Investigation of a Technique that Uses Elastic Waves to Detect Buried Land Mines

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Abstract — A technique that uses elastic waves to detect buried mines is being investigated. In the technique, an elastic wave is launched into the earth. It propagates and interacts with a buried mine causing displacements of both the mine and the surrounding soil. Because of the interactions of the wave with the mine, the soil surface displacements near the mine are quite different from those far from it. These displacements are measured using a sensor that is suspended above the soil surface. Results using two types of sensors are presented in this paper: a specially designed radar and an array of microphones. The results from measurements with both types of sensors compare well. The effects of the mine (including resonances, reflections, and non-propagating waves) can be seen in the data. The observed resonances clearly distinguish mines from common forms of buried clutter.

INTRODUCTION

Seismic/elastic techniques show considerable promise for the reliable detection of all types of buried mines, even low-metal anti-personnel mines. The reason for this is that mines have mechanical properties that are significantly different from soils and typical forms of clutter. For example, the shear wave velocity is approximately 20 times higher in the explosive and the plastics used in typical mines than in the surrounding soil. In addition, mines are complex mechanical structures with a flexible case, a trigger assembly, air pockets, etc. This complex structure gives rise to structural resonances, non-linear interactions, and other phenomena that are atypical for both naturally occurring and man-made forms of clutter. This phenomenology can be used to distinguish a mine from clutter.

Systems have been developed at Georgia Tech that employ sensors that measure local seismic displacements without physically contacting the soil surface [1-2]. The non-contact nature of these sensors allows interrogation of the soil surface near or immediately above a mine. This substantially increases the measurable effects of the mine's presence over schemes which rely on elastic waves scattered by the mine to propagate to a remote sensor location.

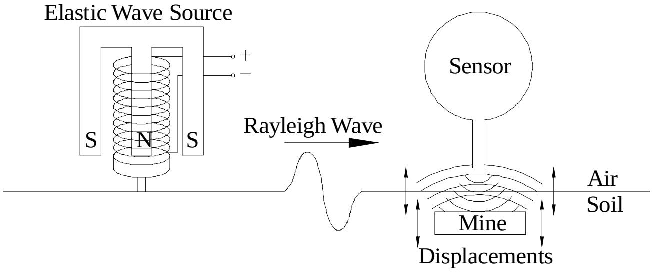

Figure 1 Diagram of the mine detection system.

Figure 1 depicts the system configuration. The system consists of a non-contact sensor and a seismic source. The source (an electrodynamic shaker coupled to the ground by a narrow foot) preferentially generates an elastic surface (Rayleigh) wave in the earth. The Rayleigh wave causes both the mine and the surface of the earth to be displaced as it propagates past the mine. Since the amplitude of Rayleigh wave displacements decreases exponentially with depth, only the soil near the surface is interrogated for the presence of mines. The depth of soil that is examined is a function of the frequency of the source. For typical mine depths and sizes, this is in the l00 to 1,000 Hz range. The motion of the mine is different from the surrounding soil, because the elastic properties of the mine are quite different than those of soil. The displacement of the surface of the earth near a mine is different than when the mine is not present because of the local and propagating waves scattered by the mine. The sensor is used to detect these displacements and, thus, the mine.

The system is currently being studied in a laboratory scale experimental model. The model, which is depicted in figure 2, consists of a wedge shaped tank filled with over 50 tons of damp compacted sand to simulate soil. The seismic source is located near the tip of the wedge and is bi-directive toward the search area and the back wall. Simulated mines, inert mines, and clutter, such as rocks and sticks, are buried within a 2 m x 2 m region in the center of the tank. The sensor can be scanned over this region with a three degree of freedom positioner fixed above the tank

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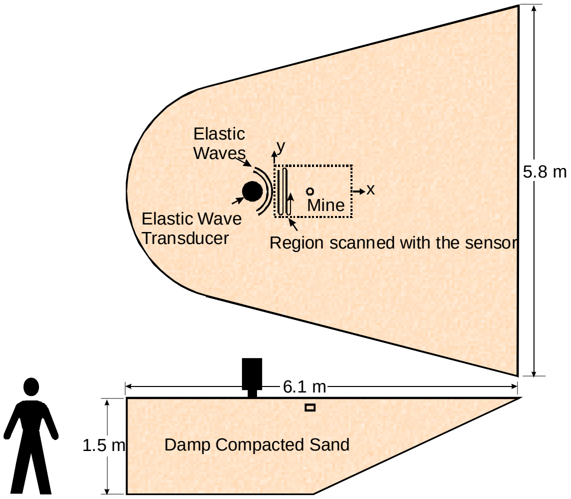

Figure 2 Diagram of the experimental model.

RADAR DISPLACEMENT SENSOR

Initial testing of the elastic wave mine detection system was conducted with a specially designed radar sensor. This idea of using elastic and electromagnetic waves concurrently has been proposed previously [3], but it has not been seriously investigated until now.

