Detection of Obscured Targets: Physical Modeling

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Outline

- Introduction
- Three Sensor Experiment
- Features/Responses
- Reverse-Time Processing
- Accomplishments/Plans
Motivation

- Every sensor works well in certain circumstances
- No single sensor has proven capable of reliable detection of obscured targets in all environments
- Can multiple sensors be used in a cooperative manner to improve their combined performance?
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Three Sensor Experiment

- A three sensor experiment has been developed to investigate the potential for multimodal processing
  - Electromagnetic Induction (EMI) Sensor
  - Ground Penetrating Radar (GPR) Sensor
  - Seismic Sensor
- Multiple Experimental Scenarios
  - Buried Landmines
  - Buried Clutter Objects
  - Target Distribution
### Three Sensor Experiment

**Properties Sensed**

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Physical Properties of Target</th>
<th>Permittivity Contrast</th>
<th>Low Conductivity (Dielectric)</th>
<th>High Conductivity (Metal)</th>
<th>Mechanical Contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMI</td>
<td></td>
<td>No</td>
<td>Weak</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>GPR</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td>Yes*</td>
<td>No</td>
</tr>
<tr>
<td>Seismic</td>
<td>No</td>
<td></td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

* Can not distinguish between highly conductive targets.
Three Sensor Experiment

Sensor Adjustments and Features

- Adjustable Parameters for all three sensors
  - Frequency range
  - Frequency Resolution
  - Spatial Resolution
  - Integration time/bandwidth
  - Height above ground

- Possible Features for sensors
  - EMI
    - Relaxation frequency
    - Relaxation strength
    - Relaxation shape
    - Spatial response
  - GPR
    - Primary Reflections
    - Multiple Reflections
    - Depth
    - Spatial Response
  - Seismic
    - Resonance
    - Reflections
    - Dispersion
    - Spatial response
Diagram of the Laboratory Model

- Length: 6.1m
- Height: 5.8m
- Width: 1.5m
Three Sensor Experiment
Three Sensor Experiment

- **Experimental Scenario #1**
  - 6 Mines
  - > 20 Clutter objects
  - Relatively uniform distribution

- **Experimental Scenario #2**
  - 7 Mines
  - > 25 Clutter objects
  - Non-uniform distribution
Burial Scenario #1

1.8m by 1.8m Scan Region

Seismic Sources

MINES VS-2.2
(7cm deep)

TS-50
(1.5cm deep)
w/ Nail

M-14
(0.5cm deep)

VS-50
(1cm deep)

PFM-1
(1.5 cm deep)

VS-1.6
(6.5cm deep)

Assorted Metal Clutter (2 to 4 cm deep)

Shells
(4cm deep)

Threaded Rod
(3.5cm deep)

Dry Sand
(5cm deep)

Penny
(5.5cm deep)

Rocks (3 and 4 cm deep)

Nails
(4cm deep)

Cans (3 and 2.5 cm deep)

Ball Bearing
(3.5cm deep)

Shells
(5.5cm deep)
Burial Scenario #2

1.8m by 1.8m Scan Region

Seismic Sources

MINES VS-50 (1.3cm deep)
VS-2.2 (5.4cm deep)
M-14 (1cm deep)
TS-50 (1.3cm deep)
PFM-1 (0.6cm deep)
VS-50 (0.5cm deep)
VS-1.6 (5.1cm deep)

Assorted Metal Clutter (<3cm deep)
Can (2.2cm deep)
CD (29cm deep)
Rocks (2, 2.2, 2.5, and 1.3cm deep)
EMI Sensor

- Frequency Domain: 600 Hz to 60 KHz
- Transmit and receive coils: Coaxial, Dipole, Shielded
  - Simple footprint
  - Greater depth potential than quadrupole coils
- Direct coupling between coils partially canceled in hardware
EMI Sensor Response

20 cm cir. loop, 20 AWG

M14

Sand (no mine)
EMI Sensor
Image (90 dB scale)

“Energy” in Imaginary part of the response 1 KHz to 60 KHz
GPR Sensor

- Data taken in frequency domain with network analyzer: 500 MHz to 8 GHz
- Antennas
  - Characteristics of Resistive Vee Dipole:
    - Radiates short, directive pulse
    - Low radar cross section
    - Low internal clutter
    - Light and array-able
    - Easy to manufacture
  - Shape & profile have been optimized.

\[ L = 6.75'' \]
\[ 2A = 62.4\text{mil} \]
\[ 2d = 4.5'' \]
\[ \theta = 3\text{mm} \]

\[ x \]
\[ y \]
GPR Sensor

Antenna

- Styrofoam

GPR

- Chip resistors
- Balun/transformer

Tx
Rx

4.5”
GPR Sensor
Raw Data-Air Data

\[ x = 68 \text{ cm} \quad x = 110 \text{ cm} \]
GPR Sensor
Energy Image of Migrated Data (50 dB scale)
Seismic Sensor

