IR Thermography for the Detection of Buried Objects: A Short Review

Carlo Santulli
Università di Roma – La Sapienza
Electrical Engineering Department
Via Eudossiana 18 00184 Roma, Italy
E-Mail: carlo.santulli@uniroma1.it

ABSTRACT

Sub-surface buried objects, such landmines and archaeological artefacts, and the surrounding environment constitute a complex system with variable characteristics. As a consequence, the detection and recognition of these objects may be extremely difficult.
IR thermography, which is widely employed in the detection of discontinuities in materials and structures, would be in principle suitable also for this kind of application. The issue in this case appears to be the presence of excessive levels of background noise, whose modelling is difficult, in that it results from a number of factors e.g., moisture content, presence of vegetation, and variation of solar radiation at topsoil level. In recent years, a number of studies have tried to overcome these limitations and improve the reliability of this method, using filtering and automatic pattern recognition techniques, specific for the detection of buried objects.
This work is aimed at revising and commenting the most recent experiences in this application of IR thermography. In particular, the possibility of combined use of IR thermography with other techniques, in particular ground probing radar (GPR), and high frequency electromagnetic techniques are discussed, in order to improve the reliability of buried objects detection by fusion of data obtained from different sensors.

Keywords: IR thermography, data fusion, soil conditions, buried objects detection

1. Introduction

In recent years, the detection of buried objects using thermographic techniques has been widely studied. A large number of scientific papers are available, a list of which, including considerations on the specificities and the novelty of each work, is presented in Table 1. In general, this application can be interpreted as a non-destructive evaluation system, whose performance depends on three elements: the intrinsic detection capability of the method (or combination of methods) employed, application-related factors, in particular the state of environment surrounding the buried object, and the human factor, connected with the skills of NDE operators. The NDE nature of this issue can be clarified e.g., by considering the electromagnetic systems for the detection of buried metallic objects, in which case the source and the sensor are arrays of loop antennas. These systems are based on the measurement of the EM field scattered by the target [1]. Discrimination is generally pursued through the empirical comparison of measured data obtained by known targets with real-field measurements. The typical working frequency band is between 30 Hz and 30 kHz (low frequency) when the target is metallic, or AM radio frequencies, when the target is mainly poor conductor (dielectric). In the latter case, soil characteristics affect the response of buried objects and increase the difficulty of discrimination [2]. In the more general case of multi-technique detection of buried objects, systems for data fusion or sensor fusion are needed, which are not always synergic in the sense of increasing the probability of detection (POD) and decreasing the probability of false indications (PFI) [3]. In this case, statistical methods to account for some aspects of the environment, such as the cooperative/uncooperative or homogeneous/inhomogeneous soil, have also been proposed [4].

Authors	**Year**	**Ref.**	**Main results of the work**
Hadas *et al.*	2003	[17]	Evaluation of the effect of soil anisotropy and sunlight on parameters for thermal transport for objects detection

Blasi & Corcione	2005	[18]	Adoption of a detection system based on a concentrated heat source and a non-contact thermometer mounted on a suspended transportation system exploring the soil surface
Agassi & Ben Yosef	1997	[13]	Effect and parametrisation of vegetation in Thermographic detection of buried objects
Deans *et al.*	2006	[8]	Thermographic detection of objects buried in sandy soil at different depth and with different humidity content
Stepanic *et al.*	2004	[4]	Study of the effect of object orientation on the signal obtained on the thermograms
Martinez *et al.*	2004	[19]	Comparison of thermographic detection results with a tri-dimensional model of heat flux transport
Muscio & Corticelli	2004	[20]	In-lab reproduction of thermographic tests for buried objects detection with parametric evaluation of scale-effect

Table 1 Some recent works on the application of IR thermography to the detection of buried objects

This paper concentrates on the possibility that some results obtained in the case of the detection of anti-personnel landmines (APL), are applicable to the more general detection of buried objects (e.g., archaeological artefacts). In this regard IR thermography is competing with a number of other methods, which are listed and detailed in Table 2.

