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Microwave Enhancement on Thermal Detection of Buried Objects

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Abstract

Underground objects of a passive type can manifest themselves only as a result of thermal stimulation of which typical is the use of natural solar radiation. In this case, a particular temperature difference between the background and the site with buried objects appears with the optimum observation time being dependent on object depth. Meteorological conditions strongly affect the ground surface temperature but their correct modelling is difficult. A microwave source was used to increase the detection probability of buried objects by using the IR thermography method. A time-gated microwave source delivers heat energy soil, thus allowing the detection of subsurface features that are sensitive to microwave irradiation. In this paper, the results of using microwave stimulation in order to enhance thermal indications over buried landmines are presented.

1. Introduction

Mines and UXOs (Unexploded Objects) still represent the most feared post-war danger. Landmines prevail in undeveloped countries which typically have no financial means to purchase modern landmine detection hardware. Indeed, to acquire and install a landmine costs from $ 3 to $ 30 per device, while the cost to detect and remove a single landmine is between $ 300 and $ 1000. In fact, there is a need for more effective and less expensive landmine detection and removal systems across the world.

Unfortunately, the ease of detecting landmines is decreasing due to two main factors. Firstly, modern landmines contain less metals and are often much smaller than those a few decades ago, thus representing a challenge when using available inexpensive technologies. The size of modern anti-personal landmines ranges from 6 to 15 cm in diameter. Therefore, detection means must be quite accurate while locating such landmines. A lack of metal in landmines usually may eliminate the efficacy of affordable existing detection devices, namely, metal detectors. For example, PMN mines, manufactured by the former Soviet Union on a large scale, are enclosed in a thick rubber casing, while PDM-7 mines (also made by the former USSR) have a wooden casing. Then, many previously-installed landmines have survived for a long period of time, therefore, possible visual indications of their planting may have disappeared, and vegetation may have grown across sites where landmines were buried.

As a result, there are presently about 20 methods available for the detection of landmines and being at various stages of development. They range from quite simple means, such as the use of dogs, to the most sophisticated modern techniques including the use of IR radiation, nuclear quadrupole resonance, thermal neutron activation, acoustic methods, magnetic measurements which implement the use of superconducting quantum interference devices and chemical detection means.

An example of unexploded objects are cluster bombs which can penetrate the soil up to depths from few mm to 150 cm. Cluster bombs are generally contained within a dispenser that is dropped from aircraft. The dropping is followed by opening of the dispenser and activation of its sub-munitions. A certain percentage of such cluster bombs (about 20-25%) do not explode but remaining activated for a long period of time without any auto-destroying mechanism being adopted. In any case, very harmful effects can be caused to both people and the ambient.

The new threat that has appeared recently is represented by improvised explosive devices (IED). According to NATO Combat Engineer Glossary, IED is a device placed or fabricated in any improvised manner incorporating destructive lethal, noxious, pyrotechnic or incendiary chemicals and designed to destroy, incapacitate, harass or distract. It may incorporate military stores, but is normally devised from non-military components [1]. At present, the limitation in matter of designing, preparation and use of improvised explosive device is often a terrorist's imagination.

IR thermography is a method that can be also used in the detection of buried objects. Passive infrared sensors can detect changes in temperature on the soil surface caused by varying environmental conditions. A main drawback of the known passive infrared thermography is a relatively small range of temperature throughout a day/night cycle. Furthermore, detection results may be greatly affected by environmental conditions.

2. Atmospherical Conditions

Some external factors that are meteorological parameters, such as air temperature, moisture, speed of wind and intensity of solar radiation, influence diversely on soil surface temperature.

The influence of weather conditions on the efficiency of IR thermographic detection of landmines is as follows [2, 3]:

Solar radiation: Both the season of a year and a daytime, as well as a level of cloudiness and local shading effects, have impact on the probability of mine detection. Obviously, prolonged periods of strong solar radiation and a low cloudiness are desirable to ensure enhanced energy stimulation of soil.

Ground surface heating/cooling conditions: A combination of these factors may cause a periodic disappearance of thermal signatures observable over landmines. This may occur not only shortly after sunrise and before/after sunset but also in other time periods depending on agro-meteorological conditions.

Cloudiness: Clouds diminish the intensity of ground heating/cooling processes thus decreasing thermal contrasts that are considered as landmine indications. There are three principle types of weather conditions that can be defined by taking into account the cloudiness of skies:

- Sunny,
- Variable,
- Cloudy.

Rain: Even short-time rain decreases to a great degree the ground surface radiation temperature. However, oppositely, a sudden moistening of a previously warmed up soil may lead to a short-time increase of thermal contrasts.

