Center for Awareness and Localization of Explosives-Related Threats (ALERT)

A DHS Center of Excellence for Explosive Detection, Mitigation, and Response

Year Three Progress
– and –
Preliminary Year Four Workplan

March 2, 2011

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Center of Excellence in Explosives Detection, Mitigation, & Response: Awareness and Localization of Explosives-Related Threats (ALERT)

Michael B. Silevitch (NU) & Jimmie C. Oxley (URI)

To protect the nation from the physical and economic harm caused by the threat of explosive attack, we have pursued research in four interrelated thrusts. These are: ***Explosives Characterization*** to understand the explosive threat and prevent it; ***Explosives Detection Sensors*** and ***Explosive Detection Sensor Systems*** to detect the explosive threat; and ***Blast Mitigation*** to minimize the effects of a successful bombing by lessening damage and loss of lives. In addition, we strive to educate ourselves, our students, and practicing and future homeland security professionals. This education includes not only the transformational research and advanced technologies, but also the principles and culture of safety in working with hazardous materials.

Inherent in all of the ALERT programs is a focus on relevance to the DHS mission. Moreover, we have strived to indicate those innovative new technologies which are poised for transition to the field in the relatively near term (1-3 years). The integration of long-range fundamental science with an awareness of the more immediate real-world needs will ensure that ALERT remains a valuable asset for DHS and its stakeholders.

This document describes the Year 4 ALERT workplan for both research and education. First, a brief overview summarizing the major programmatic areas is given (this document). This is followed by the body of the workplan which provides a detailed description (in PowerPoint format) of each research and education thrust area. These include a summary of the accomplishments and future plans for all of the projects and initiatives being supported by the ALERT Center.

F1. Explosives Characterization

Fundamental questions addressed are: What makes a chemical capable of being an explosive? Can we prevent terrorist acquisition and/or use of precursor chemicals to make explosives? Are there properties of terrorist-used explosives that pertain to safe handling, potential signatures, and creation of simulants? Can we quantify the potential performance of terrorist-used explosives in terms of potential damage that can be caused?

Characterization activities include the following:

- Characterization of signatures & properties of a variety of homemade explosives (HMEs)
- Design protocols for safe disposal of HMEs
- Design of protocols and methods to prevent common chemicals from being used to make illicit explosives while allowing their intended use
- Creation of tests and metrics to identify non-ideal explosives
- Determination of performance and safety margins of explosives on micro-scale
- Determination of physical properties of explosives to design explosive detection instrumentation and explosive simulants. Some properties may be found in the database http://expdb/chm.uri.edu

- Characterization of the surface-explosive particle interaction in order to best locate and collect explosive residue

F2. Explosives Detection Sensors

Explosives detection concentrates on understanding the fundamental problems of trace detection of explosives, and improvement of explosive sample collection. The goal is to develop sensing systems capable of detecting ultra-low amounts of explosives which are selective (i.e. able to reduce the number of false positives and false negatives), and adaptable (i.e. can accommodate new types of explosives as they become threats). Approaches to these problems include:

- Energetic material detection using hyperspectral imaging and remote IR spectroscopy
- Optimization of millimeter-wave standoff- and portal-based sensing of anomalies under clothing to detect body-worn explosives
- Investigation of the potential of generating and detecting broadband THz waves with gases as wave emitters for standoff THz spectroscopic detection
- Development of intelligent *in situ* mass spectrometry and autonomous feature classification for determining explosive type, location, magnitude, and potential multiple threats
- Development of methods to detect, identify, and interrogate electronics commonly used in explosive devices based on their unintended electromagnetic emissions
- Investigation of remote conventional and Coherent Anti-Stokes Raman Spectroscopy for detection of trace quantities of energetic materials close in and at standoff distances
- Enhancement of polymer detection techniques
- Development of tiny, inexpensive sensors for persistence surveillance
- Investigation of the fundamental physical processes underlying ion and differential mobility spectrometry
- Synthesis and evaluation of trace collection systems which are analyte specific and thus enhance particle collection and vapor plume stimulation
- Creation of sensors for massive distribution and investigation of new fiber-optics able to deliver light for stand-off detection and return information to a central site
- Fundamental materials research for next generation sensors, such as development of hybrid quantum dot/polymer array structures.
- Establishment of an academic-oriented testbed for development and evaluation of multi-modal sensors and algorithms for portal-based whole body Advanced Imaging Technology (AIT) to enable experimentation, model-based reconstruction, and automatic threat detection of body-worn explosives

F3. Explosives Detection Sensor Systems

Explosives detection systems are focused on developing the fundamental processing algorithms to extract maximal information from available sensed signals for the purposes of increased probability of correct detection and classification of explosives while reducing the number of false alarms. The objective is to develop the basic science for design and implementation of novel multi-sensor detection systems. The class of systems of interest includes both portal and standoff detection systems. Approaches to these problems include:

- Novel tomographic x-ray image formation and feature extraction algorithms integrating multiple energy excitation and restricted imaging geometries
- Simultaneous segmentation and image formation algorithms for dual-energy x-ray computed tomography
- Multispectral diffraction tomography techniques with spectral signature information for increased sensitivity and specificity motivated by THz tomography
- Sensor management and scheduling algorithms for high throughput screening and active learning using fielded systems
- Compressive sensing techniques for artifact reduction in low-dose tomography to improve throughput in screening
- Information fusion in multimodal sensor networks for standoff classification
- Distributed vision systems for area monitoring, with robust anomaly detection and multi-camera fusion
- Dynamics-based anomaly detection and object tracking using video sensing
- Video analytics for anomaly detection, surveillance and activity recognition

F4. Blast Mitigation

The research effort in mitigation will focus on basic science issues that help develop novel materials and structures to mitigate blast effects. Necessary is an underlying understanding of structural response to internal or external blast, fragmentation, or a combination of impacts such as simultaneous blast and fragmentation or blast and fire. Such understanding will be the foundation of modeling and will result in new designs and protocols for infrastructure protection. Furthermore, we are investigating ways to improve resilience of structures. Projects presently supported do not encompass the entire scope of mitigation but have been selected to provide a focus in the initial stages of research. Mitigation activities include the following:

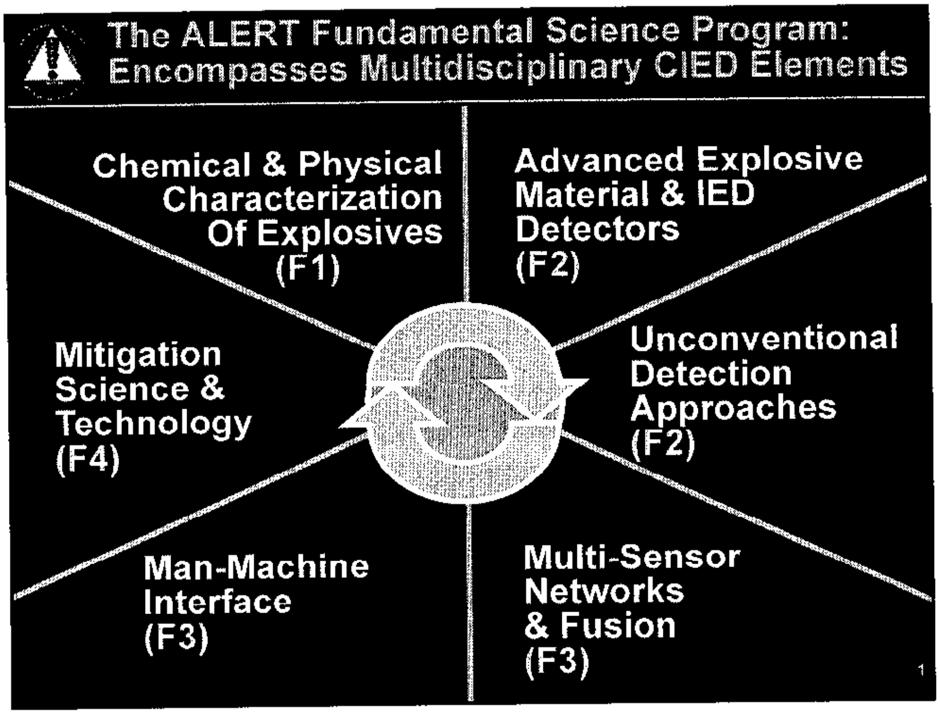
- Designing, modeling and understanding the response of novel heterogeneous materials, including particulate, sandwich composites, carbon nanotubes and layered, functionally graded materials subjected to extremely high strain rate blast loading conditions
- Understanding damage initiation and crack propagation in various types of glass subjected to high strain rate blast loading conditions
- Studying deformation and progressive failure events of structural steels subjected to coupled high strain rates and high temperatures associated with blast/fire loadings
- Studying the response of structures that couple rigid body dynamics, material deformation and load transfer
- Modeling structural response to blast waves from internal explosions, particularly non-ideal explosions
- Investigating ways to ameliorate the blast using water jet

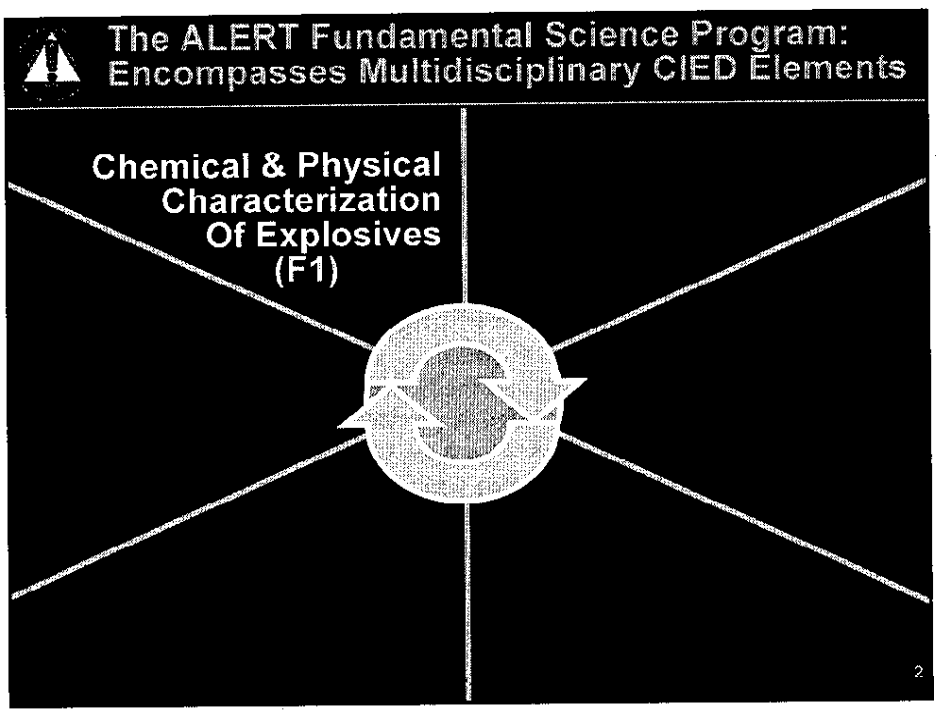
- Attempting to create more resilient structures using self-healing materials and integration of a microvascular network
- Creating coatings for structural protection during blast
- Advanced modeling and numerical simulation of response of full-scale structural systems following member loss due to explosions

Education

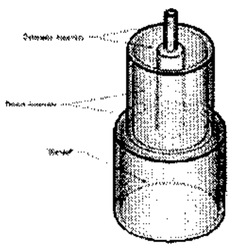
ALERT reaches out to citizens of all ages to enhance awareness of pertinent science and engineering. In particular, we recognize the need to prepare the future generation of researchers and others supporting the homeland security enterprise. To that end we will continue to support the following communities, including inculcating an overarching culture of safety:

- University students both graduate and undergraduates—new classes, research experiences, fellowships, coop opportunities
- Young people in K-12 and their teachers via special programs for the students and summer research for their teachers
- Minority-serving institutions & community colleges via research and educational support
- Military and research professionals via short courses and workshops
- First-responders and law enforcement officials via short courses and workshops

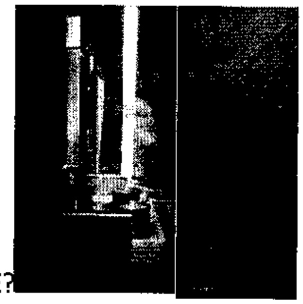

The ALERT Fundamental Science Program:
Encompasses Multidisciplinary CIED Elements
Chemical & Physical Characterization Of Explosives (F1)
Advanced Explosive Material & IED Detectors (F2)
Unconventional Detection Approaches (F2)
Multi-Sensor Networks & Fusion (F3)
Man-Machine Interface (F3)
Mitigation Science & Technology (F4)
1


The ALERT Fundamental Science Program:
Encompasses Multidisciplinary CIED Elements
Chemical & Physical Characterization Of Explosives (F1)
2

Thrust F1: Characterization

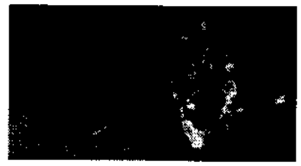


3. How can we prevent HME synthesis?



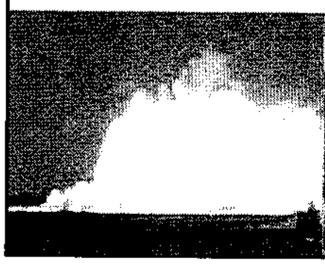
4. How can we safely destroy it?

5. What are its signatures?

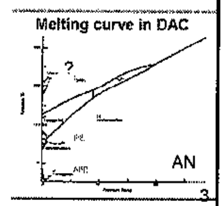


1. Is it an explosive?

2. How powerful is an HME?



6. What are its physical properties?



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F1-C: Theoretical study of explosive disposal and behavior

Ronnie Kosloff and Yehuda Zeiri (PIs), Hebrew University, Israel

- **Purpose/ Relevance**: The research effort was devoted to: a. the understanding of the role of metal ions in the decomposition of peroxide base explosives; b. detailed study of the detonation process of liquid explosives, in particular of nitro methane.
- **Innovation**: Detailed electronic structure calculations were used to understand TATP destruction in relation to the experimental study by J.C. Oxley. In the second part reactive molecular dynamics (MD) approach was used to understand the details of nitro methane decomposition process during detonation.
- **This Year outcome**: The electronic structure calculations allowed to understand and explain the behavior of selected metal ions in relation to the experimental findings. The MD simulations resulted in a detailed mechanism and the chemical reactions that take place during nitro methane detonation.
- **Long-range impact**: The first part of the research may have an important impact on suggesting a route for destruction of peroxide based explosives. The MD simulations allow a detailed understanding of the detonation mechanism and may suggest routes to inhibit explosions of liquid explosives.
- **Next Year:** The MD simulations will be extended to the study of mixture of nitro methane with different fuels as well as with possible inhibitors of detonation. In addition we will study the sensitization by cavities introduced into liquid explosives

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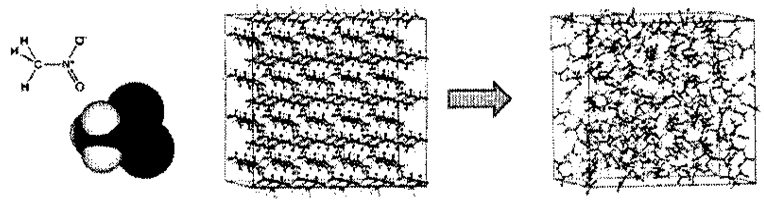
Theoretical study of explosive disposal and behavior
Ronnie Kosloff & Yehuda Zeiri, Hebrew University, Israel

- **Education Students Present & Graduate:**
  - Morag Am Shalem: Study of weak detonation.
  - David Feldmann: simulation of liquid explosives.
  - Ido Shefer: Terahertz spectroscopy.
- **Papers/Patents/Presentations:**
  - Two papers in preparation
- **Transition to Industry or Collaboration with Industry:**
  - Collaboration with RAFAEL Advanced Defense Systems LTD
  - Coordinator Dr. Noami Rom.

Transition from solid to liquid explosive of nitro-methane: study of decomposition mechanism



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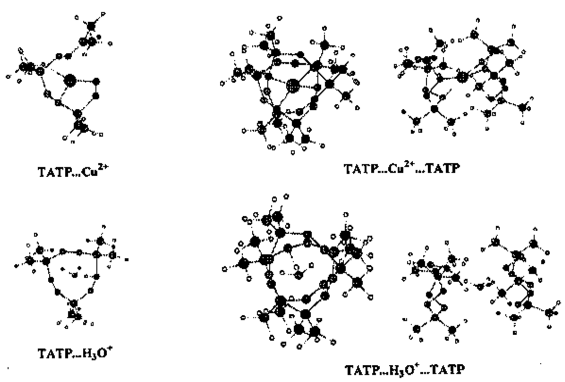
Theoretical study of explosive disposal and behavior
Ronnie Kosloff & Yehuda Zeiri, , Hebrew University, Israel

Metal ions in the decomposition of peroxide base explosives



Calculated structure and decomposition mechanism of TATP and different metal ions. Notice the possibility of stable sandwich structures.

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F1-D: Development of Simulants of Hydrogen Peroxide Based Explosives for use by Canine and IMS Detectors José Almirall, FIU

FIU International Forensic Research Institute

Purpose/relevance: Improve the knowledge base for the composition of headspace volatiles from peroxide explosives so that these analytes can be targeted for detection by a number of methods (PSPME-IMS and canines).

Approach:

- Headspace profile by GC-MS, followed by IMS evaluation of the headspace extractions by PSPME.

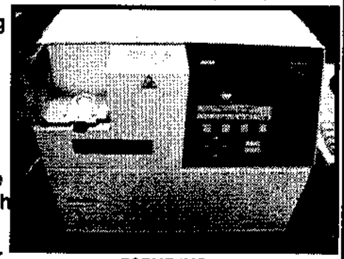
Overview of completed/iterative outcomes:

- Characterize the headspace composition of the volatiles associated with a number of different peroxides.
- Develop inexpensive permeation devices that can be used to deliver simulants to be used for canine training aids and instrumentation testing.
- Determine the limits of detection and optimal parameters for the use of PSPME-IMS for the detection of peroxide explosives.

Overview of future work:

- Improve the performance of the existing PSPME device and suggest guidelines for both training of canines with new simulant kits and the use of PSPME-IMS in field detection of peroxide-based explosives at checkpoints.

PSPME with vacuum pump and scanning electron micrograph of PSPME coating cross-section (top) and on surface (bottom).



PSPME-IMS

Development of Simulants of Hydrogen Peroxide Based Explosives for use by Canine and IMS Detectors José Almirall, FIU

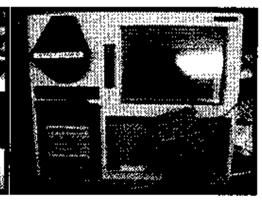
FIU International Forensic Research Institute

Purpose: Existing IMS devices do not currently target the volatiles emitted from peroxide-based explosives.

We propose to:

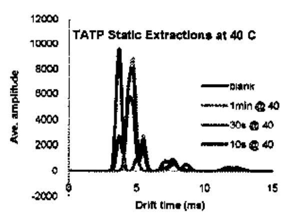
1. Characterize the odor signatures for a number of peroxide explosives.
2. Target their pre-concentration and detection using a simple and inexpensive planar solid phase microextraction (PSPME) device that can be thermally desorbed into existing IMS instrumentation infrastructure.
3. Improve the training aids for canine teams to detect peroxide explosives.

ACS (left) and SPME (right) sampling of headspace in peroxide-based explosives (URI)



Commercial IMS with FIU developed SPME interface (URI)

Canine used in law enforcement for detection of illicit compounds.



Ion mobility spectra of PSPME static extractions of TATP in ~ 30 sec.

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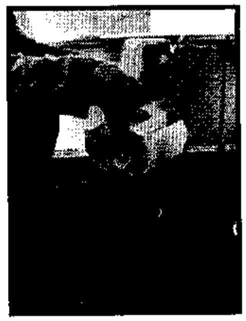
Development of Simulants of Hydrogen Peroxide Based Explosives for use by Canine and IMS Detectors José Almirall, FIU

FIU International Forensic Research Institute

Purpose: Use several methods for the improvement of analysis and identification of the composition of headspace volatiles from peroxide-based explosives.

Transition of Technology to the Field:

- Current Work Undertaken: The NIJ has funded the development and optimization of a PSPME device for rapid extraction and concentration of volatiles from MDMA tablets and smokeless powders. The proposed project aims to apply PSPME to the detection of peroxide-based explosives and applied to field analysis with a focus on meeting the needs of DHS. The FIU developed PSPME technology has been licensed to Field Forensics Inc., a Florida company that is currently marketing and selling a commercial version of the PSPME technology.



Dynamic PSPME sampling performed in a cargo container.

- Patent Development: Improvement to SPME-IMS for Detection of Explosives and Drugs using Planar Geometry Fabricated SPME devices (patent pending to FIU).

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Development of Simulants of Hydrogen Peroxide Based Explosives for use by Canine and IMS Detectors José Almirall, FIU

FIU International Forensic Research Institute

EDUCATION FORMER STUDENTS: 1. Dr. Hanh Lai, currently Research Scientist at Morpho Detection in Boston. 2. Dr. Monica Joshi, currently Assistant Professor at Westchester University in Pennsylvania and 3. Dr. Patricia Diaz-Guerra, currently a Research Associate at Field Forensics, Inc. in Clearwater, FL.

CURRENT STUDENTS: Ms. Wen Fan (Ph. D. student) and Ms. Mimy Young (Ph. D. student)

PUBLICATIONS

- FIU and URI research group collaborators, "Fast Detection of Triacetone Triperoxide (TATP) from Headspace using Planar Solid Phase Microextraction (PSPME) Coupled to an Ion Mobility Spectrometer Detector," in preparation.
- Guerra-Diaz, P.; Gura, S.; Almirall, J. R., 2010, "Dynamic Planar Solid Phase Microextraction–Ion Mobility Spectrometry for Rapid Field Air Sampling and Analysis of Illicit Drugs and Explosives." *Analytical Chemistry*, 82 (7), 2826-2835.

Dr. Diaz-Guerra (top) sampling for explosives and Ms. Fan and Ms. Young (bottom) performing static extractions inside L3 shipping containers.

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Development of Simulants of Hydrogen Peroxide Based Explosives for use by Canine and IMS Detectors José Almirall, FIU

FIU International Forensic Research Institute

TECHNOLOGY TRANSFER

Technology Transfer:

- **The PSPME device for detection of volatile compounds of illicit drugs and explosives has been commercialized by a Florida company (Field Forensics Inc.) through a licensing agreement.**

Technology Transfer: Technical Presentations and Poster Sessions

- **Almirall, J. R., "Rapid detection of drugs and explosives using planar solid phase microextraction coupled to ion mobility spectrometry", PACIFICHEM 2010, December 2010, Honolulu, HI, USA.**
- **Almirall, J. R., "Detection of Drugs and Explosives in Large Volume Headspace Using Planar Microextraction and Ion Mobility Spectrometry", FACSS Meeting, October 2010, Raleigh, NC, USA.**

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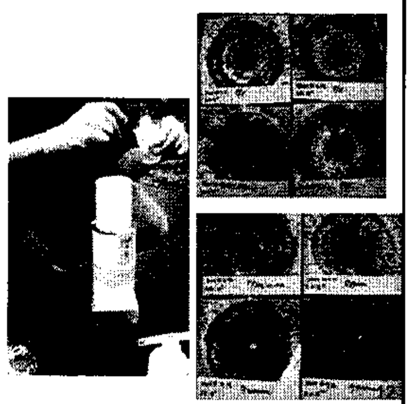
F1-E: Small-scale Tests for Identifying Explosivity

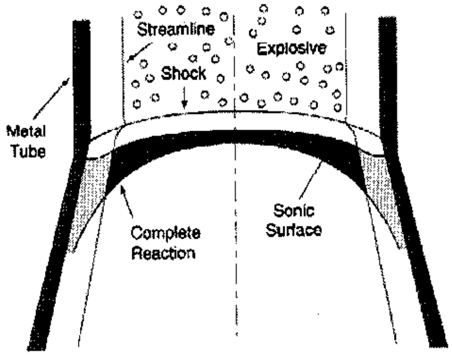
Jimmie Oxley; James Smith; Patrick Bowden; Ryan Rettinger U of Rhode Island

THE UNIVERSITY OF RHODE ISLAND

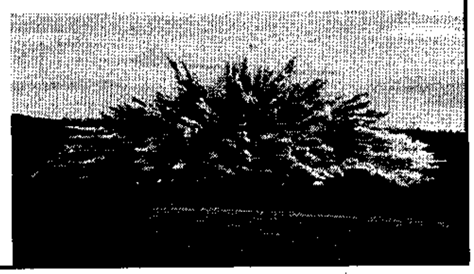
- **Purpose/ Relevance:** Explosives have a critical diameter, D_{cr}, below which they cannot propagate detonation. D_{cr} is determined by the amount and rate of energy released. Most fuel/oxidizer mixtures & many energetic chemicals do not appear explosive at normal scales of testing, e.g. DoT 1.25" x 14" or NRC 12" x 60"
  It is impractical, expensive, & dangerous to test all suspect materials at the scale they are used. We seek to develop a cheap, small-scale test which could provide early warning of potential detonability.
- **Innovation:** We use "active" confinement to bring out potential explosivity in energetic chemicals. This is done using an annular booster in an attempt to drive a concave shock wave into the material.
- **This Year's Outcome:** Three new test series (~120 devices) refined device, reveal results are inverse.
- **Long-range Impact:** If explosivity is revealed at small-scale, industrial safety is positively impacted. Engineering can anticipate potential problems. Potential threats can be recognized, & threat lists can be parsed to include only the most likely.



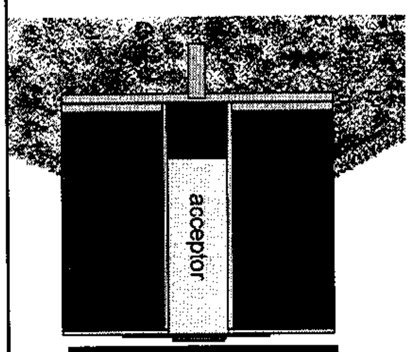
Goals: Identify explosive precursors at lab-scale to avoid the expense and danger of ton-scale charges. Develop a new small-scale test



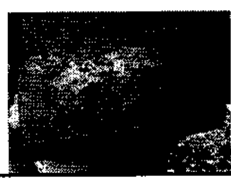
Poor explosives or "non- explosives" require large charges (for self-confinement) or heavy-wall confinement because shock isn't supported on the edges. Another possibility is "explosive" confinement



Concept & 1st Version



Annular booster H_2O_2 (HP) + EtOH

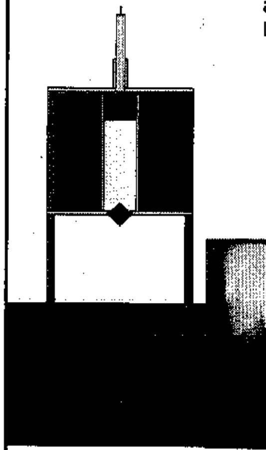


The Nickel Test –19 shots

Depth of dent was too shallow to differentiate. Observed: outer edge of nickel pushed down, while center unaffected.

Test Series 2: Flyer Ball

Major Changes: Flyer ball replaced nickel
Varied: stand-off & boosters-Detasheet & annular (NM vs. HP/EtOH)
Leaks were major problem



Test Series 3: Flyer Ball

NM booster more powerful & eliminated boiling of HP. Increased number of shots 22 → 36. Leak problem fixed. Varied height & width

Size inches	Inner Mix	Outer Mix	Dent Depth (mm)	Standoff (inch)
4x8	7/3 NM/NA	P = 7/3 NM/NA	0	10
4x4	8/2 NM/NA	O= 8/2 NM/NA	-3	10
4x4	P= 7/3 NM/NA	P	-3	10
4x8	A= 70HP/13EtOH	P	-5	10
4x4	A= 70HP/13EtOH	P	-5	10

50% HP detonability ?? → dents 9-18 mm

4X4	H2O	O	-19	10
4x4	Brine	50/50 NM/NA	-19	10
4x4	Brine	P	-24	10
4x8	Brine	P	-25	10

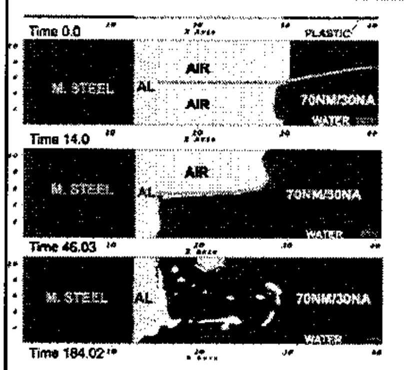
Inverted Results: Detonation gave shallowest dents & non-detonations deepest dents
Problem with multiple dents

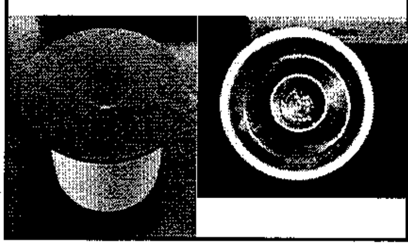
NM = nitomethane

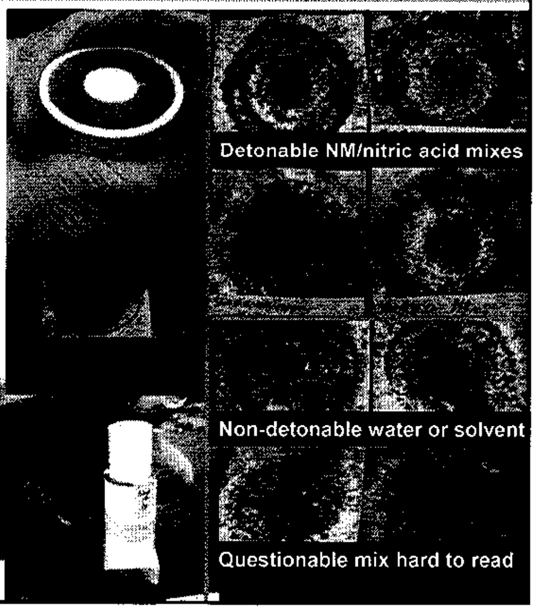
ALE3D modeling (DS Stewart) showed non-detonable center fill, e.g. water, forms jet which pushes aside ball. Smaller flyer-less device & Al top witness plate used in series 4.

Test Series 4: Flyer-less Design

Results inverse, as expected.