Method	**Advantages**	**Drawbacks**
Geo-radar	Transportability, absence of contact, possible selection of most adapted frequency band	Reflections of both soil surface and the antenna used require a very broad detection band to have a resolution lower than 10 mm, and often data filtering methods are needed
Electromagnetic induction	Ease of detection for known types of buried objects, e facility in obtaining a uniform magnetic field with remote sensing	Strong dependence on geometry and orientation of the buried object, usually avoided by the use of normalised electromagnetic spectra
Electrical impedance tomography (EIT)	Possibility and relative ease of measuring conductivity perturbations and simulate realistic conditions per la presence of the object. Advantageous for the detection on humid soil and underwater	Problems with electrical contact can be revealed in case the soil is very dry. Strong dependence of detection reliability from object geometry
Neutrons	Easy detection of small quantity of explosive substances also at significant depths (up to 300 mm)	Performance limited from presence of humidity and strongly dependant on objects scale. Need to evaluate neutron distribution to reduce false alarms. Virtual impossibility of detecting buried objects other than landmines
Gamma rays	Portability and auto-feeding. Inspection at depths exceeding 80 mm.	Dependence on density, not necessarily related to the presence of the buried object. Need for simulations and probabilistic evaluations to reduce levels of error. Resonance effects due to the substances present in the object (e.g., explosives, dust), and therefore need to know in advance its nature and composition.
Laser-Doppler vibrometry (LDV)	Capable of ensuring detection by comparing the ratio of the velocity magnitude of the ground surface over and away from the target, and the presence of wave-like or scattering phenomena. The dimension of the buried object can be measured, with suitable excitation wavelength	Requires acoustic excitation, in which case detection reliability is strongly dependant on the acoustic relaxation time of the soil surface

Table 2 Advantages and drawbacks of some techniques for buried objects detection

To optimise the rate of detection, it can also be advisable to use sensors for different methods (e.g., geo-radar and electromagnetic induction), sometimes installed on mobile stations, and operate with data fusion techniques, according to a procedure outlined in Figure 1, aimed at the comparative analysis of results with probabilistic factors. In this case, it may be useful training an artificial neural network (ANN) system in order to automatically recognise the buried object. However, the acquisition of an optimised and unique method for this purpose appears still a very ambitious objective.

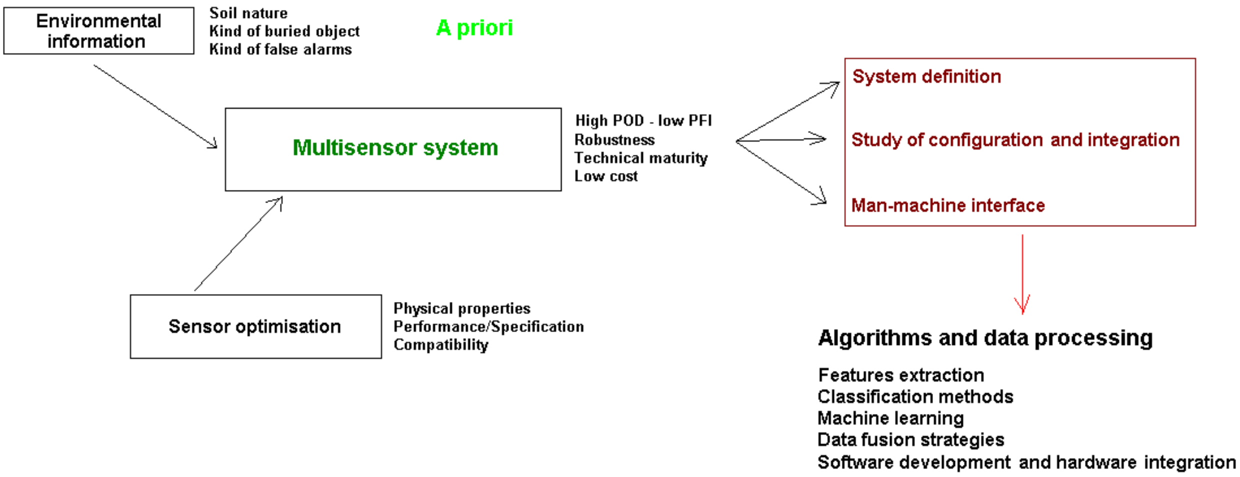

Figure 1 Structure of a typical system for data fusion aimed at buried objects detection

The use of IR thermography enables a fast no-contact detection of the artefact: in particular, the latter characteristics can be desirable both for antipersonnel landmines (APL) than in the case of archaeological artefacts, where the intervention of specialised operators follows detection [5]. In reality, the depth of buried object appears still a limiting factor: error-free detection is hardly ever achieved at depths exceeding 10 mm [6].

