heating unit.

The landmines can be categorized mainly into two sections according to their materials, metal or plastic mines. The surrogate model mine used in the experimental study is Plastic DM-11 (partly filled with wax whose thermal properties are similar to TNT) and Metal M-16 anti-personnel mines (APM's) as shown in Fig. 1. DM-11 has a diameter of 0.08 m and a height of 0.035 m. M-16 has a diameter of 0.12 m and a height of 0.20 m.

Fig.1. Experimental setup for an assessment of angular variation of emissivity. The FLIR T 650 SC was rotated about the sample and fixed at 30-degree intervals. Plastic APM DM 11 (up) and Metal APM M 16 (down) Positions.

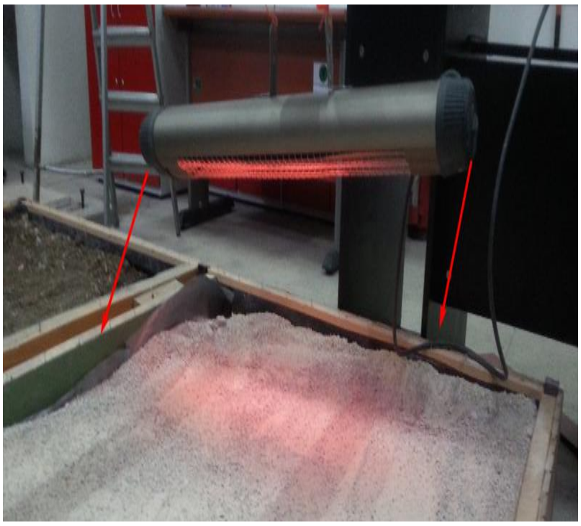

Fig.2. Heating Phase of Active Thermography

The mines were buried in a sandbox which has a height of 1.85 m length, a width of 1.55 m and a depth of 0.225 m, filled with sand. The thermo graphic imaging was performed with a portable infrared camera

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(FLIR T 650 SC) equipped with an uncooled micro bolometer, a focal plane array infrared detector with a spectral range between 7.5 – 13.0 µm and 480×640 pixels.

The camera was attached to a framework, consisting of a fixed attachment point for the camera. The sandbox was located at the base of the framework and the camera was focused on the center of the sandbox.

Infrared Heater (UFO-L2300:2400 Watt Power) was used as a heat source. The heating phase (active thermography) is shown in Fig. 2.

All measurements were performed for 1 day for each angle. Images were analyzed with commercially MATLAB and FLIR IR Research Software.

4. Results

Three types of experiments performed at the viewing angles of 90°, 60° and -60° as it is shown in Fig.3 during three days. The acquired thermal images are stored in a personal computer. The model mines were buried into a depth of 0.02 m beneath the sand surface.

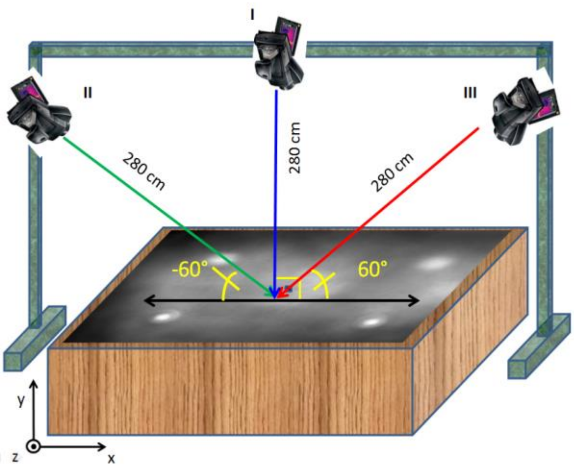


Fig.3. An IR image sequence of a minefield; images taken at (a) 90°, (b) 60° and (c) -60°.For images obtained at the same distance (2.80-m)

The sand surface was initially heated by an infrared heater (2400 W) for 10 minutes in each day. During the cooling phase of the surface, a sequence of images was captured with FLIR T-650 SC camera placed in 280 cm distance from the detection area. Images of the size of 480×640 pixels were taken at 15 seconds intervals during one hour.