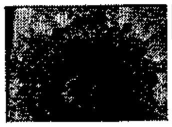
detonable

Liquid Inner Materials 8" standoff	Booster 3" x 4" OD	Dent Depth (mm)	Dent Volume (mL)
70/30 NM/NA - No Det. Int.	70/30 NM/NA	-2	0
70/30 NM/NA	50/50 NM/NA	-4	0
80/20 NM/NA	70/30 NM/NA	-4	0
70/30 NM/NA	80/20 NM/NA	-5	0
70/30 NM/NA	98/2 NM/DETA	-5	0
70/30 NM/NA	70/30 NM/NA	-5	0
70% HP/ 13% EtOH	98/2 NM/DETA	-11	9
90/10 NM/NA	70/30 NM/NA	-11	8
95/5 NM/NA	70/30 NM/NA	-11	4
99.5/0.5 NM/DETA	70/30 NM/NA	-12	13
NM	98/2 NM/DETA	-12	10
50/50 NM/NA	70/30 NM/NA	-13	8
NM	70/30 NM/NA	-13	10
80/20 NM/EtOH	70/30 NM/NA	-13	6
80/20 NM/Acetone	70/30 NM/NA	-16	7
90/10 NM/Acetone	70/30 NM/NA	-16	11
30/70 NM/NA	70/30 NM/NA	-16	10
70/30 NM/Acetone	70/30 NM/NA	-17	5
70/13 HP/EtOH	70/30 NM/NA	-19	7
50/10 HP/EtOH	70/30 NM/NA	-26	17
50/30 HP/EtOH	70/30 NM/NA	-28	12
50/5 HP/EtOH - No Det. Int	70/30 NM/NA	-37	25
50/5 HP/EtOH	70/30 NM/NA	-38	23
Acetone	70/30 NM/NA	-24	12
Turpentine	70/30 NM/NA	-29	22
70% HP	70/30 NM/NA	-33	24
70% wt NA	70/30 NM/NA	-43	23
Brine	70/30 NM/NA	-51	26

non-detonable

Results (cont) **& Way Forward**

Questionable materials gave odd "craters." Laser analysis & crater literature consulted. Solids were also shot & gave same general results. Discussion with LANL suggested need for higher input shock. New device design will have a tubular flyer to initiate inner material. Initial Gurney calculations suggest need to increase annular booster size back to 6."

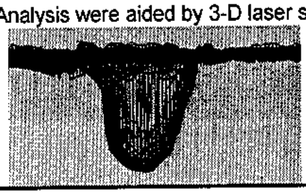


90/10 NM/NA

Solid Inner Material no detonator interruptor	Booster	Dent Depth (mm)	Volume (mL)
MagnaFrac	70/30 NM/NA	-14	4
DNT	70/30 NM/NA	-16	5
87/13 AN/icing sugar(IS)	70/30 NM/NA	-17	6
70/30 KN/IS	70/30 NM/NA	-18	8
AN	70/30 NM/NA	-20	11
PMMA	70/30 NM/NA	-33	12

We can distinguish between detonable & non-detonable materials, but more work to be done.

Analysis were aided by 3-D laser scanned images of the plates (Shot #'s: 4, 5, 41)

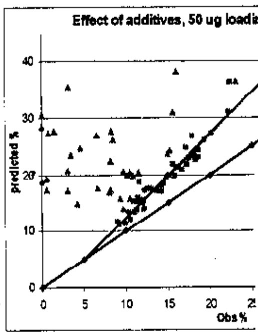


Denaturing Explosive Precursors

James Smith; Jimmie Oxley Joe Brady University of Rhode Island

THE UNIVERSITY OF RHODE ISLAND

- **Purpose/ Relevance**: A number of common chemicals can be used to make explosives (HME). This project examines counter-approaches: administrative controls; denaturing; banning. Success is preventing or making more difficult the synthesis of the HMEs; present targets are hydrogen peroxide (HP) explosives; urea nitrate (UN); TATP; ammonium nitrate.
- **Innovation**: We have found that certain additives at 1.25 ppm interfere with the concentration of HP. Boiling removes water but also decomposes the HP.
- **This Year Outcome**: Additives to HP have been identified, screened for effect on storage stability; a patent application is in preparation. Additives to acetone to prevent synthesis of TATP and additives to urea to prevent UN synthesis are being investigated.
- **Long-range Impact**: Additives are chosen with regard to their intended market. HP additives are gras (generally regarded as safe). They will prevent use of household HP & hair supply house HP in bombmaking

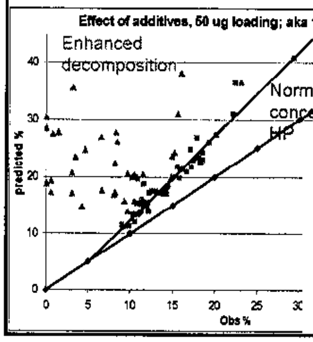


Afghani N. Zazi 9-19-09

Denaturing Explosive Precursors **Hydrogen Peroxide**

James Smith; Jimmie Oxley; Joe Brady University of Rhode Island THE UNIVERSITY OF RHODE ISLAND

- H_2O_2 >70% concentration can be explosive. Depending on choice of fuel, explosives can be camouflaged as common, innocuous liquids or pastes.
- Any concentration of H_2O_2 can be used to synthesize TATP or HMTD—an easy route to primary explosives. But terrorists/criminals recommend concentration by boiling off water.
- Our approach: additive to HP which results in decomposition rather than concentration.



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Denaturing Explosive Precursors Urea Nitrate

James Smith; Jimmie Oxley; Joe Brady;
Patrick Bowden; Lucus Steinkamp URI

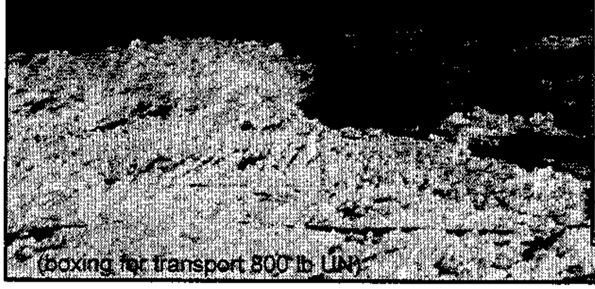
Urea Nitrate (UN) is a common HME

- 1993 World Trade Center bombing (Feb. 1993)
- Ahmed Ressam –the millennium bomber. (Dec. 14, 1999)

Urea production is huge (133 mmt); thus, instead of controlling urea, nitric acid is controlled, especially in Iraq. However, UN can be made from nitric acid made from KNO_3 & acid. Approach: an additive to KNO3 that makes for poor yield of gummy material.

$$Urea + KNO_3 + H_2SO_4 \rightarrow UreaNO_3 + KHSO_4$$

Preparation with additve 10wt% of urea	Rec. Yield (%)
HNO_3	60%
KN/HCl	23%
KN/H_2SO_4	21%
KN/H_2SO_4/TKPP	9%
KN/H_2SO_4/DAP	6%
KN/H_2SO_4/MKP	9%



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Denaturing.... **Preventing TATP Synthesis**

James Smith; Jimmie Oxley; Patrick Bowden; U Rhode Island

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Blocking TATP synthesis is difficult; it requires a fair amount 10wt% of additive. Bases work, reducing yield from 33-57% to less than 2%, but excess acid can overpowered base.

Adulterant	5% wt Adulterant HP:Ace Ratio 1:1		10% wt Adulterant HP:Ace Ratio 1:1	
	% Yield	mp range	% Yield	mp range
No Additive	33% -57%			
Water			39%	82-94
Diethyl Ether			39%	85-95
Ethyl Acetate			37%	78-94
Methanol			41%	78-94
Ethylene Glycol			38%	86-93
Ketones				
2-Pentanone			44%	73-82
3-Pentanone			38%	72-86
Cyclopentanone			41%	68-87
MEK			44%	68-80
2,3-Butanedione			42%	80-95
2,4-Pentanodione			41%	80-96
1,4-Cyclohexanedione			52%	75-95
Benzil			51%	69-82
Styrene			39%	
Isobutylene	51%	78-88		

One to one mole ratio of HP & acetone cooled to 3-15°C. After 15 min. conc sulfuric acid (10mole %) was added & allowed to react 24 hr. Percent yield is unrecrystallized; mp indicates degree purity.

Adulterant	5% wt Adulterant HP:Ace Ratio 1:1		10% wt Adulterant HP:Ace Ratio 1:1	
	% Yield	mp range	% Yield	mp range
Metal Salts	Sat'd Sol'n			
CuI	56%	77-90		
Cu(OAc)2*H2O	48%	79-89		
ZnSO4	45%	79-95		
CuSO4	44%	74-84		
SnCl2*2H2O	40%	74-89		
Cu(NO3)2*2.5H2O	39%	75-80		
CuBr2	18%	73-8 Color change in acetone		
$CuCl_2*2H_2O$	0%	--		
Salt Mixtures	Sat'd Sol'n		10% / 1%	
SnCl2*2H2O/ZnCl2			62%	83-96
ZnCl2/SnCl2*2H2O			57%	84-90
Cu(OAc)2*H2O/EDA	33%	81-96		
CuI/EDA	26%	86-95		
CuCl2*2H2O/EDA	15%	82-95		
ZnSO4/EDA	11%	90-94	Color change in acetone	
FeCl3*4H2O/EDA	2%	90-95		
Amines				
TBAI (tetrabutylammonium iodide) (old)			21%	91-94
NH_4I (old)	22%	90-94	2%	85-92
DETA (diethylene triamine) (fresh)			2%	94-96
DAP (diaminopropane) (old)			1%	91-97
EDA (ethylenediamine)(fresh)			0.07%	--

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Safe Destruction of TATP:

Jimmie Oxley; James Smith; Joe Brady; Austin Brown; Guang Zhang ; U Rhode Island

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- **Purpose/ Relevance**: To give EOD choices in addition to blow in place, we are development a gentle method for destruction of TATP.

"Federal prosecutors say the Escondido rental home contained the largest amount of certain homemade explosives ever found in a single U.S. location. Nearly every room was packed with piles of explosive material and items related to making homemade bombs, prosecutors said. In the backyard, bomb technicians found six mason jars with highly unstable Hexamethylene triperoxide diamine, or **HMDT**, which can explode if stepped on. A coffee table was found cluttered with documents and strewn with detonators, prosecutors said. The chemicals were found after a gardener accidentally set off an explosion at the home by stepping on what authorities believe was a byproduct of HMTD." KTLA News 11:53 a.m. PST, Dec 11, 2010

"Investigators with the FBI... also came across other explosive compounds known by the acronyms of ETN and PETN...." SanDiego News 10 Nov. 22, 2010

"ESCONDIDO, Calif. (AP) Authorities say the controlled burn of a home packed with explosives cost the San Diego County Sheriff's Department more than $541,000." Feb 2, 2011 CBS 8 (KFMB)

EOD in Escondido, CA Dec 9, 2010

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Safe Destruction of TATP: Jimmie Oxley; James Smith; Joe Brady

Austin Brown; Guang Zhang ; U Rhode Island

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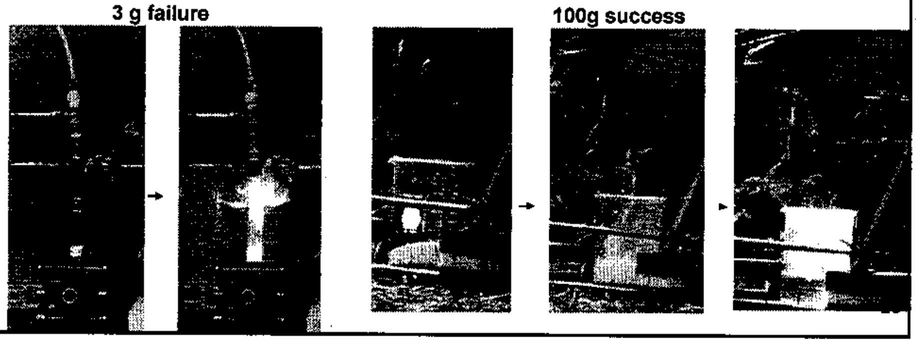
- **Innovation**: Acid destroys TATP but strong acid reacts so quickly with TATP that it can detonate. A combination of weaker acid strength and slightly solvated TATP reduces rate of heat release & makes gentle destruct possible. All variable studied.
- **This Year outcome**: Variables such as acid concentration, type & amount of solvent made the difference between success and failure. Gently destroyed 100 g TATP by moistening TATP with ethanol-water & adding dropwise concentrated HCl–success!
- **Long-range impact**: Situations like Cook County, IL; Texas City; Escondido, CA may have another outcome. **Future**: confirm it works with other peroxide explosives.

3 g failure **100g success**



Explosive Signatures & Properties Jimmie Oxley;

James Smith; Joe Brady; Lucus Steinkamp; Jon Canino; Maria Donnelly; Sravanthi Vadlamannati URI

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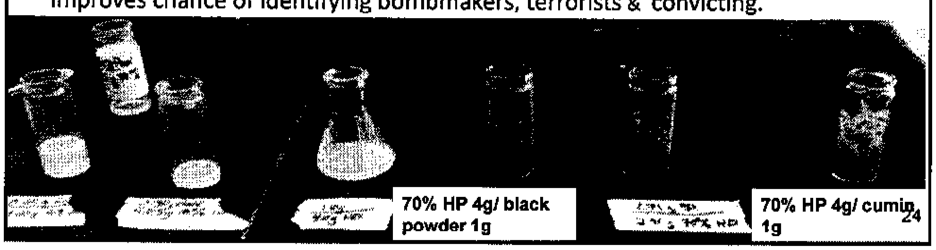
- **Purpose/ Relevance**: Identify the signatures of relevant HME—vapor pressure; density; identify the residue (amount & location); identify the properties which should be emulated to make effective simulants.
- **Innovation**: Research in 4 areas: using silica to adjust density of liquid explosives; using microencapsulation to provide a safe matrix to odor & to reduce detonability; using dye instead of explosives to trace where signature residue might be found; using hair external & internal to find evidence of explosive handling.
- **This Year outcome**: new start
- **Long-range impact**: Microencapsulation-improved safety for LEO & other explosive handlers; Simulants-improved safety for detection instrumental vendors, testers, users; Dye studies-improved chance of finding IED's and their makers; Hair-Improves chance of identifying bombmakers, terrorists & convicting.



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Characterizing New HME: e.g. Erythritol Tetranitrate

James Smith; Jimmie Oxley; Joe Brady; Austin Brown U Rhode Island

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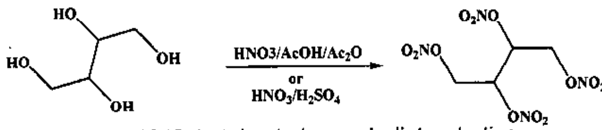
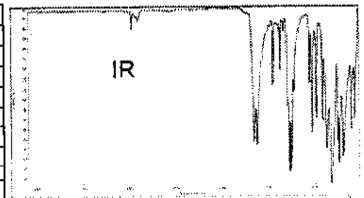
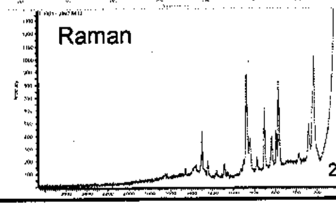


Discovered in 1849, but due to low carb diets, starting alcohol recently became widely available (cf amazon.com at 5.38 $/lb); thus, found in Escondido Nov 2010.

name	EGDN	SMX	ETN	PETN	RDX
chemical formula	$C_2H_4N_2O_6$	$C_6H_8N_6O_{18}$	$C_4H_6N_4O_{12}$	$C_5H_8N_4O_{12}$	$C_3H_6N_6O_6$
melting point C	-22	85-86	61	143	204
density g/mL	1.492	1.917	1.55	1.778	1.816
heat of formation kcal/mol	-58.08	-88.67	-113.48	-128.7	-16.73
detonation velocity km/s	7.517	9.320	7.415	8.555	8.858
CJ pressure GPa	20.37	40.32	20.08	31.12	33.42
Small Scale Explosivity %left	liquid	25.1	28.1	26.3	11.8
Standard Dev		1.14	1.37	0.43	1.19
Heat release (J/g)		3028	2995	4278	3965
DSC Exo Temp at 20 °C/min		184	200	200	246





Standard GC analytical conditions destroy ETN completely & cannot be used to detect ETN. Successfully analyzed by GC/MS with DB-5MS column, cut to 10m. Low inlet (150°C vs 250°C), transfer line allow (200°C vs 310°C) for analysis.

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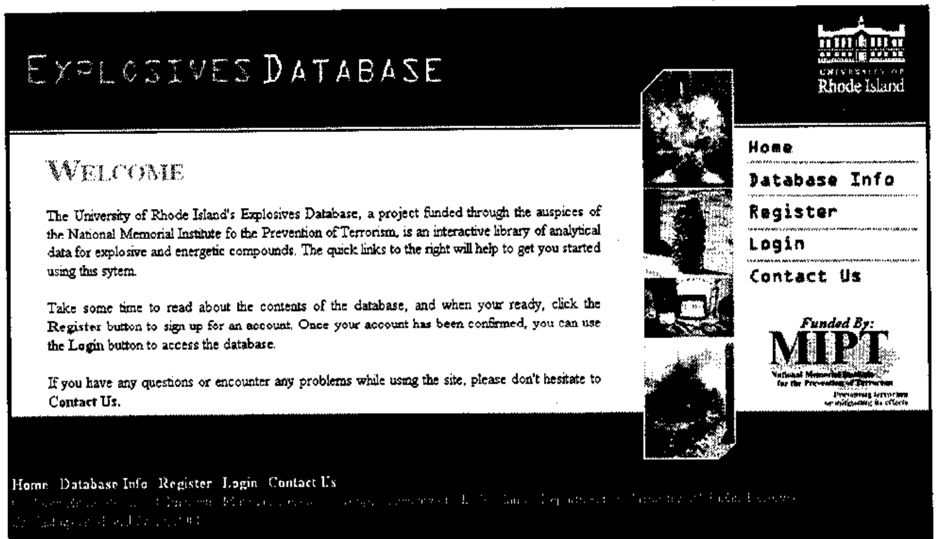

Physical properties of ~75 explosives & precursors

2007-2010 ~250 applications
Jan- Feb 17, 2011 92 new applications!

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URI Characterization Group (Jimmie Oxley; James Smith)

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Undergraduate Students: B.S. '10 Joe Stranco (US AirForce); in progress: Kayla Belanger; Alisson Boyko; Tracy Chen; Nicole Cook; Brandon Genest; Kaolin Hart; Alica Landry; Rebecca Little; Sarah McKellick; William Tavares; Joanna Ying; Alicia Zigmont; **PhD Students:** Joe Brady '11 Brookhaven National Lab; Pat Bowden '11; Lucas Steinkamp; Sravanthiat Vadlamannati; Maria Donnelly; Jon Canino; Ryan Rettinger; Guang Zhang; Austin Brown; Matt Porter; Devon Swanson; MS Student: Morgan Turano; **Visiting Student:** U Munich Matthias Trunk **Professionals: 344, 17 classes, 5 new classes**

Industry & National Lab Collaborations: AS&E; Ahura(now ThermoFisher); DetectaChem; Eastman Chemical; Exxon; Haifa Chemicals; Implant Science; Lindon Group; ICx Nomadics (now FLIR); Raytheon IDS; SQM Corp; Triton Systems; Los Alamos National Laboratory

Patents: Hair Analysis for Explosive Residue; 10-0804; #61/370,719; 8/6/10; Security Safe Hydrogen Peroxide (in prep)

Papers: Oxley, J.; Smith, J.; Kirschenbaum, L.; Marimiganti,S.; Efremenko, I.; Zach, R; Zeiri, Y Accumulation of Explosive in Hair 3: Binding Site Study accept J Forensic Sci

Gregory, O.; Oxley, J.C.; Smith, J.; Platek, M.; Ghonem, H.; Bernier, E.; Downey, M.; Cumminskey, C. "Microstructural Characterization of Pipe Bomb Fragments" Materials Characterization J **2010**, 61(3), 347-354.

IED's World book Encyclopedia article submitted

Oxley, J.C., Smith, J.L., Naik, S. "Determination of Urea Nitrate and Guanidine Nitrate Vapor Pressures by Isothermal Thermogravimetry," *Propellants, Explosives, Pyrotechnics* **2009**, 27,209-216.

Lancaster, S.L.; Marshall, M., Oxley, J.C. *Explosion Debris: Laboratory Analysis* of in Wiley Encyclopedia of Forensic Science, Jamieson, A.; Moenssens, A. (eds). Wiley, Chichester, UK **2009** p1028-1060.

Oxley, J.C.; Smith, J.L.; Junqi, Y.; Moran, J. "Hypergolic Reactions of TNT," *Propel Explos. Pyro.* **2009**, 34(5), 421-26

Oxley, J.C.; Smith, J.L.; Luo, W; Brady, J. "Determining the Vapor Pressure of Diacetone Diperoxide (DADP) and Hexamethylene Triperoxide Diamine (HMTD)," *Propellants Explos. Pyrotech.*, **2009**, 34(6), 539-543.

Oxley, J.C.; Smith, J.L.; Higgins, C.; Bowden, P.; Moran, J.; Brady, J.; Aziz, C.E.; Cox, E. "Efficiency of Perchlorate Consumption in Road Flares, Propellants and Explosives," *J. Environ. Man*, **2009** 90(11), 3629-34.

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URI Characterization Group: Publications (cont) & Presentations

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Publications (cont): Aspects of Explosive Detection, ed. M. Marshall & J C.Oxley; Elsevier **2009**.

Oxley, J.C., Smith, J.L.; Huang, J.; Luo, W. "Destruction of Peroxide Explosives," *J. Forensic Sci.*, **2009** 54(5), 1029-33. Oxley, J.C., Smith, J., Bernier, E., Moran, J.S., Luongo, J. "Hair as Forensic Evidence of Explosives Handling," *Propellants, Explosives, Pyrotechnics*, **2009** 34(4), 307-314.

Oxley, J,Smith, J, Naik, S, Moran, J"Decompositions of Urea and Guanidine Nitrates," *J Energ Mat*, **2009** 27(1), 17-39

Oxley, J., Smith, J., Moran, J. "Decomposition of Azo & Hydrazo linked Bis Triazines, *J Energ Mat*, **2009**, 27(2) 63-93.

Presentations: Wheaton College Chemistry Seminar April 6, 2011

Clinical Lab Science Convention; Providence, May 4, 2011

RI Campus Preparedness Seminar Mar. 10, 2011

MIT Lincoln Lab, Feb. 24, 2011

Warwick Rotary Club Warwick RI Jan 6, 2011

CSHEMA Reactive Chemicals Webinar Jan 19, 2011

URI Explosive Research for Safety and Security; Grand Challenge Course Dec. 9, 2010

IEEE Tutorial on the Explosive Threat; Waltham, MA Nov. 9, 2010

Soc Experimental Mechanics IMPLAST 2010 Blast Mitigation Wkp; PVD, RI Oct14, 2010

What & Where to Look ; Oakland University, Chemistry, Dept. Detroit, Sept 29 2010

Overview of DHS Center ; Texas Tech, Chemistry; Lubbock, TX; Oct 27 2010

tutorial for UnderSecretary Tara O'Toole, Washington, DC June 11, 2010

tutorial TSA Explosive Specialists; Charlotte, NC, Jun 3, Jul 15, Aug 12, Sep 16, 2010

ALERT Safety Symposium all day on web from URI April 30, 2010

Trace Detection Conference March 2010

"Pre- & Post-Blast: What to Look For, What to Look With," Am. Assoc of Forensics Scientists, Seattle, Feb 23, 2010

RI Emergency Management Advisory Council; URI Feb 9, 2010

DHS Center of Excellence: an Overview; URI Foundation Board, Jan 30, 2010

"Security: What More Can We Do?"Delta Airline; URI Jan 29, 2010

"DHS Center of Excellence" Homeland Security Sci & Tech Advisory Com, Wash DC, Jan 28, 2010

Studying Energetic Materials for Safety & Security; Miami, Florida Int U, Jan14'10

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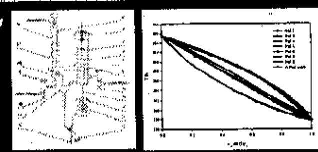
F1-A1: Vapor liquid equilibria of energetic materials (B. Weeks, TTU)

Objective: Initial project was to focus on the ternary phase diagram of peroxide mixtures. This project has been transitioning to solid explosives to determine how explosives collect on surfaces.



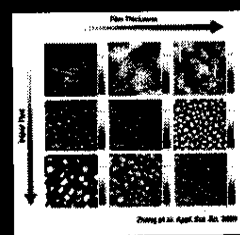
Initial experiments on vapor equilibria yielded publishable data (J. Chem. Eng. Data) on model systems and was transitioned to solid vapor equilibria.

Approach:

- Deposition of energetic materials is performed with a home-made deposition apparatus which can control the flux, vapor pressure and thickness.
- Various substrates are coated to determine the interaction between the explosive and a surface.

Significance and relevance:

- To provide information on how explosives collect on surfaces for explosives detection-
  - Will provide information on best surface to try and collect residue from to get most signal (eg. IMS)
  - Results are relevant outside of explosives field
- Currently collaborating with INEL on a DHS summer research program on this topic.



Deposition of PETN on various surfaces indicate how materials are collected from the vapor phase

F1-B: Routes to synthesize non-nitrate containing energetic materials (L. Hope-Weeks, TTU)

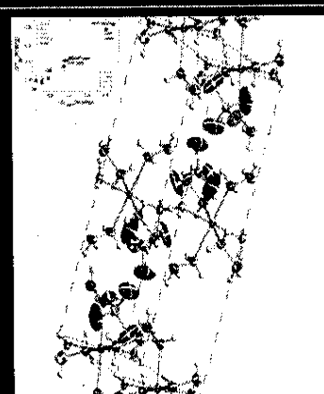
Objective: The majority of energetic materials contain a high concentration of nitrate groups and can be detected by traditional methods. The goal of this work is to investigate the synthesis and characterization of energetic materials without nitrate groups (primarily non-ideal explosives).

Approach:

- Investigated the synthesis of transition metal complexes to determine the effect of the metal on stability and energy output.

Significance and relevance:

- By understanding synthetic routes will allow for targeted detection of precursors
- Metal containing energetics may provide replacement compounds for CP (5-Cyanotetrazolpentaamine Cobalt III perchlorate) and BNCP (cis-bis-(5-nitrotetrazolato) tetraminecobalt(III) perchlorate)
- Final compounds can be used to develop new detection methodology
- Patent applications, CAS registration (paid for by company), paper submitted to Science



Crystal structure of nickel hydrazine perchlorate shows a ***polymer structure*** *never before observed in this class of materials. Collaboration with LLNL shows the energy density is over triple that of TNT: theoretical energy is 2.3 kcal/g; TNT is ~0.7 kcal/g (inset)*

F1-B: Formation of thin film energetic materials; Nanomaterials (aerogels and nanocrystals) for improved detection and mitigation (B. Weeks,L. Hope-Weeks TTU)

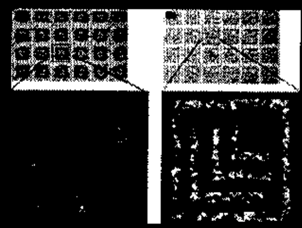
Objective: To investigate nanoscale properties of energetic materials (ideal and non-ideal) to understand propagation and surface structure.

Approach:

- Deposition of thin film energetic materials on the nanometer scale.
- Investigate the structure using AFM, FTIR, and ellipsometry
- Future studies will look at laser initiation for propagation experiments

Significance and relevance:

- Provide data for thermochemical codes (e.g. CHEETAH).
- Understand the sensitivity of non-ideal HEs with a minimal amount of material (currently working with LLNL)
- Industrial interest in commercialization of aerogels



Complex Patterns of PETN formed on a silicon surface can be used to better understand propogation

Aerogels allow for controlled density of bulk energetics. In addition, initial ballistic studies show that these gels are stronger, and lighter than Kevlar – consider use in mitigation

Education-TTU: Hands on Explosives Training; Collaboration with Midwest Research Institute

Objective: To provide hands-on training for energetic materials synthesis, small scale safety tests, and field training.

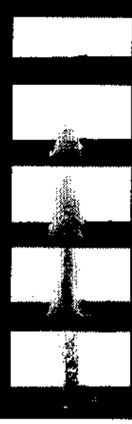
TTU short course: (L-R), student with Nonel, melon shot, first attendees

Approach:

- Four day short course (initially funded by Midwest Research Institute and Virginia Contracting Authority) to provide training on handling of homemade energetic materials
- One day refresher course is being developed

Significance and relevance:

- Over 45 attendees; including local police, FBI, US Marshalls Office, bomb squad, fire department. Next course is scheduled for end of Feb. and will include FBI field agents.
- Could easily be transitioned to other government agencies and first responder orgs.
- Proposal pending with CTTSO to develop video versions of this, and similar, courses.



High speed video of an underwater test, Phantom V710 camera. High speed images are also being used is classroom settings for undergraduates

F1-TTU: Metrics

Metrics:

- 4 GS + 2 Faculty; Gengxin Zhang (now at Intel), Alex Bushuyev, Sanjoy Bhattacharia, Victoria Smith, Brandon Weeks, Louisa Hope-Weeks
- 2 postdocs; Charly Sisk (now at DOE Waste Isolation Pilot Plant); Geneva Peterson
- 5 publications (2 submitted)
  - 'Gold modified cadmium sulfide aerogels' *Journal of sol-gel science and technology*, 57 68-75 (2011) - LJH
  - 'A device for testing the thermal impact sensitivity of high explosives' Propellants, explosive, pyrotechnics, 35 440-445 (2010) - BW
  - 'Surface morphology of organic thin films at various vapour flux' *Applied Surface Science*, 256 2363-2366 (2010) - BW
  - 'Engineering the microstructure of organic energetic materials' *ACS Applied Surfaces and Interfaces*, 1 1086-1089 (2009) - BW
  - 'Effect of Zn doping on the sublimation rate of pentaerythritol tetranitrate using atomic force microscopy' *Scanning*, 31 181-187 (2009) - BW
  - 'A new class of polymeric high explosives' Sub. to Science 2011 – LJH, BW
  - Novel energetic complexes of Copper (II) and acetonecarbohydrazide as potential flame colorants for pyrotechnic mixtures. Sub. To Inorg. Chem. 2011 - LJH
- Patents
  - Functionalized apertures for the detection of chemical and biological materials - LJH
  - Thermal drop-weight apparatus (disclosure 2010) – BW

Leveraging Funding:

- Interactions with companies and government agency on HME performance starting in 2010 ($500K) – LJH, BW: SBIR proposal with Ceradyne for commercialization of aerogels (College Station, TX) - LJH
- ONR proposal 'Resolving the complexity of hot spots caused by weak energy concentration and coupling in energetic materials' submitted Dec. 2010 – BW, LJH
- Combating Terrorism Technical Support Office 'Training video on ballistic impacts' March 2011
- University commitment to new equipment for thin film samples (XPS - $650K); August 2010.