Moreover, the issue of statistical reliability in buried objects detection using IR thermography has not been addressed yet. The background noise present in thermograms is still quite high, so that it is not easy to optimise the severity of control, whose incorrect setting may result in false alarms or else in missed detection. In practice POD and PFI are influenced by a large number of factors, which are schematically presented, divided in categories, in Figure 2, assuming for simplicity that a last generation thermographic system is used, and that human factor is optimised.

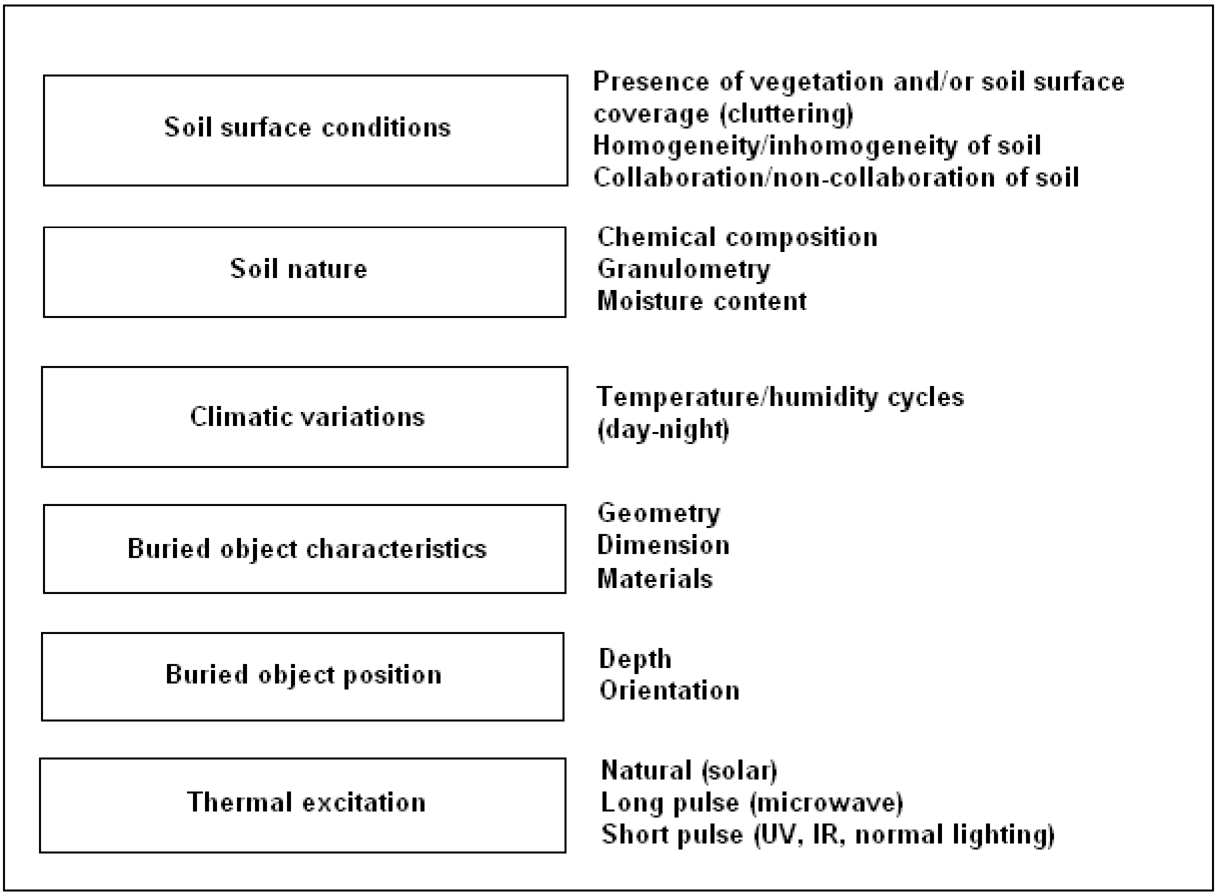

Figure 2 Principal factors to be considered in the detection of buried objects using IR thermography

2. Characteristics of Thermographic Investigation

The detection of buried objects using passive thermography technique is based on the difference in thermal conductivity between the object and the surrounding environment (soil), which ideally allows the object to be individuated from the presence of a recognisable mode of emission, the so-called "thermal signature" of the artefact.
A possibility is offered by increasing image by soil heating using microwaves [7]: more in general, the use of microwaves for sample heating has been sometimes applied in IR thermography studies, although at a larger scale obtaining a uniform heating on the sample may not be easy [8]. Also pulse thermography has been attempted, based on the assumption that distribution of temperatures around the surface is influenced by the presence of buried object, resulting in a "hot spot" on the surface, which is recognisable for a transient time, depending on the heating method used, but possibly extending also to several minutes [9]. The main limitation appears in this case the depth of the buried object, which does not exceed 20-40 mm: in a typical application of pulse thermography, temperature profiles include a faster heating phase, followed by a slower cooling phase, with time intervals growing with buried object depth [10].