Signal Generator

Radar: R.F. Source, Demodulator, and Signal Processing

Elastic Wave Transducer

Elastic Surface Wave

E.M. Waves

Waveguide

Mine

Displacements

Air

Soil
Seismic Sensor
Animation; Raw Data; 40 dB scale
Seismic Sensor
Pseudo Color Graph; y = 20 cm

Bag of Dry Sand 5 cm Deep
Crushed Can 3 cm Deep
Mine TS-50 1.5 cm Deep
Seismic Sensor
Image 30 dB Scale
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Comparison of EMI, GPR and Seismic Response
VS-50, 1 cm deep
Comparison of EMI, GPR and Seismic Response
VS-1.6, 6.5 cm deep

EMI

GPR

Seismic
Comparison of EMI, GPR and Seismic Response
Uncrushed Aluminum Can, 2 cm deep

EMI

GPR

Seismic

![Graphs and images showing comparison of EMI, GPR, and Seismic response](image-url)
Comparison of EMI, GPR and Seismic Response
Five 0.232 Shells, 5.5 cm deep

EMI

GPR

Seismic
Comparison of EMI, GPR and Seismic Response
Rock, 4 cm Deep

EMI

GPR

Seismic

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Reverse-Time Focusing

- The seismic system only works in areas where there is sufficient incident seismic energy.
  - The incident seismic energy can be blocked/redirected by inhomogeneities in the ground.
  - Only a small region may need investigating with the seismic system.
- Reverse-Time processes can focus energy in a specified region
Geometry

- Excitation sent out from source
- Signal is recorded at an array of sensors
- Signal is reversed in time
- Reversed Signal is used to excite sources at array locations
- Propagating waves should focus at location of original source

Forward Problem

Time Reverse Problem
Complex Wave Propagation

- Wave Propagation is complex
  - 5 wave types for homogeneous half space
  - More wave types for layered half space
  - Clutter
  - Isotropic vs. Anisotropic
  - Linear vs. Nonlinear
Time-Reverse Signals

![Diagram showing the concept of time-reverse signals with a source array and a receiver focus point.](image)
Introduce Rocks for Lateral Inhomogenities

Sand is Vertically Stratified

Add Rocks to Create Scatterers
Introduction of Inhomogeneities

Rocks

Rocks And More Rocks
Reverse Time Experiments

- Experiment #1
  - Demonstrate focusing
  - Multiple points

- Experiment #2
  - Demonstrate focusing can enhance the response of a mine
Experimental Results

6 Shakers – Unfocused

Identical Excitations
Maximum Displacement

Unfocused

![Image of a graph showing maximum displacement with axes labeled x in cm and y in cm, and a color scale on the right side ranging from 0 to -40. The graph has three plus signs indicating specific points.]
Experimental Results
6 Shakers – Time Reversal
Focus Point: (85,24,0)
Time Reverse Focusing

Focus: (85,24,0)

Focus: (113,-28,0)

Focus: (90,0,0)
Maximum Displacement
Three Focus Locations
Maximum Displacement

Unfocused

Time-Reverse

Time-Delayed (Beamformed)
Reverse Time Experiments

- **Experiment #1**
  - Demonstrate focusing
  - Multiple points

- **Experiment #2**
  - Demonstrate focusing can enhance the response of a mine
Maximum Displacement with TS-50 mine

Time-Reverse

Unfocused
Accomplishments

- Developed three sensor experiment to study multimodal processing
  - Developed new metal detector and a radar
  - Investigated two burial scenarios
  - Showed responses for all the sensors over a variety of targets
  - Demonstrated possible feature for multimodal/cooperative processing
- Developed reverse-time experiments, models, and processing
  - Demonstrated focusing
  - Demonstrated enhancement of mine signature
  - Demonstrated reverse-time imaging on numerical and experimental data
- Buried structures
  - Developed numerical model for a buried structure
  - Demonstrated two possible configurations for a sensor
Plans

- Three sensor experiment
  - Incorporate reverse-time focusing and imaging
  - More burial scenarios based on inputs from the signal processing.
    - More/Stronger clutter
    - Distribution of targets and clutter
    - Close proximity between clutter and targets
  - Look for more connections between the sensor responses that can be exploited for multimodal/cooperative imaging/inversion/detection algorithms
  - Develop multimodal/cooperative imaging/inversion algorithms
- Reverse-time processing
  - Improve experiments (Characterize/improve seismic sources)
  - Perform experiments to improve demonstration of reverse time imaging
  - Improve reverse-time imaging algorithms
  - Investigate the use of reverse-time ideas to characterize the inhomogeneity of the ground
- Buried Structures
  - Other scenarios
  - Signal Processing