F1-TTU: Year 4 work plan

- F1-A1: Thin film energetic materials (Weeks)
- **Next Year**: To investigate the nanoscale properties of energetic materials (ideal and non-ideal) to understand propagation and surface structure. Continue work using non-ideal energetic materials and perform laser initiation based experiments.
- **Long-range impact**: Will lead to a better understanding of how explosive vapors collect on surfaces. Information can be used to aid in detection by surface 'swiping.' The thin films are also being used for initiation studies. Collaborations with LLNL (Gee and Maiti) for enhancing thermochemical (CHEETAH) and hydrocodes.
- F1-B: Yr4: Nanomaterials for improved mitigation (Hope-Weeks)
- **Next Year:** Incorporate aerogels into materials with collaboration in F4
- **Long-range impact**: Impact of this work may lead to stronger bulk materials for explosives mitigation. The work also impacts fields outside of the explosives community including catalysis and sensors.
- F1-B: Synthesis of non-nitrate containing energetic materials (Hope-Weeks, Weeks)
- **Next Year:** Continue collaborations with LLNL for incorporation into CHEETAH.
- **Long-range impact**: Metal containing energetics may provide replacement compounds for CP (5-Cyanotetrazolpentaamine Cobalt III perchlorate) and BNCP (cis-bis-(5-nitrotetrazolato) tetraminecobalt(III) perchlorate). The materials also show promise as flame colorants for pyrotechnics and IR flares.

F1-WSU: Chemical initiation and phase stability of nonconventional explosives (PI: Choong-Shik Yoo)

Objective: To investigate phase and chemical stabilities of Non-conventional Energetic Materials (NEMs) under relevant pressure-temperature conditions of deflagration and detonation

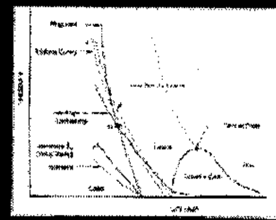
Approach:

- Examine the representative energetic oxides, nitrates, thermites, and mixtures under static conditions using a Diamond Anvil Cell (DAC)
- Investigate laser-induced chemical initiations in DAC using time-resolved spectroscopy
- Compare with shock-initiation (Gas-gun) chemistries

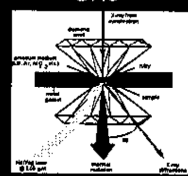
Significance and relevance:

- Accurate material properties are key to characterizing NEMs: Equation of State (EOS), melting, phase transitions, chemical reactivities.
- NEM Properties are required to develop chemical methods to characterize and mitigate the associated threats: purifications, sensitization, etc.

Different loading methods reach different PVT states and chemical kinetics



DAC



Gas-gun

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F1-WSU: Energetic nitrates - Ammonium nitrates (AN)

Motivation: Commonly used in IED, fertilizers, mining industries with basic properties not well understood

- Strong chemical sensitivity: ANFO is explosive, yet pure AN is stable
- No melting and phase behaviors above 2 GPa

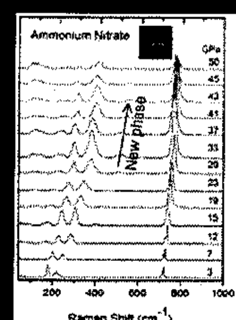
Progress: Investigated the phase stability and chemical decomposition of AN using micro-Raman spectroscopy and third-generation synchrotron x-ray at the APS

- Phase transition at 25 GPa in static conditions
- No chemical changes under shock conditions
- Presently investigating the stability in different chemicals of He, n-hexane, CO_2, carbonates, etc

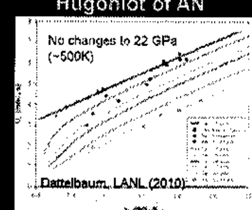
Next step:

- Characterize the crystal structure of new phase and determine the melt curve
- Investigate laser shock-induced chemistry in DAC

Phase transition in AN



Hugoniot of AN



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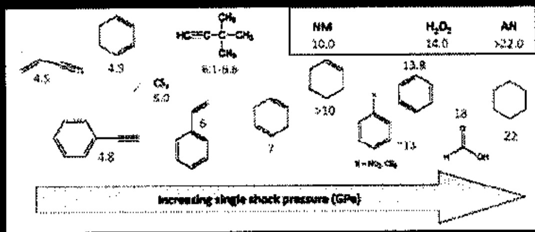
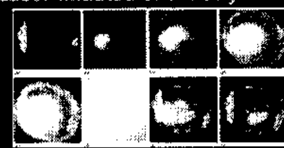
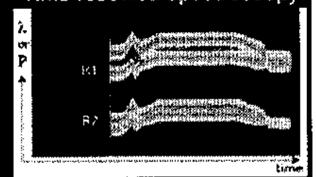
F1-WSU: Static and shock-induced chemistries



Laser-initiated chemistry in DAC



Time-resolved spectroscopy



Approach: Integration of the static, shock, explosive, and chemistry expertise at WSU and LANL to address shock-induced chemistry of energetic materials

Progress: AN, HCOOH, TATB experiments are underway in both static (WSU) and dynamic (LANL) conditions, using time-resolved spectroscopy

Significance and relevance:
- Predictive capabilities for explosive initiation
- Improved EOS models for better assessment of blast effects
- Blast-/shock-mitigating materials and methodologies
- Related basic science needs for materials in extreme conditions

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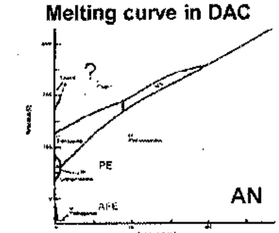
F1-WSU: Yr4 Plans and Metrics

Plans :
- Continue to investigate AN and other IED materials, especially the melting curves
- Begin chemical initiation studies on heterogeneous energetic materials during the deflagration, combustion, thermite, and metathesis stages
- Continue to collaborate with Drs. Dattelbaum and Sheffield in Shock and Detonation Physics Group at LANL

Metrics:
- 2 GS + 2 PD + 1 Faculty
- 1 in print, 1 submitted, 2 in preparation
- 1 poster for the DHS Summit
- 5 presentations: 3 invited (PacifiChem2010, GRC-HE, UI) + 2 contributed (APS_March, MRS_Spring)
- Organizing HE sessions at SMEC_2011 and MRS_Fall in 2011 meetings

Melting curve in DAC



The melting curve is the most fundamental high value thermoelastic property, but largely unknown for most energetic solids - even at its basic concept. How and where does HE melt? What is melting and how does it differ from decomposition or sublimation?

F1-WSU: Publications

Papers:
- Jing-Yin Chen, Minseob Kim, Choong-Shik Yoo, Dana Dattelbaum, and Steve Sheffield, Phase Transition and Chemical Decomposition of Hydrogen Peroxide and its Water Mixtures under High Pressures, J. Chem. Phys. 132, 214501 (2010)
- Jing-Yin Chen and Choong-Shik Yoo, High Density Amorphous Ice at Room Temperature in Dynamic-DAC, Proc. Nat. Acad. Sci., USA (2011) submitted
- Alistair Davidson and Choong-Shik Yoo, Phase Transitions in Ammonium Nitrate under High Pressures, (2011) in preparation
- Alistair Davidson and Choong-Shik Yoo, Pressure Transitions and Amorphization of Formic Acid under High Pressures, (2011) in preparation

Poster:
- Jing-Yin Chen and Choong-Shik Yoo, Physical and Chemical Changes of Hydrogen Peroxide Under High Pressures, RICC 2010 R&R, Oct. 19th, 2010, Northeastern Univ., Boston, MA

Presentations:
- Choong-Shik Yoo, Monolithic Energetic Materials, the Gordon Research Conference on Energetic Materials, June 13-18, 2010, Tilton School, Tilton, NH (invited)
- Choong-Shik Yoo, Novel Solids at Extreme Conditions. 2010 PacifiChem, Dec. 15-19, 2010, Honolulu, HI (invited)
- Choong-Shik Yoo, *Extended Solids in Extreme Conditions*, A Colloquium Lecture at Department of Physics, University of Idaho, Moscow, Idaho. March 8, 2010 (invited)
- Jin-Yin Chen and Choong-Shik Yoo,Formation of Methane Hydrates in Dyanamic-DAC: Time-resolved Spectroscopy for High Pressure Kinetic Studies, Spring 2010 MRS Meeting, April 5 – 9, 2010, San Francisco, CA
- Jing-Yin Chen, Minseob Kim, Dana Dattelbaum, Steve Sheffield and Choong-Shik Yoo, Pressure-Induced Decomposition of Hydrogen Peroxide, March 2010 APS Meeting, Mar. 15 - 19, 2010, Portland, OR

Energetic Materials Sessions (Organizing):
- Choong-Shik Yoo, Novel Energetic Materials and Phenomena in SMEC Meeting (Study of matter at Extreme Conditions), Mar. 27 - April 1, 2011 Miami, FL
- Riad Manaa, Evan Reed, Choong-Shik Yoo, and Michael Strano, Advances in Energetic Materials Research in Fall 2011 MRS Meeting , Nov. 28 – Dec. 2, 2011, Boston, MA

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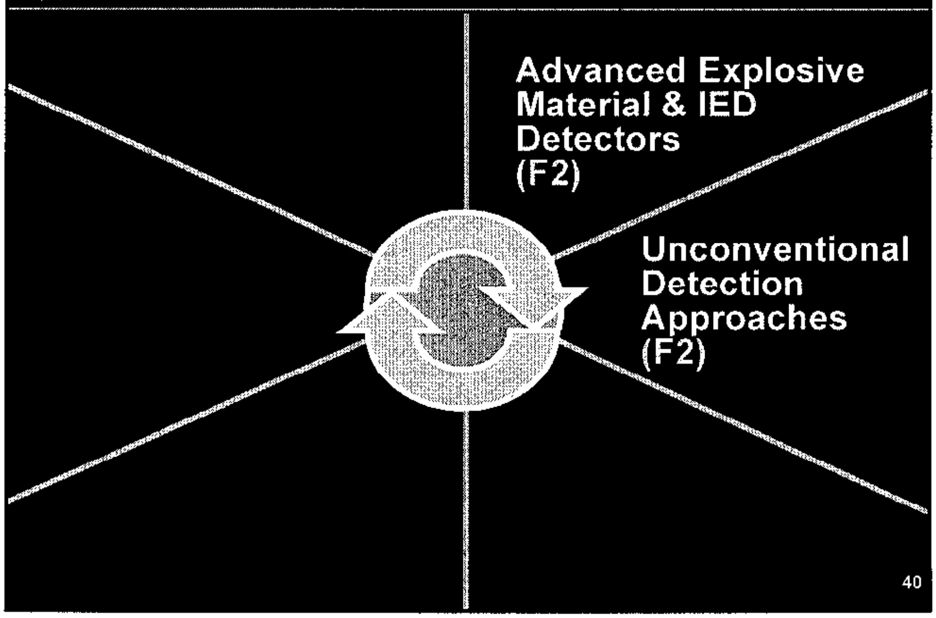
The ALERT Fundamental Science Program: Encompasses Multidisciplinary CIED Elements



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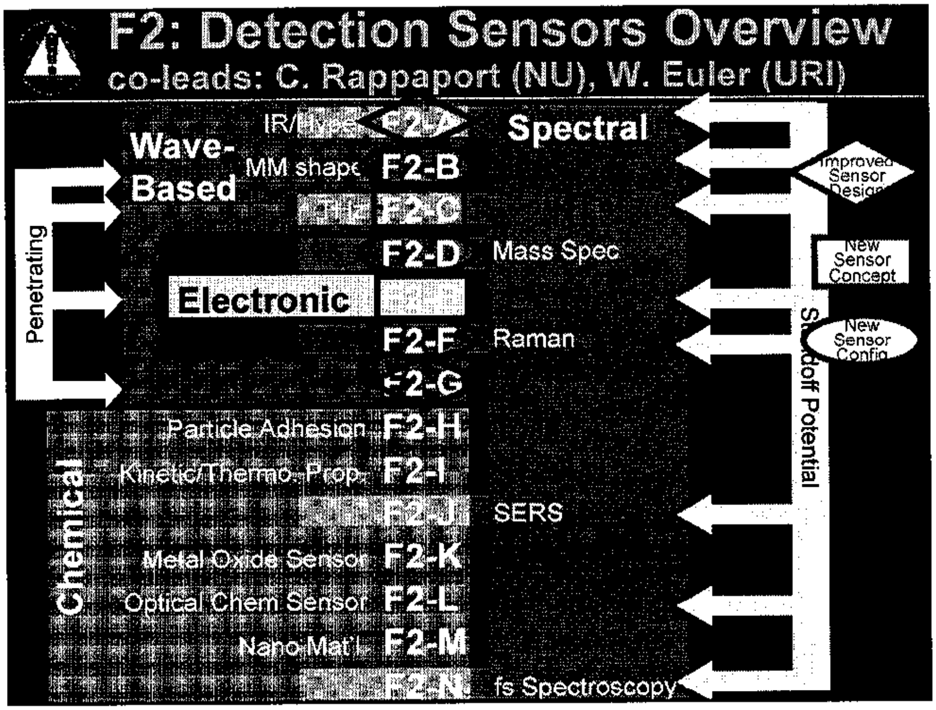

F2-A Explosive Detection using Hyperspectral Imaging

Miguel Vélez-Reyes, Nayda Santiago, and Samuel Hernández-Rivera (UPRM)

- Motivation and purpose:
  - To develop fast and reliable algorithms for detection of energetic materials and other chemical threats based on hyperspectral imaging and remote IR spectroscopy.
- Innovative Aspects
  - Use of target detection methods based on structured models, oblique projections and multivariate statistical analysis.
  - GPU-based implementation for real-time detection.
  - Pre-processing for target/background contrast enhancement based geometric PDEs to improve detection of small objects in complex background.
- Year 3 Outcomes (work started in Jan. 2009)
  - GPU Implementation of global and adaptive versions of RX, MF and AMSD detection algorithms.
  - For global versions, at least 35x were obtained for RX and MF while for AMSD an improvement of 15x was obtained.
  - For adaptive versions, only a 5x was achieved. Further tuning of algorithms is still needed to take full advantage of GPU architecture.
  - Work on application of PDE enhancement began. Interesting preliminary results.
- Long range impact
  - The expected outcome of this project is to develop target detection algorithms with optimal performance for remote detection of energetic materials.
  - Demonstrate that proposed algorithms can be implemented using the GPU platform for real-time implementation as will be needed in portal and surveillance applications.
  - Algorithms and analyses developed as a result of this work will impact other techniques being considered for remote detection of chemical and bio threats.

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F2-A Research Activities

Faculty Involved	2
Post-doctoral	0
Graduate Students	2
Undergraduate Students	5
Papers Published/Submitted	5
Presentations by Students	5

- Modeling Spectral Variability: **Development of target detection based based on geometrical models**
  - Subspace models and oblique projections, and multivariate statistical methods
  - Nonlinear manifold learning and topological models
- Small Targets: **Pre-processing for target/background contrast enhancement**
  - Geometric PDEs to improve detection of small signatures in complex background.
- Real-time Implementation: **GPU-based implementation for real-time detection**
- Testing and validation: **Generation of phantom imagery and collection of spectral data of explosives under different backgrounds (with F2-F)**

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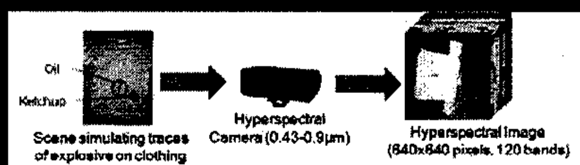
F2-A Experimental Data Tested GPU Speedup for a Class of Hyperspectral Detection Algorithms

- A scene simulating traces of different materials (as the explosive compound) on clothing was prepared.
- A set of phantom images was generated using SOC-700 Hyperspectral Imager (0.43 – 0.9 μm).



- The hyperspectral cubes were processed using different state-of-the-art target detection algorithms implemented on a NVIDIA® Tesla C1060 GPU card using CUDA™ programming environment and CULA™ libraries for linear algebra computations:
  - RX anomaly detector (full pixel detector).
  - Matched filter (full pixel detector).
  - Adaptive Matched Subspace Detector (subpixel detector, SVD and MaxD as endmember selection algorithms).
- For each detection algorithm, a CPU-based implementation was developed in C++ as a reference for speedup estimation using Intel® MKL library.

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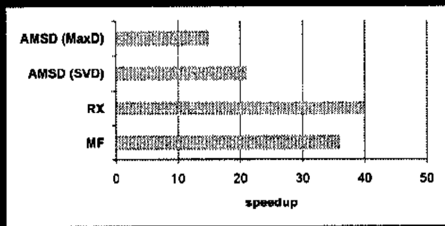
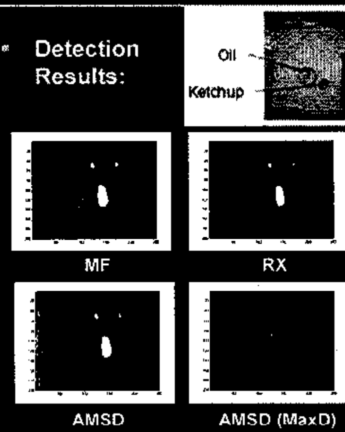
F2-A Experimental Results (cont.)

- Speedup Results (GPU vs CPU):



	Detection accuracy (%)	False alarm (%)
RX	98.4	1.1
MF	99.3	5.1
AMSD (SVD)	93.7	15.5
AMSD (MaxD)	63.5	2.5

- Detection Results:



- We achieved a speedup of over 35x for the GPU implementation of RX and MF algorithms.
- The AMSD with MaxD as endmember selection algorithm show the worst performance on GPU.
- For this data set, the full pixel detectors (RX and matched filter) show the best detection results.

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Preliminary Results: Enhancement using Diffusion PDEs

Hydice Forrest Radiance Image: Standard used in testing and validation of target detection algorithms using hyperspectral imaging

Original Image　　After Diffusion Enhancement

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F2-A Yr 4 Proposed Work

- Study structural models based on nonlinear manifolds and how to use them in target detection→ improve modeling of spectral variability
  - Outcome: Improved target detection algorithms for explosive traces (small targets) under different clutter scenarios (different levels of complexity)
- Develop GPU code library for HSI Target Detection
  - Outcome: Software library for use in implementation of future target detection algorithms
- Continue development of data sets for algorithm testing and validation with Dr. S. Hernandez-Rivera
  - Outcome: Data sets with ground truth for testing and validation
- Collaborate with Dr. S. Hernandez-Rivera in target detection using Block Engineering LaserScan™ Analyzer
  - Outcome: Case study of algorithm application to this system. Tech transfer.

Student Presentations

- Poster: "GPU-based Implementation of Target Detection Algorithms for Standoff Detection of Explosive Materials using Hyperspectral Imaging and NVIDIA® GPUs", Blas Trigueros-Espinosa, CenSSIS/ALERT 11th Annual Research and Industrial Collaboration Conference, October 19, 2010, Boston, MA
- Poster: "Hyperspectral Image Processing Algorithms for Cancer Detection on CUDA/GPUs", Humberto Diaz, Bernard M. Gordon Center for Subsurface Sensing and Imaging Systems (Gordon-CenSSIS) NSF Site Visit Poster Presentations , April 14, 2010, Boston, MA
- Poster: "Hyperspectral Image Analysis for Target Detection Using CUDA", Pedro Alemar, Bernard M. Gordon Center for Subsurface Sensing and Imaging Systems (Gordon-CenSSIS) NSF Site Visit Poster Presentations , April 14, 2010, Boston, MA
- Poster: "Hyperspectral Image Analysis for Abundance Estimation using CUDA™", Amilcar González, Pedro Alemar, Humberto Díaz, Charles Rodriguez, Beatrice Pérez, Computing Alliance for Hispanic Serving Institutions (CAHSI) Fourth Annual Poster Sessions, April 5, 2010, Redmond, Washington
- Oral Presentation: Hyperspectral Image Analysis for Target Detection using CUDA, Amilcar Gonzalez, Humberto Diaz, Pedro Alemar, Beatrice Perez, Puerto Rico Interdisciplinary Scientific Meeting 2010, March 13, 2010.

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Publications

- Submitted
  - Castro-Suarez, J.R., Pacheco-Londoño, L.C., Vélez-Reyes, M. Diem, M., Tague, Jr., T.J. and Hernandez-Rivera, S.P., Open-Path FTIR Standoff Detection of TNT on Aluminum Surfaces, Applied Spectroscopy.
- Accepted but not published
  - B.E. Trigueros, M.Velez-Reyes, S. Rosario-Torres, N. Santiago, "Evaluation of the GPU architecture for the implementation of target detection algorithms for hyperspectral imagery." Accepted for publication in Proceedings of SPIE: Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XVII, Vol. 8048, April 2011.
  - Hernández-Rivera, S.P. Castro-Suarez, J.R., Pacheco-Londoño, L.C., Rey-Villamizar, N., Vélez-Reyes, M. and Diem, M., MID-Infrared Vibrational Spectroscopy Standoff Detection of Highly Energetic Materials: New Developments, Spectroscopy Magazine Defense and Security Supplement, April, 2011.
  - Castro-Suarez, J.R., Pacheco-Londoño, L.C., Vélez-Reyes, M. Diem, M., Tague, Jr., T.J. and Hernandez-Rivera, S.P., Open-Path FTIR Detection of Explosives on Metallic Surfaces. InTech Book: Fourier Transforms, Theory and Applications", 978-953-7619-X-X.
- Published
  - C. Peña-Ortega and M. Velez-Reyes, "Evaluation of different structural models for target detection in hyperspectral imagery." In Proceedings of SPIE: Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XVI, Vol. 7695, April 2010.

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F2-B Millimeter Wave Standoff Detection of Concealed Explosives; Carey Rappaport and Jose Martinez, NU

- Purpose and Relevance:
  - Detect foreign objects on individuals under clothing at safe distance
  - Use mm-wave radar to safely and unobtrusively screen subjects
- Innovation:
  - Use wide aperture antenna for narrow scanning beam and multiple views
  - Develop model-based inversion to identify irregularities on skin surface

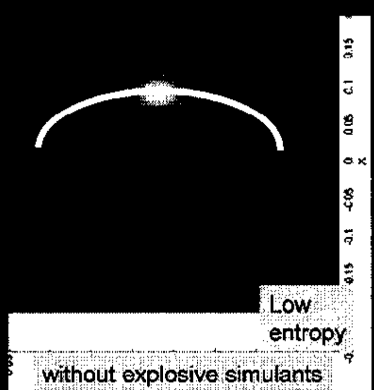
- Year 3 accomplishments:
  - Built, tested, and collected data with bistatic 2m servomotor-based rail SAR with Fraunhofer Institute in Germany
  - Developed motion correction algorithms to map time to distance and reduce target clutter
  - Created new model-based bistatic algorithms for detecting manmade objects on skin
- Long Range Impact / Relevance:
  - Detection using limited view fixed electronically scanned aperture array which can fit in a van
  - Fast, safe, automatic, standoff alert of objects hidden under clothes

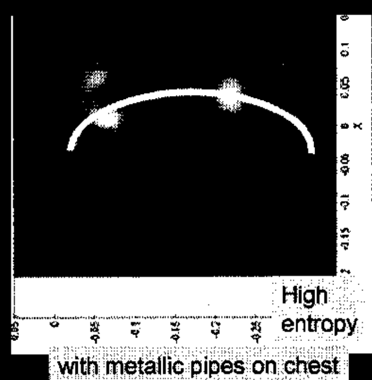
F2-B Millimeter Wave Standoff Detection of Concealed Explosives

- Year 4 Proposed Work
  - Investigate sparse fixed 2D planar array for multistatic 94 GHz FMCW radar to simulate fixed array
    - Experiments in Germany with IAF
    - Extend reconstruction algorithms for fixed aperture multistatic imaging
  - Electronically scan illumination spot in height as well as width for 2D image reconstruction
  - Continue undergrad research in modeling, signal processing, and material characterization – pipeline for grad research

Faculty Involved	2
Post-doctoral	0
Graduate Students	2
Undergraduate Students	4
Papers Published/Submitted	5
Presentations by Students	5

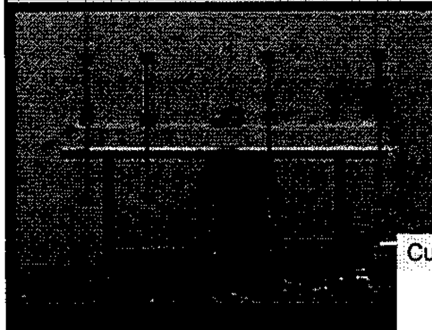
F2-B Reconstruction of Threat Features with mm-Waves at 22m – Measured Data





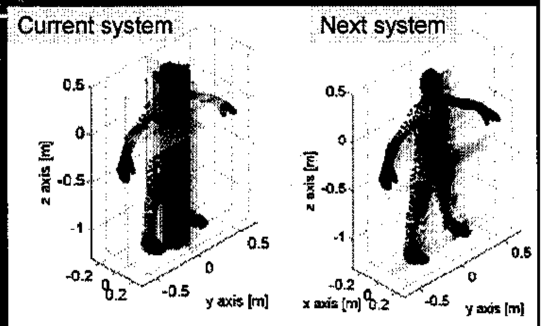
SAR images generated from measured rail SAR radar data
- Innocent subject has single specular point image
- Threat subject has multiple image maxima
- Statistical distribution of intensity levels (entropy) correlates with foreign objects on skin

F2-B Next Generation Sparse Fixed Planar Array – Proposed Configuration



- Use programmable switches to sequentially sample received signals across wide array
- Space elements non-uniformly in array to avoid grating lobes
- Position elements with vertical spacing for tight vertical spot extent

- Current 1D scanning integrates over vertical feature
- New configuration improves target interrogation
  - Better focusing in height
  - Allows vertical feature reconstruction



2D image reconstruction

3D image reconstruction

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F2-B 2010 Publications and Proposals

PUBLICATIONS

1. Fernandes, J., Obermeier, R., Martinez-Lorenzo, J.A., and Rappaport, C., "FMCW SAR imaging of body worn explosives from FDFD modeled scattered field data," *Progress in Electromagnetics Research Symposium*, Cambridge, MA, July 2010, pp. 350.
2. Fernandes, J., Obermeier, R., Martinez-Lorenzo, J. A., and Rappaport, C., "Simulation results for standoff detection of suicide bombers at millimeter-wave frequencies using a full wave numerical analysis," *Homeland Security Summit*, Washington, DC, March, 2010, one page.
3. Martinez-Lorenzo, J. A. and Rappaport, C., "SAR imaging of suicide bombers wearing concealed dielectric structures," *IEEE International Conference on Homeland Security Technology*, Waltham MA, Nov 2010, seven pages.
4. Fernandes, J., Martinez-Lorenzo, J. A., Hagelen, M. and Rappaport, C. "A comparison of experimental and simulated millimeter wave imaging system for standoff detection of person-borne improvised explosive devices," *IEEE International Conference on Homeland Security Technology*, Waltham MA, Nov 2010, seven pages

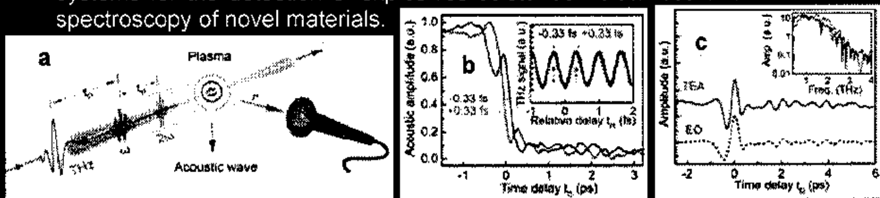
PROPOSALS

1. Martinez-Lorenzo, J.A., and Rappaport, C., "3D Millimeter-Wave Radar for Standoff Concealed Explosives Detection (3D-MIRACLE)," $750,000 (3 years), DHS International Collaboration Program, with Fraunhofer Inst. for High Frequency Physics and Radar Tech.
2. Rappaport, C., and Martinez-Lorenzo, J.A., "Development of GPR technology for reliable detection of tunnels and vertical holes for homeland security," $750,000 (3 years), DHS International Collaboration Program, with Technion, Israel Institute of Technology.

F2-C Science of broadband THz wave photonics: THz generation & detection with gases for standoff detection

X.-C. Zhang, J.M. Dai, Y.M. Sun, and M. Yamaguchi, RPI; W. Rockward, Morehouse

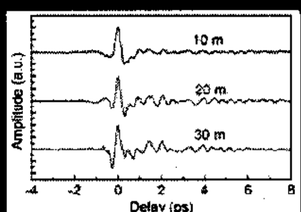
- Purpose and Relevance: Understanding the underlying science of THz wave photonics using air and gases as THz wave emitters and sensors might provide a feasible approach for the concealed items' detection at standoff distance.
- Innovative Aspects: 1. "Hearing THz waves"—Detection of THz waves with THz-enhanced-acoustics; 2. Developed an all-air based THz time-domain system utilizing REEF.
- Year 3 accomplishments: We generated THz waves from ambient air at a distance of 30 meters by sending optical pulses far away. We further increased pulsed THz field greater than 2 MV/cm for nonlinear THz spectroscopy.
- Long range Impact: The science and technology behind air-plasma merit further study and will both illuminate the path to providing useful information about the interaction of intense electromagnetic fields with gases and lead to improved THz systems for the detection of explosives at standoff distances and THz nonlinear spectroscopy of novel materials.



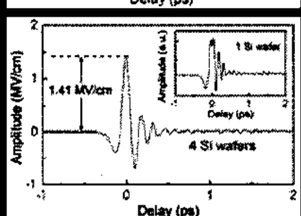
a. Concept diagram of TEA. **b**: TEA signals with two-color laser probe. **c**: Retrieved THz waveform.

F2-C Science of broadband THz wave photonics: THz generation & detection with gases for standoff detection

- Year 3 Proposed Work: 1. THz generation at a distance of over 30 m; 2. Higher field THz generation from gas plasma; 3. Investigation of THz Radiation-Enhanced Emission of Fluorescence (REEF) in different gases at different pressures.
- Year 3 Accomplishments (Some Real Data):



(1) We generated THz waves by sending optical pulses far away and creating air plasma at distances of 10, 20, and 30 m. The maximum distance has already reached our proposed goal with a total laser pulse energy of about 4 mJ.



(2) Higher peak electric field THz wave has been achieved. The figure shows THz waveforms and field strength measured with 0.106 mm GaP crystal with 1 or 4 silicon wafers to attenuate the field strength and check the effect. The real field would be higher than that indicated in the figure since the detection bandwidth of GaP is limited to about 8 THz. Using broader-band THz-ABCD detection, we estimated the field reaches over 2 MV/cm.