3. Experimental Studies and Thermal Modelling of Buried Objects Detection

From the theoretical point of view, modelling the temperature response of a buried object requires the knowledge of equation for turbulent heat flux in a soil assumed dry (zero moisture content) and homogeneous (granulometry of soil particles constant), transport which is modified from the presence of the buried object [10]. Heat transport phenomena can be modelled as bi-dimensional, although, with growing distance from buried object, also mono-dimensional models become progressively more reliable, especially if the principal objective is the determination of the maximum temperature gradient which may develop at soil surface, in correspondence with the buried object [11].

In practical NDE, thermographic modelling of buried object geometry requires evaluating thermal inertia in the soil above the object. Thermal inertia *I* is defined as: $I = (k\rho C)^{1/2}$, where k is the bulk thermal conductivity, ρ is the bulk density and C the specific heat capacity. The practical evaluation of thermal inertia would require also the measurement of the content in moisture and chemicals in the soil, which have an effect on the value of ρ in the same way a buried object would. A possible calculation of thermal inertia can be carried our by heating soil samples with different moisture content by using infrared thermometers. The measurement of soil heat flux and infrared radiation temperature allow evaluating thermal inertia [12].
In a model more respondent to reality, the presence of vegetation needs also accounting for, as a parameter affecting soil heat capacity [13]. For as regards buried objects, modelling their geometry requires also knowing their orientation with respect to soil surface, which may be expressed as a function of two angles, a θ angle between Y-axis and the symmetry axis of the object, and a ψ angle between Y-axis and a line perpendicular to the soil surface. These two angles are then statistically plotted against δ, which is the variation of object depth consequent to orientation [4].

An essential aspect of experimental studies performed using IR thermography on the detection of buried object is the possibility of obtaining reproducible results also in absence of sunlight. Studies in this field have clarified that thermal images showing buried object profile can be acquired, also in case thermal contrast owed to solar irradiation is negligible. However, it has not been possible to obtain a clear trend for probability of detection (POD) of buried objects with depth, which would have allowed establishing limits of reliability for the technique [14]. In this regard, the use of data fusion techniques with other non destructive techniques, such as geo-radar, has been suggested. On the different techniques for pixel-to-pixel data fusion it is possible to refer to information given in [15], where possibilities are suggested for almost totally excluding subjective evaluations from data fusion.
Insufficient detection reliability has been revealed also in tests for buried objects detection in sandy soil with different moisture content (0, 2.5, 5, 7.5 and 10%), heated using IR lamps [11]. In this case, the transient enabling the measurement of temperature difference following soil heating for 8 minutes, lasts for about 30 minutes, up to a level of about 40 mm below the surface. In general, higher moisture content facilitates buried object detection: however, detection at higher depth requires a longer cooling phase before the thermogram is able to produce an object signature.
In fact, the presence of an interposed air cushion in sand layer above the object modifies the conductive properties of the soil as well, since it acts as an insulating layer and can as a whole increase the POD of the buried object. As a whole, however, transient thermography following heating with IR lamps, appears to be preferable, especially in the case it is used as a stand-alone technique.

4. Conclusions

Trying to sum up the possibilities of using IR thermography for an application aimed at buried objects detection, it is noteworthy, as specified in Figure 2, that the reliability of such detection is dependant on a large number of factors, relative both to the environment and to the limitation of non-destructive technique used, obviously taking into account also the human factor.

