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Mines detection using the EMIR® method

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Abstract

The ElectroMagnetic-InfraRed technique (EMIR®) is used for the detection of buried mines. First we discuss the principle and the advantages of the technique as compared to more classical stimulated thermographic techniques applied to this problem. A simple test bed is presented and first results are given that show at least in the present case a good sensitivity where the ground consists of coarse sand. Influences of lift-off sensor, sand humidity, nature, size and depth location of mines are experimentally studied.

1. Introduction

ONERA has been developing for more than fifteen years a quantitative imaging technique for electromagnetic (EM) fields called EMIR® (ElectroMagnetic-InfraRed). The technique consists in observing a thin film (typically 25 µm) of controlled electrical conductivity with an infrared camera in the presence of an EM field. In the film, a photon-heat conversion occurs (photothermal effect). The temperature distribution of the film is an image of the space distribution in the plane of the film of the photon flux density, and consequently of the intensity of the electric field [1]. Generally the technique is used for monitoring EM fields in the microwave range (centimetre to millimetre wavelengths). The technique has been continuously improved so that it is now capable of measuring both intensity, phase and polarization of the waves [2].

Among the various possible applications, the non-destructive evaluation (NDE) of EM materials has been explored [3]. In particular, single-ended configurations have been proposed for NDE [4]. Such configuration would apply to the buried mines. First we demonstrate the interesting features of the EMIR® technique as compared to classical stimulated thermography in the detection of internal heterogeneities. Then first results in buried mines detection are presented, in particular the influences of various parameters like lift-off sensor, sand humidity, nature, size and depth location of mines are experimentally studied.

2. Comparison of EMIR® and classical stimulated thermography in single-sided detection of buried heterogeneities

In general, for NDE, single-sided methods are preferred. For “stimulated” (or “active”) infrared thermography this means that both source and camera are located on the same side of the observed structure. This configuration is sometimes improperly called “reflection configuration”. Here, the considered structure can be a man-made structure with defects inside to detect (NDE situation) or a mine buried in the ground.

The “classical” stimulated thermography technique consists in depositing energy, whatever be the means of deposition and the type of energy (sun, flash lamp, laser, hot air flow…), into the observed system (structure, ground) and in monitoring the temporal and/or local evolution of the surface temperature field of the system caused by this thermal stimulation. With a certain time lag, the heterogeneity (defect or mine) induces a distortion in the surface temperature field which reveals its presence and allows, using thermal models, to identify its depth location, “intensity” and extent (see Maldague [5], chapter 8). In such a situation, all is governed by the heat exchange between the stimulating source and the studied system and by the internal diffusion processes. Due to this last phenomenon, the deeper the heterogeneity, the poorer the results of the

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identification. In particular three-dimensional effects occur rapidly, which limit the validity domain of the simple model based identifications.

To some extent, the EMIR® technique approach is different. The source is a microwave emitter, generating photons in the metric to millimetric wavelength domain, and between the stimulating source and the studied system, in the near vicinity of this last element, a photothermal transducer is placed under the form of an electrically conductive thin film. The camera is now monitoring the thermal field of the film, which is the image of the interaction between the incident and reflected EM fields, and not the thermal field of the system surface itself (see Fig. 1 which presents the two configurations, classical thermography and EMIR®, in the case of NDE experiments). The only and very simple thermal phenomena in the EMIR® measurement are the photon-heat conversion inside the film and the consecutive heating, but the nature of the measurement is really EM, even using a thermal imager. This way, the complex three dimensional diffusion inside the system has no influence and the measurement takes place immediately during the stimulation. The time is no longer a variable to take into account. From this, a more sensitive and simpler identification procedure is possible.