F2-C Year 4 Focus: Real-Time THz Wave Imaging of Explosive Threats

Expected performance:

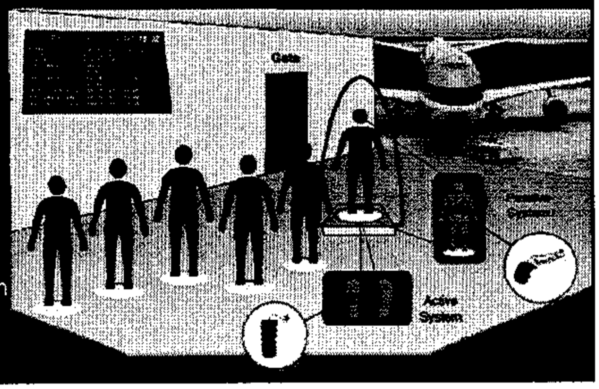
- 250 frames/s for an area of 8"x8", <4 mm spatial resolution at 0.5 THz
- Compatible with active and passive imaging
- Compatible with CW or time-domain systems

Features:

- Frequency independent (reflective system)
- Compact size 6"x4"x1.5", short distance imaging
- Portal gate imaging and shoe scanner

Benefits:

- Real-time images with high-level of averaging (high SNR)
- Single detector can be much more sensitive than array systems



F2-C: Future Plans

- Focus of Year 4 Work Plan: THz wave imaging of explosive threats.
- Year 4 Proposed Work:
    1. Technology: THz wave imaging of explosive threats; passive and active real time THz wave imaging, including shoe scanner development.
    2. Science: Following Year 3 activity, we will conclude work on: Nonlinear THz spectroscopy of novel materials, such as metamaterials; Further improvement of the THz emission efficiency for higher THz field (>5 MV/cm); Remote THz wave generation at a distance of 5 to 30 m); Field test of two-color THz-REEF; Multiple detection schemes of intense THz waves with THz-REEF, THz-ABCD, and TEA detection.
    3. Training: Undergraduate education (team with Prof. Rockward and his underrepresented minority students).

F2-C Undergraduate Student Training

Since 2009, we worked with and will continue to work with Prof. Willie Rockward on undergraduate education in the field of THz Science and Technology. Two of Prof. Prof. Rockward's students, Joshua Burrows and Ronald Celestine, presented their works at the RICC2010 as cited below. (These were already cited in the presentation list). A third student Colin Watson and Mr. Burrows were REU students at RPI in 2009 and 2010

1. Joshua Burrows, Willie Rockward, X.-C. Zhang, etc., "THz system Integration", Research and Industrial Collaboration Conference 2010 (RICC2010), Boston, Massachusetts.
2. Ronald Celestine, Willie Rockward, X.-C. Zhang, etc., "THz Laboratory at Morehouse College", Research and Industrial Collaboration Conference 2010 (RICC2010), Boston, Massachusetts.

Photo: Joshua Burrows and Colin Watson from Morehouse College did their REU projects at the RPI THz Center in summer 2009 and 2010. From left to right: Joshua Burrows, Prof. X.-C. Zhang, and Colin Watson.

F2-C National Lab Collaborations/Industrial Partners

Collaborations/Interactions (National Labs)

- Sandia National Laboratories (Igal Brener)
- Los Alamos National Laboratory (H.T. Chen)
- Navy Indian Head National Laboratory (John Wilkinson)
- Idaho National Laboratory (David Hurley)

Partners (Industrial Company)

- Zomega Terahertz Corporation, Troy, New York (Tom Tongue)
- Intelligent Optics Systems, Inc., Torrance, California (Glenn Bastiaans)
- Applied Plasmonics, Gainesville, Florida (Jane Tokarz)
- ALVA Labs, LLC, Marlboro, New Jersey (John Locks)

F2-C Transition of the outcomes to the field

- SBIR/STTR: Rensselaer THz team has transferred their patented technology of THz wave air photonics (using air as THz wave emitter and sensor) to industrial companies. Currently RPI team has four Army, Navy, Air Force, DTRA, and NSF SBIR/STTR grants with industrial companies.
- NATO THz SET124: Prof. Zhang chaired NATO SET-124 THz Task Group (2007-2010) with 13 NATO country members. This group focuses on THz Wave Technology for Standoff Detection of Explosives and other Military & Security Applications. He organized and chaired 7 business meetings. His Task Group performed field test of explosives with THz technology in Canada in August 2010. His team has been selected as one of two Emerging and Emerged Disruptive Technologies by NATO Sensor and Electronic Technology Panel.
- Glow Discharge Detector (GDD): Seeded by ALERT program, AFOSR provided a STTR Phase I to RPI/IOS to commercialize GDD detector in 2010. We are invited to submit Phase II proposal.
- Patents: In 2010, 2 patents funded by ALERT program are awarded, and 1 disclosure is submitted.

F2-C Student Awards

ALERT students won awards:

- Jingle Liu and I-Chen (Karen) Ho, recipients of the Coherent Graduate Student Award in May 2010.
- Jingle Liu, recipient of the Hillard B. Huntington Award in May 2010.
- Panagiotis Karampourniotis, recipient of the award from Gerondelis Foundation, Inc. in November 2010.
- Ben Clough, recipient of the best presenter award during IGERT annual retreat, July 2010.
- Ben Clough, one of three finalists with $1,000 prize for 2011 Lemelson-MIT Rensselaer Student Prize. The final winner with $30,000 prize will be announced on March 9 (See next slide).

In addition, two students are nominated for dissertation award and poster competition.

- Jingle Liu, nominated for the Northeastern Association of Graduate Schools (NAGS) Doctoral Dissertation Award.
- Ben Clough, nominated to represent the RPI IGERT chapter in a national poster competition, December 2010.

F2-C Lemelson-MIT Rensselaer Finalist Flyer

Join us as we celebrate student inventiveness and innovation at the 2011 Lemelson-MIT Rensselaer Student Prize Award Ceremony.

2011 Finalists:

Benjamin Clough Terahertz Enhanced Acoustics
Sevan Goenezen Breast Cancer Diagnosis with Nonlinear Elasticity Imaging
Tristan Lawry High Performance System for Wireless Transmission of Power and Data Through Solid Metallic Enclosures

Where: Center for Biotechnology and Interdisciplinary Studies Auditorium

When: March 9th, 7 pm

Reception immediately following award ceremony

F2-C Publications/Patents

1. Jingle Liu, Jianming Dai, See Leang Chin, and X.-C. Zhang, "Broadband terahertz wave remote sensing using coherent manipulation of fluorescence from asymmetrically ionized gases", Nature Photonics, 2010. 4: p. 627.
2. Benjamin Clough, Jingle Liu, and X.-C. Zhang, "Laser-induced photoacoustics influenced by single-cycle terahertz radiation", Optics Letters, 2010. 35: p. 3544.
3. Jingle Liu, Benjamin Clough, and X.-C. Zhang, "Enhancement of photoacoustic emission through terahertz-field-driven electron motions", Physical Review E, 2010. 82: p. 1359.
4. Jianming Dai, Jingle Liu, and X.-C. Zhang, "Terahertz wave air photonics: terahertz wave generation and detection with laser-induced gas plasma", IEEE Journal of selected topics in Quantum Electronics, 2011. 17: p. 183.
5. Jingle Liu and X.-C. Zhang, "Plasma characterization using terahertz-wave-enhanced fluorescence", Applied Physics Letters, 2010. 96: p. 041505.
6. I-Chen Ho, Xiaoyu Guo, and X.-C. Zhang, "Design and performance of reflective terahertz air-biased-coherent-detection for time-domain spectroscopy", Optics Express, 2010. 18: 2872.
7. Jingle Liu and X.-C. Zhang, "Remote terahertz wave sensing using laser-induced fluorescence", WuLi (Chinese Physics Today), 2010. 39: 419.
8. Jayashis Das and Masashi Yamaguchi, "Tunable narrow band THz wave generation from laser induced gas plasma", Optics Express, 2010. 18: p. 7038.
9. Xiaofei Lu, Benjamin Clough, I-Chen Ho, Gurpreet Kaur, Jingle Liu, Nicholas Karpowicz, Jianming Dai, and X.-C. Zhang, "Science, technology, and application of THz air photonics", Proc. of SPIE, 2010. 7854: p. 785406-1.

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F2-C Publications/Patents - continued

10. Lei Hou, Hongkyu Park, and X.-C. Zhang, "Terahertz Wave Imaging System Based on Glow Discharge Detector", IEEE Journal of selected topics in Quantum Electronics, 2011. 17: p. 177.
11. Jingle Liu and X.-C. Zhang, "Enhancement of Laser-Induced Fluorescence by Intense Terahertz Pulses in Gases", IEEE Journal of selected topics in Quantum Electronics, 2011. 17: p. 229.

Patents/Patent Disclosures

1. US Patent #7652253 - Method and system for plasma-induced terahertz spectroscopy. Xi-Cheng Zhang, Jianming Dai, and Xu Xie. Awarded on January 26, 2010.
2. US Patent #7718969 - Methods and systems for generating amplified terahertz radiation for analyzing remotely-located objects. Xi-Cheng Zhang, Jianming Dai, and Xu Xie. Awarded on May 18, 2010.
3. Patent disclosure – Method for terahertz wave detection utilizing terahertz-enhanced acoustics. Benjamin Clough, Jingle Liu, and X.-C. Zhang. Submitted on April 21, 2010.

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F2-C Presentations

1. Jingle Liu, Jianming Dai, See Leang Chin, and X.-C. Zhang, "Broadband terahertz wave remote sensing using coherent manipulation of fluorescence from asymmetrically ionized gases", post-deadline presentation, (CLEO), San Jose, California, May, 2010.
2. Jianming Dai, Jingle Liu, Nicholas Karpowicz, and X.-C. Zhang, "Mechanism and potential applications of THz air photonics", San Jose, California, May, 2010.
3. Jianming Dai, Nicholas Karpowicz, and X.-C. Zhang, "Coherent Polarization Coherent of THz Waves Generated from Asymmetrically Ionized Gases", POEM 2010, Wuhan, China, 11/2010.
4. Xiaofei Lu, Benjamin Clough, I-Chen Ho, Jingle Liu, Jianming Dai, and X.-C. Zhang, "Recently progress of THz generation and detection in ambient air or gases", Society of Photo-Optical Instrumentation Engineers (SPIE) Photonics West, San Francisco, California, Jan. 2011.
5. Jingle Liu, Ben Clough, Jianming Dai, and X.-C. Zhang, "THz Air Photonics for Standoff Detection", IRMMW-THz 2010, Center for Ancient Rome, Rome, Italy, September, 2010.
6. Jingle Liu, Jianming Dai, and X.-C. Zhang, "Remote Terahertz Coherent Detection using Ultraviolet Plasma Emission", (UP), Snowmass Village, Colorado, July, 2010.
9. X.-C. Zhang, Jianming Dai, Jingle Liu, and Nicholas Karpowicz, "Air-Plasma Photonics: THz wave generation, detection and applications", invited presentation, Canadian Association of Physicist Congress 2010 (CAP 2010), Toronto, Canada, June, 2010.
10. Benjamin Clough, Jianming Dai, Jingle Liu, I-Chen Ho, and Xi-Cheng Zhang, "Extending THz spectroscopy to Remote Distances", NATO SE-159, Lithuania, May, 2010.
11. Jianming Dai, Jingle Liu, and X.-C. Zhang, "THz Air Photonics for Standoff Sensing", plenary by X.-C. Zhang, NATO SET159, Lithuania, Sept., 2010.
12. B. Schulkin, T. Tongue, D. Brigada, B. Clough, J. Dai, X.-C. Zhang, "Progress Toward Handheld THz Spectroscopy and THz Air Photonics", IEEE Photonics, Majorca, Spain, January, 2010.
13. Benjamin Clough, Jingle Liu, and X.-C. Zhang, "Terahertz detection utilizing ultrafast laser-induced photoacoustics", Int'l symp. chirped pulse amplification, Quebec City, Canada, 11/2010.
14. I-Chen Ho and X.-C. Zhang, "Compact THz Air-Biased-Coherent-Detection (ABCD) Spectrometer," Connection One Semi Annual Meeting, Honolulu, Hawaii, 8/2010.

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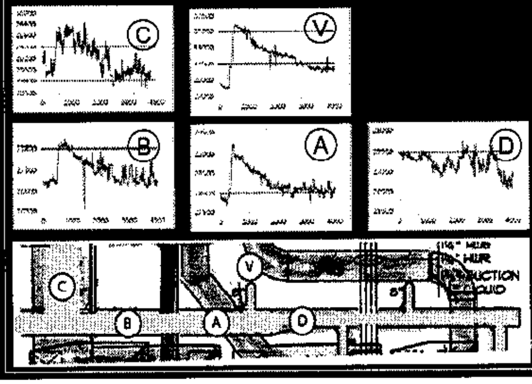
F2-D An Intelligent Mass Spectrometer for Identifying Explosives & Chemical Weapon Threats; R. Camilli, WHOI

Relevance to DHS mission:

Threat detection approaches typically involve check-point screening. This method is 'brittle' because the threat must be presented at the boundary and if the boundary is breached then the area becomes unsecure and must be 'swept' in order for it to be re-cleared. Re-establishing a secure area is typically a heuristic process that is both slow and difficult.

We are developing a CPT based approach that couples discrete component analysis with advection-diffusion estimates to forecast threat source location/s within structured environments based on vapor signal intensity and temporal variance coupled with flow path models.

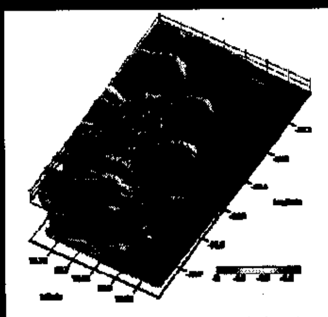
Figures at right show time series mass spectrometric records of tracer vapor intensity measured at differing locations within a building's HVAC air return duct. The path of the plume can be modeled with elements of the closed system as discrete components within a circuit (for example, threat vapor source as a voltage source; rooms as capacitors; windows, doors windows and ventilation ducts as resistors). This analysis approach provides a simple, yet principled method for establishing or verifying that an area is secure and is applicable for single mobile sensors or multiple fixed sensors.



F2-D An Intelligent Mass Spectrometer for Identifying Explosives and Chemical Weapon Threats

Transition to field operations:

- Spring 2010 leveraged CPT analytical methods developed through ALERT as the basis for an inverse model to constrain search operations at the Deepwater Horizon disaster site (conducted under Department of Homeland Security contract #HSCG32-10-C-R00020) to characterize subsurface hydrocarbon plumes emanating from the well.
- Spring 2011 survey operations scheduled for Ordnance Reef, HI (near Pearl Harbor). This operation seeks to demonstrate rapid assessment of a known underwater munitions dump. Goals are to provide a synoptic analysis of the site that positively identifies, georeferences, and characterizes the environmental condition (i.e., if leaking chemicals) as well as potential threat levels of individual munitions.



An 11000 meter deep subsurface hydrocarbon plume from the Deepwater Horizon well, mapped using an AUV equipped with a mass spectrometer (Camilli et al. 2010)

No-cost synergy:

- Working with US Dept. of Energy developing non-invasive mass spectrometric technologies for evaluating and monitoring conventional high explosive components of US nuclear warhead stockpile
- Working with Pentagon and SERDP/ESTCP developing capabilities to locate and monitor unexploded ordnance (UXO) and disposed military munitions (DMMs) in marine environments, particularly non-conventional agents (i.e., vessicants and nerve agents).
- Engaged with various explosives detector manufacturers and major defense contractors regarding replacement of ion mobility spectrometers with next-generation mass spectrometers

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F2-D An Intelligent Mass Spectrometer for Identifying Explosives and Chemical Weapon Threats

YEAR 3 DELIVERABLES

Developed CPT algorithms enabling mobile mass spectrometric identification of toxic and explosive threat sources within structured environments including:

- A simplified method for rapid wide-area search within buildings using flow path information
- A principled method for localization of threat sources with significant standoff distances within complex environments
- A unified methodology for CPT of atmospheric and hydrospheric threat sources
- Demonstration of these methods for use by terrestrial and marine autonomous robots equipped with payload mass spectrometers

This project has reached its natural conclusion. Resources for future work will be sought from other sources.

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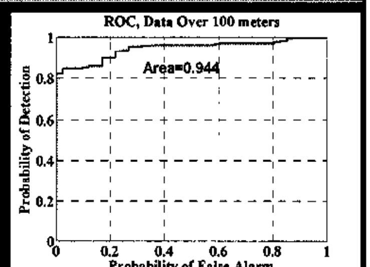
F2-E Detection of Electronically Initiated Explosive Devices

D. Beetner, S. Grant, D. Pommerenke, Missouri S & T.

- **Purpose and Relevance**
  - Develop methods to detect, identify, and interrogate electronics commonly used in explosive devices based on their unintended electromagnetic emissions
- **Innovative Aspects**
  - Potentially fast, long-range detection and location
  - Information orthogonal to information generated by many other explosives-detection methods
    - Effective sensor fusion.
    - May provide information when other sensors fail
  - Same physics used to detect devices can potentially be exploited to neutralize device without destroying forensic evidence.
  - Leveraging more than 15 years of experience performing research for a consortium of 20+ companies to help them *reduce* the emissions and susceptibility of their products.
- **Long range Impact**
  - Develop firm scientific foundation for methods to detect, identify, and neutralize electronics associated with explosive devices



ROC curve for detection of 5 different regenerative receivers at 150 m from antenna in noisy ambient environment. High detection rate enabled by stimulating change in unintended emissions. No a *priori* characterization of the receiver is required (submitted for publication).

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F2-E Detection of Electronically Initiated Explosive Devices

Year 1-3 Significant Accomplishments

Faculty Involved	[illegible]
Post-doctoral	0
Graduate Students	5
Undergraduate Students	0
Papers Published/Submitted	5
Patents	2

- Characterized emissions from superheterodyne and regenerative receivers when modified with a weak stimulation
- Reviewed, developed, and tested signal processing algorithms for detecting wireless initiators
  - Developed improved methods to detect regenerative and superheterodyne receivers
  - Developed measurement/signal processing techniques to reduce ambient noise when measuring weak emissions signal (*added task*)
- Characterized ability of several techniques to *locate* wireless initiators
  - Improved location methods under investigation
- Developed relationship with small company looking to commercialize our technology for explosive analysis and vehicle detection at remote border crossings
- Explored detection of emissions from timers, microprocessors, IR detectors
- Synergistic efforts:
  - Developed prototype for interrogating/neutralizing electronics in IEDs
  - Developed instrumentation to locate wireless <u>transmitters</u>

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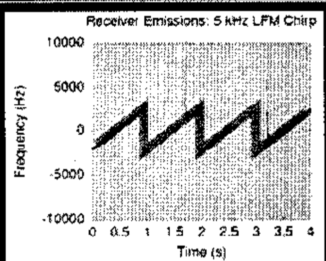
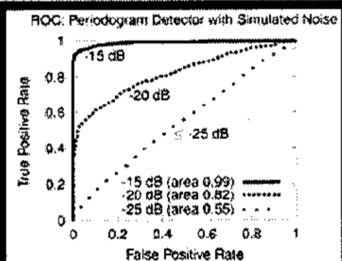
F2-E Detection of Electronically Initiated Explosive Devices



The unintended emissions from a superheterodyne receiver are modulated in frequency by a weak stimulation



Detection of receiver is improved by correlating characteristics of weak stimulation with observed emissions

Proposed Work for Year 3-4

- Complete characterization of theoretical/practical limits of *locating* electronic devices using stimulated emissions
- Develop improved algorithms to detect/identify/locate digital devices like timers, passive IR detectors, etc.
- Explore passive and active methods of determining device *state*.
- Continue working with companies to commercialize technology

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F2-E Detection of Electronically Initiated Explosive Devices

Related publications:

- C. Stagner, A. Conrad, C. Osterwise, D. Beetner, S. Grant, "A practical superheterodyne receiver detector using stimulated emissions," IEEE Transactions on Instrumentation and Measurement, in press.
- D. Beetner, A. Conrad, C. Stagner, S. Grant, S. Peng, N. Bondarenko, "Detecting Superheterodyne and Homodyne Receivers by Manipulating their Incidental RF Emissions with an External Stimulation," invention disclosure, submitted Oct. 27, 2009, U.S. Prov. Pat. App. No. 61/279,854.
- C. Osterwise, S. Grant, D. Beetner, "Reduction of Noise in Near-field Measurements," proc. of the 2010 IEEE International Symposium on Electromagnetic Compatibility, July 2010.
- D. Beetner, D. Carhoun, A. Conrad, S. Grant, C. Osterwise, J. Tichenor, "Verifying Neutralization of Electronically-Initiated Explosive Devices," 2009 MSS Battlefield Survivability and Discrimination conference, Feb., 2009.
- S. Seguin, D. Beetner, T. Hubing, "Detection and Identification of Low-Cost RF Receivers Based on their Unintended Electromagnetic Emissions," IEEE Transactions on Electromagnetic Compatibility, submitted.
- S. Seguin, D. Beetner, T. Hubing, "Controlling Unintended Emissions from Regenerative Receivers to Improve Detection and Identification," IEEE Transaction on Electromagnetic Compatibility, submitted.
- S. Seguin, D. G. Beetner, T. Hubing, "Detection of Regenerative Receivers Based on the Modulation of their Unintended Electromagnetic Emissions," IEEE Transactions on Electromagnetic Compatibility, submitted.

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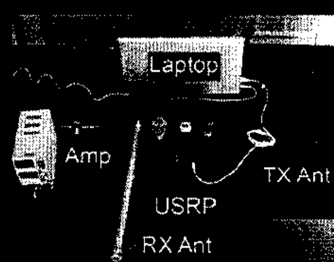
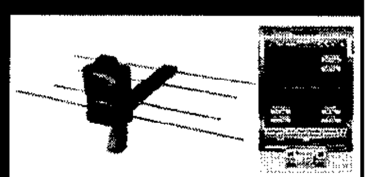
F2-E Detection of Electronically Initiated Explosive Devices

Transitions to the field.

- Results of this (and preceding) work has resulted in 3 patents/patent disclosures
- Actively working with a small company to implement technology on a hand-held field-ready platform
  - Detection/interrogation of explosive devices
  - Detection of vehicles at remote boarder stations
- Real-time demonstrations of detection of wireless initiators
  - Regenerative receivers: using laboratory equipment
  - Superheterodyne receivers: using a hand-held software-defined radio
- Related work:
  - Built and demonstrated a prototype for the Navy to determine function of and to neutralize IED electronics
  - Built and demonstrated a prototype for the Army to locate wireless transmitters and automatically cue video cameras for long-range visual identification of the transmitter
    - Currently conducting phase II of project to develop a field-ready device



Software-defined radio (USRP) used to remotely detect wireless initiators



We are working with Firestorm Emergency Services to implement algorithms on the TigerStrike hand-held platform

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F2-F Remote Vibrational Spectroscopy Detection of Highly Energetic Materials and Homemade Explosives

S.P. Hernández-Rivera, University of Puerto Rico-Mayagüez

- Purpose and Relevance:
  - The objective of this component is to develop Remote Vibrational Spectroscopy detection of highly energetic materials (HEM) and homemade explosives (HME) in range, in detection limits and discrimination/quantification studies.
- Innovative Aspects:
  - Significant improvements in design of home built telescope coupled Raman system
  - Adaptation of high brightness QCL source for remote IR detection experiments
  - Novel laser excitation/detachment source for remote detection of HEM/HME to be used in remote IR and Raman detection and possibly in sensor fusion studies
- Year 3 Outcomes:
  - First measurements of remote IR detection of traces of HEM on Al plates, both in active and passive mode using Open Path-FTIR
  - Standoff Raman detection of HEMs at very long ranges (> 140 m). Bulk detection of AN.
  - TNT detection of samples of 2 mm in diam. at 60 m range.
  - Began discrimination and quantification studies: for both remote Raman and IR detection
  - Began 2 transition projects (YR-3) and planned 2 more (YR-4) in collaboration with industries in MA: Agiltron, Block Engineering, Headwall Photonics and EOS Photonics.
- Long range Impact:
  - The expected overall outcome of this project is to improve significantly the current state of development of vibrational standoff detection of HEM/HME.
  - Results will impact remote detection of other threats: chemical and biological nature.

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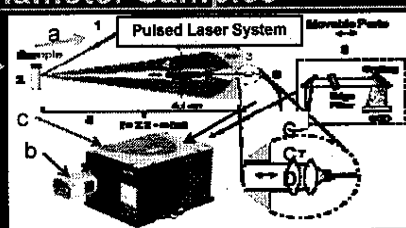
F2-F RRS Detection: Improved Range & Measurements of Small Diameter Samples

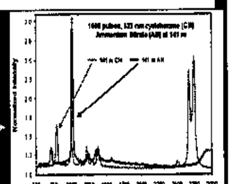
Improvements in design of RRS:

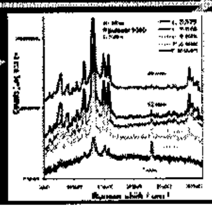
1. Began transition of CW lasers to pulsed laser based RRS systems.
2. Detector: adapted a time-gated Intensified-CCD
3. Spectrograph: switched to high throughput system
4. Telescope: switching from 12.7 to 25.4 cm (diam.) UV-VIS imaging telescope.

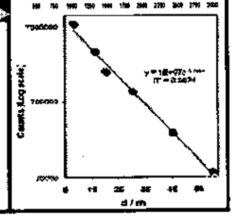


Project Outcomes:

- Measured ammonium nitrate (AN) and cyclohexane at 60-141 m.
- Studied range dependence of collected Raman signal (TNT samples)
- Began limit of detection (LOD) studies for several HEM
- Discrimination/quantification studies are scheduled to begin in second half of YR-3 and to continue in YR-4.



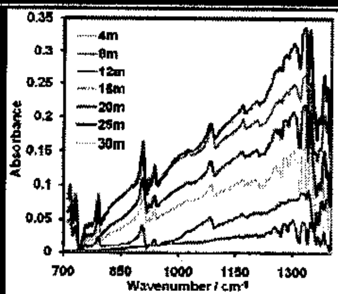




F2-F RIRS Detection: Range & Surface Loadings

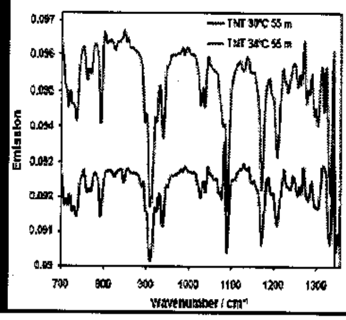
Active mode RIRS detection of TNT: →

- Active mode sensing: both source and collector were IR telescopes coupled.
- Detection of traces of TNT on aluminum plates
- Range: source-collector distances ~ 4-30 m.
- Surface concentrations: 50-400 μg/cm^2.
- Quantification studies for TNT surface loadings to 25 m (range) achieved with high significance.



Passive mode RIRS detection of TNT: →

- Tungsten lamp stimulated thermal excitation of sample at 25-32°C (ΔT: -1 to -7°C).
- IR spectra of 50-400 μg/cm^2 TNT on Al.
- Range: source-collector distances ~ 8-60 m.
- Emission spectra: from 700 to 3200 cm^{-1}.
- Quantification of TNT on Al to 60 m with high significance.



F2-F Subproject: Algorithms for Improvements of Data Analysis in Remote HEM Detection

M. Vélez-Reyes, S. Hernández-Rivera (UPRM); M. Diem (NU)

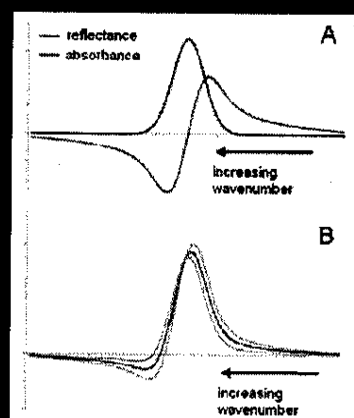
Subproject: Correction of band shape distortions in RIRS

Purpose:

- IR spectra collected in diffuse or specular reflection mode need to be corrected for reflective band shape artifacts.

Background:

- Dispersive band shape (blue trace, Figure 1A) is mixed with absorptive band shape (red trace) in reflectance measurements.
- Extent of mixing depends on nature of substrate, angle of incidence and sample morphology (granularity).
- Various amounts of dispersive band shape contributions cause band distortions, and confounded peak positions (up to 20 cm^{-1}) and intensities.



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F2-F Subproject: Algorithms for Improvements of Data Analysis in Remote HEM Detection

Importance for Standoff Detection:

- Automatic search algorithms to match observed spectral signatures against databases may miss explosive threads

Innovative Aspect / Methods:

- Two correction approaches were developed:
  - ❖ Multivariate method, using known reference spectra and the "Extended Multiplicative Signal Correction", reported earlier[1]
  - ❖ Fourier – based phase correction (PC) method[2]. In the theory of NMR[3] and Fourier Transform IR[4] spectroscopy, PC is a well-known procedure to assure symmetric line shapes. Confounded spectra are phase corrected in Fourier space and re-transformed to yield spectra that can be compared to, and perfectly match with reference spectra.

[1] B.Bird, M. Miljković and M. Diem "2 step resonant Mie scattering correction of infrared microspectral data", (2010) *J. Biophotonics* 3, 597-608
[2] M. Miljković, B. Bird, M. Silevitch and M. Diem, NU Patent Disclosure, Feb 2011
[3] J. Hornak, http://www.cis.rit.edu/htbooks/nmr/
[4] P.R.Griffiths and J.A. de Haseth, (1986). Fourier Transform Infrared Spectrometry. New York, John Wiley & Sons

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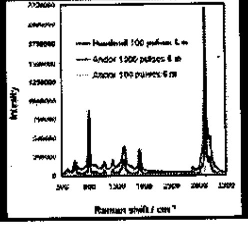
F2-F Four Transitional Projects With Industrial Partners in Remote Detection of HEM/HME

PROJECT I ~ HEADWALL:
Optimizing Imaging Spectrograph For Remote Raman Detection Experiments

- Use of Headwall's Raman Explorer™ in lieu of a Czerny-Turner spectrograph for our RRS has led to a 20-fold improvement.
- By redesigning the imaging spectrograph (working with Headwall) a more compact, lighter and higher throughput unit can be attained which in turn should result in further improvements of range and lower limits of detection in RRS experiments.



