

# Combined Seismic, Radar, and Induction Sensor for Landmine Detection

Waymond R. Scott, Jr.<sup>a</sup>, Kangwook Kim<sup>a</sup>, Gregg D. Larson<sup>b</sup>, Ali C. Gurbuz<sup>a</sup>, and James H. McClellan<sup>a</sup>

<sup>a</sup>School of Electrical and Computer Engineering

<sup>b</sup>School of Mechanical Engineering

Georgia Institute of Technology

Atlanta, Georgia 30332-0250

waymond.scott@ece.gatech.edu

**Abstract**—An experimental system to collect co-located ground penetrating radar (GPR), electromagnetic induction (EMI), and seismic data was developed to investigate the possibility of using the sensors in a cooperative manner and to investigate the benefits of the fusion of the sensors. These sensors were chosen because they can sense a wide range of physical properties. The seismic sensor is sensitive to the differences between the mechanical properties of a landmine and the soil while the GPR is sensitive to the dielectric properties, and the EMI sensor is sensitive to the conductivity.

**Keywords**- Ground penetrating radar, electromagnetic induction, seismic, landmine.

## I. INTRODUCTION

It is unlikely that any single sensor will be able to reliably detect all types of buried landmines with a reasonable false alarm rate in all environmental conditions. The reason for this is that the soil is a complex and very inhomogeneous media. Many of the inhomogeneities in the soil such as rocks, roots, moisture variations, scrap metal, etc. can cause a sensor to give false alarms. Inhomogeneities in the soil that can cause a false alarm will be referred to as clutter objects in the paper. It seems reasonable that by using multiple sensors to sense a broad range of physical properties, it will be easier to reliably distinguish between landmines and inhomogeneities in the soil.

An experiment to investigate the potential for multiple sensors was set up. In the experiment, co-located ground penetrating radar (GPR), electromagnetic induction (EMI), and seismic data was taken. These sensors were chosen because they can sense a wide range of physical properties and are compatible of operating simultaneously. The seismic sensor is sensitive to the differences between the mechanical properties of a landmine and the soil while the GPR is sensitive to the dielectric properties, and the EMI sensor is sensitive to the conductivity.

In the experiments, a range of mines and clutter objects were buried at various depths in the sandbox at Georgia Tech. Multiple burial scenarios were investigated with a variety of anti-personnel (AP) and anti-tank (AT) mines and typical clutter objects. The GPR makes use of modified resistive-vee antennas which are very “clean” in that they have very little

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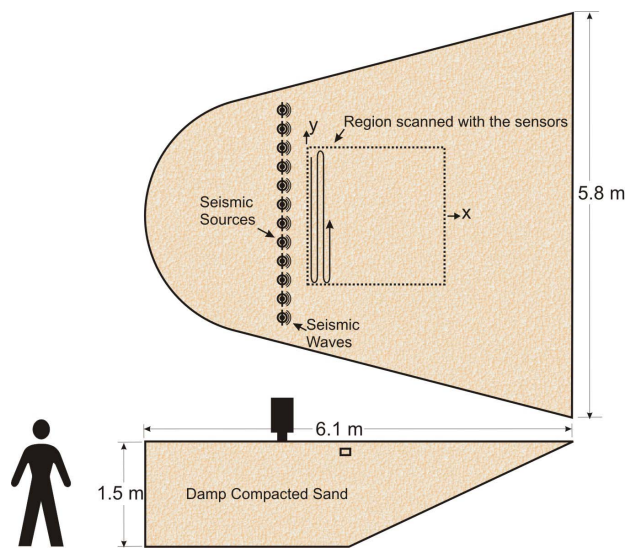


Fig. 1 Diagram of the experimental setup.

self clutter and a very low radar cross section to lessen the reflections between the ground and the antennas. The EMI sensor collects broadband data so that the relaxation spectra of the buried targets can be used to aid discrimination. The seismic system used in these experiments is an extension of our existing seismic mine detection system. The system uses electrodynamic shakers to generate seismic waves which propagate across the simulated minefield, and a specially designed radar is used to measure the displacement of the surface caused by the seismic waves. The response of each of these sensors to buried landmines and clutter are shown in this paper. In future work, methods for using the sensors cooperatively will be investigated.

