Multi-Sensor Measurements for the Detection of Buried Targets

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Outline

- Introduction
- Three Sensor Experiment
- Multi-static Radar
- Accomplishments/Plans
Experimental Test Bed

- Develop a set of experiments to investigate the potential of multi-modal processing
  - Landmine (Three sensors/six modes)
    - EMI
    - GPR
      - Bi-Static
      - Multi-Static
    - Seismic
      - Unfocused
      - Focused
      - Remote Detection
  - Buried Structure (Two sensors/four modes)
    - GPR
      - Bi-Static
      - Multi-Static
    - Seismic
      - Bi-Static
      - Multi-Static
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Diagram of the Laboratory Model
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
- Experimental Scenario #3
  - Non-uniform distribution of 7 Mines (2 AT, 5 AP) and 57 clutter objects
  - Rock field surrounding AP mine and can
  - AP mines and clutter objects grouped around and on top of AT mines
Burial Scenario #1

1.8m by 1.8m Scan Region

- 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)
- Seismic Sources
- Cans (3 and 2.5 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)

Comparison of Images

- EMI Sensor Image (90 dB scale)
- GPR Sensor Energy Image of Migrated Data (25 dB scale)
- Seismic Sensor Image 30 dB Scale
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Antenna & Array Assembly
GPR Array

We can obtain 192cm-wide synthetic array aperture by using reciprocity and synthesizing the scans at 6 positions.

3D Experiments

- Free Space (calibration)
  - Spheres, Mines, Shapes, and No target
- Buried targets (with clean surface and with surface covered by rocks)
  - No Targets
  - Grid of spheres (calibration)
  - Grid of mines and clutter
  - Buried structure
Free Space Target Measurements - Setup

GT Plywood
(38.5 x 46.5 x 1.84 cm)

11cm Shotput

1” Metal Sphere

TS-50

VS 1.6
Free Space Target Measurements - Results

H-Plane Cut at x = 0cm; 11cm Metal Sphere at 25.5cm from Radar

Free Space Target Measurements - Results

Comparison of the R1 – T1 Responses from Targets - H-Plane Cut at x = 0cm
VS 1.6 Mine

3D Experiments

- Free Space (calibration)
  - Spheres, Mines, Shapes, and No target
- Buried targets (with clean surface and with surface covered by rocks)
  - No Targets
  - Grid of spheres (calibration)
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Buried Target Measurements - Setup

Antenna height = 10cm from the surface of the ground
Scan region: 180cm x 180cm square
Rock coverage: 240cm x 340cm

Metal Spheres

Target Locations & Depths
Landmines

Target Locations & Depths

2D-plane cuts for the display of the results

$x = 0\text{cm-cut}$

Clean Scan

With-Rock Scan
Buried Structure

Target Location & Depth

\[ x = 0 \text{ cm-cut} \]

Clean Scan

With-Rock Scan
Buried Structure (Rocks)

Raw Data Energy Images for TR pairs

Accomplishments

- Developed three sensor experiment to study multimodal processing
  - Developed new metal detector and a radar
  - Investigated three burial scenarios
  - Showed responses for all the sensors over a variety of targets
  - Demonstrated possible feature for multimodal/cooperative processing
  - Developed new 3D quadtree strategy for GPR data
- Developed seismic experiments, models, and processing
  - Improved experimental measurement by incorporating a Wiener filter
  - Demonstrated reverse-time focusing and corresponding enhancement of mine signature
  - Demonstrated imaging on numerical and experimental data from a clean and a cluttered environment
  - Modified time-reverse imaging algorithms to include near field DOA and range estimates. The algorithms are verified for both numerical and experimental data with and without clutter.
  - Modified wideband RELAX and CLEAN algorithms for the case of passive buried targets. The algorithms are verified for both numerical and experimental data with and without clutter.
  - Used RELAX imaging to locate targets with cumulative maneuvering receivers.
  - Developed a vector signal modeling algorithm based on IQML (Iterative Quadratic maximum Likelihood) to estimate the two-dimensional \( \omega-k \) spectrum for multi-channel seismic data.
- Developed multi-static radar
  - Demonstrated radar operation with and without clutter objects for four scenarios
- Buried structures
  - Developed numerical model for a buried structure
  - Demonstrated two possible configurations for a sensor
  - Made measurement using multi-static radar
## Plans

- **Three sensor experiment (Landmine)**
  - Incorporate reverse-time focusing and imaging
  - Incorporate multi-static radar
  - More burial scenarios based on inputs from the signal processors
    - 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
- **Imaging/inversion/detection algorithms**
  - Extend 3-D quadtree algorithm to multi-static GPR data.
  - Investigate the use of reverse-time ideas to characterize the inhomogeneity of the ground
  - Investigate the time reverse imaging algorithm for multi-static GPR data.
  - Investigate the CLEAN and RELAX algorithms for target imaging from reflected data in the presence of forward waves with limited number of receivers.
  - Investigate joint imaging algorithms for GPR and seismic data.
- **Buried Structures**
  - Experiments with multi-static radar
  - Develop joint seismic/radar experiment
  - Signal Processing