Effect of Depth on the Thermal Signature of Buried Metallic Object

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Abstract

The use of thermography for land mine detection has become a topic of great interest in recent years. The thermal properties and burial depth of the buried object also play a role in the thermal signature at the surface. The objective of this contribution is to determine the effect of burial depth on thermal signature of buried metallic object. The object used in this work is steel material buried at depth ranging from 1cm to 50cm. The two buried objects used in this work are steel of 12cm x 12cm surface area with thicknesses of 0.5cm and 3cm respectively. The soil where the objects were buried is mainly sandy. Soil above the buried objects and below it is assumed to be the same type of soil. This work was carried out in Abeokuta, Ogun State, Nigeria. There was a remarkable phase shift which increased with burial depth. A change in burial depth from 1cm to 10cm caused the maximum positive peak to shift from 46.5°C to 38.0°C and a change in burial depth from 40cm to 50cm, caused the maximum peak to shift from 30.0°C to 29.0°C. The burial depth of the buried objects has effect on the amplitude of the temperature at the surface and thus its thermal signature. It was also observed that the thickness of the buried objects has a significant effect on its thermal signature.

Key Words: dynamic thermography, thermal capacitance, thermal signature, land mine

Introduction

The use of thermography for land mine detection has become a topic of great interest in recent years. The basic principle of all dynamic thermography based techniques is the idea that the thermal signature of the soil is altered by the presence of shallowly buried objects. This fact makes this approach very well suited for land mine (including Buried Objects and Unexploded Ordinances) detection since their different thermal properties will result in perturbations of the expected thermal pattern that can be measured by sensors (infrared and thermocouple). Moreover, this holds for every type of mine and other buried objects, despite the amount of metal content, if any, making possible the detection of small plastic antipersonnel mines. (Lopez et al., 2003)

The thermal properties and burial depth of the buried object also play a role in the thermal signature at the surface (De Jong et al., 1999). The situation becomes more complex as a result of the diurnal and annual heat flux cycles that drive the transport of heat to and from the surface (Remke et al., Accessed 2007).

The difference in the thermal capacitance between soil and mine affects their heating/cooling rates and therefore their associated infrared emissions. Infrared cameras are used to map heat leakage patterns from the ground which, nevertheless, makes this thermography method an anomaly identification technique.
Effect of Depth on the Thermal Signature of Buried Metallic Object: J. A. Olowofela et al. (Ashley, 1996). The technique essentially measures the thermal emissivity of the ground and interprets changes in emissivity as being caused by the presence of a foreign object; therefore, material characterization information is not provided. However, this technology has the advantages of being passive, can be performed remotely, by aerial search, and can cover a large area in a short time. Infrared thermography is best suited for identifying minefields (global area search), rather than searching for individual mines (local area search). It cannot, however, work when the soil and mine are in thermal equilibrium, and therefore is generally limited for use either at sunset or sunrise where a temperature gradient can be established at the ground surface (Hussein and Waller, 2000). All bodies (surfaces) with temperature greater than absolute zero emit electromagnetic radiation at all wavelengths of the spectral $(0, \infty)$ (Lienhard and Lienhard, 2004).

IR sensor systems respond to the electromagnetic radiation in the infrared spectral range. In practice, two spectral bands mostly used in IR sensor systems are the midwave infrared (3-5 µm) and the longwave infrared (8-12 µm) (Jacobs, 1996). Although IR signatures of a source depend on its temperature, IR sensor systems do not measure directly the temperature of the surface but the thermal energy emitted from the surface. Theoretically, it is possible to convert from the measured IR signatures to the temperature of the surface provided the spectral emissivity of the surface and the hypothesis that the energy comes only from a gray surface is usually composed of emitted (self–emission) and reflected (environmental) radiation (Thanh, 2007).

The objective of this contribution is to determine the effect of burial depth on thermal signature of buried metallic object. The object used in this work is steel material buried at depth ranging from 1cm to 50cm. It was assumed that the soil above the buried object has the same thermal characteristics as the soil below and away from the buried object.

**Materials and Method**

The two buried objects used in this work were steel of 12cm x 12cm surface area with thicknesses of 0.5cm and 3cm respectively. The equipment used were four temperature sensors and data logger (Hoboware by Onset Corporation, USA) to store the data. The temperature sensor is a 12-Bit temperature smart sensor designed to work with the HOBO Data logger. All sensor parameters are stored inside the smart sensor, which automatically communicates configuration information to the logger without any programming or extensive user set up. It has measuring range of $-40^\circ$ to $+100^\circ$C with an accuracy of $<\pm 0.2^\circ$C from $0^\circ$ to $+50^\circ$C and a resolution of $<0.03^\circ$C from $0^\circ$ to $+50^\circ$C. The dimension of the sensor is 7 x 38mm with a measuring averaging option. The soil where the objects were buried is mainly sandy. The soil above and below the buried objects is assumed to be the same type. This work was carried out in Abeokuta, Ogun State, Nigeria.

