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DETECTION OF BURIED OBJECTS BY ACTIVE INFRARED THERMOGRAPHY METHOD IN DISADVANTAGEOUS ATMOSPHERIC CONDITIONS

Waldemar Swiderski(*)
Military Institute of Armament Technology, Zielonka, Poland
(*)*Email:* waldemar.swiderski@wp.pl

ABSTRACT

Underground objects of a passive type can manifest themselves on the surface only as a result of thermal stimulation that usually occurs in the form 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. The ground surface temperature is strongly affected by meteorological conditions and their correct modelling is difficult. A microwave source was used to increase the detection probability of buried objects by using the IR thermography method. In this paper the results of outdoor experiments carried out at disadvantageous conditions for active detection approach are presented.

Keywords: infrared thermography, microwave, buried objects.

INTRODUCTION

Thermography is one of many techniques used for nondestructive testing for which both passive and active approach could be taken. The passive approach is effective for materials and structures which for natural reasons have different temperature than the environment. The active approach requires an external heating source to stimulate the materials or structures to be tested. These methods can be also applied to detect objects hidden in the ground. Passive approach is used when natural heating of soil by sun radiation is exploited. This passive mode of heating has to last relatively long to deliver solar energy and raise temperature of the soil layer that confines the objects. Such slow process of heating comes out from quite a low thermal conductivity of the soil. In addition the effectiveness of such heating is limited by weather conditions – diurnal and seasonal. Due to these processes the temperature on the surface of the earth and its sub-surfaces changes in a characteristic way.

Exchange of heat between soil surface and the atmosphere goes on as:

- Short-wave sun radiation absorbed by the atmosphere and ground surface;
- Thermal conductivity between soil surface and its ground;
- Heat transfer between ground surface and the atmosphere, or between land and water surface thanks to turbulent movements.

The temperature on the ground surface depends on the following factors: ground moisture, thermal conductivity, absorption ability of the surface, coverage of the terrain by plants or by snow, degree of cloudiness [Kimball et. al., 1976].

From the point of view of passive approach on detecting buried objects the disadvantageous conditions can be described as small differences of the 24 hours temperatures and cloudiness or falls that happen very often at winter, autumn or spring for the zone of moderate climate where we made our investigations (Poland). The favourable conditions for using passive approach on detecting buried objects usually exist in the summer. In the case of active approach it is used an external heating source for example a microwave source to provide thermal stimulation.

DISADVANTAGEOUS CONDITIONS TO DETECTION OF BURIED OBJECTS

The average value of percentage ratio of heat sum penetrating to soil regarding the total sum of solar radiation was about 17.7% and in majority of cases it ranges from 15% to 20% and can be found in paper [Kossowski, 2007]. Smaller values relating this problem are in another works. This value is from 4.8% to 12.6% basing on measurements carried out on soil without plants [Enz et al., 1988] but in another work [Olivier et al., 1987] the value of this relation is from 9.7% to 12.7%. Basing on these works it can be assumed that quantity of heat penetrating to open soil during all day is less than 20% of twenty four hours sum of total solar radiation. Inflow of solar radiation to soil is not only limited in case of vegetation covering the soil but the vegetation causes time and spatial variability of heat exchange conditions also.

Maximum flux density of solar radiation could be about 900 W/ m^2 in summer months about noon at clear sky in Poland and average daily density can be accepted at level of 500 W/m^2. In winter the average daily flux density of solar radiation (clear sky) is about 100 W/ m^2. Taking under consideration that quantity of heat which penetrates to soil is less than 20% the density of heat flux penetrating into the depth of soil is less than 20 W/ m^2. Of course, this value decreases at cloud cover.

In Poland the most disadvantageous atmospheric conditions to detection of buried objects by passive IR thermography method are from November to March. Average temperature decreases below + 5ºC in these months and in the coldest month (January) it decreases below - 5ºC. Most cloudy days of year are in this time.

For modelling the detection of buried objects by passive IR thermography method by the influence of atmospheric conditions as well as thermal parameters of soil to this detection the software "ThermoCalc – Mine™" was used. It was developed by Prof. Vladimir Vavilov from the University of Technology in Tomsk (Russia) for needs of work conducted in the Military Institute of Armament Technology (Poland) [Swiderski et al., 2012]. Selected results of the simulation are given in Fig.1-4. Thermal parameters of materials used for computer simulation are presented in Table.1.

Table 1 Thermal parameters of materials used for computer simulation

Material	**Conductivity [$W{\cdot}m^{-1}{\cdot}K^{-1}$]**	**Heat capacity [$W{\cdot}s{\cdot}kg^{-1}{\cdot}K^{-1}$]**	**Density [$kg{\cdot}m^{-3}$]**
wood	46.0	440	790
TNT	0.23	1703	1500
Sand, water content 0,4 m^3/m^3	2.057	2840	1400
Sand, water content 0,4 m^3/m^3	1.144	2429	1000
Sand, water content 0,0 m^3/m^3	0.157	1170	1400

In order to analyse a possibility of passive thermal detection of buried objects a simulated model of PMD-7 anti-personnel mine was developed. PDM-7 is anti-personnel mine that consists of a wooden box with a hinged lid and a slot cut into it. The slot presses down against a retaining pin that holds back the striker. When sufficient pressure is applied to the lid of the box the retaining pin moves, allowing the striker to hit the detonator. PDM-7 has a form of parallelepiped with 51 mm height and 76 mm width and 152 mm length. The weight of mine is 300 g and there is 75 g TNT.