An experimental validation of this has been done in the NDE domain. The specimen under test is a plate of carbon-loaded glass-epoxy composite in which two 50 µm-thick foils of stainless steel have been embedded at different depths. The size and the depths are given on the right of Fig. 2. In this figure the thermal images obtained by both techniques are compared. The EMIR® image is clearly less noisy and the shape of the two defects is better recovered, in spite of using a power density which is lower by a factor of 7. It must be noted that the first defect gives an extra heating and the second one a shortage of heating. This is the result of the additive or subtractive composition of the incident and reflected microwave fields, in relation with the depth position of the reflecting defects. In the classical stimulated configuration, if the microwave source would have been replaced by a more conventional radiant heating source (e.g. infrared lamps) the two defects will have lead both to the same type of differential heating, positive or negative depending on the relative importance of the differential conductivities between specimen and inserts and of the thermal resistance at the two interfaces between them. Furthermore, in this case, the signal to noise ratio would have been lower since the thermal signals would have to travel back and forth between the surface and the defects. Microwaves are the most efficient way to produce images of buried objects (see e.g. Ref. [6]). This simple experiment demonstrated the higher sensitivity of the EMIR® technique in the detection of buried heterogeneities. If we consider now that the sample is the ground and the artificial defect is a mine, we obtain a typical configuration of demining.

3. Test bed for EMIR® evaluation in buried mines detection

To evaluate the possibilities of the EMIR® technique in a configuration representative of demining situations, a simple test bed was prepared consisting of a wooden box ($1.04 \times 0.74 \times 0.70$ m^3) filled with sand (see photos in Fig. 3). The microwave source is a horn operating at 2.45 GHz with a maximum power of 150 W. For this experiments, the horn is illuminating the soil under an angle of about 45°, which is not optimum for energy deposition since the absorbed power decreases with increasing angle as a result of the changing Fresnel reflection at the surface [6], but is interesting because it helps to separate the reflected field from the incident one which is stronger and contains no information on the mine. On the left photo, four minelike targets are lying on the soil surface. They consists of 10 mm-thick, 100 mm- and 200 mm-dia. discs made of metal or plastic. On the right photo, the mines simulants are embedded in the sand and the soil is covered by a photothermal film positioned at 70 mm from the surface (lift-off). The camera, not seen in these photos, is an AGEMA 880 LW camera (thermal sensitivity of 35 mK rms for one single image), viewing the sand box surface under an incidence angle of 45°. The field of view in these conditions is 300 x 775 mm^2. Fig. 4 describes the experimental arrangement.

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4. Image processing used in the present experiments

In the present experiments a very simple image processing is used, although being not representative of what could be done in a real situation. In fact the aim here is only to understand how the technique works. The idea is to use a reference image which does not contain information on the buried object. The reference image is the EMIR® image of the soil without mine. This reference image is subtracted from the EMIR® image obtained when the embedded mine is present. Of course, in a real situation such operation is impossible. The reference image in that case could be one previous image taken in a nearby location, assuming that the soil characteristics remain nearly constant. A variant could be to use the average image resulting from a series of previous images taken when moving the system. It is clear that the present conditions are optimistic and that in the real situation the induced noise will be higher.

5. First results for a dry sand soil and a metallic mine

Fig. 5 presents the images taken with and without the metallic minelike target of 100 mm-dia., embedded in dry sand, at a depth of 50 mm. The third image is the differential image resulting from the subtraction described above. The apparent distribution of EM energy, corresponding to the half total field, is influenced by both the incident field generated by the horn and the incidence of the line of sight of the camera. The scheme of the configuration and the passive infrared image of the mine lying on the soil, given in Fig. 4, explain why the shape of the object does not appear strictly circular. Nevertheless, a good estimate of its size is obtained.

In these conditions, the influence of the location depth of the minelike object has been studied. The images corresponding to depths of 50, 100, 150 and 200 mm are given in Fig. 6. The noise of the image increases with depth. After 100 mm, even the size slightly decreases and at a depth of 200 mm the object is hardly visible in the noise. Therefore this depth can be considered as the detection limit under the present experimental conditions.