## II. EXPERIMENT

The experimental model, illustrated in fig. 1, consists of a wedge shaped tank filled with over 50 tons of damp compacted sand to simulate soil. Inert mines and clutter are buried within a 1.8 m x 1.8 m region in the center of the tank. The sensors are scanned over this region with a three degree of freedom

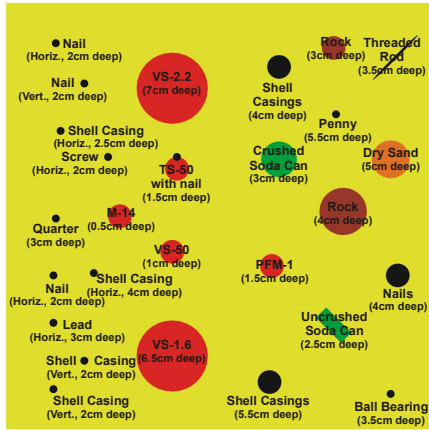


Fig. 2 Diagram showing location of objects buried in the sandbox.

positioner fixed above the tank. An array of seismic sources is located on one end of the scan region. The landmines and clutter items have been buried in multiple scenarios. The scenario depicted in fig. 2 has six buried mines (two AT landmines: VS-1.6 and VS-2.2; four AP landmines: TS-50, M-14, VS-50, and PFM-1) and 21 clutter objects such as gun shells, nails, rocks, cans, etc. All three of the sensors were scanned over the simulated minefield and their output recorded.

#### A. EMI Sensor

The EMI sensor consists of dipole transmit and receive coils located coaxially on the same plane. The coils are made from 20 turns of 24 AWG solid copper wire which is shielded to minimize the capacitive coupling between the coils. An auxiliary bucking transformer is used to cancel the mutual coupling between the transmit and receive coils. This configuration has the simple footprint of the dipole coils while having the sensitivity of quadrupole coils because of the cancellation from the bucking transformer. The response of the EMI coils is measured with a network analyzer over the frequency range of 600 Hz to 60 kHz.

Figure 3 is a graph of the measured real and imaginary parts of the response of the EMI sensor as a function of frequency for two targets: a 20 cm diameter loop of 20 AWG wire and an M-14 mine. The targets were placed on the surface of the sand and the height of the EMI sensor was varied from 0 to 6 cm above the surface of the sand. The loop of wire has a theoretical relaxation frequency of 5.6 kHz which is in excellent agreement to the measured results. The response of both targets decrease as the height of the sensor above surface of the sand is increased as expected. The response of the M-14 mine is as expected; it has a relaxation but the real part is offset because of its ferrous content. The response for the M-14 mine is seen to be noisy at the lower frequencies due to interference of power line harmonics. The response of the M-14 mine is fairly weak but is clearly discernable even at the 6 cm height.

Figure 4a is an image formed from the measured seismic data by calculating the energy in the imaginary part of the response of the EMI sensor over the frequency range of 1 kHz to 60 kHz. The response of all of the landmines can be seen in

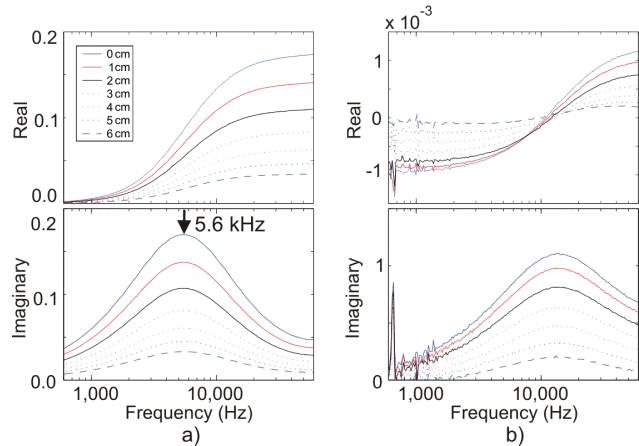


Fig. 3 Real and imaginary part of the EMI response of a a) loop of 20 AWG copper wire with a 20 cm circumference and b) a M14 antipersonnel landmine.

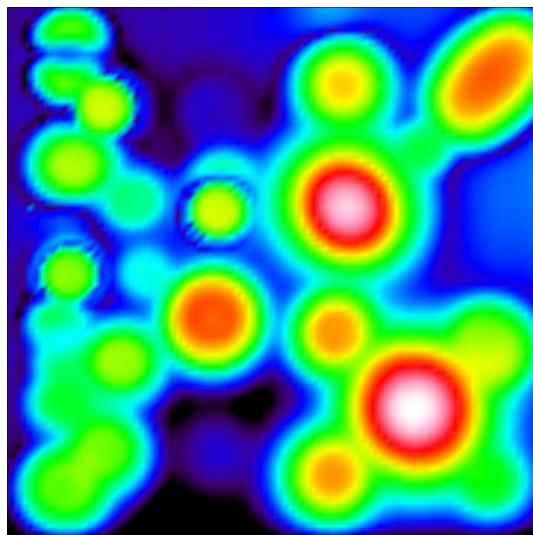
the image but the response for the two AT mines is very weak, about 50 dB weaker than that of the VS-50 mine. This is because the two AT mines have low metal content and are buried deeper than the AP landmines. The response of all the metal clutter items can also be seen, but the response of the rocks and bag of sand can not be seen. Using the EMI sensor with an “energy detector” will produce many false alarms, as is evident from the image in figure 4a. However, with more advanced signal processing it is possible to use the broadband frequency response of the EMI sensor to distinguish between the mines and many of the clutter items [1].