Fig.1 compares the changes of temperature on the surface for sand with the same thickening degree (1400 kg/m^3) and content of water (0%) but in different conditions of season of the year (winter and summer). In simulation it was accepted that heating time of solar radiation during sunny weather (clear sky) was 16 hours in summer and 8 hours in winter. Average daily solar radiation density was 500 W/m^3 for summer and 100 W/m^3 for winter. Amount of heat penetrating to soil was considered. Plots presented in Fig.1 show that there are essential differences between summer and winter in possibility of detection of wooden mines. Taking under consideration that level of noise in NDT IR thermography methods may be higher up 0.1ºC, then limit of detection is the value of temperature over mine in winter.

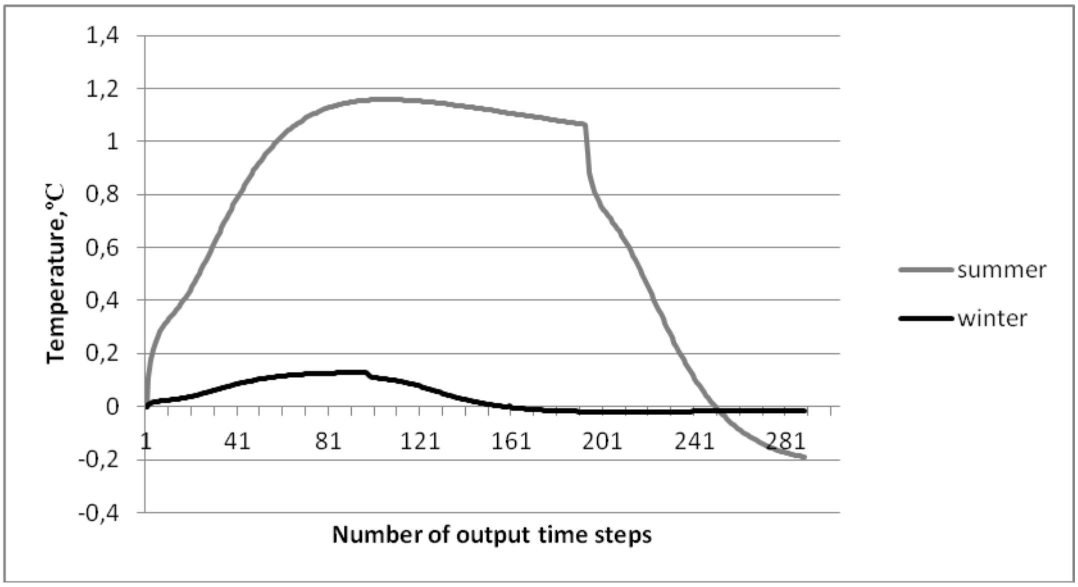

Fig.1. Comparison of temperature changes on the surface of sand over the buried wooden mine for summer and winter conditions (Output time step 300 s)

The works [Pregowski et. al., 1999 and Usowicz, 2000] show that moistening degree and thickening degree of the soil have essential influence on possibilities of detection of buried objects. In Fig. 2 is presented determined characteristics of heat conductivity for sand.

Fig.3 presents comparison of detection possibility of wooden mine buried (5 cm) in sand with the same moistening degree (0.4 m^3/m^3) but different thickening degree in winter conditions and clear sky. From the plots presented in Fig.3 it appears that better conditions to detecting buried object are for smaller thickening degree of the sand.

Comparison of detection possibility of wooden mine buried in sand of the same moistening degree and thickening degree but in winter conditions for clear sky and overcast shows Fig.4. It is visible that detection of buried mine in condition of overcast is practically impossible.