Moisture: Dew and hoarfrost may significantly change thermal signatures because of variations in surface emissivity and latent heat effects. The speed of such change is inversely proportional to thermal masses of particular soil sections;

Enhanced air moisture: This parameter strongly influences the intensity of evapotranspiration processes and typically decreases landmine thermal contrasts;

Change of phase: This phenomenon can rapidly change the distribution and the level of observed radiation temperatures. When the temperature of air approaches to the water freezing point, the surface water transforms from a liquid state to solid thus causing a latent-heat discharge. In case of transition from a solid state to liquid or liquid to steam, the post-phenomenon of decreasing radiation temperature may occur. This phenomenon, that can be observed only in some special cases (open soils and small depth of buried landmines), can shortly improve the detection of mines but in general it is undesirable;

Inversions: Variations in the air temperature cause faster variations of surface temperature where the soil heat capacity is lower. Again, this can enhance the visibility of buried landmines only in some being in general undesirable;

Wind: Strong wind causes a very quick change of soil surface being dependent on a surface profile and water content in soil. The presence of wind is always unpleasant when using a thermal method.

3. Microwave radiation

Active infrared detection methods utilize several ways to thermally stimulate buried objects in order to artificially improve their thermal signatures detected by IR cameras. Microwaves represent one of such stimulation techniques. In general, the microwave-enhanced thermography involves the delivery of a high-energy microwave signal onto the soil surface in the area of interest by using an aerially-suspended microwave antenna and the capture of IR thermograms with an IR camera. These thermograms are to be compared with the images taken in the same areas prior the microwave stimulation, then the difference between these images is analyzed in order to reveal possible thermal indications of buried objects [4, 5].

A part of microwave energy is reflected from the surface of soil, as well as from buried objects. The residual part penetrates the soil and is transformed in heat. The behaviour of the microwave reflection coefficient for sand with about 10 % moisture in the frequency range from 3.5 to 6 GHz is shown in Fig. 1. On average, there is about 80% of microwave energy that penetrates into soil and 20 % is reflected in this range of frequency. The influence of the landmine depth on the landmine depth is illustrated with Fig. 2.

Thus, a bunch of parameters affects thermal indications that appear over buried landmines in the case of microwave stimulation, namely: microwave power and frequency, temperature of soil and environment, surface profile and moisture content and, in particular, type of landmine casing and depth of burying.

4. Experimental Results

All experiments were carried out by using a FLIR SC 7600 thermal camera and a set of instruments for measuring the temperature of buried mine, the soil temperature on the surface and in-depth, the soil moisture, the intensity of solar radiation and the state of outdoor conditions. The area of interest included an isolated plastic container with dimensions 1000x850x1000 mm (Fig. 3). The temperature sensors and the landmines were placed in precisely determined points in the soil-filled the container. In the laboratory experiments, we have used a PDT-7 landmine (wooden casing filled with beeswax) and a MS-64 landmine (metallic casing filled with beeswax). Two types of heat sources have been used for thermal stimulation. The first one included two infrared lamps generating the heat power density about 500 W/m^2 thus simulating solar radiation. The second was a microwave source with power of about 180 W placed at about 11 cm over the surface of sand. Tests were conducted for different microwave frequencies (900 MHz, 2.45 GHz, 5 GHz and 7.5 GHz) but the power of microwave source remained the same.

The PDT-7 mine has the form of a parallelepiped-shaped 51x76x152 mm wooden box. The landmine total weight was 300 g including 75 g of TNT. The MS-64 mine also has the form of a parallelepiped-shaped 95x100x250 mm metallic box of the 1800 g total weight including 1200 g of TNT.

