# ACOUSTIC/SEISMIC METHODS (PAPER II)

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## PHYSICAL PRINCIPLES

The essence of the acoustic/seismic approach is to excite low-frequency (typically below 1,000 Hz) vibration of a buried mine and measure surface "vibration signature" above the mine using remote sensors. Excitation of a mine and surrounding soil is achieved by using airborne (acoustic) and/or solid-borne (seismic) waves. Remote sensing is achieved with laser Doppler, microwave, or ultrasonic vibrometers.

The technique does not depend on the material from which the mine is fabricated, whether it be metal, plastic, wood, or any other material. It depends on the fact that a mine is a "container" whose purpose is to contain explosive materials and associated detonation apparatus. The mine container is in contact with the soil in which it is buried. The container is an acoustically compliant article whose compliance is notably different from the compliance of the surrounding soil. Dynamic interaction of the compliant container and the soil on top of it leads to specific linear and nonlinear effects used for mine detection and discrimination. The mass of the soil on top of a compliant container creates a classical mass-spring system with a well-defined resonance response. In addition, the connection between mass (soil) and spring (mine) is not elastic (linear) but rather nonlinear because of the separation of the soil/mine interface in the tensile phase of applied dynamic stress. These two effects, constituting the mine's "vibration signature," have been measured in numerous laboratory and field tests, which proved that the resonance and nonlinear responses of a mine/soil system can be used for detection and discrimination of buried mines. Thus, the fact that the mine is buried is turned into a detection advantage. Because the seismo-acoustic technique intrinsically detects buried "containers," it can discriminate mines from noncompliant false targets, such as rocks, tree roots, chunks of metal, bricks, etc. This was also confirmed experimentally in laboratory and field tests.

## STATE OF DEVELOPMENT

The technology is at the applied research stage. This consists of a considerable amount of laboratory research. The University of Mississippi and Stevens Institute of Technology have gone into the field to take data under semi-realistic conditions at Army test lanes. The Georgia Institute of Technology may soon initiate field tests as well. The University of Missouri, University of Florida, Ohio State University, SAIC, and Scientific Systems Company Inc. make efforts in the area of data processing and automatic target detection using seismo-acoustic data. MetroLaser Inc. has a program to build improved laser Doppler vibrometers, which would improve speed and sensitivity. Stevens Institute of Technology, in collaboration with Land Mine Detection System Inc., is in the process of developing an inexpensive microwave vibrometer/seismometer. The Army's Night Vision and Electronic Sensors Directorate has an in-house research program, funds most of the preceding organizations, and provides test facilities, coordination, and oversight.

Field testing is an integral part of the overall program and cannot be priced separately.

## CURRENT CAPABILITIES AND OPERATING CHARACTERISTICS

Excellent receiver operating characteristic (ROC) curves have been obtained against antitank mines. ROC curves do not exist against antipersonnel mines, although for some implementations very promising results were demonstrated.

Scan times are at present relatively slow: An off-the-shelf scanning laser Doppler vibrometer scans at discrete points with 50–100 m per dwell point. Antitank mines may require approximately 5–10 cm spatial resolution, while antipersonnel mines may require 1–2 cm resolution. Scan time is 6–45 seconds per square meter for antitank mines and 125–1,000 seconds per square meter for antipersonnel mines. However, several efforts are under way to greatly improve the speed. Specifically, an array of inexpensive sensors could increase scanning speed to at least an order of magnitude.

## KNOWN OR SUSPECTED LIMITATIONS

The technology is most sensitive to dynamically compliant mines. As a rule, nonmetallic mines are more compliant and easier to detect with seismo-acoustic detection.

To the extent that it has been tested, the technology is insensitive to most clutter and environmental conditions. While the technology has been shown to work in short grass, the use of a laser Doppler vibrometer prevents operation in moderate to heavy vegetation, and new types of sensors are needed to overcome this limitation.

The principal factor limiting current performance is limitation of existing sensing technology. Commercially available laser Doppler vibrometers cannot perform continuous scanning, do not provide adequate sensitivity because of speckle noise, exhibit unstable behavior in outdoor use because of environmental factors (temperature, humidity, etc.), and have inadequate laser power for soils with low reflectivity, degrading performance for oblique angles.

## POTENTIAL FOR IMPROVEMENTS

Potential improvements include increased operating speed (order of magnitude), improved sensor sensitivity and stability of operation under variable outdoor conditions, and development of vegetation-penetrating sensors to measure ground vibrations. Realistic ROC curves are expected to be excellent.

## OUTLINE OF A SENSIBLE RESEARCH AND DEVELOPMENT PROGRAM

A research program should address the following major tasks:

- sensor development to overcome limitations outlined above
- efficient acoustic/seismic energy delivery systems
- algorithms for data processing
- field testing and large-scale data collection.

The estimated cost of this program is $10–12 million per year for three to four years.

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