Raman Explorer vs. Shamrock
Peak heights ~ 21.3 : 1.0

PROJECT II ~ AGILTRON:
Mobile Device Operated Handheld Raman Spectrometer

A breakthrough in the area of handheld solutions for First Responders:

- development of Raman system with capabilities to detect and identify HEM and to transmit in a bidirectional way data from the field to a central database using a Smartphone.
- main objective: to develop a spectral database for in-field detection of HEM.
- evaluate detection of
  - explosives mix: pentolite and ANFO
  - explosives formulations: C-4 and SEMTEX
  - HME

Agiltron's PinPointer™ handheld Raman system controlled by Smartphone

F2-F Four Transitional Projects With Industrial Partners (Cont.)

PROJECT III ~ BLOCK ENG.:
QCL Scanner HE Proximity Detector

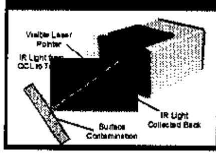
ALERT research teams will test this unit for detection of HEM/HME and develop algorithms to enhance detection, particularly addressing two main of explosives research:

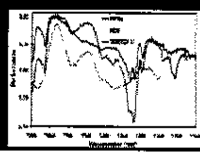
- Interferents: effects of substrates, mixtures and atmospheric interferences
- Differentiating Explosives from Background: Differential spectroscopy can discriminate between a substance of interest and background by looking at a large area to train the algorithm on what the background is and the differences when it encounters contamination.

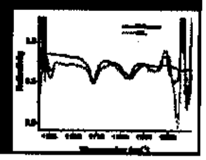
PROJECT IV EOS PHOTONICS:
QCL excitation sources for RIRS

Current limitations in RIRS detection of HEM/HME: range and low limits of detection (LOD) resides primarily in the excitation source when using Open Path FTIR.

- Development of QCL lasers with high power (> 3 W, CW) and broad excitation envelope (800-1600 cm^{-1}; 6-12 μm).
- Adaptation to reflective MIR telescopes is proposed. Figures shown depict the proof of concept of the idea in which a modest power QCL and an OP-FTIR (without the collection telescope) were capable of measuring TNT spectra of samples < 1 mg on a reflective metal substrate.







F2-F ALERT Project Statistics: Research & Education

FACTORS	YR-1	YR-2	YR-3
Faculty Involved	1	2	1
Post-doctoral	0	0	0
Graduate Students	2	3	11
Undergraduate Students	2	4	6
Papers Published	0	14	14*/6**

FACTORS	MS	PhD
YR-1	2	3
YR-2	2	1
YR-3	1	2

*Papers published in YR-3 as of Feb/2011.

**Papers submitted in YR-3 as of Feb/2011

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F2-F Project Publications: YR-3 Published + Accepted: 14

1. Hernández-Rivera, S.P. Castro-Suarez, J.R., Pacheco-Londoño, L.C., Rey-Villamizar, N., Vélez-Reyes, M. and Diem, M., MID-Infrared Vibrational Spectroscopy Standoff Detection of Highly Energetic Materials: New Developments, Spectroscopy Magazine Defense and Security Supplement, April, 2011.
2. Hernández-Rivera, S.P. and Infante-Castillo, R., Predicting heats of explosion of nitrate esters through their NBO charges and 15N NMR chemical shifts on the nitro groups, **2011**, Comput. Theor. Chem. ACCEPTED.
3. Peña-Quevedo, A.J., Laramee, J.A., Durst, H.D. and Hernández-Rivera, S.P., Cyclic Organic Peroxides Characterization by Mass Spectrometry and Raman Microscopy, **2011**, *IEEE J. Sensors*, ACCEPTED.
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5. Hernández-Rivera, S.P. and Infante-Castillo, R., A systematic theoretical investigation of the relationship between heats of detonation and NBO charges and ^{15}N NMR chemical shifts of nitro groups in nitramines and nitro paraffins, **2010**, 960: 57-62.
6. Ramirez, M. L., Félix-Rivera, H. Sánchez-Cuprill, R. A. and Hernández-Rivera, S. P., Thermal-spectroscopic characterization of acetone peroxide and acetone peroxide mixtures with nitrocompounds, **2010**, *J. Therm. Anal. Calorim.* 102 (2): 549-555.
7. Wrable, M., Primera-Pedrozo, O.M., Pacheco-Londoño, L.C. and Hernandez-Rivera, S.P. "Preparation of TNT, RDX and Ammonium Nitrate Standards on Gold-on-Silicon Surfaces by Thermal Inkjet Technology", **2010**, *Sens. Imaging.* 11: 147-169.
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9. Hernández-Rivera, S.P. and Castillo-Chará, J., *Ab initio*, DFT calculation and vibrational analysis of 2,4,6-trinitrotoluene, **2010**, *Vib. Spectrosc.* **53**: 248–259.

83

F2-F Project Publications: YR-3 (cont.)

10. Espinosa-Fuentes, E.A., Peña-Quevedo, A.J., Pacheco-Londoño, L.C., Infante-Castillo, R. and Hernández-Rivera, S.P., A Review of Peroxide Based Homemade Explosives: Characterization and Detection, in "Explosive Materials: Classification, Composition and Properties", Janssen, T.J., ed., Chemical Engineering Methods and Technology Series, Nova Science Publishers, Inc. Hauppauge, NY fourth quarter **2010**, ISBN: 978-1-61761-188-9.
11. Hernández-Rivera, S.P., Pacheco-Londoño, L.C., Ortiz-Rivera, W., Castro-Suarez, J.R., O.M. Primera-Pedrozo and Félix-Rivera, H., Remote Raman and Infrared Spectroscopy Detection of High Explosives, in "Explosive Materials: Classification, Composition and Properties", Janssen, T.J., ed., Chemical Engineering Methods and Technology Series, Nova Science Publishers, Inc. Hauppauge, NY, fourth quarter **2010**, ISBN: 978-1-61761-188-9.
12. Fierro-Mercado, P.M., Primera-Pedrozo, O.M., Hornedo, A., Hernández-Rivera, S.P., An In situ FTIR Fiber Optic Method for the Detection of Active Pharmaceutical Ingredients and Excipients on Metallic Substrates, in "Fourier Transform Infrared Spectroscopy: Developments, Techniques and Applications", Rees, O.J., ed., Chemical Engineering Methods and Technology Series, Nova Science Publishers, Inc. Hauppauge, NY, third quarter **2010**, ISBN: 978-1-61668-835-6.
13. Pacheco-Londoño, L.C., Primera-Pedrozo, O.M., Hernández-Rivera, S.P., Evaluation of Samples and Standards of Energetic Materials on Surfaces by Grazing Angle-FTIR Spectroscopy in "Fourier Transform Infrared Spectroscopy: Developments, Techniques and Applications", Rees, O.J., ed., Chemical Engineering Methods and Technology Series, Nova Science Publishers, Inc Hauppauge, NY, third quarter **2010**, ISBN: 978-1-61668-835-6.
14. Primera-Pedrozo, O.M., Soto-Feliciano, Y.M., Pacheco-Londoño, L.C., Hernández-Rivera, S.P., Fiber Optic-Coupled Grazing Angle Probe-Fourier Transform Reflection Absorption Infrared Spectroscopy for Analysis of Energetic Materials on Surfaces, in "Fourier Transform Infrared Spectroscopy: Developments, Techniques and Applications", Rees, O.J., ed., Chemical Engineering Methods and Technology Series, Nova Science Publishers, Inc. Hauppauge, NY, third quarter **2010**, ISBN: 978-1-61668-835-6.

84

F2-F Project Publications: YR-3 Submitted: 6

1. Hernández-Rivera, S.P. and Infante-Castillo, R., Predicting the heat of explosion of nitroaromatic compounds through their NBO charges and the ^{15}N NMR chemical shifts of the nitro groups, **2011**, Comput. Theor. Chem.
2. Espinosa-Fuentes, E.A. Pacheco-Londoño, L.C. Barreto-Cabán, M.A. and Hernández-Rivera, S.P. Novel Uncatalyzed Synthesis and Characterization of Diacetone Diperoxide, **2011**, Propellants Explos. Pyrotech.
3. Castro-Suarez, J.R., Pacheco-Londoño, L.C., Vélez-Reyes, M. Diem, M., Tague, Jr., T.J. and Hernandez-Rivera, S.P., Open-Path FTIR Detection of Explosives on Metallic Surfaces, InTech Book: Fourier Transforms, Theory and Applications", 978-953-7619-X-X.
4. Primera-Pedrozo, O.M., Pacheco-Londoño, L.C. and Hernandez-Rivera, S.P., Applications of Fiber Optic Coupled-Grazing Angle Probe FT Reflection-Absorption IR Spectroscopy, InTech Book: Fourier Transforms, Theory and Applications", 978-953-7619-X-X.
5. Castro-Suarez, J.R., Pacheco-Londoño, L.C., Vélez-Reyes, M. Diem, M., Tague, Jr., T.J. and Hernandez-Rivera, S.P., Open-Path FTIR Standoff Detection of TNT on Aluminum Surfaces, Applied Spectroscopy.
6. Pacheco-Londono, L.C., Aparicio-Bolaño, J. Primera-Pedrozo, O.M. and Hernandez-Rivera, S.P., Growth of Ag, Au, Cu, and Pt Nanostructures on Surfaces by Micropatterned Laser Image Formations, Applied Optics.

85

F2-G AIT for Whole Body Imaging
Carey Rappaport and Jose Martinez, NU

- **Purpose and Relevance:**
  Unbiased academic testbed for multi-modal sensors and algorithms for AIT
  - Optimize sensor configurations
  - Optimize scanning modes
- **Innovation:**
  - Multistatic radar
  - Model based vs. Fourier inversion
  - High resolution fused imaging
- **Year 3 (first 6 months of project) accomplishments:**
  - Designed, acquired parts and built rugged, flexible cylindrical scanning stage to mount radar hardware
  - Designed and built wideband 60GHz multistatic radar using COTS components
  - Acquired AS&E single-sided SmartCheck x-ray backscatter system through JAII
  - Created new fast model-based multistatic portal-specific algorithms for detecting manmade objects on skin
- **Long Range Impact / Relevance:**
  - Improved resolution with reduced intensity non-ionizing radiation
  - Minimal artifacts from dihedrals
  - Full depth information presented

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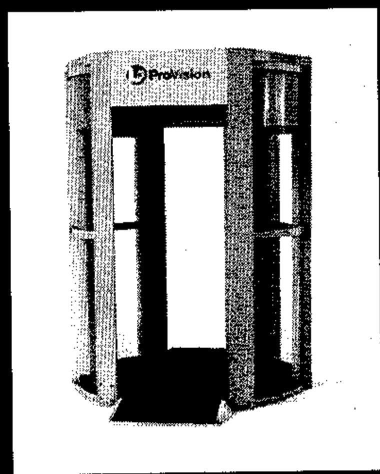
F2-G Current State-of-the-Practice Example: L3 ProVision mm-Wave Imager

- TSA qualified Advanced Imaging Technology (AIT) system
- Detects many types of materials based on shape (metallic and non-metallic): liquids, gels, plastics, metals, ceramics
- Uses two linear antenna arrays, scans through 240 degrees
- Limitations
  - "Dead Spots"
  - No spectroscopic info
  - Limited views
  - Poor penetration through leather and metallic clothing
  - No penetration through skin or into body cavities



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F2-G 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

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F2-G Whole Body Imaging Testbed Plan

- Acquire precision portal multi-axis sensor array positioning system
  - Designed to accommodate various types of sensors
    - Separately, for analysis
    - Together, to test fused sensor information
    - Built to be flexible for reconfiguration
- Provide access to raw measurement data
  - Allows specific, modality-based inversion
  - Allows joint modality reconstruction
- Ultimate Goals
  - Establish performance metrics for sensor modalities
  - Develop and evaluate novel inversion and multi-modal threat detection algorithms

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F2-G AIT for Whole Body Imaging

- Year 4 Proposed Work
  - Test and validate wideband radar hardware
  - Apply new reconstruction algorithms to measured multistatic portal data
  - Electronically scan illumination across full body for 2D image reconstruction
  - Optimize antenna placement for most efficient effective imaging
  - Investigate SmartCheck x-ray imaging capabilities and opportunities
  - Continue undergrad research in modeling, signal processing, and material characterization – pipeline for grad research

Faculty Involved	2
Post-doctoral	2
Graduate Students	3
Undergraduate Students	4
Papers Published/Submitted	0
Presentations by Students	2

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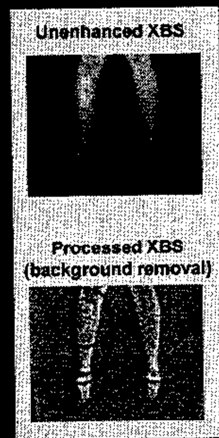
F2-G Advanced Imaging Technology – XBS Analysis
H. Pien, MGH

- Motivation and purpose:
  - Apply medical imaging science to x-ray backscatter (XBS) data
  - Examined ability to perform consistent subjective assessment and image pre-processing
- Year 3 accomplishments
  - Developed a robust methodology for subjectively assessing XBS data
  - Three PhDs acted as TSO's to assess 100 runs and 246 coupon placements and produced highly consistent results
- Year 2 results
  - Examined conspicuity as a function of
    - Coupon, location, material, coupon orientation, and pose
  - Developed approaches to enhance conspicuity of coupons
  - Most conclusions are SSI



F2-G Advanced Imaging Technology – XBS Analysis

- Publications / Reports
  - Final report submitted to ALERT in January
    - SSI document
- Relevance
  - Using best practices from radiology to provide feedback to DHS on the impact of the number of poses and coupon locations on the concept of operations
- Year 4 Plan
  - Expand conspicuity study to millimeter wave (MMW) data
  - Develop XBS-based anomaly detection pre-screening algorithm
    - Approach 1: two-class discrimination problem on small over-lapping tiles over the image
    - Approach 2: statistical model of "normal" anatomy and assess deviations from normal
  - Develop XBS/MMW-based fusion and anomaly detection algorithm
    - Requires SNL to collect "registered" XBS/MMW datasets
- Long range impact
  - Improved robustness of AIT checkpoint screening
  - Training and education of students and researchers in security screening

Trace Explosives Detection

The challenge for trace detection of explosives is to correctly identify a threat based on explosives hidden behind a barrier (metal, packaging, clothes, etc.). This requires being able to identify small amounts of residual materials (**picograms** or less) on the surface of the sample or low concentrations (**parts per trillion** or less) of vapor.

Collected Sample – requires processing	Near (cm) Sample – gas phase	Remote (m) Sample – gas or surface phase
Y. Zeiri, Ben-Gurion Studies of sampling challenges – fundamental interactions of explosives particles with substrate surfaces.	O. Gregory, URI Arrays of metal oxide catalysts decompose analytes; pattern recognition of the heat flow achieves selectivity and sensitivity.	Y. Silberberg, Weitzmann Fundamental studies of laser pulses shapes are used to be able to collect Raman spectra from large distances.
G. Eiceman, NMSU Fundamental studies of the reactions undergone in classical IMS detection. The goal is to improve the sensitivity of IMS.	N. Lewis, Cal Tech Arrays of polymers & composites absorb analytes; pattern recognition of electrical resistivity achieves selectivity and sensitivity.	
R. Narayanan, URI Development of a solution phase Raman spectroscopic method using signal amplification from gold nanoparticles.	W. Euler, URI Specific fluorescent or absorption modulation gives selectivity; large surface area substrates achieve sensitivity.	

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F2-H: Particle adhesion to substrates and their efficient collection
Faculty: Yehuda Zeiri Students: Paz Elia, Yevgeny Zakon, Ben-Gurion Univ.

Purpose/ Relevance: Determine the adhesion forces between explosive articles and various substrates of interest at different conditions.

Approach: The measurements carried out utilizing both AFM measurement and aerodynamic jet experiments. The later approach also allows us to improve particle collection in gates at airports.

Overview of completed/iterative outcomes:

- A large set of experiments using the AFM approach was carried out to characterize the interaction between three explosives (RDX, PETN and HMX) and various substrates including: glass, metal, car color coupons and polypropylene samples.
- Experiments using the aerodynamic gas jet method were carried out to study the influence of particle size, substrate morphology roughness and existence of finger prints on particle-surface adhesion forces.
- The strength of the interaction between single monolayers with various end groups and four explosives were measured using the AFM approach.

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F2-H Cont'd: Particle adhesion to substrates & their efficient collection

Overview of future work:

- Use a very fast camera to study the temporal details of the particle removal using aerodynamic inert gas jets.
- Carry out simulation of the experiment using the Discreet Element Method (DEM).
- Try to measure and characterize adhesion forces between sub micron particles and various substrates.
- Extend the AFM measurements to more explosives and substrates of interest.

Purpose: **Activity 1-** Analysis of the time evolution of a particle-substrate system exposed to an inert gas pulse. Such characterization may. be very helpful in the optimization of sample collection systems.

- **Current work:** The aerodynamic jet experiments carried out at present compare the initial and final particle distribution on the substrate (before and after the gas pulse). These were carried out in a large variety of experimental conditions simulating different scenarios.
- **Future work:** Recording of the experiments using a very fat camera will allow to follow the evolution of the particle-substrate system during the gas pulse with a time resolution of about 10 micro-seconds. Such information will shade light on the details of the gas-jet interaction with the particles and the substrate.

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F2-H Cont'd: Particle adhesion to substrates and their efficient collection

Purpose: **Activity 2-** Numerical simulation of the aerodynamic gas jet experiments will allow a direct comparison with the results obtained in the fast photography experiments. These simulations are expected to enhance our understanding of the sample collection process using air jets.

- **Current work:** No numerical simulations have been carried out till now.
- **Future work:** We plan to use the DEM approach to describe the time evolution of single as well as multiple particles on substrate during their exposure to a gas jet. The equations of motion to be solved will incorporate the forces applied by the gas jet on the particle.

Purpose: **Activity 3-** Adhesion force measurement of sub-micron particles using the aerodynamic method is difficult since the particles cannot be seen via the light microscope. We shall try to utilize sub-micron fluorescent particles to carry out these measurements under a fluorescence microscope.

- **Current work:** We purchased fluorescent polystyrene particles with different diameter sizes in the range of 200 nm p to 5 microns. The particles are sold in a liquid suspension and we had difficulties to prepare a homogeneously dispersed dry sample of particles on a substrate.
- **Future work:** The main goal during the coming year is to develop a procedure to prepare good reproducible samples of sub-micron particles for the aerodynamic experiments. A number of approach will be examined.

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F2-H Cont'd: Particle adhesion to substrates and their efficient collection

Purpose: **Activity 4** – Extension of AFM force measurements to more explosives and additional substrates will extend our understanding of a larger variety of systems. In particular we plan to carry out measurements using "soft" substrates such as rubber, different clothes and various nylons (and other elastic polymers).

- **Current work:** Few preliminary experiments have been carried out using a rubber substrates.
- **Future work:** Adhesion force measurements for four different explosives on rubber (2-3 different types), nylon 6-6, PFPE (teflon), cotton and silk will be attempted.

ZEIRI ALERT PROJECT METRICS: Prof. Yehuda Zeiri (faculty), Mr. Paz Elia (PhD student), Undergraduate Research Assistant (1), Mrs. Raya Zach (technitian)

PUBLICATIONS

Arcady P. Gershanik and Yehuda Zeiri, J. Phys. Chem. A 2010, **114**, 12403–12410 .

A continueation paper was submitted for publication:

Arcady P. Gershanik and Yehuda Zeiri, "Sublimation rate of Energetic Materials in air: RDX and PETN " Submitted to J, Phys. Chem. A.

Two additional papers related to particle–substrate adhesion force measurements (by AFM and by aerodynamic approaches) are being written at present.

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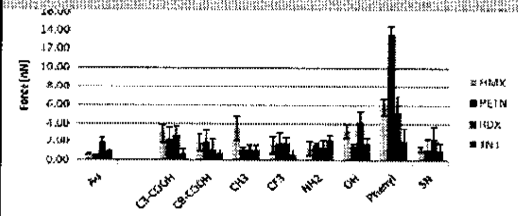
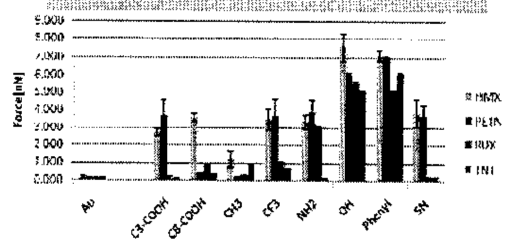
Sample of measurements carried out this year:

AFM force measurement – under water



AFM force measurement – in air



Adhesion force measurements between a gold plated tip covered with a monolayer of molecules with different end groups. The horizontal axis describes the different molecular-end groups examined.

Measurements under water eliminate contributions of capillary forces.

Measurements in air correspond to forces due to dispersion interactions as well as contributions from forces related to capillary condensation.

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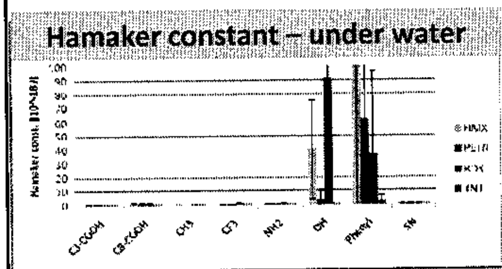
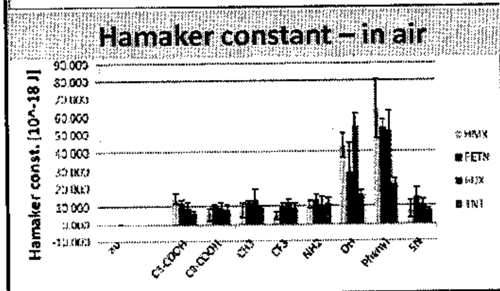
Cont'd: Sample of measurements carried out this year:





Hamaker constants obtained from the distance at which "jump-to-contact" occurred. Derived from force measurements between a gold plated tip covered with a monolayer of molecules with different end groups.

The horizontal axis describes the different molecular-end groups examined.

Measurements under water eliminate contributions of capillary forces.

Measurements in air correspond to forces due to dispersion interactions as well as contributions from forces related to capillary condensation.

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F2-H Cont'd: Particle adhesion to substrates and their efficient collection

Transition to Industry or Collaboration with Industry:

The group is in continues contact with various end users, in particular with a group in the Prime Minister Office.

Picture:

A short movie describing the variation of number of particles on a substrate during an aerodynamic experiment to study adhesion forces will be available soon.

100

F2-I: Decomposition rate constants, heats of associations, and ion lifetimes of explosives in air at ambient pressure

G.A. Eiceman, R. Rajapakse, M. Menlyadiev, New Mexico State University

- **Purpose/ Relevance**: Determine kinetic and thermodynamic properties (in title) of gas phase ions of explosives at ambient pressure using a broad selection of high explosives and improvised explosives.
- **Innovation**: No measurements or understandings of these properties are reported for explosives and yet these properties underlie the fundamentals of response in trace detectors of all kinds where atmospheric pressure ionization is employed including mass spectrometers and mobility spectrometers.
- **This Year outcome**: The thermal properties of product ions of a range of explosives including chloride adduct ions for DNT, TNT, and PETN were found to exceed temperatures of 240°C with ion lifetimes in excess of 20 ms in air at ambient pressure.
- **Long-range impact**: These ions are more robust than previously expected and could influence design considerations on designs of automated sampling of materials and designs of new generations of trace detectors.
- **Picture:**

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Decomposition rate constants, heats of associations, and ion lifetimes of explosives in air at ambient pressure

G.A. Eiceman, R. Rajapakse, M. Menlyadiev, New Mexico State University

- **Education Students Present & Graduate**:
- PhD Student, X. An, graduated with thesis entitled: KINETICS OF DECOMPOSITION OF GAS PHASE IONS OF ESTERS AND KETONES IN AIR AT AMBIENT PRESSURE USING DIFFERENTIAL MOBILITY SPECTROMETRY AND ION MOBILITY SPECTROMETRY, staff at company in Houston, TX
- PhD Student- R. Rajapakse, thesis work in progress
- PhD Student -M. Menlyadiev , thesis work in progress
- **Papers/Patents/Presentations**:
- FIELD DECOMPOSITION OF IONS IN DIFFERENTIAL MOBILITY SPECTROMETRY, 19th International Conference for Ion Mobility Spectrometry, Albuquerque, NM July 19, 2010.
- **Transition to Industry or Collaboration with Industry**:
- Beginning discussions with a company on sampling. Discussions with second company on proposal for innovative sampling of IEDs.
- **Next Year:** Extend temperature range of studies to 350C with improved materials in kinetic mobility spectrometry.

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F2-J: Gold Nanoparticles of Different Shapes as SERS Substrates for Detection of Ultralow Levels of Explosives

Radha Narayanan, Benjamin Saute, Nicole Cook, URI

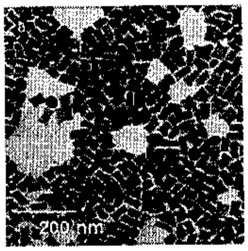
THE UNIVERSITY OF RHODE ISLAND

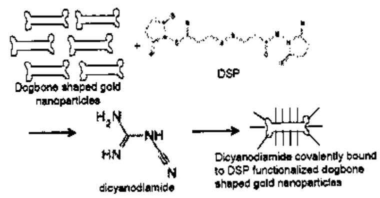
Purpose/ Relevance: The goal is to use a solution based direct readout surface enhanced Raman spectroscopy (SERS) method as a quantitative analytical tool for detection of ultra-low levels of important explosives.

Approach: Gold nanoparticles of different shapes in colloidal solution have not been used as colloidal SERS substrates for the detection of explosives. We are developing a solution based direct readout SERS method for detection of ultra-low levels of explosives in solution.

Overview of Completed/Iterative Outcomes: SERS data have been obtained for solution based, direct readout SERS based detection of ultra-low levels of dicyanodiamide using dogbone shaped gold nanoparticles functionalized with DSP

Overview of Future Work: We will be monitoring the SERS intensity as a function of dicyanoamide concentration to determine the limit of detection.





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Gold Nanoparticles of Different Shapes as SERS Substrates for Detection of Ultralow Levels of Explosives

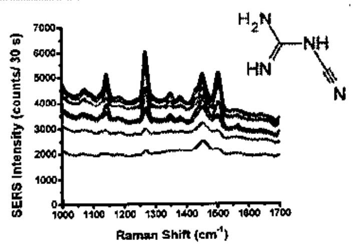
Radha Narayanan, Benjamin Saute, Nicole Cook, URI

THE UNIVERSITY OF RHODE ISLAND

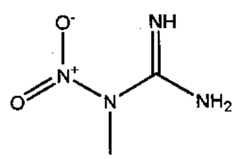
Purpose: The goal is to use dogbone shaped gold nanoparticles as colloidal SERS substrates for detection of ultralow levels of dicyanodiamide and methylnitroguanidine explosives.

Current Work: SERS data have been obtained for solution based, direct readout SERS based detection of ultra-low levels of dicyanodiamide. A calibration curve is being plotted to determine the limit of detection for dicyanodiamide.

Future Work: Obtain SERS spectra for methylnitroguanidine, which also forms a covalent amide bond when reacted with DSP functionalized dogbone shaped gold nanoparticles.



SERS Spectra of dicyanodiamide



methylnitroguanidine

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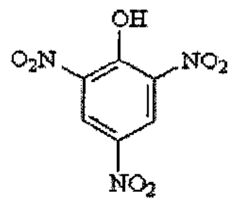
Gold Nanoparticles of Different Shapes as SERS Substrates for Detection of Ultralow Levels of Explosives
Radha Narayanan, Benjamin Saute, Nicole Cook, URI
THE UNIVERSITY OF RHODE ISLAND

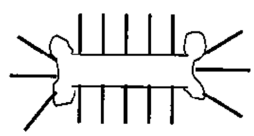
Purpose: **The goal is to use dogbone shaped gold nanoparticles as colloidal SERS substrates for detection of ultralow levels of the explosive, picric acid.**

Current Work: **The picric acid can be deprotonated by adjusting the pH of the solution to be basic. The optimal pH that can be used for obtaining deprotonated picric acid is currently being determined.**

Future Work: **Obtain SERS spectra for picric acid, which can covalently bind to the gold nanoparticles through the Au-O bond. Determine the limit of detection for picric acid.**



Picric acid



| = picric acid

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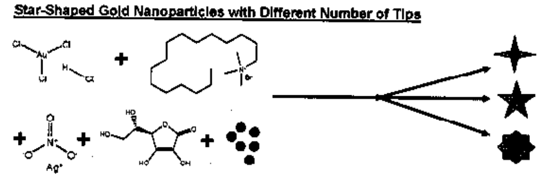
Gold Nanoparticles of Different Shapes as SERS Substrates for Detection of Ultralow Levels of Explosives
Radha Narayanan, Benjamin Saute, Nicole Cook, URI
THE UNIVERSITY OF RHODE ISLAND

Purpose: **The goal is to synthesize star-shaped gold nanoparticles to harness the lightning rod effect which results in higher SERS enhancements and lower limits of detection.**

Current Work: **Star-shaped gold nanoparticles are currently being synthesized. Also, modifications of the synthesis to result in different number of tips or lobes in the star-shaped gold nanoparticles are also being investigated.**

Future Work: **Obtain SERS spectra for the explosives: dicyanodiamide, methylnitroguanidine, and picric acid using the star-shaped gold nanoparticles. Plot a calibration curve of the SERS intensity as a function of the concentration. Compare the limits of detection to those obtained using dogbone shaped gold nanoparticles.**

Star-Shaped Gold Nanoparticles with Different Number of Tips



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Gold Nanoparticles of Different Shapes as SERS Substrates for Detection of Ultralow Levels of Explosives

Radha Narayanan, Benjamin Saute, Nicole Cook, URI

THE UNIVERSITY OF RHODE ISLAND

Project Metrics: Dr. Radha Narayanan (Faculty), Benjamin Saute (Ph.D. student), Nicole Cook (undergraduate student)

Papers & Presentations:

Paper: Saute, B.; Narayanan.R, "Solution-Based Direct Readout Surface Enhanced Raman Spectroscopic (SERS) Detection of Ultra-Low Levels of Thiram with Dogbone-Shaped Gold Nanoparticles", *Analyst*, 2011, *136(3)*, 527-532.