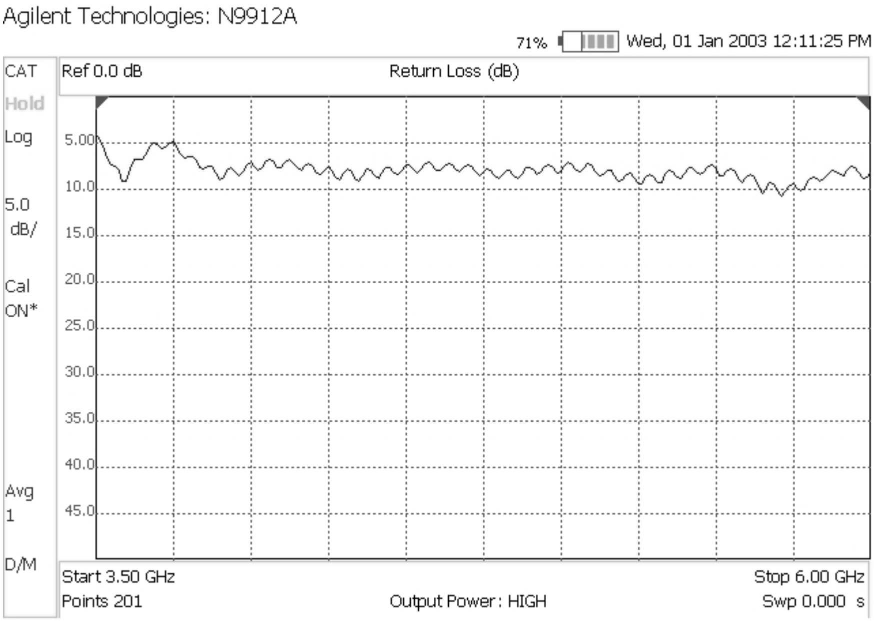

Fig.1. *Reflection coefficient vs. microwave frequency for sand (10 % moisture) in the frequency range from 3.5 to 6 GHz (microwave antenna axis perpendicular to the surface of sand).*

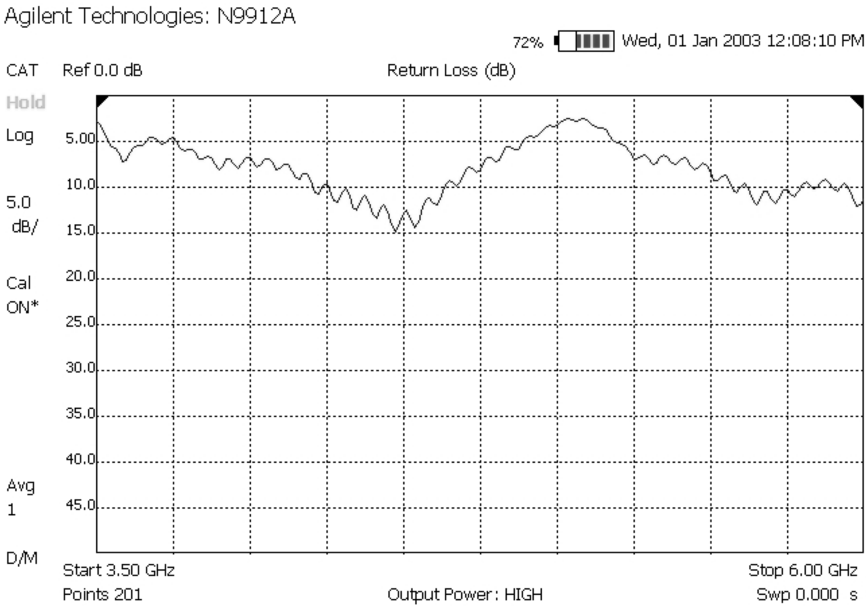

Fig.2. *Reflection coefficient vs. microwave frequency for a metallic-casing landmine buried at 3 cm depth (microwave antenna axis perpendicular to surface of sand).*

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Fig. 3. *Laboratory set-up*

A thermogram that reflects the temperature distribution in the area of interest in the cooling stage (heating for 160 min. with infrared lamps) is presented in Fig.4. In parallel with the IR thermographic survey, the moisture of sand and the temperature of landmines were measured. Two mines were buried in sand: the PDT-7 at the depth of 2.5 cm and on the MS-64 at the depth of 3.5 cm. The thermogram shows no good indications of two buried landmines thus making their detection difficult. The heating conditions implied in this test were similar to those occurring at a summer cloudy day. The change of the temperature under the surface of sand (Fig. 5) did not exceed 5ºC (T3 – over the wooden-casing mine and under the surface of sand at the depth of 0.5 cm, T2 – over the metallic-casing mine and under the surface of sand at the depth of 1 cm). The sand moisture along the vertical profile was from 1 to 3%.