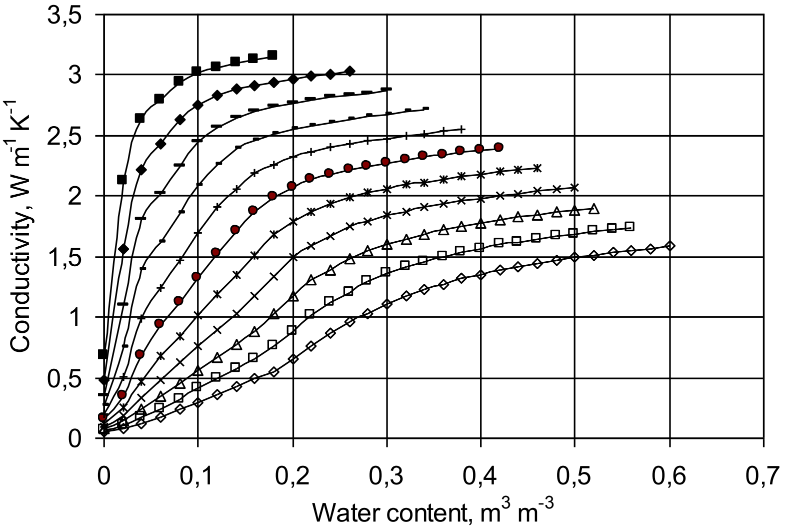

Fig.2. Heat conductivity of tested sample of sand

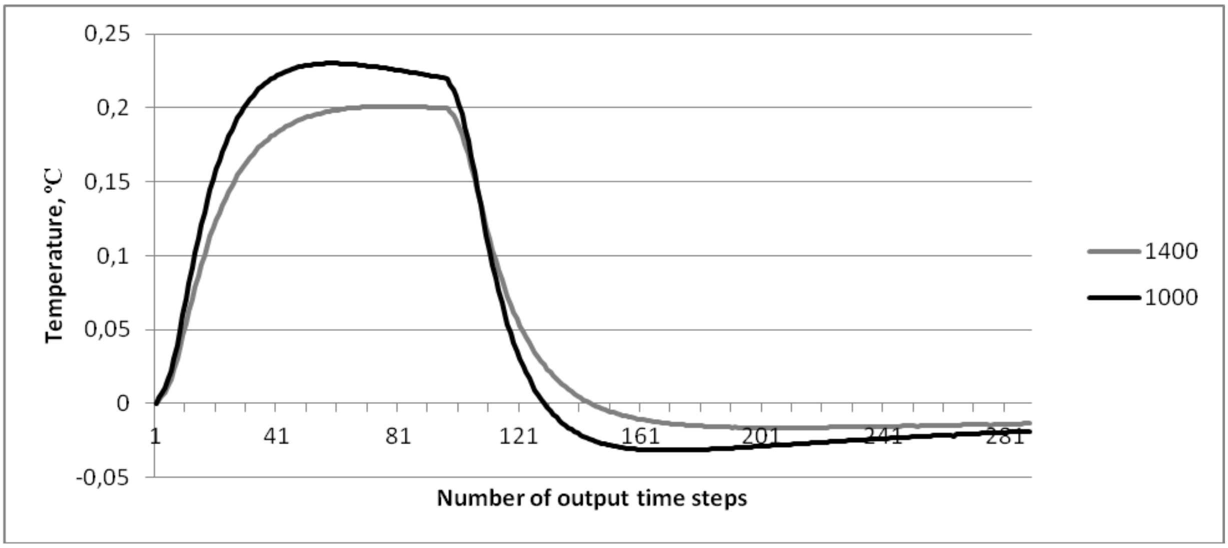

Fig.3. Comparison of temperature changes on the surface of sand over the buried wooden mine at different thickening degree (Output time step 300 s)

The results of simulation indicated that in majority of cases detection of buried objects by passive IR thermography method is impossible in winter conditions. Only use of active method (microwave source) could increase probability of detection of buried objects.

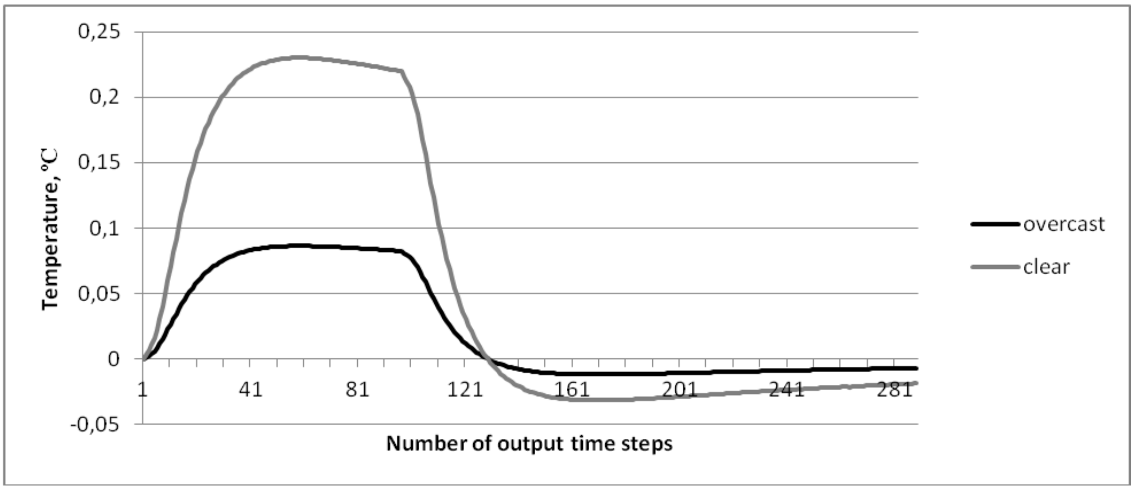

Fig.4. Comparison of temperature changes on the surface of sand over the buried wooden mine with different cloud cover of sky in winter conditions (Output time step 300 s)

