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## ELECTRICAL IMPEDANCE TOMOGRAPHY

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### **BASIC PRINCIPLES**

Electrical impedance tomography (EIT) is a technology developed to image the electrical conductivity distribution of a conductive medium. The technology is of interest because of its low cost and also because the measurement of the electrical conductivity brings direct information about the composition of the conductive medium. Because the ground is conductive to a certain extent, the technology can also be used to detect buried objects. The application of landmine detection is of particular interest because the object is usually buried at shallow depths and causes a discontinuity in the soil conductivity that can be sensed from the surface of the ground.

EIT uses low-level electrical currents to probe a conductive medium and produce an image of its electrical conductivity distribution. While a pair of electrodes is stimulated, the electrical voltage is measured on the remaining pairs of electrodes. After all the independent combinations of interest have been stimulated, an algorithm using the measured data reconstructs an image of the electrical conductivity distribution within the volume. In the case of ground probing, an array of electrodes is placed on the surface of the ground to provide an image of the conductivity distribution below the surface. The EIT technology will detect mines buried in the ground by detecting ground conductivity anomalies. The presence of a metallic or non-conductive mine will disturb the conductivity distribution in the soil. The signal characteristics are based on the size, shape, conductivity, and depth of the buried mine.

Figure I.1 shows an EIT detector prototype optimized for antitank landmines. A typical EIT detector has three major components: the electrode array, the data acquisition system, and a data processing unit. In this case, the electrode array comprises 8 columns and 8 rows of electrodes—for a total of 64 electrodes. The electrodes are spring-loaded and can adjust with the terrain variations. The data acquisition system incorporates the electronics and firmware required for the electrical stimulation of the electrodes and the recording of the resulting potentials. Typically the stimulation current is on the order of 1 mA and the frequency of the stimulation is about 1 kHz. The data processing unit is a software application that processes the raw measurements using a mine detection algorithm based on a matched filter approach. The detector response is precalculated for a replica of the size and shape of the object of interest—for a number of grid locations underneath the detector. A correlation is then performed between the detector response for the replica and the actual detector response obtained from the measurements, for all the replica positions considered. The position that yields the largest correlation value is identified as the most likely position for the mine. Figure I.2 shows an example of the detector

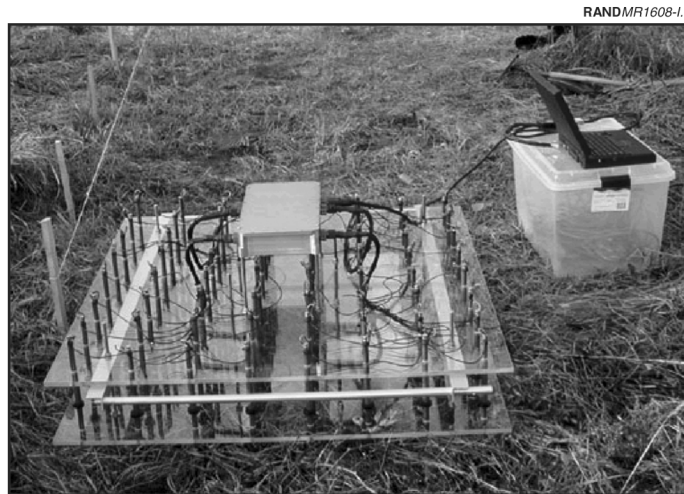


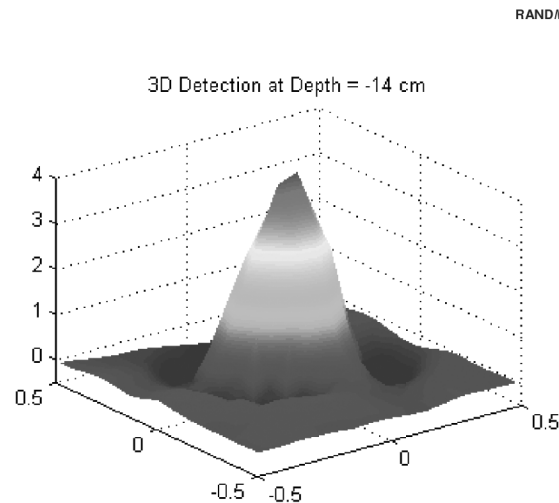
Figure I.1—EIT Landmine Detector Prototype

response for a nonconductive mine-like object buried at a depth of 14 cm in a sandy soil. The three-dimensional graph represents the detector response as a function of the positions in the x-y plane, in units of meters. The detector provides a similar response for a metallic object, with a sign reversal.

The prototype shown in Figure I.1 was built in view of evaluating the EIT technology as a confirmatory detector for antitank mines. A smaller lab unit was also built, suitable for objects with a size typical of antipersonnel landmines.

### STATE OF DEVELOPMENT

The EIT technology is relatively recent and has been researched mostly for medical diagnostic applications. The research done in the application of EIT to detect landmines has been very limited. Under the sponsorship of Defence R&D Canada–Suffield (DRDC-Suffield), research has been conducted to assess the EIT technology capability



**Figure I.2—Detector Response for an Antitank Mine-Like Object Buried at a Depth of 14 cm**

to detect, first, buried unexploded ordnance (UXO) and, later, buried antitank mines. Wexler was one of the first investigators to apply EIT to the detection of UXO in the ground [1,2]. The detection of UXO requires probing depths that are large relative to the size of the surface electrode array and EIT may not be the best technology for this particular application. The EIT technology is sensitive to noise, which prevents its use at depths that are large with respect to the electrode array size.

