Standoff detection of trace level explosive residue using passive LWIR hyperspectral imaging

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Outline

- Program Overview
- Strategic Framework
- Technical Approach
- Technology Overview
- Summary of Test Results
- Next Steps, Challenges
Program Overview

- **Ultimate goal:** Develop sensor to attack terrorist networks
  - Covert & Passive standoff detection of explosive residues on surfaces

- **Goal of S&T efforts:** Assess and demonstrate the capability to detect trace level explosive residue on surfaces using passive LWIR hyperspectral imaging

- **Technical Objectives:**
  - Library signature development as a function of environmental conditions
  - Demonstrate wide area detection from true standoff ranges (10 - 100m)
  - Demonstrate detection and identification of explosives (RDX, TNT, PETN, TATP, UN, AN, C4, dynamite) present at low surface densities
  - Conduct sensor performance evaluation as a function of contamination loading, range, environmental conditions, surface types, interferents, vehicle speed

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Strategic Framework for Standoff Explosive Detection
Strategic Framework: Program Plan to Build an IED

Concept Development
- Device structure
- Triggering mechanisms
- Explosives
- UXO
- Device Packaging
- Concealment
- Identify targets
- CONOPS

Acquisition
- Recruit personnel
- Identify sources
- UXO or explosives
- Triggers
- Packaging
- Concealment
- Move parts to assembly bldg

Weaponization
- Modify UXO
- Build new Device
- Build trigger
- Test trigger
- Build packaging
- Build concealment
- Integrate System
- Cache or deploy

Deployment
- Select target
- Recon target area
- Prep target site
- Select CONOPS
- Assault Force movement
- PSTOPS movement
- Rehearse Attack
- Move and emplace IED
- Initiate attack
- Escape
- PSTOP dissemination
- Lessons learned

Command Authority
- Finance
- Facilities
- Equipment
- Personnel

Targets and Detection Methodology

Residue Transfer

Fugitive Emissions
Strategic Framework:
How Low (Sensitivity) Do You Need To Go?

- Fabricating an IED contaminates its maker, who spreads detectable residues – the trail to finding them

- High resolution imaging provides a richer target set
  - Spatial discrimination & awareness of residues

- Fluorescent dye studies indicate spot concentrations that are exploitable with a passive LWIR hyperspectral imager

Technology Overview
Technical Approach - Explosive Identification

Detection & Identification Basis
- Molecular absorption spectroscopy
  - Detect changes in reflectance of IR radiation from surfaces due to presence of explosive residue
  - Characteristic explosive spectral “finger prints” in LWIR region (7 – 12 µm)

Simplified Surface Reflection Model

- Contamination detected as differential change in reflectance due to reflection/absorbance of background thermal radiation
- Model sensor signal as linear combination of radiances from each path
Combined Path Radiances

- Contaminant layer in thermodynamic equilibrium with surface ($N_S = N_C$)

$$N_D = N_S \varepsilon_S + N_B (1 - \varepsilon_S) + 2 \alpha \rho (N_S - N_B)(1 - \varepsilon_S)$$

- Does not consider impact of atmospheric transmission

The SED System
Adaptive Infrared Imaging Spectroradiometer (AIRIS)

- Leverages standoff system developed for chemical weapon agents and toxic industrial chemicals
  - Fabry-Perot Interferometer provides rapid sequential sampling of pre-programmed discrete spectra
  - FPGA-based real time processor provides spatial-spectral detection
  - Integrated advanced algorithms for “on the move” detection of chemical releases without a priori knowledge of background
  - Simultaneously detects up to 4 materials using 20 spectral bands in 200ms
  - Larger explosive databases possible in 10 - 30 seconds
AIRIS-WAD Technology Overview

- 32° x 32° FOV direct imaging
- Detections overlaid on thermal infrared image of scene using a real-time processor
- Color coded target identification
- Data acquired and processed at 5 per second
- 10 meter spatial resolution at 5 km range for smaller release detection
- Archival data storage

Dugway Simulant Release

Ground

Airborne

Summary of Experimental Program
Detection on Non-Porous Real World Surfaces – Feasibility Assessment