6. Influence of baneful parameters

6.1 Influence of film lift-off

In real situations the soil surface can be rough and the soil-film distance can greatly vary from point to point. Then, it is crucial to verify that the lift-off influence is weak. For this, the lift-off has been increased from 70 to 170 mm and the corresponding images of a 100 mm-dia. metallic target embedded at a depth of 50 mm have been compared. They are given in Fig. 5c and 7a, respectively. The second image is slightly more noisy but the shape and size of the detected object are very close, demonstrating the weak influence of this parameter.

6.2 Influence of soil humidity

Humidity is one of the important causes of variability of the electrical soil properties which can affect EMIR® images. The experiment with the 100 mm-dia. metallic target embedded at a depth of 50 mm was repeated after enhancing the moisture of the sand by adding 5 litres of water per square meter. The so-obtained image is given in Fig. 7b, to be compared to Fig. 5c. The signal to noise ratio has decreased but the size and the shape of the object are still correct.

6.3 Influence of the nature of the mine

The metallic nature of the minelike object induces a strong reflection of the incident field giving a good detection. In the case of a non-metallic target, the contrast must be weaker. To estimate the loss of performance, the 100 mm-dia. metallic disc has been

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replaced by a plastic one having the same dimensions. The resulting image is given in Fig. 7c. An important increase of the noise is noted, but still the detection of the object is possible, with a relatively good estimate of its size.

6.4 Combined influence of soil humidity and mine nature

Of course several baneful parameters can influence the measurement at the same time. The combined influence of humidity and mine nature has been studied. The target is a 100 mm-dia. plastic disc embedded at 50 mm depth inside a sand which received the same quantity of water as previously. The resulting image is given in Fig. 7d, where the presence of the target is hardly visible. For the present source (whose radiation pattern is not optimized) and for the given power of 150 W, these conditions correspond to the limit of detection, limits which are not reached even at a depth of 200 mm for the metallic mine in dry sand.

7. Conclusion

From these set of experiments, all performed at 2.45 GHz at an emission power of 150 W, it is obviously impossible to draw definitive conclusions. Nevertheless, we have demonstrated that:

- The EMIR® technique presents serious advantages as compared to stimulated infrared thermography, even when this technique uses a microwave source for enhanced stimulation,
- for metallic minelike targets and dry sand, the detection limit is not reached even at a depth location of 200 mm, which correspond to the very low diameter/depth ratio of 0.5,
- the lift-off influence is weak, which allows to use the system with irregular and rough soil surfaces,
- though all baneful parameters studied (depth of location, humidity of the soil, dielectric nature of the target) reduce the signal to noise ratio and consequently the detection limits, the size and shape are still recovered.

The only strong limitation of these experiments is due to the homogeneous nature of the soil, since only sand is used. This was justified for exploratory tests aiming just to estimate the feasibility of the technique. It is obvious that, in a second step, the technique must be validated by experiments on more realistic soils comprising natural and man-made objects which are sources of clutter, e.g. stones and rocks of different sizes, wooden sticks, grass, metallic parts often encountered on war theatre…

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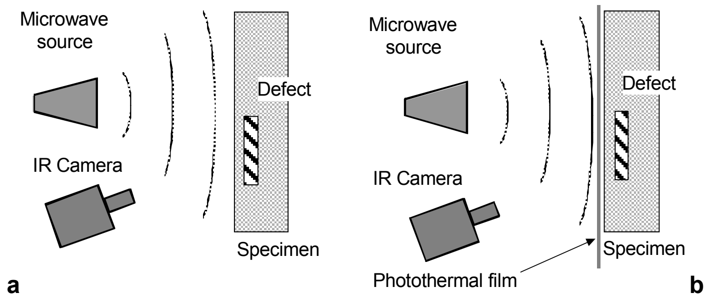

