Wave-based Electromagnetic Methods for Homeland Security & Infrastructure Applications

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Outline

- ALERT as an extension of CenSSIS
- Sensing concealed objects
- Remote THz spectroscopy
- Radar anomaly detection
- Whole body imaging
- Bridge deck focusing lens
ALERT: Awareness and Localization of Explosives-Related Threats

A Department of Homeland Security Center of Excellence

- Direct extension of the ERC for Subsurface Sensing & Imaging Systems (includes all core ERC partners)
- Awarded 2008
- Funding for 4+ years, at least $2.5M/yr
  - $4.2M Year 1
  - $3.6M Year 2
- MA state support of $1.6M
- Translational research extensions
- Integrates Education and Research
The ALERT Structure Is Directly Related to The CIED Trade-offs Between Systems and Science
Detection Regimes

- **Distant targets (10 m to >100 m),**
  - Stand-off detection of hazards
  - Far enough away to minimize threat

- **Mid-range targets (3 to 10m)**
  - Enhanced sensing discrimination
  - Not explicitly surrounding target

- **Intimately near targets (< 3 m)**
  - Non-invasively examined
  - Mostly portal sensors
The Suicide Bomber Problem

- Walking bomb
- Can kill tens of innocent people
- Doesn’t show under clothing
- Doesn’t make noise
- Doesn’t give off odors
- Doesn’t weight more than a bag

HARD TO DETECT
Detecting and Identifying Explosives

Sense within hidden / concealed / shielded / non-stationary environments

- **Wave-based** imaging to detect suspicious shapes (THz, mm-wave radar, acoustics, NMR, X-ray, video)
- **Material spectral** response to characterize molecular structure (Hyperspectral, IR, UV, THz, NQR, LIBS)
- Imaging to detect suspicious shapes (video, X-ray)
- Chemical detection to identify suspicious materials (Mass Spec., Ion Mobility Spec., Gas Chrom., “Artificial Dog Nose”)
- Device electronic response to identify wireless electronic triggers (EM emission sensing)
Standoff Explosives Detection

- Detect (not distinguish, not identify) potential explosive threats
  - Safely (eye safe, no ionizing radiation)
  - At standoff distance (>50m)
  - Under clothing
  - Without trace chemicals on clothing
  - Detect shape rather than composition

- Reasonable sensor array
  - Not too big
  - Not too expensive
Remote THz Wave Sensing with Fluorescence

incident THz pulse
plasmas
reflected THz pulse
flourescence emission

800 nm pulse
400 nm pulse

Telescope

PMT
Monochromator

C4

Graph: 4A - DNT
Absorption (a.u.)
Frequency (THz)

0.0 0.2 0.4 0.6 0.8 1.0
0.4 0.8 1.2 1.6
1.25 THz
0.5 THz
FDFD Modeling Guides Radar Design

Innocent Case Geometry

Threat Case with 9 Pipe Bombs
Focused Radar Beam to Highlight Specific Spot on Torso: Seen from Above

- Superposition of 13 UPW with phase adjusted according to position of focus
Experiments at FGAN in Germany

100 GHz MMIC radar with 5 GHz bandwidth

High gain parabolic reflector radar antenna
Reconstruction Feasibility for 94 – 100 GHz: FDFD Computational Model, 10m Range

• 1 m aperture multistatic array
• Inexpensive wideband FMCW radar elements
• Parabolic reflector antenna elements
• Point-to-point focusing rather than Fourier-Based reconstruction (New Approach)

With optimized nearfield focusing, clear concealed threat reconstruction feasible at standoff distance with limited size aperture

No pipes on torso, showing clear specular reflections

9 metal pipes, showing multiple scattering sites on torso
Intimately Near Detection: Advanced Imaging Technologies (AIT) for Whole Body Imaging

NEU Testbed: Unbiased academic-oriented testbed

- Evaluate multi-modal sensors and algorithms
- Enable experimentation with new sensing modalities
  - Optimize sensor configurations
  - Optimize scanning modes
- Explore new algorithm concepts
  - Model based vs. Fourier inversion
  - High resolution fused imaging
  - Automated anomaly detection
- Develop approaches to information fusion and adaptive multisensor processing
Whole Body Imaging Sensors with Multimodal Fusion Potential

- **Mm-Wave**
  - Penetrates clothing
  - Distinguishes body-worn objects other than flesh (i.e., metal, explosives, water, plastic)
  - Active system provides target contour info

- **THz**
  - Spectroscopic responses for explosives characterization
  - Penetrates thin clothing

- **X-ray Backscatter**
  - Penetrates all concealing layers
  - Dual energy distinguishes foreign materials
  - Ionizing radiation but very low dosage

- **IR Thermography**
  - Shows unusual heat patterns on body

- **NQR**
  - Non-localizing, but unique explosive discrimination
  - Penetrates throughout body
Civil Infrastructure Example: Inexpensive Time Domain Focusing Lens Invention

- Noninvasively interrogate bridge deck subsurface
- Must be simple, fast and cheap
- Use impulse GPR
- ...But don’t image, just concentrate on rebar position
- Similar to focusing with microscopy
- FDTD model of wave focusing:
Time Domain Model of Focusing Lens Wave Propagation

16 elements at 20 cm above surface

Antenna Array

Bridge Deck

Target Point
Time Domain Model of Focusing Lens Wave Propagation
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Conclusions

- Finding hidden things extends to many applications
- Detecting explosives at distance is challenging
  - THz sensing has the potential to give penetrating spectral information
  - Millimeter-wave radar can see through clothing and resolve features on skin at distance
- Portal-based sensing is timely, important and uses many wave-based subsurface sensing modalities
- Civil infrastructure defect sensing is a ripe area for focused GPR sensing
- All applications benefit from advanced processing and fusion algorithms

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