The radar sensor radiates electromagnetic waves toward the earth. These waves are reflected from the surface of the earth and the mine, where they are amplitude and phase modulated by the transient displacements of the earth and the mine. The reflected waves are received and demodulated. The resulting demodulated signals are proportional to the surface displacement. The radar operates at a frequency of 8 GHz and can measure vibrations as small as 1 nm (10^{-9} m) as currently configured. The end of a waveguide, which functions as both transmit and receive antennas, illuminates an area on the earth's surface comparable to its cross section (1cm x 2 cm) over which the measurement is averaged.

MICROPHONE ARRAY

An array of microphones is also being investigated as a possible low-cost alternative or supplement to the radar. In this scheme the acoustic pressure in the air immediately above the soil surface is measured with a microphone array. Due to the low wave speed of the Rayleigh wave, the acoustic wave that it radiates into the air is evanescent. It can, however, be measured very near the ground surface. If this measurement is made at many locations on a sufficiently large array of calibrated microphones, the pressure measurement can be inverted to determine the surface displacements. This measurement is averaged over an area proportional to the square of the height of the array. This is known as planar near-field acoustic holography and has been employed in the study of structural acoustics problems [4].

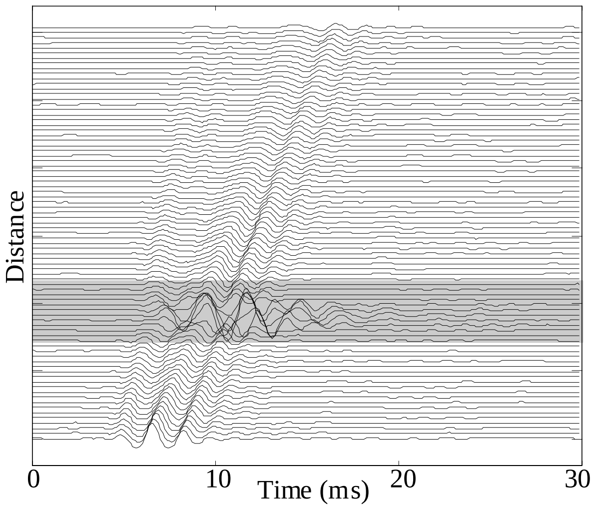

Figure 3 1-D Radar Scan Over Buried TS-50 AP Mine

EXPERIMENTAL RESULTS

The primary detection cues used for all of the inert mine types that have been studied in the experimental model have been resonances of the mine case, trigger mechanism, and overlying soil [1,2,5]. These are excited by the passage of the Rayleigh wave and characterized by large displacements that persist after the passage of the incident pulse. Although mines exhibiting resonances scatter a larger propagating wave field than similarly sized non-resonant objects, the most pronounced feature of the field scattered by these mines is its primarily local nature. This appears to result from a mostly reactive soil loading. For the mine types studied thus far, the localized resonant motion has been an excellent indicator of a mine's location and extent. Figure 3 shows a waterfall graph of a linear scan over a TS-50 antipersonnel (AP) mine with the radar sensor. Measurements were made in 1 cm increments from the source and the graphs of successive measurements are offset vertically. The presence of the mine is apparent in the figure due to the amplification of motion above the mine and ringing at this location that can be observed after the incident pulse has propagated beyond the mine.

The same scan was performed using an uncalibrated microphone 1 cm above the soil surface. The measured signals are shown in figure 4. Here the incident wave and the mine resonance are again clearly apparent. Since the 1-D scan that was performed does not contain sufficient information to invert the acoustic propagation and determine the soil surface displacements, pressure is plotted in figure 4 rather than displacement. There is, therefore, an exaggeration of the received signal contributions from the direct air acoustic path and from the faster bulk waves in the soil relative to the Rayleigh wave contributions in figure 4 versus figure 3.

An experiment was performed to address the issue of imaging a minefield containing a mine and several false targets, all covered by surface vegetation. For this study, the false targets were four mine-sized rocks and two sticks. The