***Fig. 1**. Stimulated thermography (a) and EMIR® technique (b) in single-ended NDE configuration*

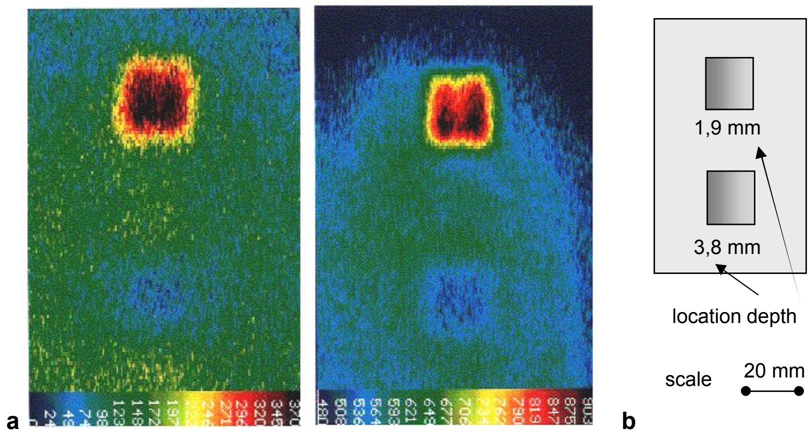

***Fig. 2.** Stimulated thermography and EMIR® technique in single-ended NDE configuration: detection of two thin metallic foils embedded at different depths inside a carbon-loaded glass epoxy composite structure.*

a) Direct monitoring of the surface temperature of the structure with an incident power density of 110 mW.cm^{-2};

b) Monitoring of the photothermal film with an incident power density of 17 mW.cm^{-2}.

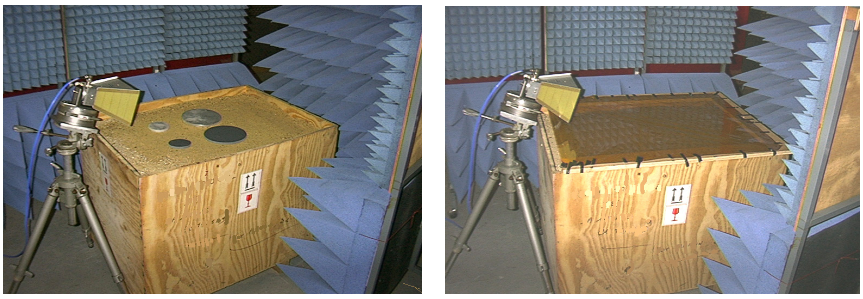

***Fig. 3.** Soil test bed for evaluation of the EMIR® technique in buried mine detection. Left: Mine simulants are laying on the soil. Right: Mines simulants are embedded and the soil is covered by the photothermal film with a lift-off of 70 mm.*

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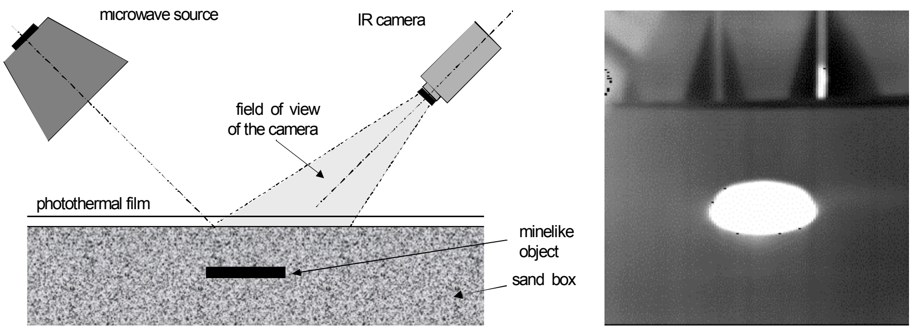

Fig. 4. *Relative position of the different EMIR® system elements and of the minelike object* (left) *and dimension of the 100 mm-diameter target as seen by the IR camera when lying on the soil without EM stimulation (apparent emissiviy image)* (right)