It holds promise, however, when the problem is constrained to the detection of objects buried at shallow depths. The author of this report, in conjunction with John McFee of DRDC-Suffield, has recently developed a prototype EIT detector aimed at antitank landmine detection. Additional details on the detector design and performance are reported in previous reports by the authors [3,4].

An amount of approximately \$400,000 has been invested so far in the evaluation of that technology for landmine detection. A prototype EIT detector has been built and evaluated in a laboratory environment and in a limited set of field trials. Further evaluations are required to assess its performance in various environmental conditions.

## **CURRENT CAPABILITIES**

### **Detection Performance**

Currently, insufficient data exist to derive a statistically meaningful set of receiver operating characteristic (ROC) curves. The detector has been evaluated in soils of conductivity varying from 1 mS per meter to 15 mS per meter. The detector performed well in detecting antitank mines and antitank mine-like objects down to a depth of 15–20 cm, where the depth is measured from the top of the object to the surface of the ground. As a general rule, reliable detections were obtained down to a range of 1.0–1.5 electrode spacings for objects with a size on the order of two electrode spacings. The matched filter approach is also very efficient at reducing the false alarms caused by objects of different sizes.

## Data Acquisition and Processing Time

The acquisition and processing time is determined by the number of independent configurations of stimulating and recording pairs of electrodes. For a 64-electrode detector, there are approximately 2,000 independent configurations. The data acquisition time, using currently available data acquisition electronics, is on the order of 1 second for a complete scan. The core of the data processing developed for the current prototype is based on a matched filter implemented through matrix operations. This takes a few seconds in the Matlab™ tool environment but would take only a few milliseconds on a dedicated processor.

## STRENGTHS AND LIMITATIONS

### Strengths of the Technology

In a mine detection application, EIT technology has the following strengths:

**Metallic and nonmetallic landmines.** Because the EIT technology detects a perturbation in the local soil electrical conductivity, it does not matter whether the perturbation is caused by a conductive or nonconductive object.

**Performance in wet areas.** The EIT technology appears to have a special niche in wet environments, such as beaches, ocean littorals, rice paddy fields, marshes, and other wet areas, because this is where EIT works at its best, mostly because the environmental wetness ensures a good electrical contact. The detector has proven to be unexpectedly efficient in sand, even if the sand is poorly conductive, as long as it holds a bit of moisture. Currently, very few detectors can detect nonmetallic mines buried in wet, conductive areas.

**Low cost.** The hardware required to build an EIT detector is simple and of relatively low cost.

### Limitations of the Technology

In a mine detection application, EIT technology has the following limitations:

**Electrode-soil contact.** The EIT detector requires an electrical contact between the electrode array and the soil. Electrical contact cannot be ensured in some environments, and the deployment of electrodes in close proximity to explosives is a potential operational issue, although no large force is required to achieve the electrical contact. The use of the detector in a water environment eliminates the need for a direct contact because the electrical conduction is achieved through the water medium.

**Environment.** The EIT detector requires an environment that is electrically conductive in order that it work properly. The detector cannot work properly in such environments containing dry sand or rock covered surfaces.

## POTENTIAL FOR IMPROVEMENT

There is significant room for the improvement of the EIT technology applied to landmine detection. In particular, further work would be especially useful in the areas of environmental evaluations, deployment, and instrumentation. This is discussed in more detail below.

**Environmental evaluations:** Elaborate field trials are required to better understand the performance of an EIT detector in terms of ROC curves, in a variety of environments. The EIT technology is showing a significant potential for the detection of mines in wet environments. Further evaluations should be carried out in environments, such as beaches and marshes, where this detection approach can make a difference with respect to other landmine detection modalities.

**Deployment platforms:** Further work is required to design and evaluate deployment platforms for environments where the EIT technology is especially promising. Conceptual deployment platforms include, for example, remote-controlled rovers equipped with electrodes embedded in tracks to go over beaches or flexible mats with embedded electrodes to be dragged on the bottom of a body of water.

**Instrumentation improvements:** Current technology allows for data acquisition and processing on the order of 1 second. This could be improved with faster electronics and dedicated processors. The

development and evaluation of fast algorithms capable of identifying a conductivity perturbation in environments having a complex conductivity distribution, such as multiple conductivity layers, is also of interest.

### SUGGESTED RESEARCH AND DEVELOPMENT PROGRAM

It is suggested that a research and development (R&D) program aimed at advancing the EIT technology for mine detection applications should include the items identified above as “potential for improvement.” A rough order of magnitude (ROM) cost estimate to perform such an R&D program is provided in Table I.1.

**Table I.1**  
**Suggested R&D Program**

R&D Component	ROM Cost	Description
Environmental evaluations	\$1–2 million	Field trial evaluations in environments for which the EIT technology is especially well suited, such as beaches and marshes. <ul style="list-style-type: none"> <li>• Preparation and execution of the field trials</li> <li>• Analysis of the data</li> <li>• Preparation of a report and recommendations</li> </ul>
Deployment platforms	\$5–10 million	Design and build prototype platform(s) that are adapted for the environments where the EIT performs best.
Instrumentation improvements	\$2–4 million	Improvements to data acquisition electronics and data processing algorithms.

## REFERENCES

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