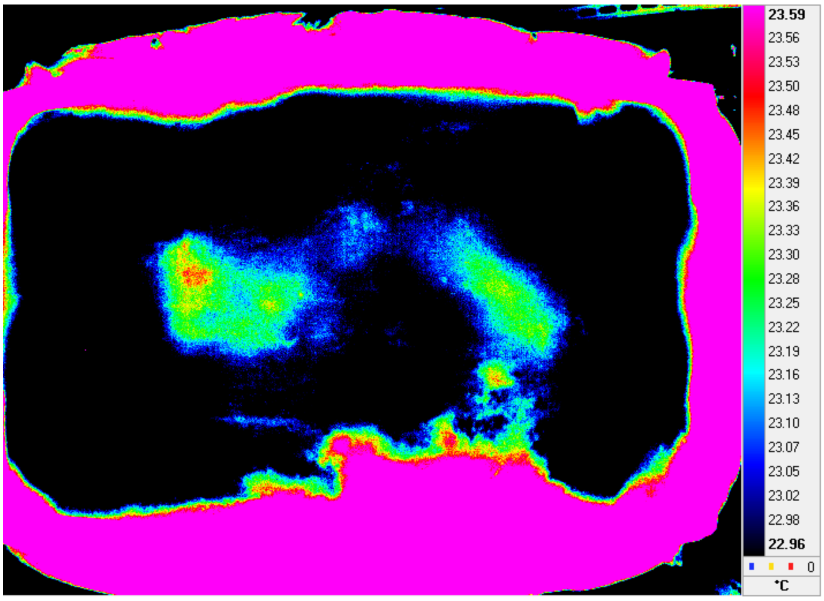

Fig. 4. *Thermogram of the area of interest with the buried wooden-casing PDT-7 (left) and the metallic-casing MS-64 (right) landmines after heating*

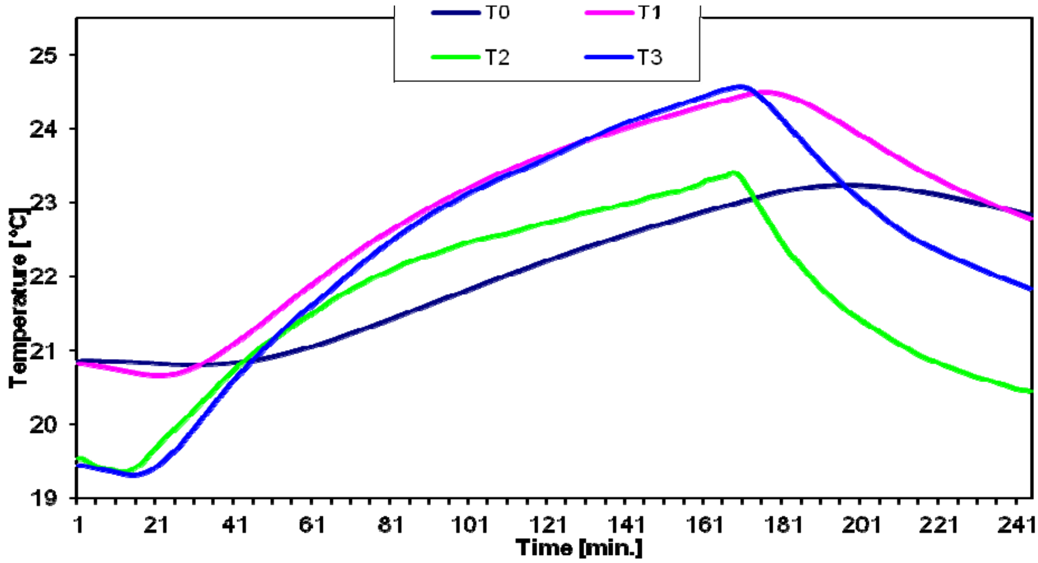

Fig. 5. *Experimental temperature profiles in sand and across the landmines (wooden- and metallic-casing) in the heating and cooling stages*

The results obtained by using the microwave source at the frequency of 5GHz for the detection of the wooden-casing mine are presented in Figs. 6 and 7 whereas Fig. 6 shows the situation where the microwave source was placed over the buried landmine and Fig.7 corresponds to the case where the microwave source was aside the landmine. The significant improvement of landmine visibility is well seen in these thermograms.

Since the power of the used microwave source was rather low (180 W), the duration of heating was relatively long (20 min.). In the future experiments, we plan to use a microwave source with the power of about 2 kW. This should significantly shorten the time of heating and also increase a heated area thus improving landmine identification across larger areas.

The essential influence of the sand moisture and density on the surface thermal patterns when using microwave heating has been found in the aqbove-described experiments thus confirming the earlier-published data [3, 7, 8].

