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**ACOUSTIC/SEISMIC METHODS (PAPER I)***James Sabatier, University of Mississippi*<sup>1</sup>

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**BASIC PHYSICAL PRINCIPLES AND MINE FEATURES  
EXPLOITED BY THE TECHNOLOGY**

Acoustic-to-seismic (A/S) coupling-based mine detection is based on the ability of sound to penetrate the ground and excite resonances in buried compliant objects [1]. Sound produced in the air efficiently couples into the first 0.5 m of the soil because of the porous nature of weathered ground resulting in acoustic vibrations that are sensitive to the presence of buried mines. This phenomenon has been termed “acoustic-to-seismic coupling” in the research literature. Off-the-shelf loudspeakers are used as the sound source and readily available laser Doppler vibrometers (LDVs) are used to measure the increased ground vibrations due to the presence of the buried mine [2]. The use of airborne acoustics for mine detection exploits three new phenomena that previously have not been explored for the purpose of buried mine detection. First, a landmine is a man-made, acoustically compliant object that is much more compliant than soils. This results in a high-vibration contrast between soils and buried mines that does not occur because of the presence of rocks, roots, and other man-made solid objects, such as concrete and metal. Second, the mine is a nonporous object that offers additional contrast to the porous soil in the presence of coupled sound. Third, the interface between a mine and the soil has been shown to be nonlinear; the interface between the soil and the

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mine is not continuous when vibrating. This phenomenon results from the strong acoustic compliance of the mine compared with soil. This nonlinear phenomenon allows for unique measurements that are in theory absolutely free of false alarms [3].

## STATE OF DEVELOPMENT

*Is the technology in basic laboratory research, or has it been field tested? What organizations and research programs are examining it? What are the realized or projected costs of field testing?*

Extensive laboratory and field research of A/S coupled buried mine detection has been performed in recent years. Because of the applied research development level, an operational configuration for system-level development test and evaluation and operational test and evaluation has not been established. Both nonlinear and linear acoustic techniques are currently being field tested by the University of Mississippi's National Center for Physical Acoustics (NCPA) and Stevens Institute of Technology (SIT). NCPA, working with Planning Systems Inc. of Slidell, La., and MetroLaser Inc. of Irvine, Calif., is developing an acoustic-based antitank mine detection data collection platform with multiple laser vibrometers for the U.S. Army Communications-Electronics Command Night Vision and Electronic Sensors Directorate (NVESD), Fort Belvoir, Va., that will move at a few kilometers per hour with a 1-m-wide swath. The Army Research Office and the Office of Naval Research have also provided additional funds for related research to NCPA. Current budgets for the NCPA and SIT efforts are provided by the congressional plus-ups and have totaled approximately \$3 million per year. Because of the expressed interest of the sponsor, the majority of the funds are used for the antitank mine detection effort.

## CURRENT CAPABILITIES AND OPERATING CHARACTERISTICS

*What receiver operating characteristics (ROCs) have been realized in either laboratory or field tests? What are typical implementation (e.g., scan and investigation) times?*

NCPA has collected A/S coupled mine detection data on more than 300 separate buried antitank and antipersonnel landmines and hundreds of square meters of clutter spots at U.S. Army field sites in Northern Virginia and Arizona. These sites have allowed for the technology to be tested under a wide range of environmental conditions. Blind tests of this technology, sponsored by the Army, have resulted in unprecedented results for the high probability of detection and low false alarms [4]. NCPA has provided A/S coupled mine detection data to the Army which has in turn been provided to university faculty in Florida and Missouri and to other Army contractors for the purpose of automatic target algorithm development. The use of these algorithms has resulted in almost perfect detection and zero false alarm rates [5]. The current implementation using a single LDV for data collection requires approximately two minutes to scan a square meter since it can only interrogate a single point on the ground at any given time.

#### **KNOWN OR SUSPECTED LIMITATIONS OR RESTRICTIONS ON APPLICABILITY**

*Under what conditions (background clutter, mine type, environmental conditions, etc.) should the technology perform exceptionally well or poorly? What are the principal factors limiting current performance?*

The ideal operational condition for A/S coupled mine detection is a desert, sandy soil environment. The most serious limitation of the physics of A/S coupled buried mine detection is attenuation of the acoustic signal with depth, realistically limiting the detection depth to less than 30 cm. The technique is immune to moisture, weather, acoustic, and seismic noise sources as well as most natural clutter, including rocks and roots. Some man-made compliant objects, such as empty soda and paint cans, will emulate landmines. Based on winter testing in Alberta, Canada, hard frozen ground may also limit the capability of this sensor. From a measurement standpoint, detection speed is currently a limiting factor, as is the presence of heavy vegetation on the ground. Detection speed is limited by the measurement technology, which currently uses only a single LDV. Also, heavily covered grassy surfaces, particularly those with dead vegetation not directly rooted into the soil, present a challenge to the

LDV currently used to measure the A/S coupled vibrations at the ground's surface.

### **ESTIMATED POTENTIAL FOR IMPROVEMENT IN THE TECHNOLOGY OVER TWO TO SEVEN YEARS**

*Can the current limiting factors be overcome, and if so, what is the best realistic performance (in terms of ROCs and operational times) that could be expected?*

Considering that the ideas presented thus far have been funded and investigated for less than five years, the results are phenomenal. The most significant progress to be made will be in the area of the sensor used to measure the surface vibrations. Europe leads the world in the development of optical techniques for vibration sensing and the sensors used to date in the program are purchased from European countries. Significant increases in detection speed up to a 3-m swath at a few kilometers per hour may be accomplished through the use of multiple LDVs operating in parallel or development of alternative sensors. Potential alternative sensors for vibration measurement include Doppler focal plane array cameras, optical tilt cameras, Doppler radar, Doppler acoustics, and holographic speckle sensors. These alternatives face challenging sensitivity issues, and some, including Doppler radar and acoustics, have been able to sense the vibrations from mines in vegetation under laboratory conditions.

### **OUTLINE OF A SENSIBLE RESEARCH AND DEVELOPMENT PROGRAM THAT COULD REALIZE THIS POTENTIAL, WITH ROUGH PROJECTED COSTS TO THE EXTENT POSSIBLE**

The crucial elements of an A/S coupled mine detection research and development effort must include development of a continuously moving LDV array, further research into nonlinear acoustic phenomena, and investigation of alternative sensors. To further increase the probability of detection and reduce false alarms, NVESD is planning to fund an effort to fuse NCPA's A/S technology with a ground-penetrating synthetic aperture radar (GPSAR) developed by Planning Systems Inc. These two technologies are orthogonal in that they exploit disparate physical phenomena yet produce data in similar formats allowing fusion at the pixel level. They optimally operate

under different conditions. Whereas A/S mine detection is limited to shallower depths, GPSAR works best at greater depths. A/S mine detection works best against plastic mines, while GPSAR works better against metallic mines [6]. Consequently, an ideal mine detection program would not only address the A/S issues but would also incorporate sensor fusion to include the GPSAR capability as well.

As mentioned above, the current mine detection effort is primarily focused on antitank mine detection at the direction of the sponsor. Because of the smaller size and multiplicity of shapes encountered in antipersonnel mine detection [7], a separate, independent program is advisable. NCPA estimates a need for approximately \$3.5 million per year for four to five years to make this system ready for use.

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