Presentation: 240th ACS National Meeting, August 22-26, 2010, Poster, "Colloidal Dogbone Shaped Gold Nanoparticles as Surface Enhanced Raman Spectroscopy (SERS) Substrates for Detection of Thiram", Benjamin Saute and Radha Narayanan

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F2-K: A Persistent Surveillance Technique for the Detection of Explosives and Explosive Precursors

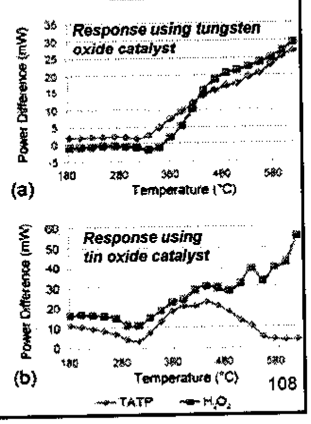
(Faculty: O.J. Gregory, M.J. Platek; URI; Students: Y. Chu, K. Waterman, C. Hurley, M. Amani)

University of Rhode Island

Purpose/Relevance: To develop an inexpensive metal-oxide gas sensor that is capable of unambiguously detecting trace levels of target gases. With our sensor, explosives and explosive precursors can be detected in air, under ambient conditions, using optimized combinations of metal oxides as catalysts.

Approach: Very low concentrations of specific target molecules can be detected with our gas sensors, which rely on a thermodynamic response, rather than a conductometric or other type of transducer response. A thermodynamic response occurs at a specific temperature for a given target molecule and catalyst, as the sensor is thermally scanned, similar to that in a microcalorimeter.

This Years Outcome: An inexpensive, robust gas sensor, capable of detecting TATP at levels less than 1 part per million, was developed using nickel microheaters coated with various metal oxide catalysts including tungsten oxide, iron oxide, vanadium oxide, copper oxide, zinc oxide and tin oxide.



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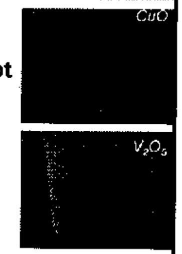
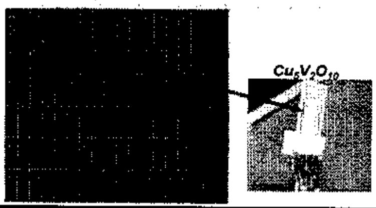
A Persistent Surveillance Technique for the Detection of Explosives and Explosive Precursors cont'd

University of Rhode Island

Innovation: A TATP gas detection platform was developed using nickel microheaters coated with different metal oxide catalysts. TATP contains neither metallic elements nor nitro groups, does not fluoresce and has no significant absorption in the ultraviolet region, suggesting that a non-spectroscopic approach for the detection of TATP has considerable merit. Novel catalysts were developed for the TATP sensors using combinatorial chemistry techniques in conjunction with co-sputtering from multiple oxide targets. Rapid screening protocols were facilitated by "printing" large arrays of sensor elements, so that a wide range of catalyst chemistries could be investigated for a specific target molecule.



Co-sputtered copper-vanadium-oxide library



Long-range impact: Arrays of microheater sensors containing individual "catalyst pixels", each optimized for a particular target gas, are envisioned. These sensors will be integrated onto a chip such that an unknown gas sample could be analyzed for a large number of potential threat molecules in real time.........a detection capability that persists in the presence of high concentrations of background gases.

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A Persistent Surveillance Technique for the Detection of Explosives and Explosive Precursors cont'd

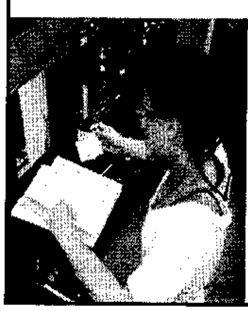
University of Rhode Island

Education: Present Students and Outreach: Yun Chu- PhD student in Chemical Engineering, Kellie Waterman and Caitlin Hurley - Undergraduate students in Chemical Engineering, Matin Amani- Undergraduate student in Electrical Engineering and Chemical Engineering, Mary Stoukides- chemistry teacher from Mount St. Charles High School.

Papers/Patents/Presentations for the year:

O.J. Gregory, H. Ghonem, M.J. Platek, J. Oxley, J. Smith, M. Downey, C. Cummiskey and E. Bernier, "Microstructural Characterization of Pipe Bomb Fragments", Materials Characterization, Vol.61, No. 3, p.347-354, (2010).

219th Electrochemical Society Meeting 2011, Montreal, Canada, "Detection of TATP Using Thermodynamic Based Gas Sensors with Metal Oxide Catalysts", Y. Chu, K. Waterman, C. Hurley, M. Amani and O.J. Gregory.



Microscopy and Microanalysis 2010, Portland, OR, "Characterization of Pipe Bomb Fragments using Optical Microscopy and Scanning Electron Microscopy", M.J. Platek, O. J. Gregory, T. Duarte, H. Ghonem, J. Oxley, J. Smith, E. Bernier.

Y. Chu, K. Waterman, C. Hurley, M. Amani, O.J. Gregory, "Detection of TATP Using a Thermodynamic Based Gas Sensor", submitted to Sensors Letters

"Thermodynamic Based Gas Sensors Using Metal Oxide Catalysts", O.J. Gregory, M. Platek and A. Cote, URI Patent Disclosure filed Feb. 2011

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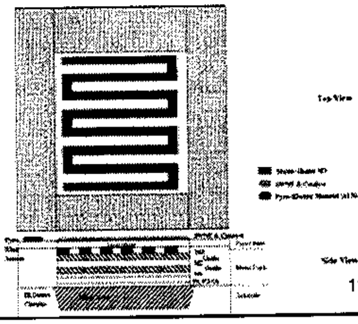
A Persistent Surveillance Technique for the Detection of Explosives and Explosive Precursors cont'd

UNIVERSITY OF Rhode Island

This Years Outcome: An inexpensive, robust gas sensor, capable of detecting TATP at levels less than 1 part per million, was developed using nickel microheaters coated with various metal oxide catalysts including tungsten oxide, vanadium oxide, copper oxide, zinc oxide and tin oxide.

Transition to Industry or Collaboration with Industry: We have collaborated with SensorTech, Inc. (Savannah, GA) over the past few years on gas detection protocols for the US Army and DARPA. Raytheon, Smiths and Draper Labs have engaged in dialogue regarding our technology and key personnel from these organizations are updated on a regular basis.

Next Year: Partnering with engineers from the Navy (NUWC) in Middletown RI, we are designing and developing a mixed-mode MEMS catalytic gas detector that incorporates free standing diaphragms with embedded microheaters in a silicon architecture to improve the response time and sensitivity of the sensor. This MEMS based sensor platform will initially be demonstrated using TATP as the target gas to show the improvement in performance metrics with this approach.



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F2-L: Optical Chemical Sensors using Nanocomposites from Porous Silicon Photonic Crystals & Sensory Polymers

PIs: William B. Euler, Igor A. Levitsky; Students: Drew Brodeur,[1] Meredith Matoian

THE UNIVERSITY OF RHODE ISLAND

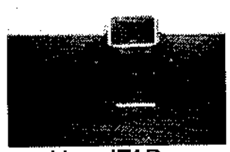
Purpose/Relevance: Improved sensitivity, selectivity, and adaptability for detection of low vapor pressure explosives such as TNT, RDX, PETN, etc.

Innovation: A high surface-area porous substrates filled with chemistry selective to explosives

This Year outcome: The sensor has been transitioned into working devices by Emitech, Inc.[2] Two versions have been made:

Picture:

Mark I:
Hand held
Mobile



Mark II:
Remote detection
Vehicle borne

Long-range impact: Emitech, Inc. is seeking ITAR approval for international commercialization. Filed deployment is anticipated in the next 12 – 18 months.

Next Year: New transducing materials for the sensor are being explored. In particular, introduction of quantum dots into the pores may lead to a quantum confinement effect that can be exploited.

[1] Ph. D. to be awarded May, 2011
Currently employed at Worcester Polytechnic Institute

[2] 150 Harvard Street, Fall River, MA 02720
Phone: (508) 324-0758, Fax: (508) 324-1139
Email: mkatayeva@emitechinc.com
Website: www.emitechinc.com

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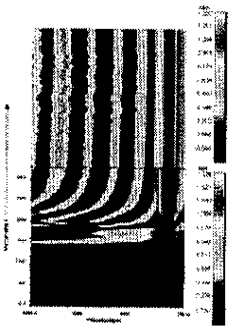
PIs: William B. Euler, Igor A. Levitsky; Students: Drew Brodeur,[1] Meredith Matoian
THE UNIVERSITY OF RHODE ISLAND

Goal 1: Rapid Spectroscopic Methods for Pore Characterization

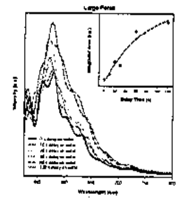
- FTIR Microscopy of unfilled pores

The spectra shown are a false color image the IR absorption spectrum (x-axis) as the detector is moved along a line on the sensor (y-axis). The image shows the transition from edge of the sensor, at the bottom, to the interior. At the edge there are no pores and the image is color is uniform, indicating no pore formation. In the middle of the image the curved stripes show the transition to the center of the sensor. The top of the image shows the uniform striping of the active sensor region, which is constant throughout.



- Fluorescence spectroscopy of filled pores

Pores filled with fluorescent MEH-PPV provide a characteristic signal that depends upon the pore depth. The figure shows the emission signal for pores filled to different depths. This is accomplished by delaying the initiation of spin-coating to allow the polymer to fill the pores. The inset shows the integrated area of the emission signal as a function of delay time.



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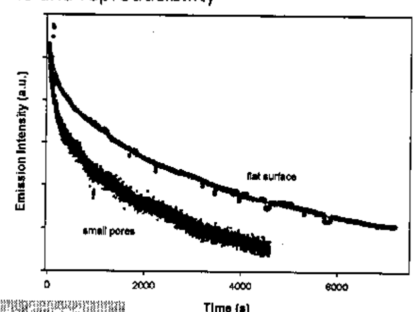
Optical Chemical Sensors using Nanocomposites from Porous Silicon Photonic Crystals & Sensory Polymers
PIs: William B. Euler, Igor A. Levitsky; Students: Drew Brodeur,[1] Meredith Matoian
THE UNIVERSITY OF RHODE ISLAND

Goal 2: Understanding Photobleaching of MEH-PPV

- Photobleaching of the polymer can limit lifetime and reproducibility

The pores influence the nature of the photobleaching, as shown in the figure to the right. The emission intensity as a function of time (with constant light exposure) is shown for a flat surface and for small pores (the pore size did not change the kinetic results). The kinetic data can be fit to a bi-exponential decay (shown in red). There also is an effect based on the solvent that the polymer is deposited from. The rate constants for various solvents are shown in the Table.



Deposition Solvent	[illegible]	[illegible]
chloroform	4.2	40.
methylene chloride	1.1	2.7
toluene	2.3	51
chlorobenzene	1.8	19.2
xylenes	3.3	47
1,2-dichlorobenzene	3.0	16

Solvents are listed in increasing order of boiling point

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"Optical Chemical Sensors using Nanocomposites from Porous Silicon Photonic Crystals & Sensory Polymers" "Fundamental Materials Research for Next Generation Sensors" PI: William B. Euler

THE UNIVERSITY OF RHODE ISLAND

- **Education Students Present & Graduate:**
  - Graduate students:
    - Drew Brodeur (Ph.D., May 2011, employed as a Lecturer at WPI)
    - Christopher Latendresse
    - Meredith Matoian
  - Undergraduate students
    - Eunhae Hwang (B. S., May, 2010, dental school , Boston University)
    - Sarah Decato (B. S. May, 2010, graduate school, UW – Madison)
    - Justin Gharavi (B. S. May, 2011)
    - Hyun Yang
    - Jungmin Hwang
    - Syrena Fernandes
  - High School teacher
    - Mark Bartley
- **Papers/Patents/Presentations:**

  "Optical Humidity Sensing and Ultrasound Effect for Mesoporous Silicon One-Dimensional Photonic Crystals," I. G. Kolobov, W. B. Euler, I. A. Levitsky, *Appl. Optics*, **2010**, *49*, 137.

  "Gas Phase Sensors for Bases Using Rhodamine B in Nafion Films," E. Hwang, I. A. Levitsky, W. B. Euler, *J. Appl. Polym. Sci.*, **2010**, *116*, 2425.
- **Transition to Industry or Collaboration with Industry:**
  - Emitech, Inc.

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F2-M: Fundamental Materials Research for Next Generation Sensors

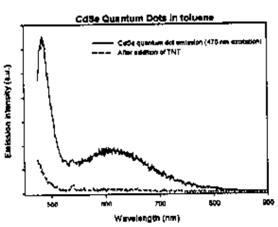
PI: William B. Euler; Students: Chris Latendresse, Jungmin Hwang

THE UNIVERSITY OF RHODE ISLAND

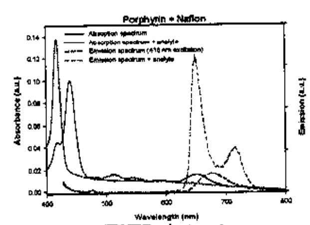
Purpose/Relevance: To develop inorganic/polymer hybrid nanomaterials with improved sensing capabilities.

Innovation: Design of inorganic/organic composites of nanometer dimensions tailored to provide ultrasensitive and selective response to trace levels of explosives, including TNT, RDX, TATP, and others.

This Year outcome:



New type of TNT detector: fluorescence quenching of CdSe quantum dots. Quenching is fast (seconds) but can be tuned by changing the size of the quantum dots.



New TATP detector

TATP $\rightarrow H_2O_2 + CH_3COCH_3$

Next Year: The above results are for solution phase. The set of experiments is to test against common interferants to establish selectivity and to determine the sensitivity of each approach. The sensor platform must also be transitioned to a solid mechanical support. For the quantum dots, these will be incorporated into porous silicon. For the porphyrin/Nafion system, the Nafion polymer will act as the support.

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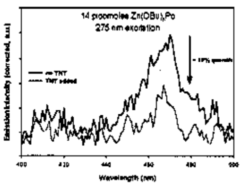
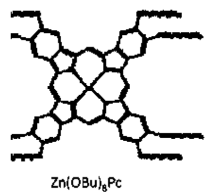
Fundamental Materials Research for Next Generation Sensors
PI: William B. Euler; Students: Chris Latendresse, Jungmin Hwang

Goal 1: Identify new fluorophores that can sensitively detect TNT

Porphyrins and phthalocyanines interact well with TNT with significant quenching. We have found that a variety of Rhodamine dyes and CdSe quantum dots also are quenched by TNT.

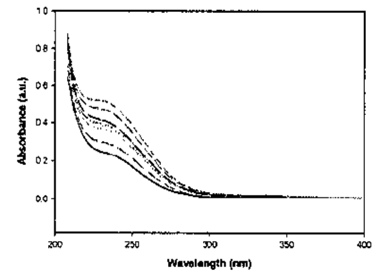




$Zn(OBu)_8Pc$

Goal 2: Exploit Meisenheimer chemistry to develop new sensors

UV Absorption Spectrum as TNT is added to a solution of dipropylamine. As TNT is added the formation of the Meisenheimer complex increases the absorbance at 240 nm.



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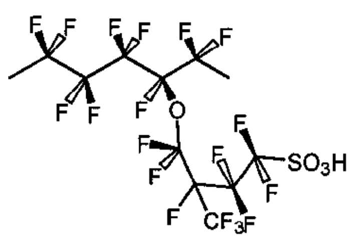
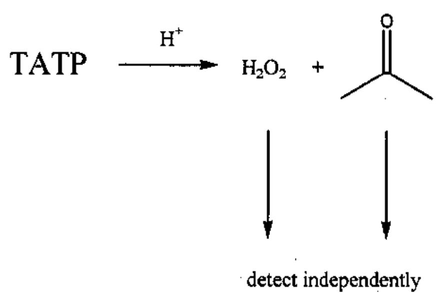
Fundamental Materials Research for Next Generation Sensors
PI: William B. Euler; Students: Chris Latendresse, Jungmin Hwang

Goal 3: Use the strong acid chemistry and pore structure of Nafion to prepare TATP sensors

Nafion is a perfluoropolymer with a sidechain containing a sulfonic acid group (pKa ~ −3). Both mechanically robust and chemically stable, Nafion forms a pore structure that allows a hydrophillic pocket around the acid group that can interact with analytes. The strong acid can decompose TATP into hydrogen peroxide and acetone. These are detected independently, giving a unique signature for the explosive.



Nafion



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F2-N: Shaped Femtosecond Pulses for Remote Chemical Detection

Yaron Silberberg, Weizmann Institute

Purpose/ Relevance: Remotely detecting and identifying traces of hazardous materials such as biological warfare agents and explosives via their molecular vibrational spectrum (CARS and SRS spectroscopy) that could provide an excellent fingerprint for chemical species identification.

Innovation: The group has demonstrated several pulse-shaping techniques allowing remote detection and identification of minute amounts of chemicals at a standoff (>10m) distance, using a single laser source of shaped femtosecond pulses. Through careful spectral-phase shaping, spectroscopic resolution more than 30 times better than the pulse bandwidth is obtained.

This Year outcome: "Shaperless" standoff remote detection of explosives traces using femtosecond pulses shaped by a special filter element. The Shaperless setup offers much simpler solution compared with our previous setups.

Long-range impact: Single laser beam standoff detection offers the most practical route for extracting vibrational information at large distances.

Next Year: Pushing distances to >20m and extending our methods beyond CARS, to include single pulse SRS.

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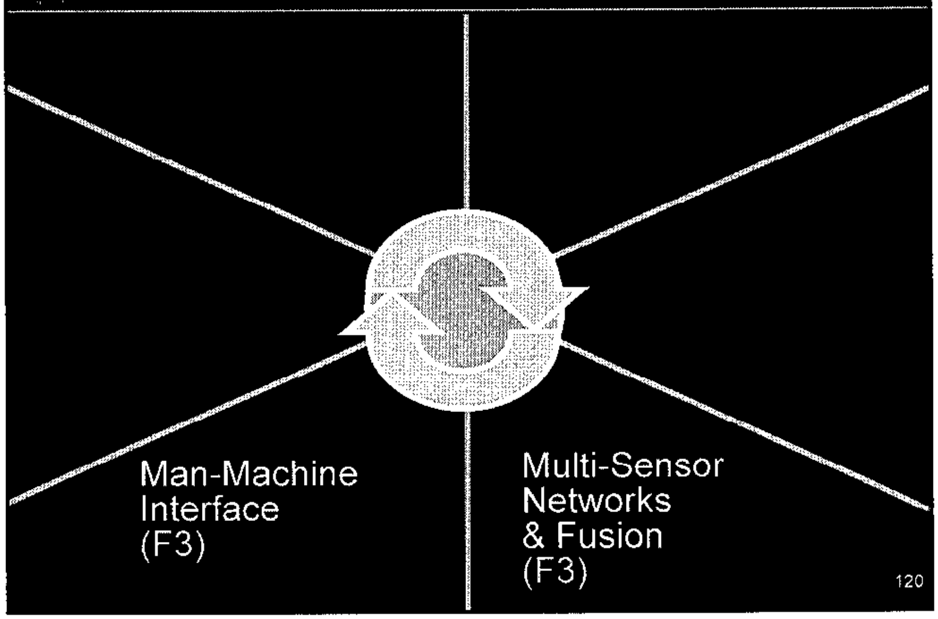
The ALERT Fundamental Science Program: Encompasses Multidisciplinary CIED Elements



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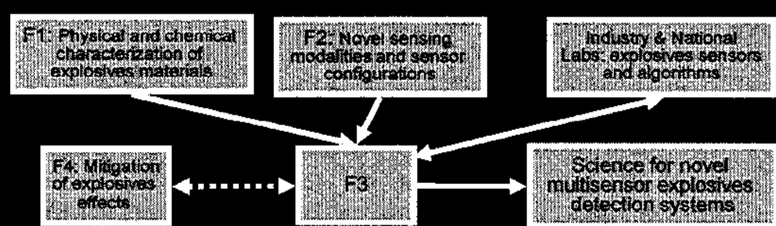
F3: Explosives Detection Systems
Lead: David Castañón, BU

- Design and implementation of novel explosive detection and identification systems
  - Multisensor systems
  - Unconventional approaches involving alternative signatures
- Major themes
  - Information fusion from heterogeneous sources
  - Sensor distribution and sensing control
  - Novel algorithms for extracting enhanced signature information and improved explosives detection and classification
  - Human factors both in system design and alternative signatures



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Portal and Standoff Systems

- Portal systems
  - Suite of sensors in controlled environments
  - Key requirements: detection accuracy, throughput, clutter rejection, integration with human operators
- Standoff systems
  - Spatially distributed, heterogeneous networks of sensors, perhaps mobile
  - Moving targets, lots of clutter → lots of data
  - Key requirements: area coverage, early detection, accurate warning





Current Projects

- Two groups of projects: Portal and Standoff
- Projects: Applications-motivated basic research
  - Connections to existing sensor concepts to provide representative domain components
  - Focus on fundamental basic research questions of design, processing and control to enhance system effectiveness
  - Exploit ties to industry, national labs and other DHS resources for assistance in concept evaluation
- Key cross-cutting themes
  - Principled foundations for information fusion in multisensor, multimodal systems
  - Enhanced automation for increased throughput
  - Improved detection/classification performance: reduced false alarms, improved accuracy
  - Active, adaptive management of information acquisition and processing
  - Emerging theories for systems design and architectural tradeoffs

Major Changes in Program

- F3-A Next Generation Image Formation
  - Added F3-A4 as outgrowth of summer collaboration with PNNL, AS&E
  - Added F3-A5 as new direction resulting from outreach to academia in critical area as result of ADSA workshops
- F3-B Multimodal Imaging for Portal-Based Screening
  - Deemphasize effort on THz diffraction tomography due to weak signal penetration
  - Refocus student into techniques for X-ray diffraction as orthogonal imaging to multi-energy CT
- F3-D Compressive Sensing
  - Refocused effort in compressive sensing as redundant with F3-A, instead working on new image formation techniques for enhanced segmentation
- F3-E Multimodal Sensor Networks
  - Terminating effort on group testing, refocusing students on compressed classification for robust recognition

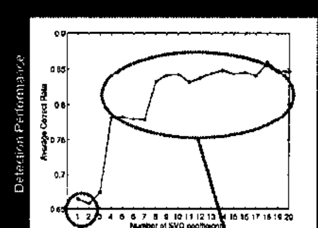
F3-A1: Next Generation Image Formation: Exploiting Energy Diversity in CT explosive detection

Faculty: W. C. Karl BU; Student: L. Eger, BU

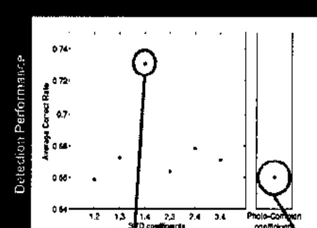
- Motivation and purpose:
  - Increased specificity and sensitivity of explosive detection
  - Reduction of false alarms for increased throughput
- Focus
  - Understanding of information available in multi-energy X-ray measurements
  - New and improved approaches using advanced signal processing and machine learning methods
- Year 3 accomplishments
  - Understand impact of different levels of spectral diversity on detection performance
  - New learning-based, classification-aware feature selection methods to improve classification performance
  - New, optimal, adaptive alternatives to Photo-Compton basis functions
- Impact
  - Understanding of fundamental limits of multi-spectral X-ray sensing
  - Improved methods of information extraction from multi-energy CT
  - Greater sensitivity and reduced false alarms in X-ray-based screening.

Exploiting Energy Diversity in CT explosive detection

- More information may be available in multi-energy CT than currently thought
- Current methods of information extraction may be sub-optimal



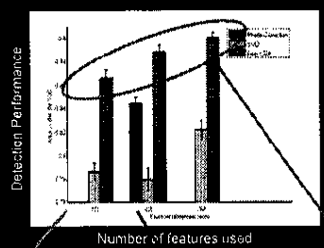
Number of features used

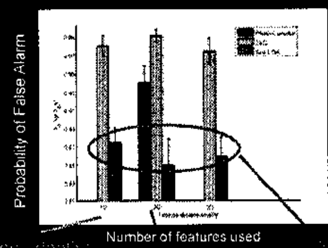


Different Choices of 2 Energy Features

Exploiting Energy Diversity in CT explosive detection

- New learning-based, adaptive features can improve performance
  - Choose features focused on *detection* rather than conventional *representation*





A single adaptive feature is better
than the two conventional features!

Exploiting Energy Diversity in CT explosive detection

- Publications
  - L. Eger, W. C. Karl, P. Ishwar, H. Pien, ``Classification-aware dimensionality reduction methods for explosives detection using multi-energy X-ray computed tomography," in Computational maging, C. A. Bouman, I. Pollak, P. J. Wolfe, editors, Proc. SPIE, Vol. 7873, SPIE, San Francisco, CA, January 23-27, 2010.
  - L. Eger, W. C. Karl, P. Ishwar, H. Pien, ``A Learning Based Approach to Explosives Detection Using Multi-Energy X-Ray Computed Tomography,". Proc. 2011 IEEE Int'l Conf. on Acoustics, Speech, and Signal Processing, Prague, Czech Republic, , May 22-27, 2011.
  - L. Eger, S. Do, P. Ishwar, W. C. Karl, H. Pien, A Learning-based Method for Explosives Detection from Multi-energy X-ray Computed Tomography Measurements," CenSSIS RICC, Oct 2010.
- Plans for Year 4
  - Continue investigation of incremental value of spectral diversity
  - Continue application and development of learning-based based method to improved explosive detection in multi-spectral CT to increase sensitivity and specificity
  - Incorporate tomographic model in feature selection process

F3-A2: Next Generation Image Formation: Limited Angle Linear Tomography

Faculty: W. C. Karl BU; Student: Z. Sun, BU

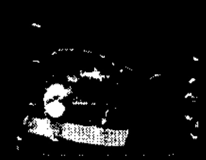
- Motivation and purpose:
  - Development of new reconstruction algorithms with limited angle, limited dose scanners for faster reconstruction
- Year 3 accomplishments
  - Developed a novel linear-motion-based tomograpic 3-D baggage scanner based on existing carry-on baggage screening hardware.
  - Extended 2-D model to fully 3-D system configuration including simulations
  - Initial coding of 3-D approach using GPUs as first step in practical scale implementation
  - Developing associated image formation algorithms to perform high quality reconstructions from the corresponding limited data
- Long range impact
  - Robust, enhanced image formation methods with limited view data sets
- Year 4 Plan
  - Continue developing optimized image formation algorithms to allow high quality reconstructions from the corresponding limited data
  - Optimize the system configuration

Limited Angle Linear Tomography

- Aim: Capability of helical CT with the size/power/cost of a line scanner
  - Projection diversity obtained from object motion – *fixed* source/detector
  - Advanced algorithms necessary for reconstruction

System Configuration

Slice of test object from helical CT



Corresponding slice from simulation of new configuration

3D render obtained by new method

Relevance to DHS Mission

- Education
  - 1 PhD student thesis in progress in area of multi-spectral X-ray tomography
  - 1 PhD student thesis in progress in the area of advanced reconstruction algorithms for limited angle, limited dose tomographic image formation
  - Invited co-author of Chapter in textbook on low dose X-ray CT
- Industry and third party contacts
  - Participation in special session on Multispectral Tomographic Imaging at 2011 IS&T/SPIE Electronic Imaging, organized jointly with Morpho Detection
  - 2 PhD students (Eger, Sun) invited participation in 1st and 2nd UK-US Greenfield Aviation Security Workshops
  - Interaction with industry and national labs (PNNL, Livermore) at algorithm development workshops
  - Low dose and multi-energy research involves commercial medical devices and data
  - Invited speaker at Workshop on Tomography in Materials Science
- Applications
  - High specificity, low false alarm material screening with multi-energy CT
  - Compact, high-throughput, low-cost 3-D imaging scanners for carry-on baggage
  - High quality image formation and threat identification with reduced dose and limited data

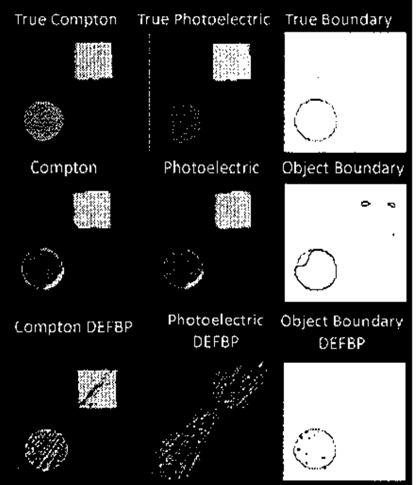
F3-A3: Next Generation Image Formation: Object-Based Methods for Dual Energy CT

Faculty: E. Miller, Tufts   Students: O. Semerici , C. Mutzel Tufts

- Purpose and relevance
  - Automatic detection of explosives is crucial for aviation security
  - Dual energy, X-ray CT capable of characterizing material properties to identify compounds of interest
  - Current state of the art suffers difficulties recovering photo-electric component
- Innovation: Unified approach to image formation, object detection, and object characterization
- Year 3 Accomplishments
  - Refined approach initially developed in years 1 and 2 to improve robustness and performance
  - Developed simulation tool based on MCNP Monte Carlo code for generation of realistic simulation data. A stepping stone between synthetic data generated using matched model and complications associated with processing of real sensor data.
- Long range impact
  - Increasing the probability of detection of explosive type objects significantly enhances security.
  - By providing accurate material characterization the false alarm rate would decrease which in turn would increase efficiency of the aviation screening process.
  - Provision of Monte-Carlo based data generation tool adapted to luggage screening application to the larger community

F3-A3 cont.: Object-Based Methods for Dual Energy CT

- **Year 3 Results**
  - MCNP used to generate realistic data
  - Parallel beam measurements for 60 angles between 0°and 180°
  - Materials:
    - Background: Air
    - Square: Water
    - Circle: TNT
  - Object of interest is orange circle
- **Year 4 Directions**
  - Looking for Mr. Semerici to spend summer at Morpho Detection to develop ideas for continued research and seed collaboration between vendors and academia
    - Possibilities include improved scatter mitigation; robust processing in presence of metal objects; specialized methods for identifying sheet-like objects
  - Working to place one or two undergraduates at Lawrence Livermore Labs working with Dr. Martz on collecting experimental data for further algorithm validation and (pending clearances) improved detection of HMEs



F3-A4: Anomaly Detection in X-ray Backscatter Leg Images

Faculty: E. Miller, Tufts; Student: C. Allen (BS) Tufts
Industry: O Al-Kofahi, J. Callerame (AS&E)

- **Purpose and relevance:**
  - X-ray backscatter whole body imaging is a cornerstone of the airport screening procedure
  - Full-body scan is processed and displayed to operator and anomalous regions are marked for further screening
  - Difficulties in the identification of anomalies in lower leg regions where image edges due to the tibia edges cause high false-alarm rate
- **Innovation: Developed advanced image processing methods to reduce false alarms caused by tibia**
- **Year 3 Accomplishments**
  - Development and initial validation of an image processing chain to improve anomaly detection
  - Method involves image denoising, image registration, and statistical processing
  - Strong initial results from limited AS&E test data
- **Long range impact**
  - Method can be adapted to other parts of the body such as arms and head
  - Registration and statistical methods can be extended to address highly challenging regions such as torso.
  - Approach provides the basis for fusion approach combining in a rational and robust manner X-ray and other data such as millimeter wave images.
  - Project was performed by an undergraduate summer student and demonstrates the potential for university collaboration with vendors.