One temperature sensor was placed on each of the buried objects; another temperature sensor was placed at the same depth without buried object. This is to show that heat was actually being emitted from the buried objects. The fourth temperature sensor was placed on the surface to serve as control experiment. This measures both the heat from the sun and the heat emitted from the soil surface. Fig. 1 shows the equipment used and the burial site.
On day one of the work, the objects were buried at a depth of 1cm with all the sensors arranged as described above. On day two, the depth was increased to 10cm with sensors arrangement the same as in day one. The depths were increased in step of 10cm in the subsequent days up to a depth of 50cm. The work was stopped at 50cm depth because at this depth, there were no longer significant difference in the thermal signatures of the two buried objects and the third sensor buried at the same depth. It should be noted that weather parameters have effect on the thermal signature at the soil surface but have little effect on the thermal signature of the buried object.

**Results and discussion**

Burial depth of buried object has an effect on the temperature at the surface, and thus its thermal signature. There was a remarkable phase shift which increased with burial depth (Remke et al., 2007). A change in burial depth from 1cm to 10cm caused the maximum positive peak to shift from 46.5°C to 38.0°C and a change in burial depth from 40cm to 50cm, caused the maximum peak to shift from 30.0°C to 29.0°C.

The plot showed that the temperature difference decreased with depth. A change in burial depth lead to a phase shift of the temperature curves (Fig. 2-7). The amplitude variation decreased rapidly for deeper burial depth and any significant amplitude variation was absent for deeper depth, this was in agreement with the observation of Remke et al., 2007.
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**Fig. 2:** Temperature emitted by the objects at burial depth of 1cm.

**Fig. 3:** Temperature emitted by the objects at burial depth of 10cm.
Fig. 4: Temperature emitted by the objects at burial depth of 20cm.

Fig. 5: Temperature emitted by the objects at burial depth of 30cm.
Fig. 6: Temperature emitted by the objects at burial depth of 40cm.

Fig. 7: Temperature emitted by the objects at burial depth of 50cm.
Another aspect that played a role in the amplitude variation of buried objects at the surface are the thermal properties of the buried objects. The strength and phase of the thermal signature also depend on the thermal properties and burial depth of the object. Effect of thickness of buried objects on thermal signature was also observed. It was observed that the smallest one absorbed heat quickly during the day but loses its heat faster at night. This shows that heating and cooling rates of buried objects could be used to predict the size or thickness of the buried objects.

The surface temperatures for all the days of the experiment reached peak between 1300 hours and 1330 hours except on the last day which reached its peak at 1430 hours. Variation observed in the last day was attributed to changes in weather conditions. The anomalies observed in the surface temperature for burial depth of 20cm and 30cm was due to light showers that occurred at that period.

The thermal signatures of the buried objects reached their peaks at times which depend on the depth of burial. For depth of 1cm, the peak temperatures occurred at time ranges from 1330 hours to 1430 hours with very close relationship with the surface temperature. For depth of 10cm, the peaks occurred at 1400 hours. The peaks of the thermal signatures for depth of 20cm occurred between 1630 and 1700 hours. For burial depths of 30 cm and 40cm, the peak of the thermal signatures occurred at 1900 hours and 21 hours respectively while the peak could not be defined for burial depth of 50cm where the thermal pattern appear almost horizontal.

With the observations above, it could be seen that considering burial depths of 10cm to 40cm, there was two hours shift for every 10cm in the time the thermal signatures of the buried objects reached their peaks. It was also observed that the temperature of the emitted heat by the buried object decreased with burial depth. For depth of 1cm the peak temperature occurred between 44°C and 47°C while for 40cm it occurred at 30°C.

**Conclusion**

Thermal sensors hold much promise for the detection of metallic, non-metallic mines and other buried objects. However, the prediction of their thermal signatures depends on a large number of factors. In this work, effect of burial depth and thickness of buried object on thermal signatures of metallic objects was investigated. The burial depth of the buried objects has effect on the amplitude of the temperature at the surface and thus its thermal signature. It was also observed that the thickness of the buried objects has a significant effect on its thermal signature, but this effect reduced gradually with increasing depth until no effect was observed at depth of 50cm. This work has shown that the deeper the burial depth of landmines and other buried objects, the lesser it will be to detect. Also, light or small landmines or other buried objects will easily be detected as lighter or small objects will emit more temperature that big or thicker objects.
References


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