RESULTS OF EXPERIMENTAL TESTS

Preliminary experimental tests were conducted on an outside measurement field. This measurement field consisted of four parts each having the surface about 1 m^2 (1m x 1 m). Each of these parts was filled with different kind of material on depth about 0.5 m: sand (Fig.5), gardening ground, gardening ground from upper layer (about 5 cm) of peat and gravel. Military objects (different kinds of mines) and another objects: a tin filled with air, plastic bottle filled with water, glass bottle filled with water and a white brick were buried on depth 5 cm. Microwave source was placed about 1.5 m over the surface of measurement field and generated power about 2 kW at frequencies of 2.45 GHz. During tests with buried objects the surface of measurement field has been heated for 10 min. All experiments were carried out using FLIR A645 thermal camera and set of instruments for measuring following data: temperature on buried mine, temperature on profile of the soil, temperature on surface of the soil, moisture of the soil, irradiance of the surface and state of external conditions.

The location of wooden mine and tin on the outside measurement field (filled with sand) before burying is present in Fig.5. Fig.6 shows this field after burying these objects. Experiment was carried out on 4 January, 2013 at following atmospheric conditions: temperature of air - +3.5 - +4.0ºC, humidity of air – 75 – 80%, without precipitation, atmospheric pressure – 1017 hPa, wind velocity – about 6 m/s (northwest), overcast and the results are presented below. In the night before test there were following atmospheric conditions: temperature of air – about 0.0ºC, humidity of air – 85 – 95%, rainfall about 0.5 mm/h by 5 hours, atmospheric pressure – 1012 hPa, wind velocity – about 7-8 m/s (west), overcast.

Fig. 7 shows example of experimental results - thermal signature of objects (anti-personal mine - wooden box filled with beeswax and air-filled metal canister).

Fig.5. Outside measurement field (filled with sand) before objects were buried (tin and wooden mine)

Fig.6. Outside measurement field (Fig.5) after burying objects

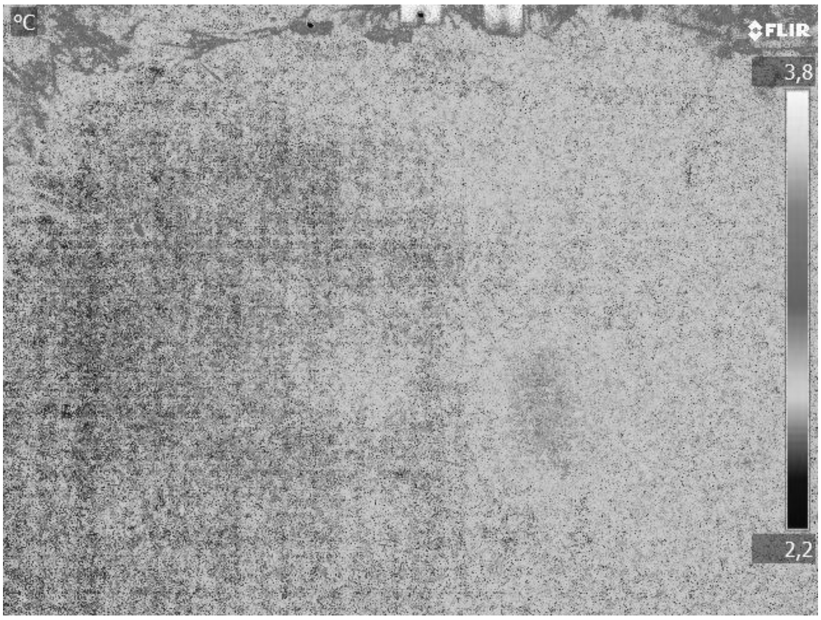

Fig.7. Thermogram of outside measurement field (filled with sand – Fig.6) with buried wooden mine and tin filled with air before heating with microwave source

Thermogram and temperature signals presented on Fig. 8 and 9 show that detection of buried objects by passive thermography method is very difficult and merely on the basis of prior acquaintance of places where the objects were buried there is possible to find their faintly visible thermal traces.

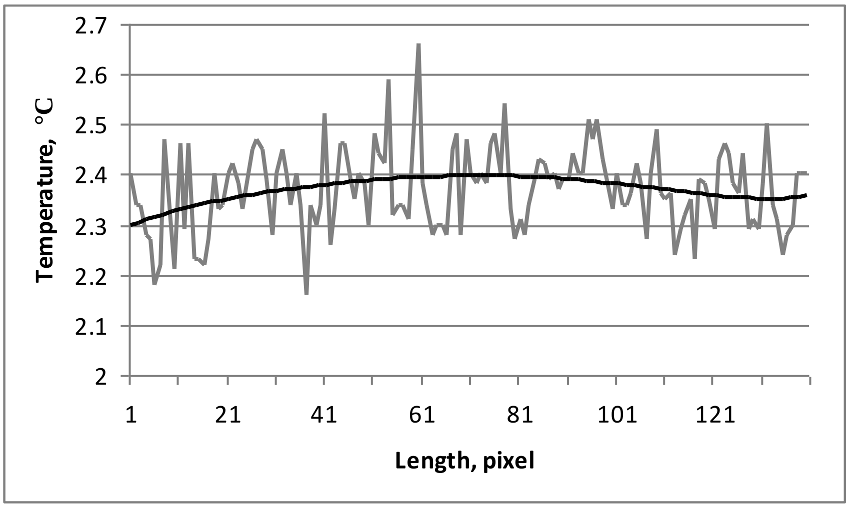

Fig.8. Temperature changes along buried tin on the surface of outside measurement field before heating by microwave source (Fig.7)