- Detection on a variety of non-porous metal surfaces demonstrated
  - Semi-quantitative approach
- Inability to detect on exterior glass surfaces not yet understood
  - Could be related to IR coatings used on auto glass

Detection Capability as a Function of Range

- Detection demonstrated to 20 meters using RDX
- Ranges to 100 meters possible depending on humidity and concentration levels
- Optics optimization required to align spatial resolution with CONOPS
- At 20 meters detected RDX spot is only 2x2 pixels
  - ATR could flag operators
  - Zoom lens needed
Quantitative Performance Assessment
Sample Preparation: Technical Approach

- Explosive material is dissolved in a solvent (methanol) and injected into a Sono-Tek Accumist ultrasonic nozzle via syringe pump.
- Nozzle is stationary and motion of the deposition target (substrate) is actuated via a computer-controlled x-y stage (NEAT 300).
- Compressed air injected into the diffuser area of the nozzle:
  - Aids in evaporation of solvent
  - Carries the droplets to the substrate surface
- Gravimetric analysis to determine efficiency and accuracy of method:
  - Results indicate a coating uniformity of 2.2%.
- Conclusion: Method yields accurate and uniform explosive deposits.

RDX Detection Sensitivity Measurements:
Data acquired with AIRIS-WAD (8 – 11 µm coverage)
**RDX on controlled Al surfaces: Black Anodized and Polished Al**  
**Range = 5 m**

- **Conclusions:**
  - RDX detection demonstrated in complex scenes at 5 m range
  - RDX observed at low concentrations on polished Al surface
  - High probability of detection ($P_d > 90\%$) for low surface densities
  - No false alarm pixels

**Detection of RDX Concentrations at 5 meter range**

![Detection Graph](image)

**RDX on controlled Al surfaces: Black, Polished Al, and Painted Steel**  
**Range = 10 m**

- **Conclusions:**
  - RDX detection demonstrated in complex scenes at 10 m range on surfaces with a range of emissivities
  - No false alarm pixels

**Detection of RDX Concentrations at 10 meter range**

![Detection Graph](image)
**RDX on controlled Al surfaces: Black, Polished Al, and Painted Steel**

**Range = 20 m**

- Conclusions:
  - Detection demonstrated in complex scenes at 20 meters range
  - RDX observed at low concentrations on various emissivity surfaces

**Extended Range Detection – 37 meters**

- **RDX Detection**
  - Car with Aluminum plates at 37 m standoff
  - 3 surface loadings on polished Aluminum
**7.5 – 10.5 µm vs. 8 – 11 µm Spectral Coverage**

- Enables use of stronger absorption features
- Additional spectral bands allow multi-band correlation using Automated Target Recognition Algorithm
- **Conclusion:**
  - Expect 3x – 4x improvement in detection sensitivity with a system capable of 7.5 – 10.5 micron spectral coverage
  - In addition, the system would be capable of detecting HMEs

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**HME Detections using early generation PAIRIS (7.5 – 10.5 micron spectral coverage)**

- **HME Detection - Urea Nitrate**
  - UN primary IR signature below 8 microns
    - Employ PAIRIS (lower performance than AIRIS-WAD, easier to modify)
    - Polished Aluminum Test Plates
    - 3 contamination loadings

- **Conclusion:**
  - Successfully demonstrated detection on all 3 concentration levels at 5 m standoff range
Challenges and Next Steps

• Library signature generation as a function of environmental conditions – signature robustness

• Development of next generation detection algorithms for improved sensitivity and detection statistics ($P_D$ and $P_{fa}$)

• Evaluation of sensor performance (ROC curves) as a function of contamination loading, range, environmental conditions, surface types, interferents, vehicle speed, etc.
  – Impact on signal from surface emissivity, extent of cloud cover, and sky obscuration
  – Variation in sensitivity due to surface porosity, chemical permeability, and roughness

• Engineering development to align sensor with CONOPs
  – Adjustable FOV for increased spatial resolution at long standoff ranges
  – Integration with other sensors for a system of systems approach