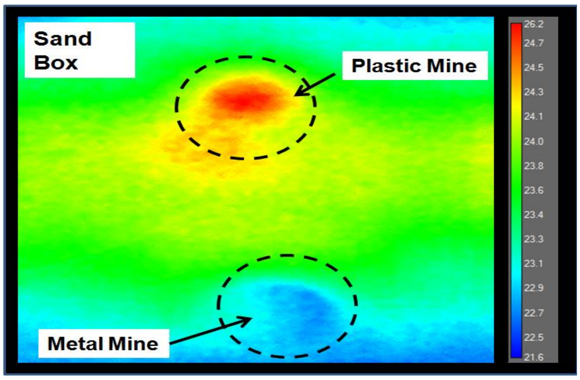
The temperature effect of the presence of the mine on the sand surface at each angles are clearly shown in Fig. 4 (a, b, and c).

As it is shown in Fig.4, the surface temperature of the sand above plastic mine was higher than the surface temperature of the sand beside mine. However, the situation was just opposite when it comes to metallic mine. The hot and cold surface spots caused by the energy reflected from the surface over mines generally became apparent within a similar time frame [4].

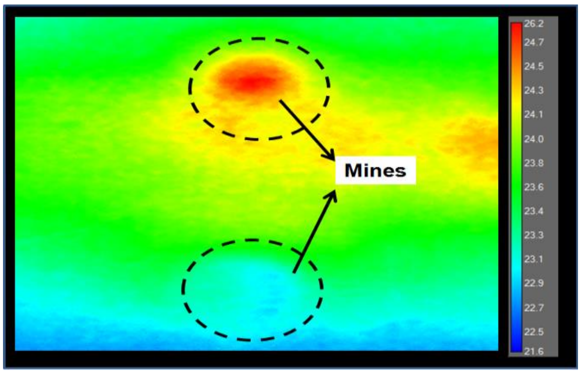
The results showed that the amplitude of the surface temperature change above the mine was much greater than that on the surface beside it: this was caused by the heating method. In all tests, the locations of the mines were identified using FLIR T-650 SC thermal camera and Research IR Program. The evolution of the “hot spot” and “cold spot” above the mines can be observed from the results shown in Fig. 4.

Our experiments confirmed that emissivity nearly remains constant from 60° to -60° degrees from the horizontal. These results were in agreement with what reported in the textbook of Infrared Thermal Imaging Fundamentals, Research and Applications [1], which explains the influence of viewing angle on emissivity of a surface.

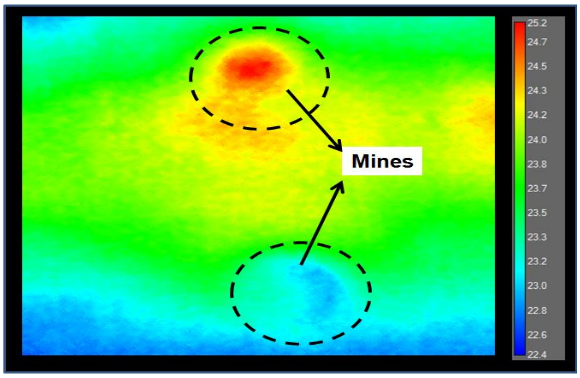
Angular dependency of emissivity (angle of observation) that has an influence on images was recorded with an IR camera system. However, Figure 5 demonstrates an effect that fortunately holds for nearly all practically important surfaces: the emissivity is nearly constant from the normal direction 0° to at least 40 or 45° [1].



a)Viewing at 90°.



b) Viewing at 60°.



c) Viewing at -60°.