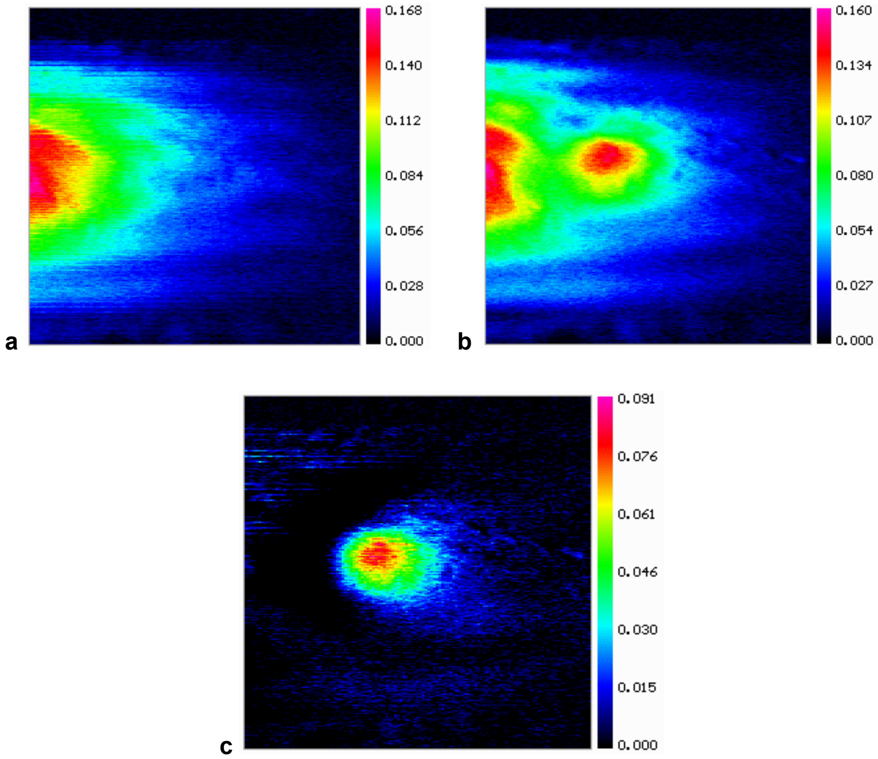

Fig. 5. *Detection of a metallic mine (100 mm diameter) located at 50 mm depth in dry sand by the EMIR® technique at 2.45 MHz.*

a) Image of the soil without mine simulant;
b) image of the soil with a mine simulant;
c) EMIR® differential image showing the mine position and size.

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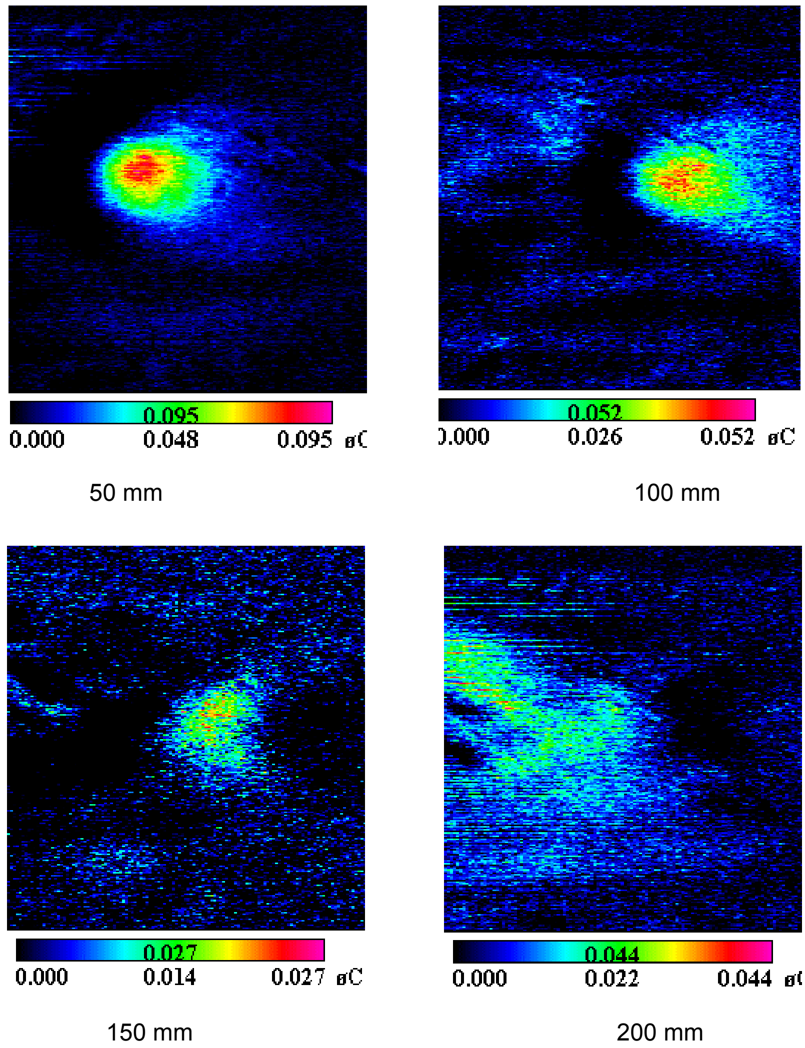