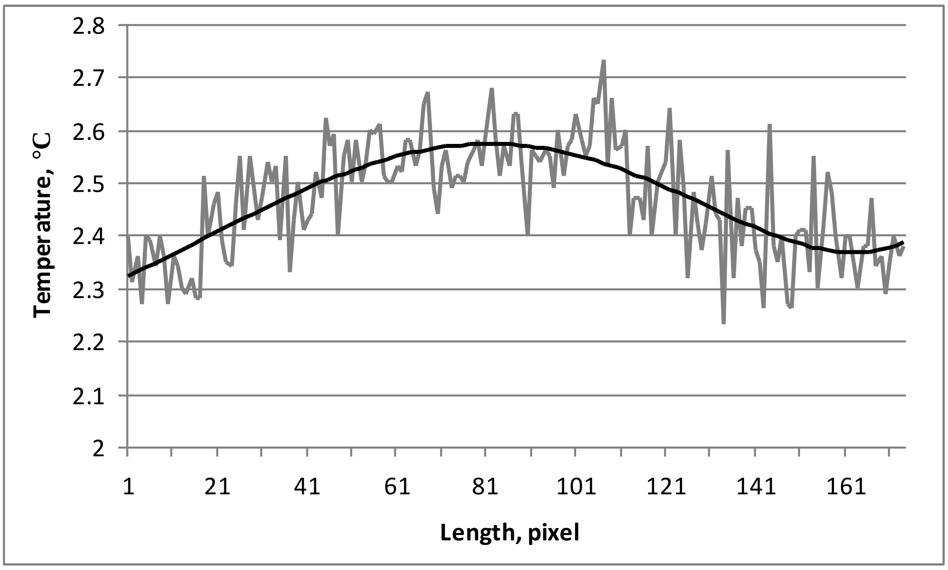

Fig.9. Temperature changes along buried wooden mine on the surface of outside measurement field before heating by microwave source (Fig.7)

Fig. 10 shows thermogram after heating the outside measurement field by the microwave source. Both thermal traces of the tin and mine are very well visible on surface of measurement field. This is also clearly visible on graphs (Fig. 11 and 12). After heating the difference of temperature on the surface over the tin and outside it is about 0.6ºC (Fig. 11) whereas before heating it was less than 0.1ºC (Fig.8).

The difference of temperature over mine and outside mine after heating was about 2ºC (Fig.12) whereas before heating it was about 0.15ºC (Fig. 9).

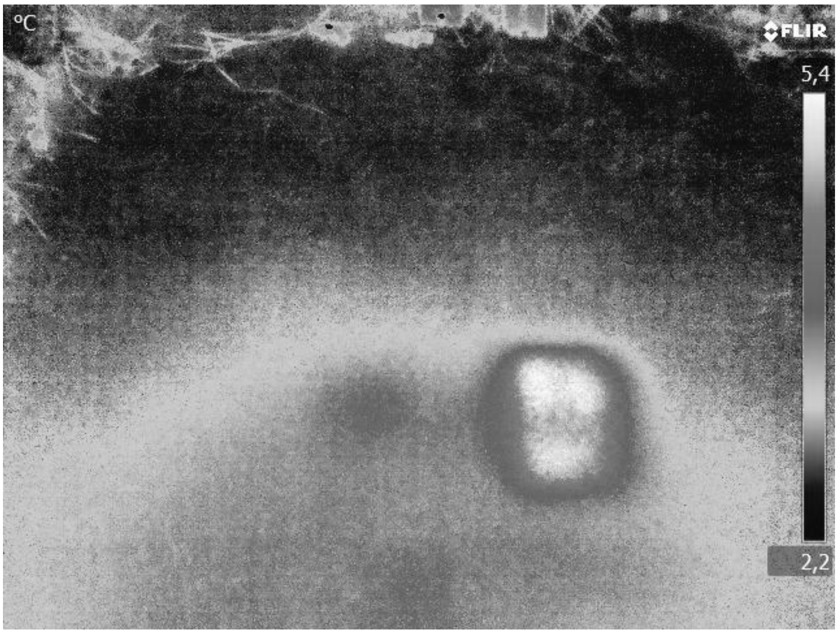

Fig.10. Thermogram of outside measurement field (filled with sand – Fig.6) with buried wooden mine and air filled tin after heating by microwave source