Fig.4. The mines locations ; images taken at (a) 90°, (b) 60° and (c) -60°

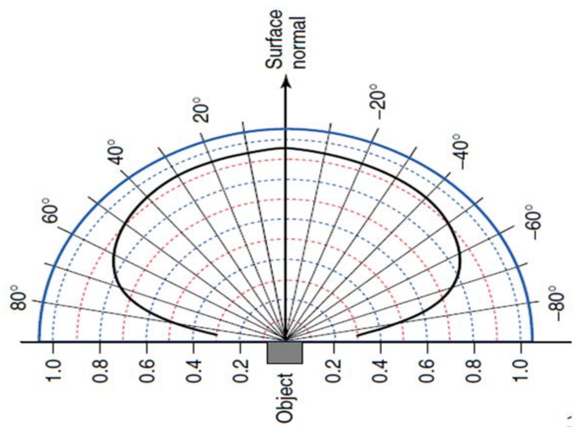
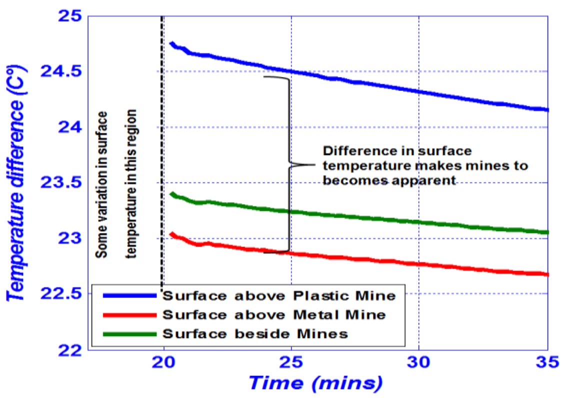
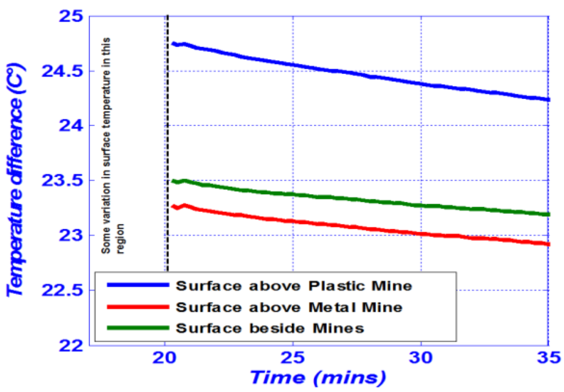


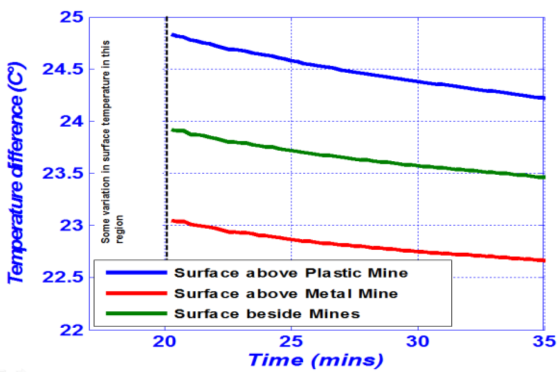
Fig.5. The emissivity values at different angles [1].



a)Viewing at 90°.



b) Viewing at 60°.



c) Viewing at -60°.

Fig.6. Thermal signatures of a minefield ; images taken at (a) 90°, (b) 60° and (c) -60°.

The study was carried out to understand how the viewing angle was influenced to the emissivity. Changing in the emissivity was recorded in each direction, and the results are shown in Fig. 6 (a, b, and c). The difference between the two temperature signature profiles (sand and mines) was plotted in MATLAB for each test.

5. Conclusion

In our study the effect of viewing angle is investigated by combining the analysis of temporal IR image sequences, showing the dynamic scene behavior during time variant heating by an infrared heater. The results show that different viewing angles (for 90°, 60° and -60°) have relatively little effect on the temperature at the surface. The emissivity is approximately constant at the viewing angles between 60° and -60°.

Experiments have shown that active thermography has strong positive effect on thermal signature in a short time. It can be especially useful in military tasks.

The thermal properties of the mine itself can play a significant role according to the thermal signatures. Also, it is shown that 60 minutes duration is enough to produce thermal signatures for buried mines at a depth of 2cm from the surface with active thermography.

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