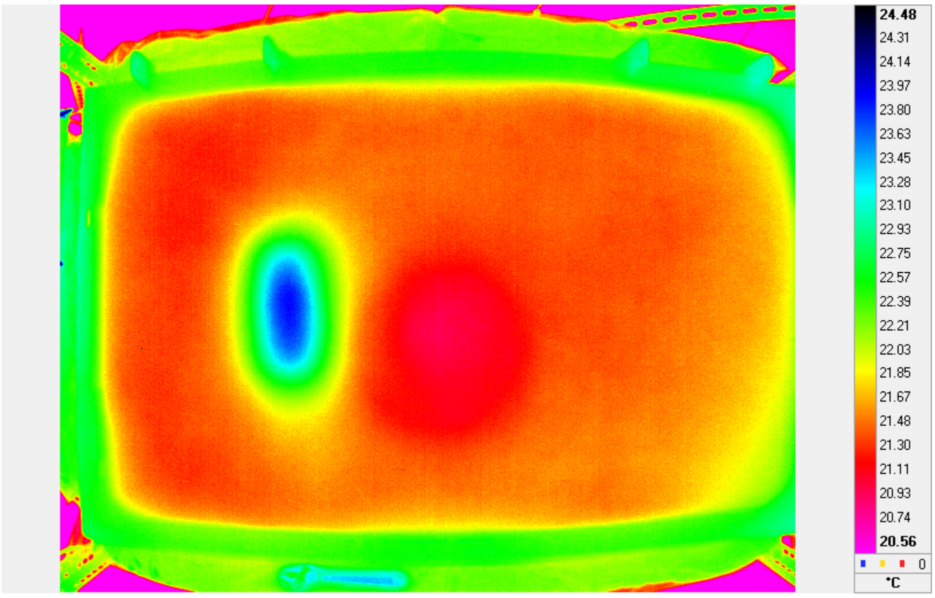

Fig. 6. *Thermogram of the area of interest with the buried wooden-casing mine after heating (microwave antenna placed over the landmine)*

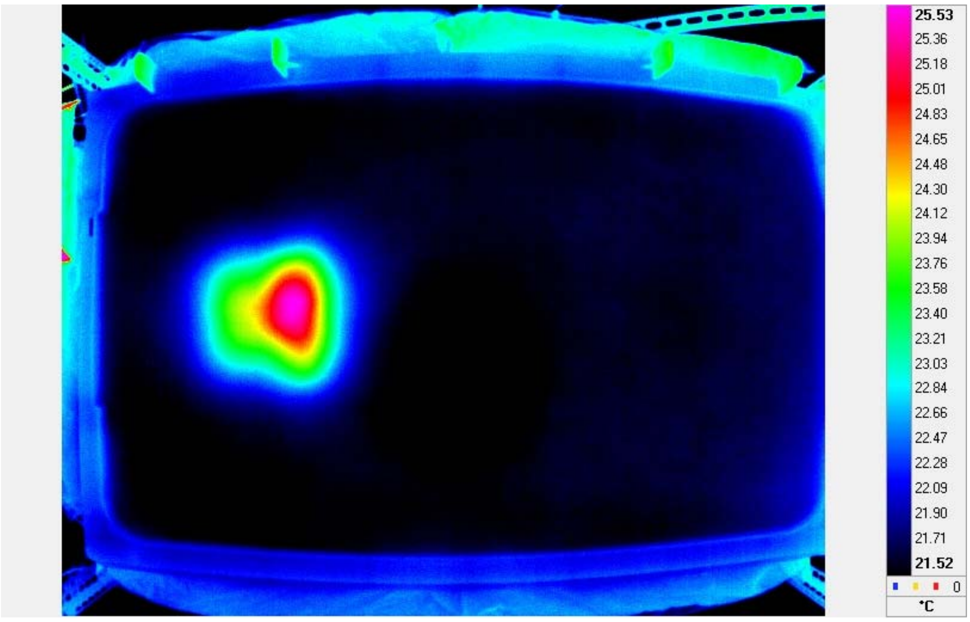

***Fig. 7*.** Thermogram of the area of interest with the buried wooden-casing mine after heating (microwave antenna placed near the landmine)

5. Conclusions

The benefits of microwave-enhanced IR thermography include a relatively high resolution, the possibility to control a heating cycle and fast analysis. It has been noted that the microwave-enhanced IR thermography method as described above can work well when the tested surface is relatively smooth, but its performance suffers if the surface has considerable irregularities or points of roughness. It is believed that such degradation is conditioned by distortions of the microwave field caused by the irregularities, thus resulting in such variations of heating uniformity that are greater than those associated with buried objects. This effect has been referred to as “noise” inducted by surface roughness. If this noise is sufficiently high, it becomes more difficult to identify signal features caused by buried objects, thus leading to missed detections and false alarms. Therefore, the future research will be forwarded to the implementation of a more powerful microwave source, as well as to the development of such image processing algorithms which may significantly reduce false alarms.

Acknowledgements

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