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The detection of landmines by neutron backscattering: Exploring the limits of the technique

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Abstract

Neutron backscattering (NB) sensors have been proposed for Humanitarian De-mining applications. Recently, a prototype hand-held system integrating a NB sensor in a metal detector has been developed within the EU-funded DIAMINE Project. The results obtained in terms of performance of the NB systems and limitations in its use are presented in this work. It is found that the performance of NB sensors is strongly limited by the presence of the soil moisture and by its small-scale variations. The use of the neutron hit distribution to reduce false alarms is explored.

Keywords: Back-scattered neutrons; Explosive detection; Humanitarian De-mining

1. Introduction

It is estimated that several millions of active mines have been deployed so far in about 70 countries, resulting in about 2000 causalities per month, most of them (85%) being civilians (ICBL, 2003). The anti-personnel (AP) and anti-tank (AT) mines are mostly non-metallic or with minimum metal content, buried at a maximum depth of about 20 cm.

Localization and identification of landmines with classical technologies is a time consuming, expensive and extremely dangerous procedure. In addition, it will take a long time to de-mine the suspected areas in the affected countries. The mined areas are, indeed, close to the battlefields, being consequently heavily polluted by metal pieces from the explosions of different ordnances. The presence of the metal clutters produces a large number of false alarms in the metal detectors (MD) commonly employed in de-mining operations. Consequently, there is a strong need for a technological breakthrough in this field to definitively solve the land-mine problem within the dead-line established by the Ottawa treaty.

In this respect, a device based on the neutron interrogation can be used as a confirmation detector in the multi-sensor systems. Sensors using thermal or fast neutron-induced γ-ray emission have been proposed and used in the past for Humanitarian De-mining operations (Cinausero et al., 2004; Lunardon et al., 2004; McFee et al., 1998; Cousins et al., 1998; Kuznetsov et al., 2004; Vourvopoulos and Womble, 2001). One of the major limitations in the use of such sensors is represented by their weight and size that makes them not usable as hand-held devices but only in vehicle-mounted systems, with a specific limited impact on the improvement of the Humanitarian De-mining operations.

A particular nuclear technique has shown in the past the capability of being used in hand-held systems: the so-called neutron back-scattering technique (NBT) (Bom et al., 2004; Borgonovi et al., 2000; Brooks and Buffler, 1999; Brooks and Drosg, 2005; Brooks et al., 2004; Csikai et al., 2004; Datema et al., 2001, 2002; Kiraly et al., 2004).

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The principle of the technique is very simple: when a fast neutron source (like a ^{252}Cf radio-isotopic source) is used to irradiate the soil, the yield of thermalized, backward scattered neutrons depends on the hydrogen content of the irradiated volume. Therefore, to confirm the presence of the mine, a NB sensor will verify the presence of anomalous hydrogen concentration in the target point, previously identified by using, for instance, a common tool as the MD. From an operational point of view, it is mandatory to have a unique hand-held system that integrates a NB probe inside a MD. Moreover, such system has to fulfil a number of technical and operational requirements dictated by the end user needs. First, the total weight of the system head should not be larger than 2 kg, having dimensions typical of a standard MD and, in any case, not exceeding an area of $20 \times 30\,\mathrm{cm}^2$. In addition, the system should provide clear and simple information, as the usual man–machine interface (MMI) employed in commercial MD. Finally, its cost-effectiveness has to be verified in comparison with the operation costs of the currently available techniques (i.e. MD as scanning and prodding as confirmation tools).

Such requirements imply a number of technological challenges in the design of individual components, with the goal of maintaining the performance of the single detectors when integrated in a unique sensor head.

The integration of a NB sensor with a MD head has been the major task of the DIAMINE project (Viesti et al., 2003). Within this project, the capability and the limits of the NBT have been studied in details in laboratory conditions and using Monte Carlo simulations. The results obtained are presented in this paper.

2. General characteristics of the NBT

Within the DIAMINE project, it has been established that sensors based on the NBT are characterized by intrinsic limitations that have to be clearly explored before fielding such tools. A landmine can, indeed, be detected only when the signal due to the hidden object is significantly larger with respect to the background due to:

(i) the primary ionizing radiation (fast neutrons and γ-rays) emitted from the source that hits directly the detector;
(ii) the secondary neutrons scattered from the nuclei of the soil.

The first kind of background depends on the type and position of the source employed (typically a ^{252}Cf radio-isotopic source) and on the detector intrinsic sensitivity to γ-rays and fast neutrons. In order to optimize the final performance of the system, such background can be effectively minimized by the proper selection of the thermal neutron detector and of the source type and geometry. Particular measurement techniques might also by effective: as an example, a significant improvement in the signal-to-noise ratio has been obtained by using a time-tagged ^{252}Cf source, as reported in the work of (Craig et al., 2000).

On the other hand, the background associated with the soil moisture sets an intrinsic limitation to the method. The landmine detection is possible, indeed, only when the thermalization capability of the buried mine is significantly greater than that of the surrounding soil, the latter being essentially due to the soil moisture. Since the thermalization capability is mainly determined by the hydrogen content inside a given material, the condition for the detection lies in the hydrogen density difference between the landmine and the soil. In this respect, as discussed in detail in (Obhođaš et al., 2004), each type of mine can be characterized by a specific average H density, determined not only by the explosive charge but also by the external case, made often from plastic materials. Consequently, it is possible to define for each type of mine a critical value of the soil moisture for which the detection is impossible, when the contrast between the buried mine and the bare soil is absent.

A specific analysis of this problem, reported in (Obhođaš et al., 2004), brought us to the conclusion that the best use of the NBT is in countries where the soil moisture is generally lower than about 10% in weight, so that a large number of land-mines can be safely detected. This condition is expected to be valid in case of aridic soils that are characteristic of countries as Afghanistan, Ethiopia, Eritrea, Egypt, and Somalia, where a large part of the landmine problem is localized. Also in such countries, however, a detailed determination of the soil moisture is necessary, when planning the use the NBT.

As an example, we have performed moisture measurements of soil samples taken in some Afghanistan locations during the summer 2002. Some samples exhibited a very low soil moisture value ($<1\%$ in weight), documenting an ideal condition for the use of the NBT. On the contrary, other samples exhibit a higher soil moisture values (about 8% in weight), which is close to the suggested 10% limit for the use of the NBT. This seems to demonstrate that also in those countries generically defined as ''aridic'', the use of the NB sensor might be limited to some type of soils and/or specifically dry seasons and/or locations. It is worth mentioning that the knowledge and the monitoring of the soil characteristics during de-mining operations seems to be a relevant issue for a number of tools, including those based on electro-magnetic induction (Das et al., 2002).

This means that the hydrogen content of the soil in a given mine filed needs to be monitored, when the NBT is employed. This can be easily obtained, as an example, by monitoring the absolute ''background'' count rate in a calibrated NB detector, when a well-defined geometry is used. The problems related to the ''background'' due to the soil moisture will be further discussed in Section 6.

3. NB sensor description

The NB detector employed in this work makes use of a large area ($20 \times 20\,\mathrm{cm}^2$) multi-wire proportional counter (MWPC) as a neutron detector (Fioretto et al., 2004). The