The majority of studies demonstrate that a simple mono-dimensional modelling yields results, measured as temperature gradients on the buried object, very close to the experimental ones. Thermal transient may be sufficiently high to possibly allow a high precision in detection and reduce the incidence of false alarms. In addition, variations of soil characteristics do not necessarily appear critical for object recognition. As a consequence, the real limiting factor appears to be represented by the shallow depth at which IR thermography is capable of offering indications on the buried object. It is likely that the use of thermographic systems with higher accuracy in the measurement of temperature (up to differences of less than 100 mK) would allow making sense also of shorter thermal transient (possibly in the order of the second or less) for buried object detection at “realistic” depths (e.g., between 100 and 300 mm), where other techniques, such as e.g., neutron backscattering or neutron activation [16].

This publication has been financed by the Programme "Incentivazione alla mobilità di studiosi stranieri e italiani residenti all'estero"

REFERENCES

1. Bell TH, Barrow BJ, Miller JT “Subsurface discrimination using electromagnetic induction sensors,” IEEE Transactions Geoscience Remote Sensing **39,** 2001, pp. 1286–1293.
2. Araneo R, Celozzi S, “Numerical Analysis of Subsurface Object Discrimination Systems”, IEEE Transactions on Magnetics **39**, 2003, pp. 1219-1222.
3. Müller C, Scharmach M, Gaal M, Guelle D, Lewis AM, Sieber AJ “Performance demonstration for humanitarian demining” Materialprüfung **45**, 2003, pp. 504-512.
4. Stepanic J, Malivovec M, Svaic S, Krstelj V, "Parametrisation of non-homogeneities in buried object detection by means of thermography", Infrared Physics & Technology **45**, 2004, pp. 201-208.
5. Boras I, Malinovec M, Stepanic J, Svaic S, "Modelling of buried object detection using thermography", QIRT Conference Proceedings, Reims, 2002, pp. 176–181.
6. Di Marzio CA, Rappaport CM, Wen L, Sauermann GO, "Microwave-Enhanced Infrared Thermography", Proceedings of SPIE, vol. 3710, 1999, pp.173-179.
7. Santulli C, Jeronimidis G, "Measurement of surface void content on balsa wood using IR thermography", E-Journal of Non-Destructive Testing **11** n.6, June 2006.
8. Deans J, Gerhard J, Carter LJ, "**Fehler! Hyperlink-Referenz ungültig.**Infrared Physics & Technology **48**, 2006, pp.202-216.
9. Boras I, Malinovec M, Stepanic J, Svaic S, "Detection of underground objects using thermography", 15th WCNDT proceedings, October 2000, Rome.
10. Moukalled F, Ghaddar N, Kabbani H, Khalid N, Fawaz Z, "Numerical and experimental investigation of thermal signatures of buried landmines in dry soil", Journal of Heat Transfer **128**, 2006, pp.484-494.
11. Khanafer K, Vafai K, "Thermal analysis of buried land mines over a diurnal cycle", IEEE Transactions on Geoscience and Remote Sensing **40**, 2002, pp.461-473.
12. Sun XM, Zhu ZL, Tang XZ, Su HB; Zhang RH, "A new measuring technique of soil thermal inertia", Science in China Series E - Technological Sciences **43**, 2000, pp.S62-69.
13. Agassi E, Ben Yosef N, "Parameterization of sparse vegetation in thermal images of natural ground landscapes", Optical Engineering **36**, 1997, pp.2910-2917.
14. Carter LJ, Kokonozi A, Hosgood B, Coutsomitros C, Sieber A, "Landmine detection using stimulated infrared imaging", Geoscience and Remote Sensing Symposium, 2001, IEEE, vol. 3 pp. 1110-1112.
15. Grosse XE, Bousigue J, Takahashi H, "NDT data fusion at pixel level", NDT&E International **32**, 1999, pp. 283-292.
16. Datema CP, Bom VR, van Eijk CWE, “Landmine detection with the neutron backscattering method”, IEEE Transactions on Nuclear Science **48**, 2001, pp.1087-1091.
17. Hadas Z, Wilner K, Ben-Yosef N, "Introducing anisotropy in the autocorrelation function of natural terrain infrared images", Optical Engineering **42**, 2003, pp.1683-1689.
18. Balsi M, Corcione M, "Thermal detection of buried landmines by local heating", International Journal of Systems Science **36**, 2005, pp.589-604.

19. Lester J, Bernold LE, "Innovative process to characterize buried utilities using ground penetrating radar", Automation in Construction **16**, 2007, pp. 546-555.
20. Muscio A, Corticelli MA, "Experiments of thermographic landmine detection with reduced size and compressed time", Infrared Physics & Technology **46**, 2004, pp. 101-107.