Fig. 6. *Detection of a 100 mm-diameter metallic mine located at various depths in dry sand.*

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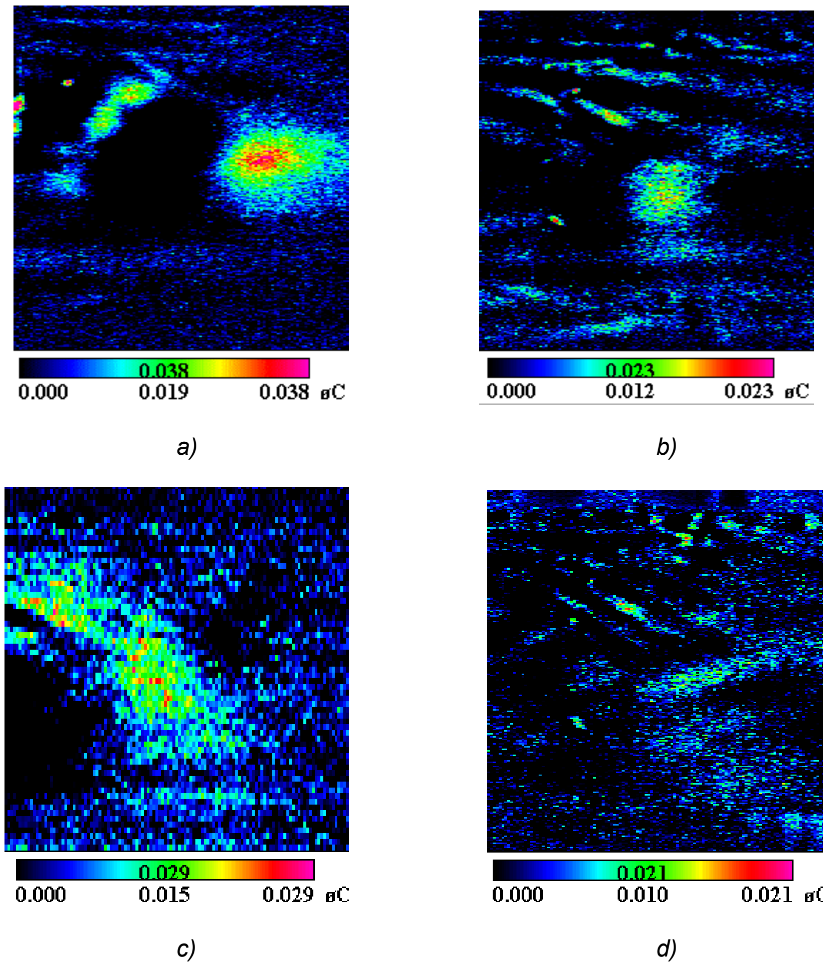

Fig. 7. *Influence of various parameters:*

a) lift-off;
b) sand humidity;
c) mine nature;
d) combined influence of humidity and mine nature