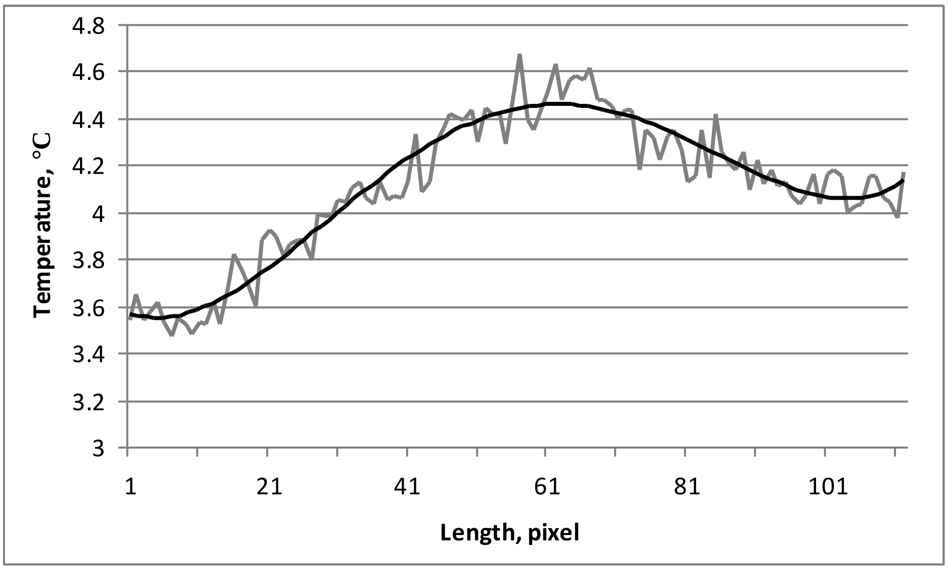

Fig.11. Temperature changes along buried tin on the surface of outside measurement field after heating by microwave source (Fig.10)

Temperature changes of wooden mine during heating are presented in Fig. 13. This temperature increases from +5.6ºC to +7.1ºC which causes that temperature of thermal trace on surface of measurement field increases from +2.6ºC to +5.5ºC (Fig.12). Arrows show points on the graph of the buried wooden mine temperature changes (Fig.13) where microwave heating of measurement field begins and ends. Instantaneous decrease of temperature of mine is visible after the end of heating by microwave source, then temperature of mine increases by 20 minutes and exceeds a temperature of mine about 7,2 ºC as a result of heat flow from sand surrounding the mine which was heated to higher temperature by microwave source.

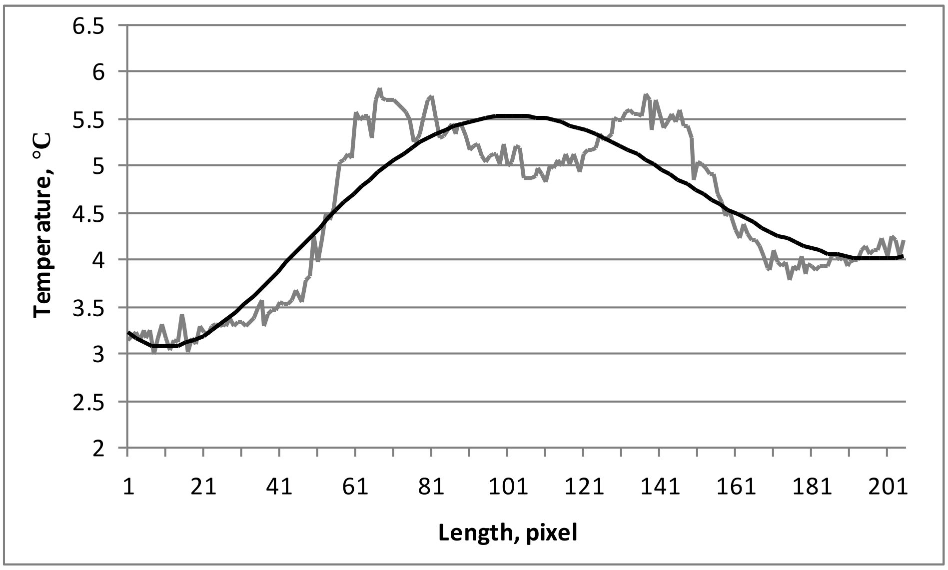

Fig.12. Temperature changes along buried wooden mine on the surface of outside measurement field after heating by microwave source (Fig.10)

Better results were obtained during detection of metal mine buried in gardening ground. Difference of temperature before heating was about 0.15ºC (Fig. 14) and after heating it was about +5ºC (Fig. 15).