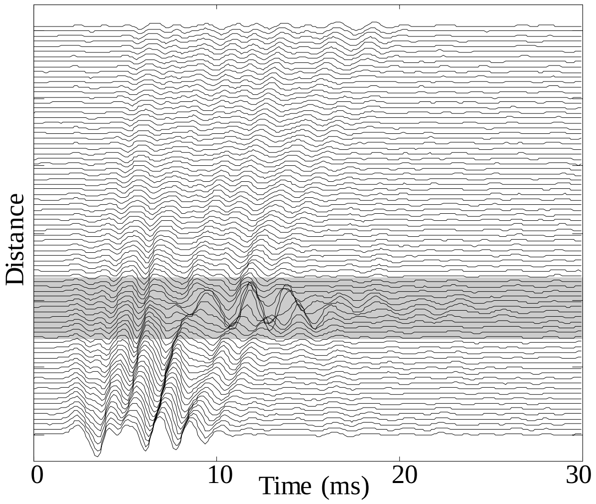

Figure 4 Microphone Scan Over Buried TS-50 AP Mine

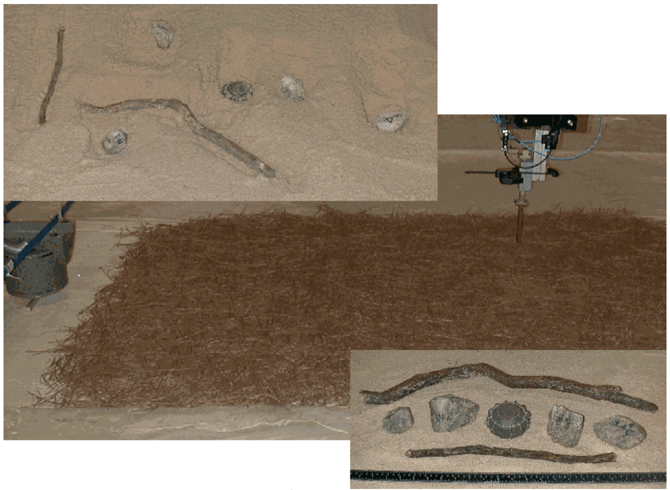

Figure 5 Photographs of the experimental configuration. Top left: Uncovered mine and clutter items. Center: the scan region covered in pine straw. Bottom Right: mine and clutter items.

mine was a TS-50 AP mine, and the ground cover was 2.3 cm of pine straw. The mine and the false targets were buried at depths of one to three centimeters within a 120 cm by 80 cm search area. The layout of this experiment and the relative scale of the buried objects are shown in figure 5. The goal was to determine whether the mine could be distinguished from the false targets and whether the radar could see through the pine straw. The image formed of this search area is shown in figure 6. The image clearly shows the location and extent of the mine and virtually no evidence of the non-resonant clutter objects. The pine straw did not prove problematic for the radar sensor. Its performance was degraded slightly by the increased surface standoff distance due to the layer of pine straw.

Imaging of mines from surface displacement measurements can be done in many ways. This image was formed by a multi-step process that filters forward travelling waves (those components directed away from the source) out of the data in the wave number domain leaving the reflected waves and a portion of the non-propagating waves. The energy in these remaining waves at times near the time of arrival of the incident Rayleigh wave is assigned to each measurement point forming an image. Unlike background subtraction, this algorithm does not rely on information that would be unavailable to a mine detection system operating in the field. Previous work has shown that this technique can be used to image several types of AP mines and distinguish them from non-resonant buried clutter [1,5].

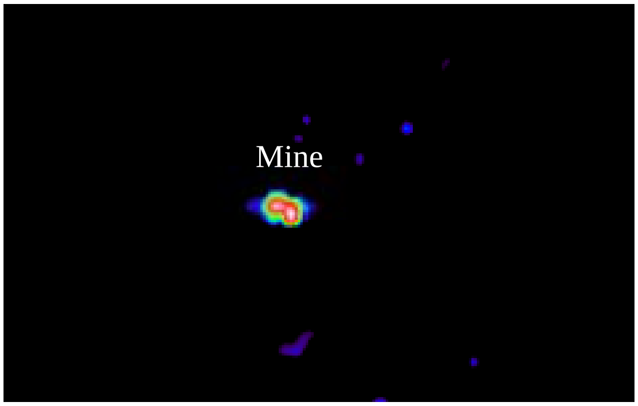

Figure 6 Mine Image Formed from 2-D Radar Scan Data

CONCLUSIONS

Detection and imaging of inert AP mines using elastic waves and non-contact displacement sensors have been demonstrated under laboratory conditions that mimic a variety of realistic mine detection scenarios. These conditions include the presence of natural surface covering and buried clutter in close proximity to the mine. Two different sensing techniques have been demonstrated which can accomplish these detections. These should have different susceptibilities to noise and surface cover. Although not as well developed, one of these methods, the microphone array technique, offers a significant savings in the hardware requirements of the mine detection system.

REFERENCES

1. Scott W.R., Jr., Larson, G.D. and Martin J.S., “Simultaneous Use of Elastic and Electromagnetic Waves for the Detection of Buried Land Mines,” *Proceedings of the SPIE: 2000 Annual International Symposium on Aerospace/Defense Sensing, Simulation, and Controls*, Orlando, FL, Vol. 4038, April 2000.
2. Scott, W.R., Jr., Schroeder, C., and Martin, J.S., “A Hybrid Acoustic/Electromagnetic Technique for Locating Land Mines,” *Proceedings of the 1998 International Geoscience and Remote Sensing Symposium*, Seattle, Washington, July 1998
3. C. Stewart, Summary of Mine Detection Research, Vol. I, pp. 172-179, *Tech. Report* 1636-TR, May 1960, U.S. Army Engineering Res. and Devel. Labs, Corps. of Eng., Belvoir, VA.
4. E. Williams et. al., “Sound Reconstruction Using a Microphone Array,” Journal of the Acoust. Soc. of Am., Vol. 68, No.1, pg 340-44, July 1980
5. Behboodian, A., Scott, W.R., Jr. and McClellan, J.H. "Signal Processing of Elastic Surface Waves for Localizing Buried Land Mines," *Proceedings of the 33rd Assilomar Conference on Signals, Systems, and Computers*, Assilomar, CA, October 1999

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