#### B. GPR Sensor

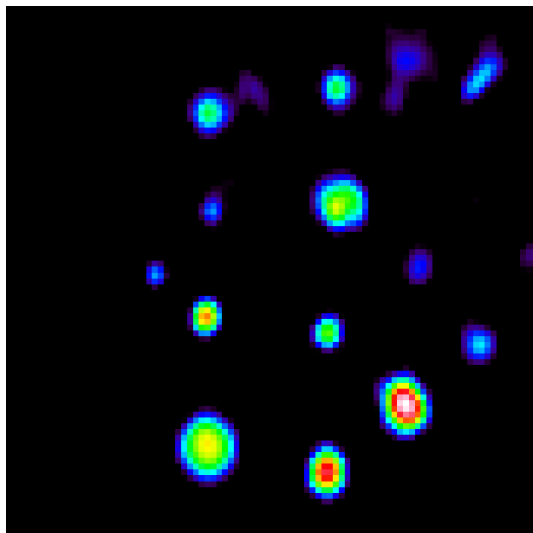
The GPR sensor consists of a pair of resistively loaded vee antennas used in a bistatic configuration. These antennas are very “clean” in that they have very little self clutter and a very low radar cross section to lessen the reflections between the ground and the antennas. The antennas have an aperture length of 11.4 cm and are spaced 11.4 cm apart [2,3]. The response of the antennas is measured with a network analyzer over the frequency range of 60 MHz to 8 GHz. The data is then transformed into the time domain to give the response of the antennas to a differentiated Gaussian pulse with a center frequency of 2.5 GHz.

The response of the GPR is graphed in fig. 5 for a single line across the scan region at  $x = 68$  cm which goes over four landmines: VS-1.6, VS-50, TS-50, and VS-2.2. The signal graphed is the response of the system when scanned minus the response of the system when pointed toward free space. The graph is on a 30 dB color scale. At times near 1.5 ns, the reflection from the surface of the sand is apparent. At times near 2 ns, the reflections from the two AP mines can be seen. At times between 2.4 and 4 ns, the reflections from the AT mines can be seen.

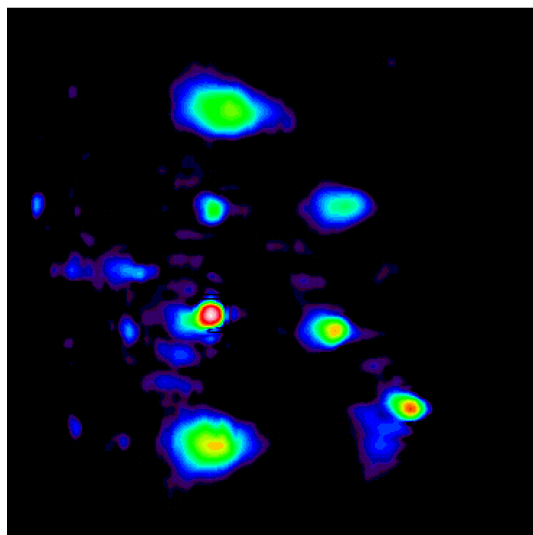
An image formed from the GPR data is shown in fig. 4b on a 20dB scale. The imaged is formed by migrating the data and summing the energy over all the depths. All of the landmines can be seen in the image although the response of the M14



a)



b)



c)

Fig. 4 Images formed from the sensor data: a) Image formed from the EMI data on a 90 dB scale. b) Image formed from the GPR data on a 20 dB scale. c) Image formed from the seismic data on a 30 dB scale.

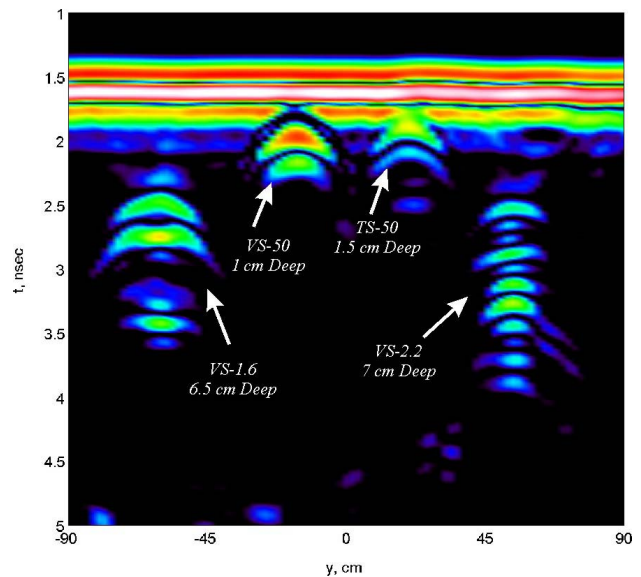


Fig. 5 Pseudo color graph of the response of the GPR when scanned over the line at  $x = 68$  cm.

mine is very weak. The smaller clutter items on the left of the image are not apparent in the image. The larger clutter items on the right side of the image are apparent including the rocks and bag of dry sand. As with the EMI sensor, it is possible to use the nature of the GPR response to distinguish between the mines and many of the clutter items by using more advanced signal processing techniques [4].