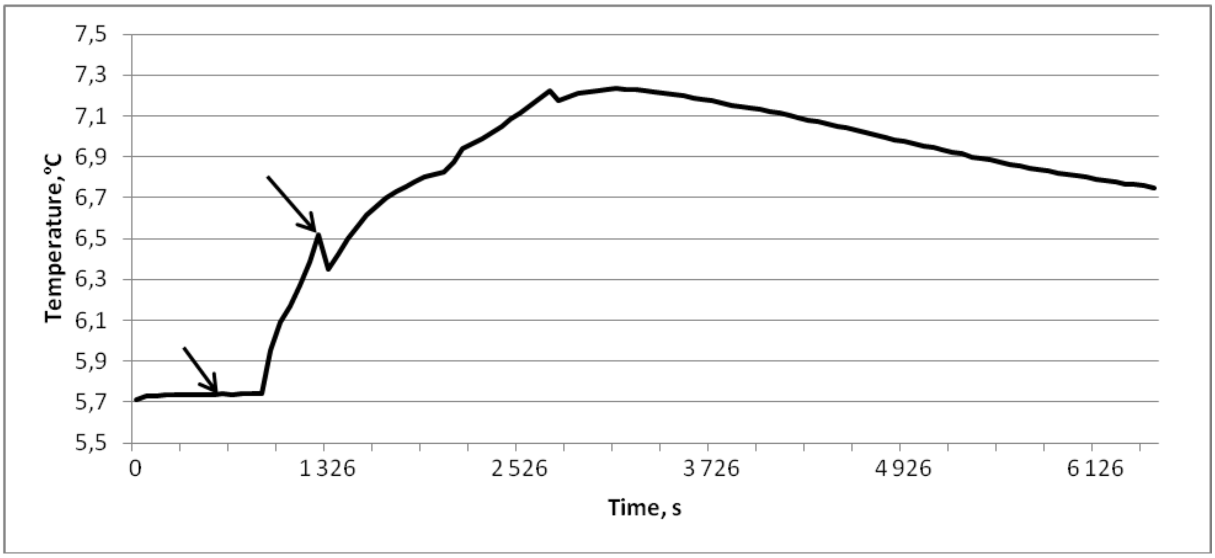

Fig.13. Changes of temperature of buried wooden mine during heating by microwave source

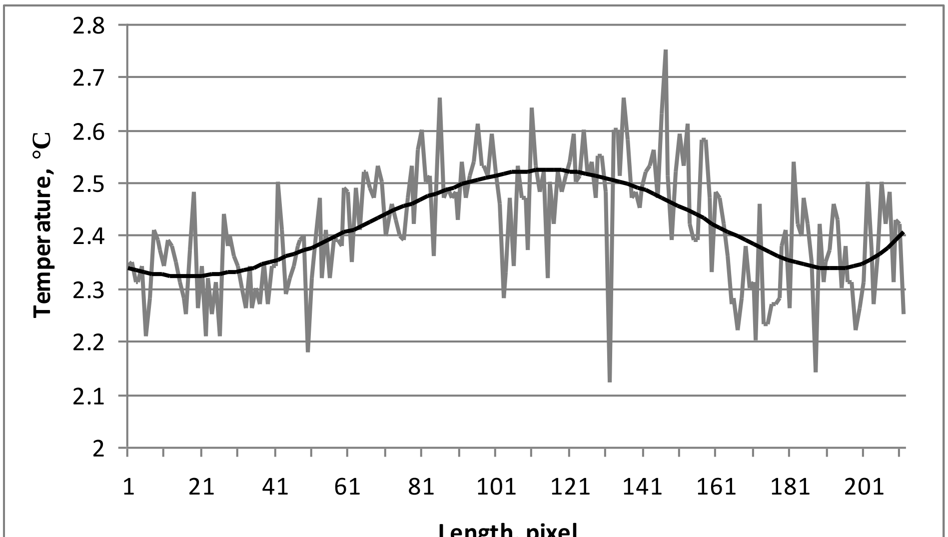

Fig.14. Temperature changes along buried metal mine on the surface of outside measurement field (filled with gardening ground) before heating by microwave source

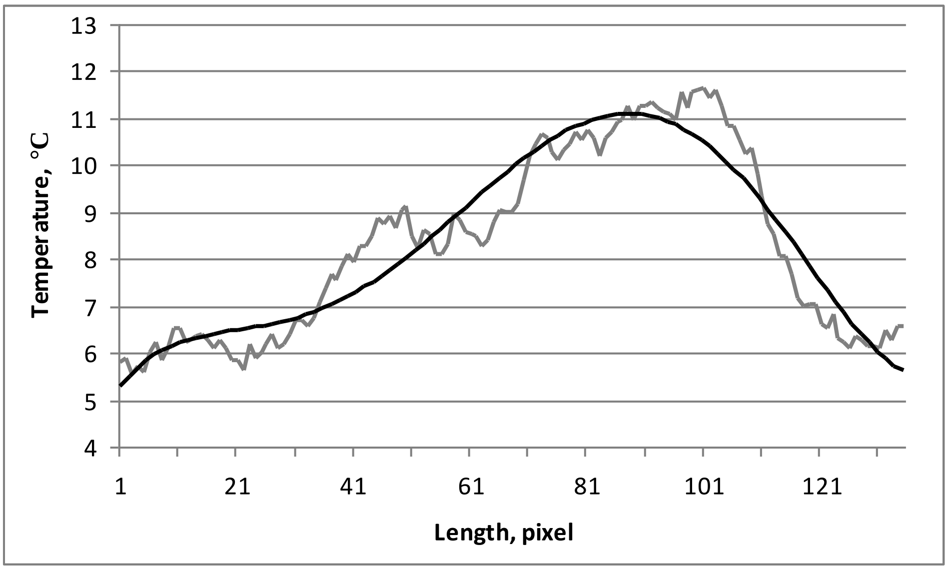

Fig.15. Temperature changes along buried metal mine on the surface of outside measurement field (filled with gardening ground) after heating by microwave source

Plastic mine buried in gravel before heating was not detected practically (Fig. 16) and after heating difference of temperature was about 1.5ºC (Fig.17).