F3-A4 cont'd: Anomaly Detection in X-ray Backscatter Leg Images

- Year 4 Directions
  - Post doc started Feb 2011 to continue collaboration between Tufts and AS&E
  - Extend the work to other areas of the body
  - Will necessitate improved registrations and machine learning
  - Validate on larger data set

Sample Detection Results

F3-A4 cont'd: Next Generation Image Formation: Object-Based Methods for Dual Energy CT

- Publications
  - O. Semerici and Miller, E. L., "A Parametric Level Set Approach for Dual Energy Computerized Tomography," 2009 Gordon-CenSSIS Research and Industrial Collaboration Conference, Oct. 27-28, Northeastern Univ., Boston MA. This presentation was named the Best ALERT poster at the 2009 RICC.
  - O. Semerici and Miller, E. L., "A Parametric Level Set Approach for Dual Energy Computerized Tomography," submitted to - Student Poster Competition at the The Fourth Annual DHS University Network Summit March 10 - 12, 2010
  - O. Semerci, E. Miller, "An image based Dual Energy Computerized Tomography Method for Detection of Explosive Objects," *Research & Industrial Collaboration Conference (RICC)* 2010, Northeastern University, USA.
  - C. Mutzel, O. Semerci, E. Miller, "A Simulation Tool for Parallel Beam Computed Tomography Based on MCNP" *Research & Industrial Collaboration Conference (RICC)* 2010, Northeastern University, USA.
  - O. Semerici and Miller, E. L., "Shape-based methods for vector-valued inverse problems with highly inhomogeneous, unknown backgrounds," SIAM Conference on Imaging Science, Chicago, April 2010.
  - C. Mutzel, O. Semerci, E. Miller, "A Simulation Tool for Parallel Beam Computed Tomography Based on MCNP," National Conference for Undergraduate Research, Ithaca, NY, March 30 – April 2, 2011
  - O. Semerici and Miller, E. L., "Geometric inverse methods for dual-energy CT," to be submitted to IEEE Trans. Image Processing February 2011

F3A-3 and F3A-4 Relevance to DHS Mission

- Education
  - 1 PhD student thesis in progress in area of X-ray tomographic image formation
  - 2 undergraduates supported to date
    - AIT whole body imaging in collaboration with AS&E
    - Monte-Carlo modeling for generation of realistic X-ray data to test and validate advanced algorithms
- Industry and third party contacts
  - AS&E summer project on algorithm development for whole body imaging will continue with support for as post doc who will split time between Tufts and AS&E
  - PhD student has applied for a summer position at Morpho Detection under supervision of Dr. Samit Basu. Goal is to further focus basic research on problems relevant to tird party vendors
  - In planning stage to place Tufts summer students at Lawrence Livermore Labs to pursue work on X-ray reconstruction, image processing, and materials identification

F3-A5: Next-Generation Priors for Model-Based Reconstruction in Scanned Baggage Security Applications

Faculty: C. Bouman, Purdue, K.Sauer, Notre Dame; Students: E. Haneda, P.Jin

- Motivation and purpose:
  - Incorporate advanced stochastic image models into iterative CT reconstruction for improved NDE and threat detection
  - Provide framework for training models from scan data
- Contribution to DHS mission:
  - Improving reconstructed image quality can reduce explosives detection errors.
- Current goals (Note project start date: 1/1/11):
  - Define metrics of reconstruction quality for evaluating iterative vs. conventional reconstruction
  - Create software base for demonstrating viability of iterative reconstruction (IR) in baggage scanning
  - Use preliminary results to tune existing image models
- Future goals:
  - Develop training of next-generations models from varied sample scans
  - Incorporate spatial adaptivity into priors
  - Improve convergence speed of iterative technique
  - Study robustness under varied scan conditions

F3-A5: Next-Generation Priors for Model-Based Reconstruction in Scanned Baggage Security Applications

- Quality metrics:
  - Edge rendering accuracy
  - MSE of uniform density objects
  - Metal artifact energy
- Current status:
  - Defining CT system geometry parameters
  - Defining software architecture for forward model
  - Coding and debugging forward system model
- Next steps:
  - Implement Bayesian using forward model
  - Tune regularization parameters to scan data
  - Present IR results on test data under quality metrics
- Remainder of Year:
  - Study in-plane vs. cross-plane character of models
  - Refine forward system model
  - Expand experimental scan ensemble

F3-A5: Next-Generation Priors for Model-Based Reconstruction in Scanned Baggage Security Applications

Engagement and Education Activities:

- Special Session on "Advanced Methods in Tomographic Imaging" held at Computational Imaging Conference, Jan. 2011.
  - Co-organized by Samit Basu, Morpho Detection, and C. Bouman.
  - Brought in leading researchers in CT to present 9 papers on advanced CT methods.
- Running Vertically Integrated Projects (VIP) group at Purdue
  - "Explosive Detection" group consists of 12 undergraduate and graduate students.
  - Students are studying object detection from publically available CT data sets.

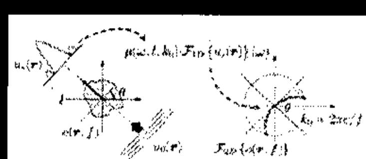
F3-B: Multimodal Imaging for Portal-based Screening: Multispectral Methods for Diffraction Tomography

Faculty: D. Castañón, W. C. Karl, BU; Student: K. Chen, BU

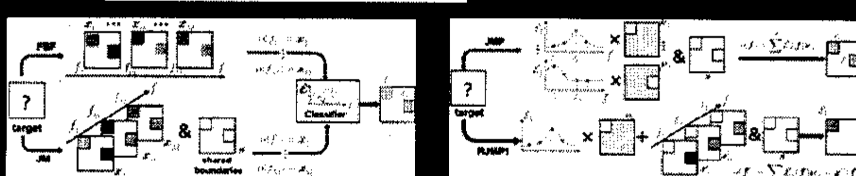
- Motivation and purpose:
  - Increased specificity and sensitivity
  - Reduction of false alarms with increased throughput
- Focus:
  - Enablement of fusion of multiple modalities at image formation level for enhanced resolution and signal/noise ratio
  - Explore modalities that could be fused with X-ray CT imagery
- Year 3 accomplishments
  - New theories for multispectral diffraction tomography for increased signal/noise ratio, motivated by THz tomography
  - Techniques for integrated imaging/detection with improved performance
  - Robust techniques with limited prior spectral information on components
- Long range impact
  - Principled methods for multi-modal tomographic imaging with increased signal/noise ratio for explosive detection

Multispectral Methods for Diffraction Tomography

- Year 3 results
  - Born approximation models for multispectral diffraction tomography
  - New algorithmsfor inversion and spectral fusion exploiting different prior information (e.g. shared object structure across frequency, partial or full knowledge of spectral characteristics of components, ...)
  - Robust algorithms for identification of components with limited prior information in heavy clutter



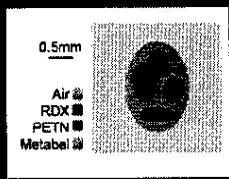
Diffraction tomography geometry: Fourier Diffraction theorem relates transform of detected waves to samples of spatial transform



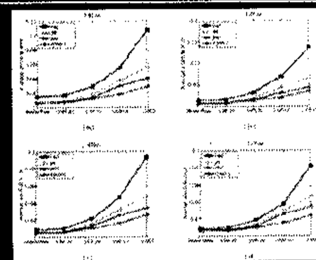
Multiple processing architectures investigated for signal fusion

F3-B Sample Results

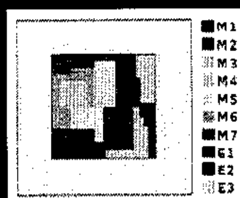
- **Experiment 1 Phantom and results**

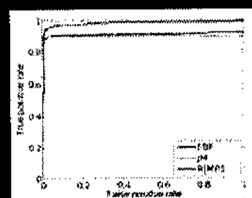


Improved reconstruction accuracy with enhanced prior knowledge



- **Experiment : More complex clutter**





Improved recognition performance in complex, cluttered environments

F3-B cont'd: Multispectral Methods for Diffraction Tomography

- Lessons Learned
  - Significant improvements in reconstruction and recognition accuracy using multispectral fusion in image formation
  - Large attenuation in THz regime limits practical applicability to thin objects only – explore other modalities.
- Plans for year 4
  - Robust algorithms to incomplete or imprecise prior information
  - 3-D algorithm extensions and evaluations
  - Higher-fidelity evaluation of techniques, possibly with lab data
  - Near-term transition adaptation:
    - Extensions to multi-energy X-ray tomography
    - Extensions to X-ray diffraction tomography
  - Evaluation on multi-energy X-ray data
- Publications
  - K. Chen and D. Castañón, Multifrequency tomographic reconstruction in terahertz imaging, *Research & Industrial Collaboration Conference (RICC)* 2009, Northeastern University, USA.
  - K. Chen and D. Castañón, Robust multifrequency tomographic reconstruction, *Research & Industrial Collaboration Conference (RICC)* 2010, Northeastern University, USA.
  - K. Chen and D. Castañón, Robust Multifrequency Inversion in Terahertz Diffraction Tomography, Proc. IS&T/SPIE Electronic Imaging, January 2011, San Francisco, CA

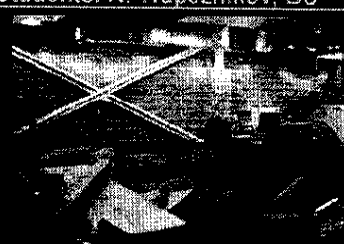
F3-B: Relevance to DHS Mission

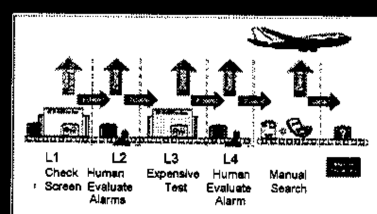
- Education
  - 1 PhD student thesis in progress in area of diffraction tomography and THz image tomographic image formation
- Industry and third party contacts
  - Participation in special session on Multispectral Tomographic Imaging at 2011 IS&T/SPIE Electronic Imaging, organized jointly with Morpho Detection
  - PhD student participated in development of dual energy imaging algorithms in summer internship at Analogic
  - Interaction with industry and national labs (PNNL, Livermore) at algorithm development workshops
- Applications
  - Improved multi-energy imaging
  - Multi-energy x-ray diffraction tomography
  - Multi-modal (mm wave, THz, x-ray) joint imaging

F3-C: Sensor Management for High Throughput Screening

Faculty: D. Castañón, V. Saligrama, BU; Students: K. Trapeznikov, BU

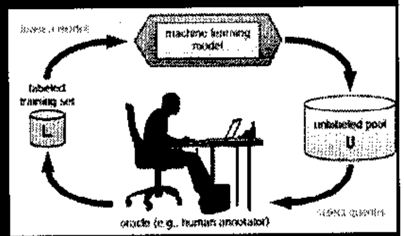
- Motivation and purpose:
  - Increase throughput while maintaining high probability of detection
- Focus:
  - Optimal sensor and algorithm management
  - Sequential design of experiments integrated into detection/classification
  - Increased throughput to remove airport/port bottlenecks
  - Improved machine learning/recognition
- Long range impact
  - High throughput screening management algorithms with good sensitivity/specificity



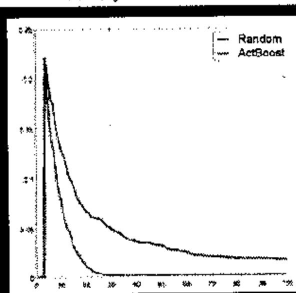


Sensor Management for High Throughput Screening

- State of the Art
  - Most automated decision systems trained to provide final decision, irrespective of future stages
  - Lack principled design techniques for automated sequential classification
  - Must also address unbalanced training data, lack of labeled real-time data
  - Active learning focuses on selecting examples "near" current decision boundaries, fail to discover new boundaries



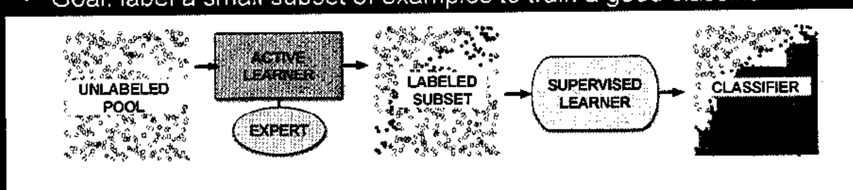
- Year 2 & 3 results:
  - Development of new theories for training classification algorithms tailored to sequential testing
    - Extensions of support vector machines
  - Development of new machine learning concept for active learning in boosting classifiers: ACTBOOST
    - Real-time learning for fielded classification systems that yield improved performance with less training by choosing the right training data



Active learning (ActBoost) requires less data to train

Active Learning

- Large amount of data available (e.g. scanners), but all unlabeled
- Labeling is expensive (requires an expert)
- Goal: label a small subset of examples to train a good classifier

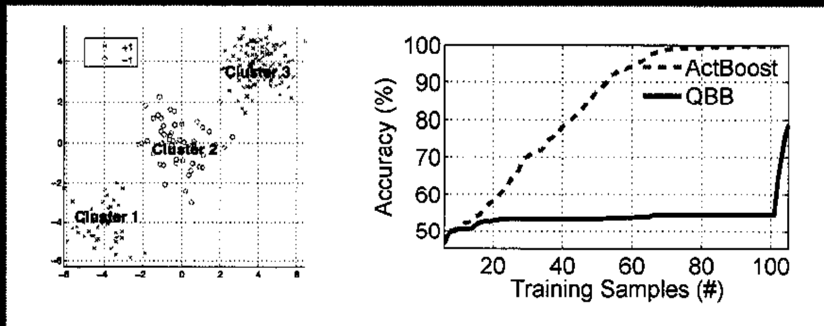


Security Applications

- Airport Luggage Scanning:
  - Many bags scanned daily, large potential training pool, all unlabeled
  - To label a bag requires manual inspection, costly
- Whole Body Imaging:
  - Many subjects imaged
  - Labeling requires a human to analyze image, time consuming

New Algorithm: Active Boosted Learning

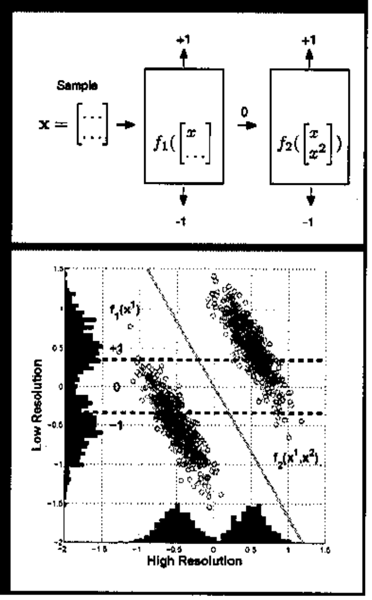
- Boosting: combine simple classifiers and get powerful classifier by weighting their outputs
- ActBoost: Identifies data that should be used for training and boost performance



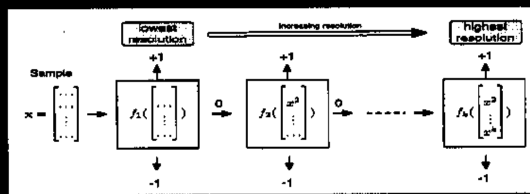
QBB: State-of-the-art active learning tool, learns much slower than ActBoost

Hierarchical Classification for high throughput, high accuracy screening

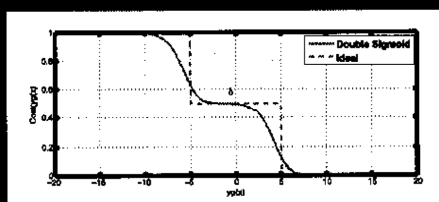
- High Resolution Features
  - Expensive to acquire
  - Informative for classification
- Low Resolution Features
  - Cheap but less informative
- System Design
  - 1^{st} stage use low resolution
  - Classifies majority of samples
  - Passes few difficult examples
  - 2^{nd} stage uses full resolution
- Reduces Classification Cost
- Example: Airport Luggage Screening
  - 1^{st} Stage: X-Ray Machine, fast, not perfect
  - 2^{nd} Stage: Human Inspector, slow, very accurate

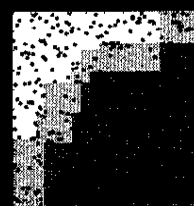


Hierarchy of Boosting Classifiers



- Cascade of Boosting Classifiers with Reject Option
- Each stage designed to optimize a surrogate to ideal cost





F3-C Work & Metrics

- Personnel
  - Faculty: D. Castañón, V. Saligrama, Boston U
  - Student: K. Trapeznikov, Boston U, PhD
- Publications
  - D. Castañón and E. Rodriguez Diaz, ``Support Vector Machine Classifiers for Sequential Decision Problems," Proc. 2009 Conf. on Decision and Control, Shanghai, China, Dec. 2009
  - K. Trapeznikov, V. Saligrama and D. Castañón, Active Boosted Learning, *Research & Industrial Collaboration Conference (RICC)* 2010, Northeastern University, USA.
  - K. Trapeznikov, V. Saligrama and D. Castañón, "Active Boosted Learning (ActBoost)" accepted to AISTATS 2011.
- Proposed Year 4 work
  - Evaluation of ACTBOOST on Luggage Screening data sets as available
  - Development of Hierarchical Classification Algorithm along with hierarchical active learning
  - Integration of hierarchical classification with multi-modality sensing motivated by whole-body imaging

F3-C Relevance to DHS Mission

- Education
  - 1 PhD student thesis in progress in area of machine learning for security applications
- Industry and third party contacts
  - PhD student worked at Sandia Summer, 2009 and collaboratied with PNNL on Sandia whole body imaging data for anomaly detection, summer 2010
  - In discussions with LLNL to explore opportunities for shared work and evaluation of algorithms
  - Participating in algorithm development workshops focused on grand challenge
- Applications
  - Automated threat detection in luggage screening
  - Automated anomaly detection in whole body imaging
  - High throughput automated luggage screening with low false alarm rate

F3-D : Computationally Efficient Simultaneous Segmentation and Image Formation for X-ray CT EDS

Faculty: B. Yazici (RPI)

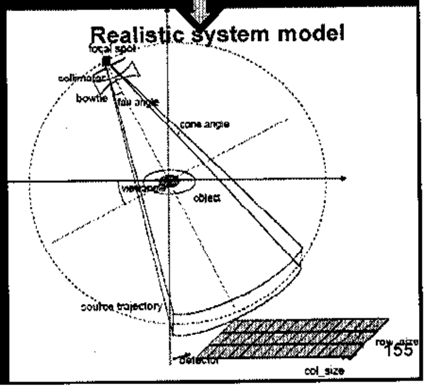
- Motivations, objective and advantages:
  - Motivations: X-Ray CT based EDS requires three main processing steps: Image formation, segmentation and classification
  - In current EDS systems pattern recognition, segmentation and reconstruction are independently addressed. They are computationally expensive.
  - Objective: Simultaneous image formation, segmentation and pattern recognition optimized for explosive detection application.
  - DHS Relevance : Optimized data processing chain for EDS, tailored image reconstruction → potentially superior performance in explosive detection systems
  - Fast implementation of the data processing chain

F3-D : Computationally Efficient Simultaneous Segmentation and Image Formation for X-ray CT EDS

- Technical Approach: Fundamental question – Can we develop an analytic model for x-ray cone-beam data and a fast analytic inversion for simultaneous reconstruction, segmentation and classification?
- Answer: Yes!
  - Model X-ray cone-beam data as a Fourier Integral Operator (FIO) with realistic system parameters and arbitrary imaging geometries
  - Use microlocal techniques for simultaneous reconstruction, segmentation and classification in a statistical setting. Incorporate x-ray properties of explosives into inversion.
  - Take advantage of fast computation of FIOs to implement data processing chain
  - Fast data processing chain outperforming decoupled, discrete iterative algorithms

Idealized model

- Summation along lines – Infinite system bandwidth
- Point source –infinitesimally small focal spot
- No collimation or bow-tie filter
- Flat or cylindrical detector surface
- Circular or spiral source trajectory



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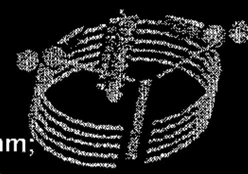
F3-D : Computationally Efficient Simultaneous Segmentation and Image Formation for X-ray CT EDS

- Technical Accomplishments -
- (1) Reparametrized cone-beam transform in its native (detector) geometry. Showed that it is a FIO and developed a filtered-backprojection type inversion method for image reconstruction
  - New representation of the cone-beam transform can be extended to include system related parameters. New method can be combined with edge detection and pattern recognition
  - Implemented the method numerically and demonstrated feasibility in a realistic phantom simulation
- (2) Coupled the new inversion method with edge detection for simultaneous segmentation and reconstruction of images directly from projection data
- (3) Developed an analytic iterative approach for cone-beam inversion

F3-D : Computationally Efficient Simultaneous Segmentation and Image Formation for X-ray CT EDS

- Reconstruction of Forbild-like thorax phantom
- Generated using GE's simulation tool CATsim with circular source trajectory
  - Number of views per rotation = 984
  - Number of detector columns = 888
  - Detector size ~ 1mm-by-1mm
  - Slice thickness in z- direction = 0.625 mm
  - Distance from source to detector = 949 mm;
  - Distance from origin to detector is 545 mm



center slice of the Forbild phantom

Feldkamp (FDK) algorithm FIO (microlocal) inversion

Comparison with widely used FDK algorithm indicates feasibility of the new inversion

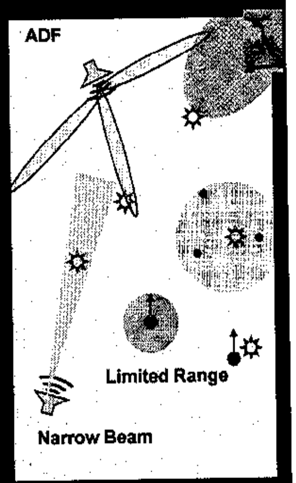
F3-D : Computationally Efficient Simultaneous Segmentation and Image Formation for X-ray CT EDS

- Interactions/Transitions to Industry :
  - Strong interest from GE Research
  - Obtained license for GE's proprietary CT simulation and reconstruction toolbox CATSim. Collaborating with GE to obtain real phantom data to test new methods.
- Publications:
  - H.C. Yanik, Z. Li, B. Yazici, "Computationally Efficient FBP-type Direct Segmentation of Synthetic Aperture Radar Images" to appear in the proceedings of SPIE Defense and Security Conference, April 2011.
  - Z. Li, B. Yazici, "A FBP-type Analytic Segmentation Method for X-ray CT Images from Cone-beam Projection Data," accepted for SPIE Medical Imaging Conference, 2011.
- Year 4 Plans :
- Incorporate system related parameters and constraints into the FIO representation and extend the inversion method.
- Test simultaneous edge detection and reconstruction algorithm using real phantom data and fully developed simultaneous classification and reconstruction method

F3-E1: Multi-modal Sensor-Networks: Group Testing and Multi-camera Fusion

Faculty: D. Castañón, V. Saligrama, BU; Student: J. Quian, J. Wang, BU

- Motivation and Purpose
  - Pervasive wide-area explosive threat detection
- Innovative Aspects
  - Multi-modal fusion of distributed/mobile sensors
  - Theory for active, adaptive employment of sensors
- Year 2 & 3 Accomplishments
  - Markov Group Testing(MGT): New Algorithms for group testing in crowds using area sensors
  - Multi-camera Fusion: matching of uncalibrated cameras, decreased training time
  - Performance analysis of algorithms
- Long range Impact
  - Tools for robust, reliable, real-time threat detection, localization & classification
  - Development of novel sensing systems



Group Testing

- Main idea: area sensors (e.g. air trace detectors) that identify presence of compounds without localizing source
- System objective: integrated processing of temporal detections from distributed sensors
- Goal: detection in areas where high throughput is needed, so portals impractical

- Results
  - Characterization of sensors required and number of measurements to isolate threats
  - Analysis of time required for classification and training
  - Demonstration of reduced training time in multi-camera systems

MGT: Algorithms for identifying explosives in a crowd with distributed sensors

- Approach: N individuals walking in a random pattern
  - Small number k carrying explosive materials
- Distributed trace sensors can detect presence of explosives in close-in area
  - But multiple individuals present
  - Exploit motion diversity to isolate individuals with explosives
- Analysis questions:
  - Time required to identify individuals carrying explosives?
  - Effect of sensor range?
  - Effect of number of sensors?

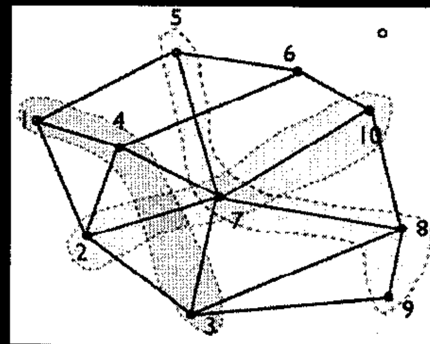
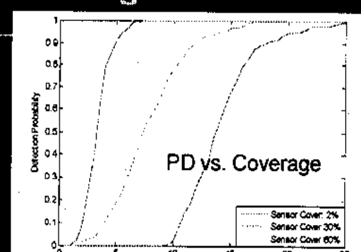


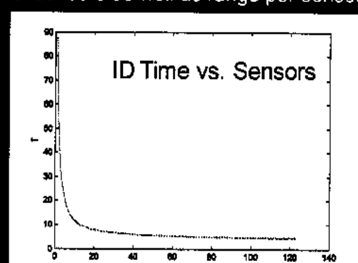
Illustration of Individuals walking around in a mall. Red circles denote locations of sensors. Goal is to identify individuals that pose an enhanced threat

Results: Markov Group Testing

- Design problem: choose # deployed sensors
  - Compute ID time to identify persons with explosives
- Example
  - 200 individuals, 3 with suspicious material
  - One centrally-located sensor testing groups every 30 seconds
  - Results: after 6.5 minutes, can ID persons carrying suspicious material with 99% guarantee
  - More sensors reduce time required



Performance dependence on number of sensors as well as range per sensor



Time to isolate individuals with suspicious materials identifies architectural trades

Year 3 Proposed Work and Metrics

- Personnel:
  - Faculty: D. Castañón, V. Saligrama, Boston University
  - Postdoc: G. Atia, Boston U (Summer '09)
  - Students: J. Qian, J. Wang, Boston University
- Year 4 directions
  - Evaluation of algorithms on realistic crowd data sets
  - Couple Multi-Camera Fusion and tracking with group testing
- Publications
  - G. Atia, V. Saligrama, "Boolean Compressed Sensing and Noisy Group Testing," Submitted IEEE Trans. on Information Theory
  - G. Atia, V. Saligrama, "Noisy Group Testing" Proc. Allerton 2009, UIUC, Urbana, IL
  - M. Cheraghchi, A. Karbasi, S. Mohajer, V. Saligrama, "Graph Constrained Group Testing," International Symposium on Information Theory, 2010
  - J. Wang, V. Saligrama, D. Castanon, "Group Testing and Coupled Random Walks (Allerton 2010)

Relevance to DHS Mission

- Education
  - 1 PhD student thesis in progress in area of machine learning and group testing
- Industry and Third Party Contacts
  - Discussing possible sources of test data using chemical detectors plus video surveillance sources with Balfour Technologies
- Applications
  - Surveillance systems for public areas using trace particle sensors
  - Integration with video surveillance to keep track of individuals in groups
  - Multi-sensor systems for area surveillance

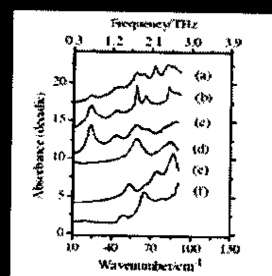
F3-E3: Multimodal Sensor Networks: Compressed Classification

Faculty: D. Castañón, V. Saligrama, BU
Students: J. Wang, D. Motamedvaziri, J. Qian, BU

- Motivation and purpose:
  - Develop new classification algorithms with improved robustness in the presence of limited training data and high variability in explosives signatures
  - Applications to luggage inspection, anomaly detection, wide area surveillance
- Approach
  - Exploit and extend recent techniques in nonlinear data mining, compressive sensing and clustering to identify robust features
- Year 3 accomplishments (start 9/09)
  - New non-linear manifold clustering and classification techniques through rank minimization
- Long range impact
  - Improved automated classification techniques with robust performance in the presence of explosives variability

Motivating examples: High-dimensional data

- THz classification in AIT
  - Reflection frequency spectra at multiple frequencies
- Multi-frequency 3-D CT images
  - Lots of pixels, high variability in shape, other
- AIT imagery with mm wave, x-ray backscatter
  - Imagery, possibly multi-mode

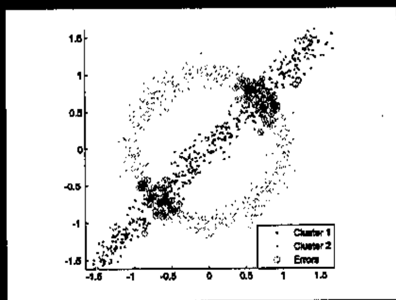


Spectral signatures of common explosive s

- Standard approach: project high dimension data to low dimension features to train detector
  - Often manually intensive
  - Objective: find robust features based on limited data

New Result: Kernel Low Rank Representation (KLRR) for clustering and classification

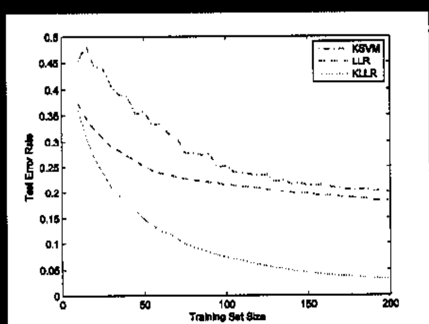
- Identify small number of nonlinear manifolds in feature space where data clusters exist
  - Previous state of the art: Linear manifolds



Clustering of simulated 2-d data illustrating nonlinear manifold. Points in blue and green are grouped into clusters 1 and 2, respectively, with red circles representing errors from truth

New Algorithm: Kernel Low Rank classification

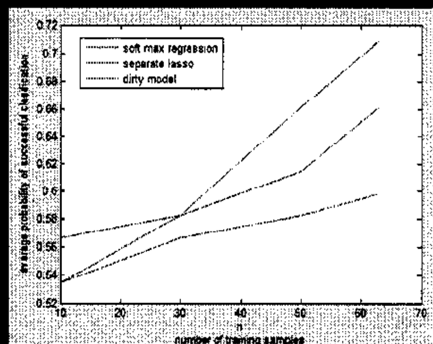
- Classification on KLLR allows for independent classification on manifolds
- High performance on real world data, such as USPS digits
- Calculation independent of feature vector dimensionality



Comparison of K-LLR with state-of-the-art Kernel Support Vector Machine classifier (KSVM), linear subspace identification (LRR) on recognition of digit images from USPS. K-LRR has much better performance on small training sets

Additional Result: Dirty Model Learning

- Multi-class classification problem where class have overlapping structure
- High dimensional features, limited training samples, looking for features that are robust across classes
- Extension of previous ideas to multi-class problems



Comparison of dirty model learning on microarray data using 100 features to estimate types of cancer (www-stat.stanford.edu/~tibs/ElemStatLearn
Dirty Model has improved performance with limited data

F3-E3: Multimodal Sensor Networks: Compressed Classification

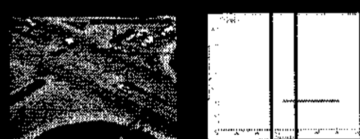
- Lessons
  - Promising new theoretical approach for identification of robust features, classification
  - Useful for high-dimensional data sets such as imagery or spectral features – robust features from limited training data
- Plans for year 4
  - Continue development and documentation of clustering and classification techniques
  - Test algorithms on segmentation grand challenge data and other DHS-motivated data sets
- Publications
  - J. Qian, M. Zhao, V. Saligrama, Density Modulated Spectral Clustering, (CISE Tech Report).
  - J. Qian, M. Zhao, V. Saligrama, Rank-Weighted Spectral Clustering, AISTATS 2011
  - J. Wang, V. Saligrama, D. Castañón, Kernel Low Rank Learning, (CISE Tech report)
  - D. Motamedvaziri, V. Saligrama, D. Castañón, "Dirty Model Learning for Improved Classification," In preparation
  - D. Motamedvaziri, V. Saligrama, D. Castañón, Distributed Compressed Classification, (ALLERTON 2011)

F3-E Relevance to DHS Mission

- Education
  - 2 PhD student thesis in progress in area of compressive learning and matrix completion for clustering and classification problems
- Industry and third party contacts
  - Interaction with industry and national labs (PNNL, Livermore) at algorithm development workshops for multispectral classification
  - Explored application of clustering and classification to x-ray backscatter AIT imagery provided by Sandia and PNNL
  - Collaborations with PNNL, MGH to define segmentation challenge
- Applications
  - Improved classification for multi-sensor fusion through identification of robust features
  - Improved segmentation through applications of clustering techniques for automated classification in luggage scanning

F3-F: Dynamics-Based Detection and Tracking of Explosive Threats (Faculty: O Camps, M Sznaier, G Tadmor, NU; Students: M Ayazouglu, BL Li, N Ozay (graduated), O. Lehmann, C. Dicle, T. Mao, A. Vasile NU)

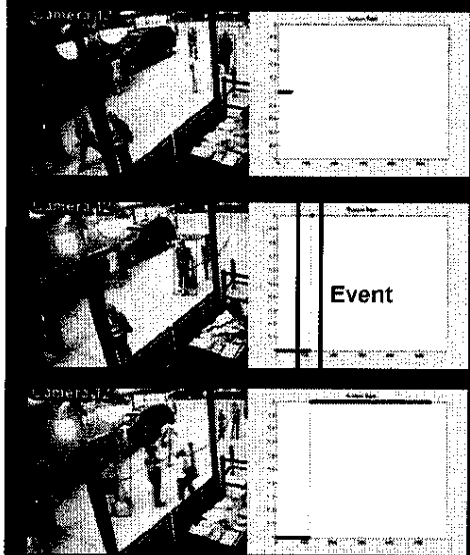
- Purpose and Relevance:
  - Robust detection of potential threats using multimodal (e.g. video, micro-pulse radar, IR), physically distributed sensors.
- Innovative Aspects:
  - Dynamic models as the key to handle a "data deluge":



Detecting events via jumps in Hankel rank

- Year 3 Outcomes:
  - Anomalous event detection, activity parsing and recognition, 3D reconstruction from 2D video, constrained interpolation of noisy data, model reduction tools for mass-flows.
- Long range Impact:
  - Real time threat detection/assessment via integration and analysis of very large amounts of surveillance data.
  - Sensor coordinated threat response and impact mitigation.