### C. Seismic Sensor

The seismic landmine detection system interrogates the near-surface layers of the scan region by generating a Rayleigh surface wave that propagates through the region of interest interacting with buried landmines and clutter objects. By scanning a custom-built, non-contact, 8 GHz radar sensor over the region of interest, the system measures the normal surface displacements directly above the scan region, thus eliminating the problems of propagation losses due to absorption and geometrical spreading which are encountered in traditional pulse-echo seismic systems. The seismic waves excite resonances of the buried landmines, resulting in increased surface displacements directly above the landmines; the seismic waves are also scattered by the presence of buried objects. Post-processing of the measured surface displacements takes advantage of these detection cues to determine the locations of buried landmines. Landmines have been successfully detected with this technique in multiple scenarios in the experimental model in the presence of typical buried clutter (i.e., rocks, sticks, cans, shrapnel, etc.) and surface clutter (i.e., 10 cm thick layer of pine straw) [5]. Field measurements have detected multiple AT mines in a roadbed site at a U. S. government testing facility in a temperate climate [6].

The measured normal displacement as a function of time for a single line across the scan region at  $y = 20$  cm is shown in a waterfall plot in figure 6. The dominant wave is a Rayleigh

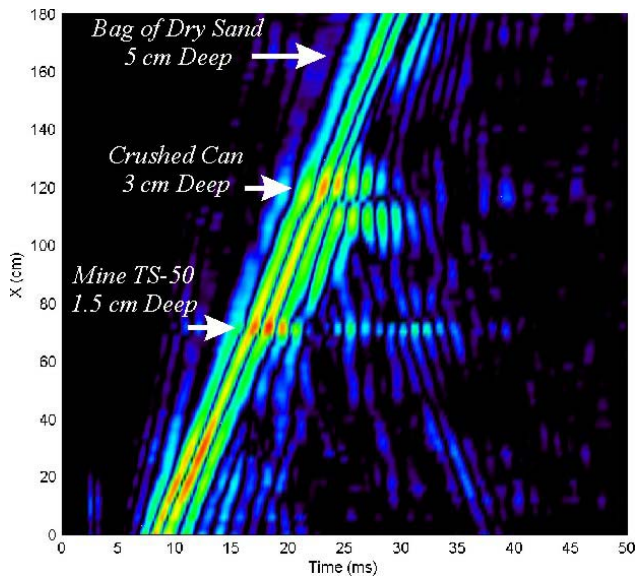


Fig. 6 Pseudo color graph of the response of the seismic system

(surface) wave, propagating at 91 m/s. When the surface wave reaches the TS-50 AP mine, it excites a resonance of the landmine-soil system which can be seen to persist well beyond the passage of the surface wave; this same effect can be seen as the surface wave interacts with the crushed can. Reflected waves are apparent when the surface waves are scattered by all three buried objects in the data presented in figure 6; the largest reflections are seen to come from the interactions with the crushed can.

An image formed from the seismic data is shown in fig. 4c of a 30 dB scale. To form the image, the measured data is filtered in the wavenumber domain to remove all components propagating away from the source leaving the reflected waves and a portion of the non-propagating waves. The image is then formed by taking the product of the energy measured at each location and the energy that propagates back towards the line of sources. The image indicates the location of the two AT landmines, the four AP landmines, and the cans. The indication of the M-14 AP landmine is weak in this image as the scale of the image was dictated by the fairly strong

response of the VS-50 AP landmine. While the cans show up quite well in this image, the other clutter items such as the rocks and pieces of metal do not appear.

### III. CONCLUSIONS

The initial results of an experiment to collect co-located EMI, GPR, and seismic data is presented. All three of the sensors were capable of detecting the buried landmines using very simple detection algorithms, but they were all fooled by some of the clutter objects. The EMI sensor was the most sensitive to the clutter objects and the seismic system was least sensitive to the clutter objects. The aluminum cans created a strong response in all three sensors while the buried rocks only affected the GPR sensor. By using more advanced signal processing techniques it is possible to greatly improve the false alarm rate of these sensors. By fusing the response of the three sensors together or by using the sensors in a cooperative manner it may be possible to improve their combined performance.

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