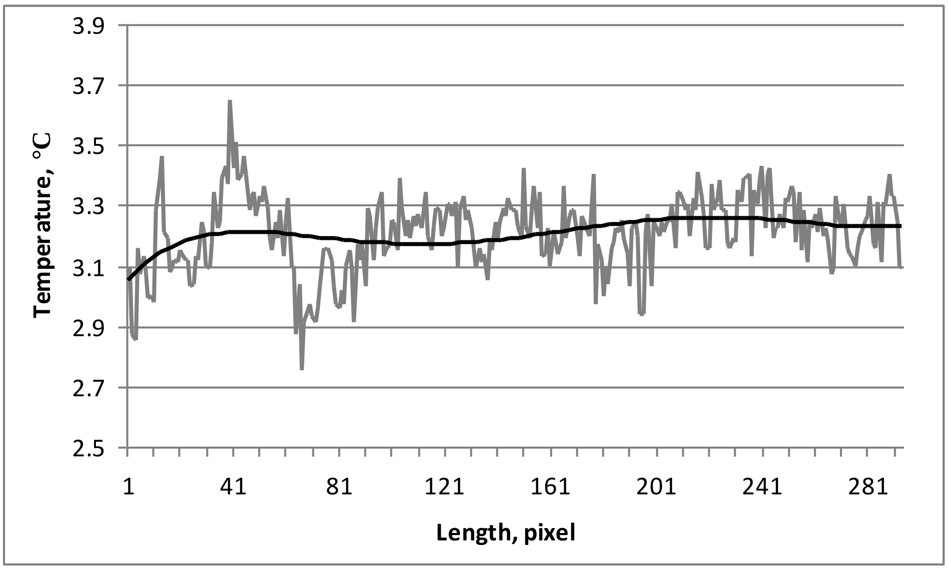

Fig.16. Temperature changes along buried plastic mine on the surface of outside measurement field (filled with gravel) before heating by microwave source

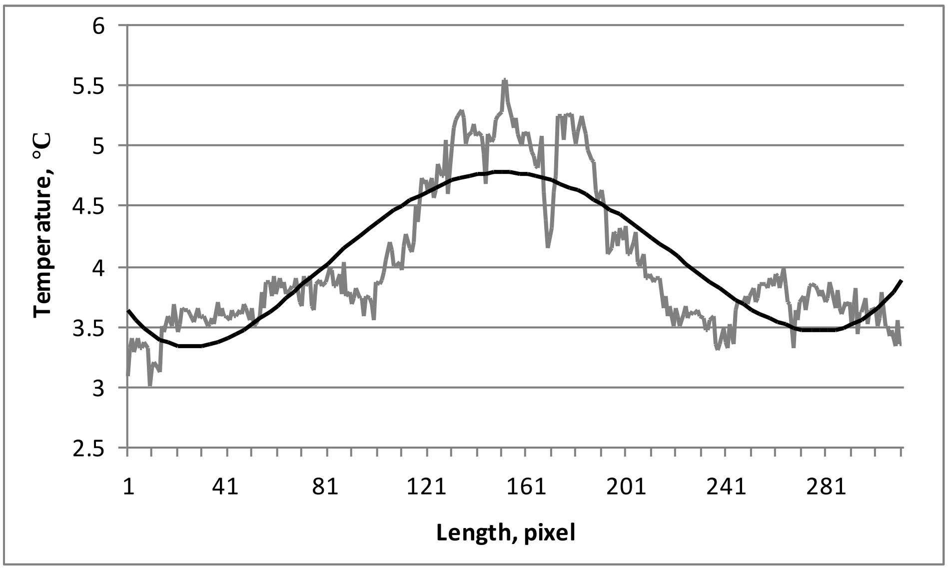

Fig.17. Temperature changes along plastic mine on the surface of outside measurement field (filled with gravel) after heating by microwave source

CONCLUSIONS

This experiment shows that there are possibilities of detection of buried objects by active IR thermography method in disadvantageous atmospheric conditions.

To improve efficiency of active IR thermography method in our further experiments we would like to focus on the following objectives:

- Choice of algorithms for processing the images
- Application of data fusion including analysis of test results obtained from usage of active and passive thermography method, multispectral method (UV, VIS and NIR) and ground penetrating radar (GPR) method. Such analysis should limit the noises resulting from non-uniform heating the soil surface, local moistures, different type objects being on surface of soil etc. and increase in considerable degree the probability of detection of searched objects. More precise identification of shape and dimensions and depth of searched buried objects could also be provided.

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