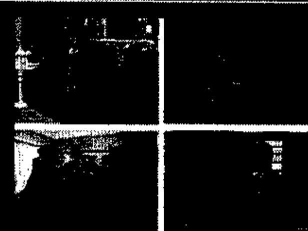
F3-F Fast Event Detection: Analyzed NYC 2009 bombing attempt suspect-Tracking algorithm reveals anomalous behavior



- Year 3 Result
- Reduced Data Overload
  - Reduce surveillance operator's load by calling attention to events that might be of interest.
    - Ex: suspect stops and removes clothing.
  - Events are detected as changes in the underlying dynamics.
  - Efficient solution via monitoring rank of a matrix.

F3-F Interactive Activity Recognition: Improvement Over the State of the Art Enhances Ability to Detect Threats

- Automatic Behavior Understanding
  - Dynamical systems are compact, yet powerful models of human activity interaction.
  - Accurate classification using discriminative canonical correlations of dynamic subspace angles and support vector machines.
  - Significant Accuracy Improvement
    - 24% accuracy improvement over the state of the art (TV sitcoms: Hand shaking, high-five)
    - Also works better than state of the art (93.6%) on single actor activities. (KTH dataset: Walking, running, boxing, hand clapping, hand waving, jogging)



Algorithm	Accuracy on TV dataset
Ours (2010)	**68%**
Patron-Perez et al (2009)	54.45%

Algorithm	Accuracy on KTH dataset
Ours (2010)	**93.6%**
Wang et al (2009)	92.1%
Laptev et al (2008)	91.8%

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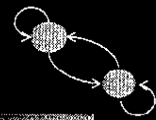
F3-F Activity Sequence Analysis: Enables Assessment of Complex Threat Scenarios

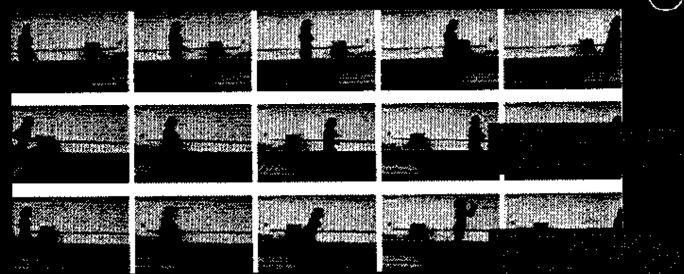
- Parsing Enables Identification of Suspicious Behavior
  - Detect contextually abnormal sequences of activities.
  - Validation of hybrid models described mathematically by graphs.
  - Reduces to a Semi-definite Programming Optimization via semi-algebraic geometry



Walking/wait/walking

running

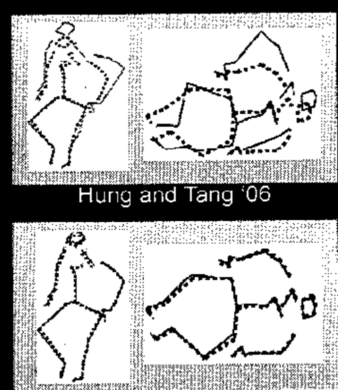
Walking/jumping



F3-F Dynamics-Based 3D Geometry Reconstruction: Enables Discrimination of Anomalous Shapes

- New 3D Reconstruction Method Much More Accurate
  - Create 3D models from 2D images by reconstructing the states of a nonlinear system from observations of its outputs.
  - Solution via rank minimization of Hankel matrices.
  - Works with flexible objects, uncalibrated perspective cameras.

3D Structure
——— Recovered
------- Ground truth



Hung and Tang '06

Ours

F3-F Target Tracking Through Occlusion and Clutter: Enables Persistent Surveillance of Potential Threats

- Improved Algorithm Enables Effective Multi-Target Monitoring
  - Maintain target identity through occlusion and clutter
  - Data as manifestation of hidden dynamic structures
  - Missing data recovery through rank minimization of Hankel matrices

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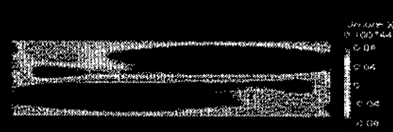
F3-F Fluid Dynamics Analogy: A New Approach to Dense Crowd Modeling

- Simple Models Can Describe Complex Crowd Behavior
  - Characterization of crowd behaviors inspired by fluid dynamic models
    - A Navier-Stokes / Multiphase /Compressible mass-flow model
    - Behaviors encoded by parameters of Partial Differential Equations
    - Suitable for real time crowd identification
    - Provides Model Reduction Tools:
      - Global modes methods including mode deformation, moving boundarics & stochastic properties
      - Galerkin model reduction & observer based estimation of characteristic parameters



Lane formation: a generic pattern of crowd motion in opposite directions, recreated by our model

F3-F cont'd: Dynamics-Based Detection and Tracking of Explosive Threats

- Year 4 Proposed Work
  - Tracking/ event detection under appearance changes.
  - Data integration from multiple cameras
  - Multiple Actors Activity Recognition
  - Parameter estimation of mass-flow, multiple-population crowd models from video scenes
  - Event characterization by model parameters in dense crowds
- Underlying basic science problems:
  - Dimensionality reduction via time-varying incremental nonlinear embeddings.
  - State reconstruction from observations for nonlinear systems
  - Finding parsimonious descriptions of dynamic data

F3-F cont'd: Dynamics-Based Detection and Tracking of Explosive Threats

- Technology Transfer:
  - Siemens Corporate Research
    - Intelligent Pedestrian Surveillance Platform (An extension to the Suicide Bomber Detection Program)
      - Persistent tracking and Fast Event Detection in small crowds
      - Collection of Surveillance Data at Camp Edwards National Guard Base
  - Balfour Technologies, Morrelly Center
    - Incorporation of Persistent Tracker to fourDscape browser
    - Automated situational awareness for first responders
    - Direct user feedback from first responders and law enforcement forces

SIEMENS

Morrelly Center

F3-F cont'd: Dynamics-Based Detection and Tracking of Explosive Threats

- **Year 3 related publications:**

- M. Sznaier, O. Camps, N. Ozay, T. Ding, G. Tadmor and D. Brooks, *"The Role of Dynamics in Extracting Information Sparsely Encoded In High Dimensional Data Streams," in* Dynamics of Information Systems, Hirsch, M.J.; Pardalos, P.M.; Murphey, R. (Eds.), pp. 1- 28, Springer Verlag, 2010 .
- N. Ozay, M. Sznaier, O. Camps and C. Lagoa, *"GPCA with Denoising: A Moments-Based Convex Approach,"* 2010 IEEE Conf. Comp. Vision and Pattern Recognition (CVPR), June 2010.
- Z. Ma, C. W. Rowley and G. Tadmor, *"Snapshot-based balanced truncation for linear time-periodic systems,"* IEEE Transactions on Automatic Control 55 (2010), 469 – 473
- B. .R. Noack, M. Schlegel M. Morzynski and G. Tadmor, *"System reduction strategy for Galerkin models of fluid flows,"* Intl. J. Numer. Meth. Fluids 63 (2010) 231 -- 248.
- C. Feng, C. Lagoa, and M. Sznaier, *"Hybrid System Identification via Sparse Polynomial Optimization,"* Proc. 2010 American Control Confererence, June 2010.
- M. Sznaier and O. Camps, *"Dynamics-based Extraction of Information Sparsely Encoded In High Dimensional Data Streams,"* (invited, lead tutorial paper), Proc. 2010 IEEE Multi-Conference on Systems and Control, Sept. 2010.

F3-F cont'd: Dynamics-Based Detection and Tracking of Explosive Threats

- **Year 3 related publications:**

- M. Ayazoglu, M. Sznaier, and O. Camps, *"Euclidean Structure Recovery from Motion in Perspective Image Sequences via Hankel Rank Minimization,"* Proc 2010 European Computer Vision Conference, Sept. 2010.
- N. Ozay, M. Sznaier, C. Lagoa and O. Camps, *"A Sparsification Approach to Set Membership Identification of a Class of Affine Hybrid Systems,"* IEEE Trans. Aut. Contr., conditionally accepted for publication, 2010.
- G. Tadmor, O. Lehmann, B. R. Noack and M. Morzynski, Mean Field Representation of the Natural and Actuated Cylinder Wake, Physics of Fluids 22 (2010), 034102.
- M. Ayazoglu, M. Sznaier, C. Lagoa, and O. Camps, *"A Moments-Based Approach To Estimation and Data Interpolation for a Class of Wiener Systems,"* 2010 IEEE Conf. Decision and Control.
- C. Feng, C. Lagoa, N. Ozay and M. Sznaier, *"Hybrid System Identification: An SDP Approach,"* 2010 IEEE Conf. Decision and Control.
- N. Ozay, M. Sznaier and C. Lagoa, *"Model (In)validation of Switched ARX Systems with Unknown Switches and its Application to Activity Monitoring,"* 2010 IEEE Conf. Decision and Control.
- B. Li, M. Ayazoglu, T. Mao, O. Camps and M. Sznaier, "Activity Recognition using Dynamic Subspace Angles," 2011 IEEE Conf. on Computer Vision and Pattern Recognition (CVPR). To appear.

F3-F cont'd: Dynamics-Based Detection and Tracking of Explosive Threats

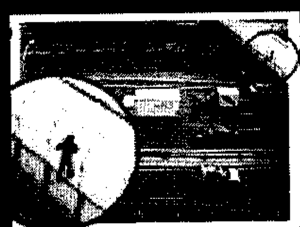
- **Year 3 related publications:**

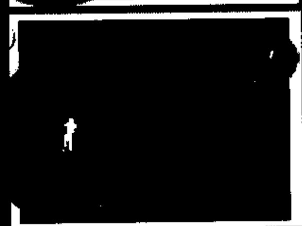
- M. Sznaier and O. Camps. A rank minimization approach to trajectory (in)validation. In *Proc. 2011 American Control Conference.* To appear.
- C. Feng, C. Lagoa, and M. Sznaier. Identifying stable fixed order systems from time and frequency response data. In *Proc. 2011 American Control Conference.* To appear.
- B. R. Noack, M. Morzynski and G. Tadmor (Editors), Reduced-Order Modeling for Flow Control, Springer Verlag, in press.
- M. Morzynski, B. R. Noack and G. Tadmor, Global Stability Analysis for Linear Dynamics (34 pages), a chapter in Reduced-Order Modeling for Flow Control, B. R. Noack, M. Morzynski and G. Tadmor (Editors), Springer Verlag, in press.
- B. R. Noack, M. Schlegel, M. Morzynski and G. Tadmor, Galerkin Methods for Nonlinear Dynamics (39 pages), a chapter in Reduced-Order Modeling for Flow Control, B. R. Noack, M. Morzynski and G. Tadmor (Editors), Springer Verlag, in press.
- G. Tadmor, O. Lehmann, B. R. Noack and M. Morzynski, Galerkin Models Enhancements for Flow Control (102 pages), a chapter in Reduced-Order Modeling for Flow Control, B. R. Noack, M. Morzynski and G. Tadmor (Editors), Springer Verlag, in press.

F3-G1 Anomaly Detection in Video Analytics

Faculty: V. Saligrama (BU), students: E. Ermis (PhD '10), M. Zhao (BU)

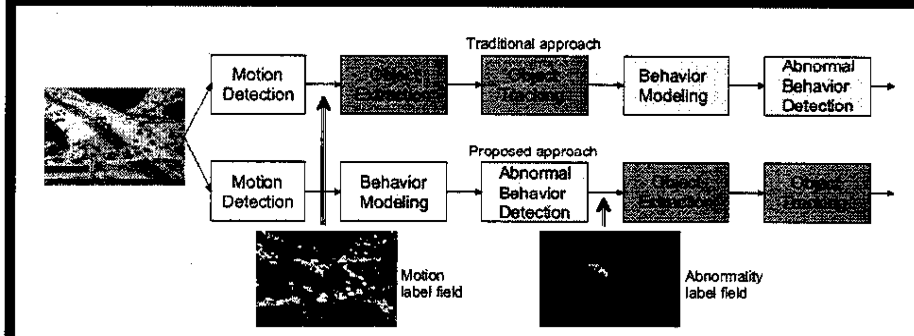
- Motivation and Purpose
  - Detection of suspicious, anomalous, irregular behavior in realistic, crowded indoor/outdoor urban scenarios
- Innovative Aspects
  - Adaptive learning and detection of normal vs. anomalous patterns of behavior
- Long range Impact
  - Robust surveillance system for pervasive and persistent detection of anomalies on roads, open areas, terminals
  - Creation of framework for analysis of high dimensional data





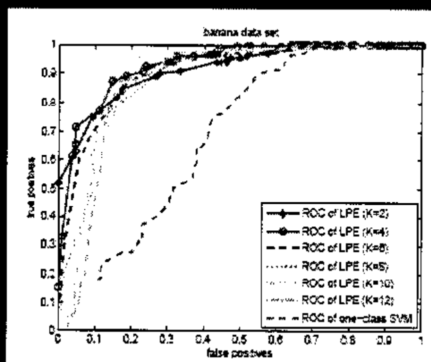
Architecture for Anomaly Detection

- **Conventional Architecture:**
  - Object based: Tag, Track each object, and model anomalous behavior to detect
- **Our Architecture**
  - Location Based: Pixel Level Anomaly Detection where areas of anomalous activity are detected



Foundation: New Approach and Algorithm for Anomaly Detection

- Robust Anomaly Detection using K-Nearest Neighbor Graphs (K-LPE)
  - Significant improvement in performance vs alternative machine learning techniques
  - Exploits modern results in non-parametric statistics
- Automated Methods for anomalous pattern discovery in high-dimensional data



(a) SVM vs. K-LPE for Banana Data

K-LPE versions have better ROC curves than standard classification algorithms

Sample Results: (In/Outdoor, On water, Shaking Camera, ...)

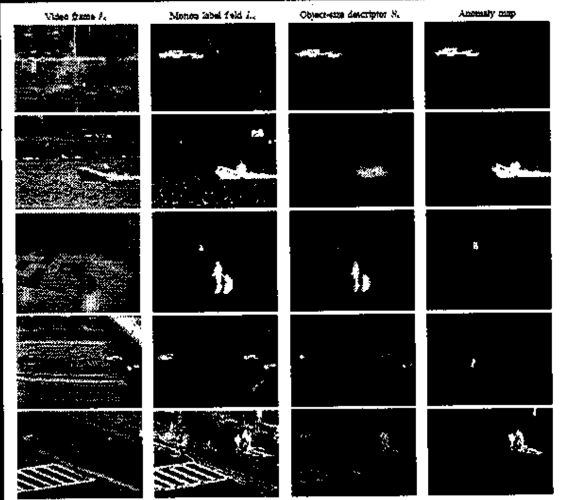


Fig 2. Behavior subtraction results for the maximum-activity nominal map (5) on video sequences containing shimmering water surface (two top rows), sporadic (third row) and steady (fourth row) traffic, and very small abnormally-behaving object (fourth row), as well as for the average-activity nominal map (6) on video sequence captured by a vibrating camera (bottom row).

Robust performance in the presence of moving backgrounds, lighting, size variations

Inter-Camera Activity Matching

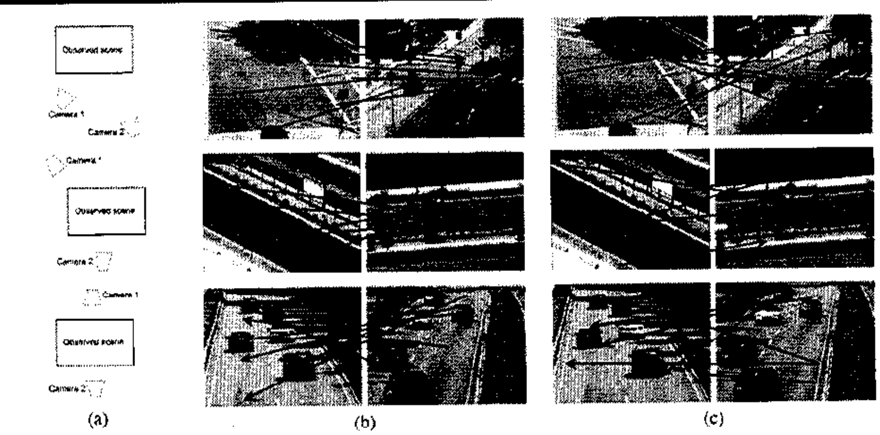


Fig. 3. Inter-camera matching based on temporal signatures: (a) camera setup; (b) matching results from 90 seconds of video using temporal signatures as proposed here; (c) matching results using spatial signatures from SIFT [39]. Note that the cameras have different zoom levels. The proposed approach is able to match the corresponding pixels with a small error, whereas the method based on SIFT fails to find correct matches. Although our method provides a dense mapping, we show only a few correspondences for legibility.

Work and Metrics

- Lessons Learned
  - Promising robust anomaly detection algorithms suitable for real-time monitoring
  - Need to evaluate utility for specific DHS environments
- Plans for year 4
  - Extension of concepts for forensic indexing: video search & retrieval
  - Evaluation of concepts on data provided by surveillance cameras for security in collaboration with industry partners
  - Extension to long term & semantic anomaly detection
- Publications
  - Abnormality Detection Using Low-Level Co-occurring Events, Benezeth et. al., Pattern Recognition Letters, to appear
  - Activity Based Matching in Multicamera networks, Ermis et. al., IEEE Trans. on Image Processing, Oct 2010
  - Video Anomaly Identification, Saligrama et. al., IEEE Signal Proc. Mag. Nov. 2010.
  - Y. Benezeth, P. Jodoin, V. Saligrama, C. Rosenberger, "Abnormal Events Detection Based on Spatio-Temporal Co-occurences," Comp. Vision & Pattern Rec. 2009
  - M. Zhao, V. Saligrama, "Anomaly Detection Based on Score Functions on K-nearest Graphs," Neural Info. Proc. Systems 2009

F3-G1 Relevance to DHS Mission

- Education
  - 1 PhD student graduated (Ermis '10), another in progress in area of video anomaly detection
- Industry and third party contacts
  - Discussions with Balfour Technologies for joint evaluation of video anomaly detection on indoor and outdoor video as part of Applied Science Foundation for Homeland Security work (R. Balfour, contact)
  - Interaction with industry and FFRDC (BAE, Lincoln Labs) concerning possible applications for defense
- Applications
  - Fast, robust anomaly detection in indoor settings such as arenas, convention centers
  - Outdoor anomaly detection in cluttered urban environments
  - Front end alerts to human operators

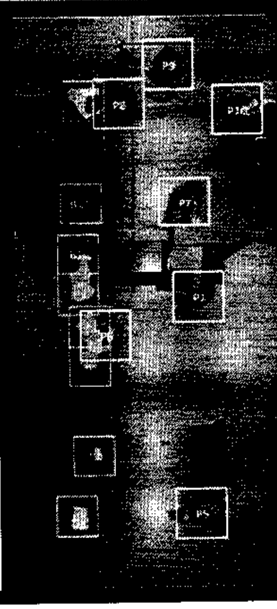
F3-G2: Distributed Anomaly Detection: Video Analytics Testbed for Detection and Tracking of Suspicious Behavior

Faculty: R. Radke, RPI; Students: Z. Wu (Ph.D.), E. Ameres, A. Calcutt (MS), RPI

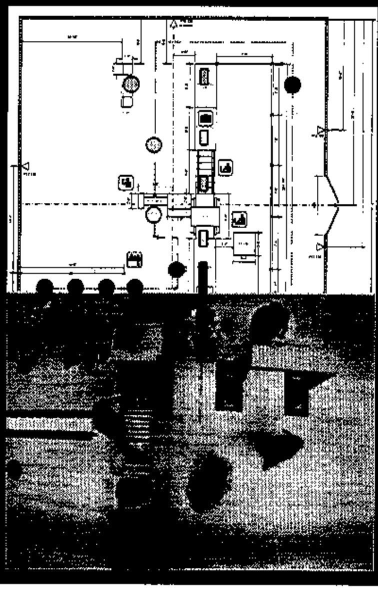
- **Motivation and Purpose**
  - Detection of suspicious, anomalous, irregular behavior in realistic, crowded indoor/urban scenarios
- **Innovative Aspects**
  - Learning, detection of normal vs. anomalous patterns of behavior
  - Many-camera video processing in large, complex environments
- **Year 3 accomplishments**
  - Full-scale simulation of airport security screening checkpoint
  - Automatic tracking/association of all passengers and bags
- **Long range Impact**
  - Large-scale, reconfigurable testbed for research in camera networks, surveillance, tracking, activity recognition, anomaly detection, crowd motion

F3-G2 cont'd: Video Analytics Testbed for Detection and Tracking of Suspicious Behavior

- **Year 3 Results**
  - **14 ceiling-mounted fixed-focus network cameras, 5 pan-tilt-zoom cameras in 50x40x30 ft[3] reconfigurable studio at EMPAC**
  - **Large-scale environment mock-up (airport security screening line) involving crowds and anomalous behavior**
  - **Real-time multi-object tracking (passengers, bags) and automatic object-to-person association**



F3-G2 cont'd: Video Analytics Testbed for Detection and Tracking of Suspicious Behavior



- Year 4 Proposed Work
  - Careful analysis of complex situations and introduced anomalies (e.g., bags left or incorrectly taken)
  - Larger-scale environment mock-ups (e.g., complex disaster response) in collaboration with experts in high-pressure decision-making, networking
  - Investigate new sensors and actuators for large-scale environment modeling (how and where to look)

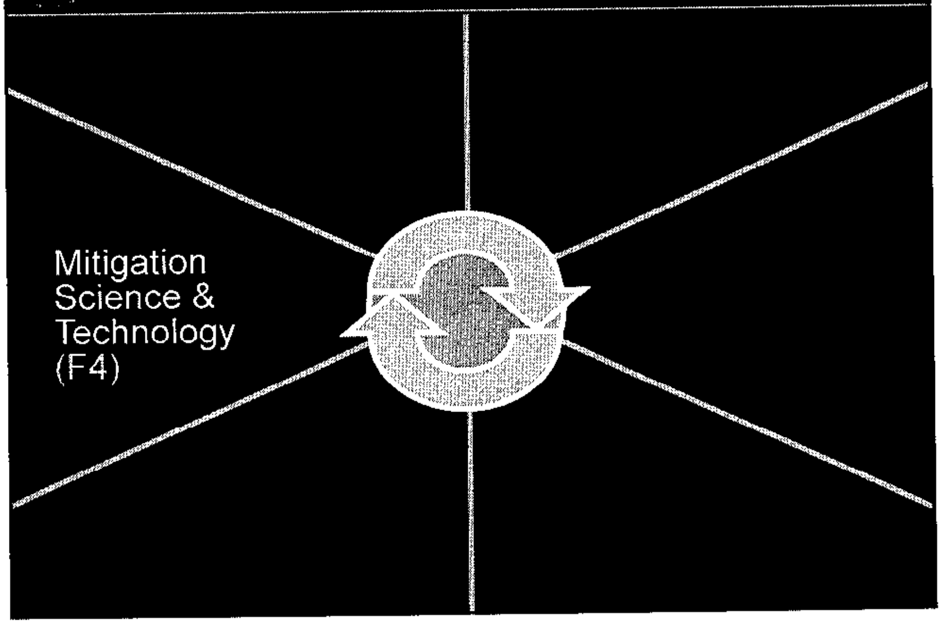
F3-G2 cont'd: Video Analytics Testbed for Detection and Tracking of Suspicious Behavior

- Publications/Presentations:
  - Z. Wu and R.J. Radke, Automatic Person-to-Object Association in a Large-Scale Camera Network, in review for *IEEE Workshop on Camera Networks and Wide Area Scene Analysis*
  - Z. Wu, Full-Scale Airport Security Checkpoint Surveillance Using a Camera Network, invited oral presentation at Fifth Annual DHS University Network Student Day
- Relevance to DHS mission:
  - Camera network testbed is a focus for DHS-specific undergraduate research experiences, both inside and outside the ALERT partners
  - Goal is to create increasingly-accurate simulations of mission-critical interest and transition algorithms to real environments (DHS advice/resources would be appreciated here)
  - Initial interactions with local FBI

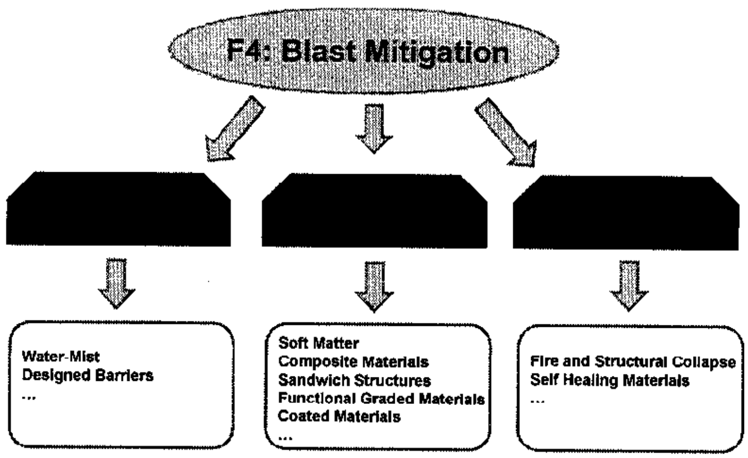
F3-G2 Vision for Expanded Video Analytics Testbed

- Large-scale, crowded environment scenarios designed by experts in event simulation, environment instrumentation, signal/image processing, cognitive science, visualization
- Large but controlled indoor environments enable:
  - precisely calibrated, multimodal data collection (video, audio, range, spectral, chemical, radiological, ...)
  - realistic, full-scale simulations of DHS-interest scenarios (disasters, multi-car crashes, evacuations, hostage situations, ...)
- One major event per summer; competition to select idea
- Promotes interaction between algorithm designers, sensor designers/vendors, DHS customers at all levels (undergrad, grad, faculty, research labs, contractors, DHS, DOD). Unique opportunities for data generation/sharing.
- Requires additional resources, DHS buy-in to create realistic, interesting environments; lead time to source materials and reserve space

The ALERT Fundamental Science Program: Encompasses Multidisciplinary CIED Elements



F4 Blast Mitigation: Overall Effort



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F4-A: Blast Attenuation by Water Barriers & Small-scale Characterization of Non-ideal explosives

Prof. S.F. Son, A. Zakrajsek, and R. Janesheski

PURDUE UNIVERSITY

Purpose/relevance: Conduct fundamental experiments to elucidate physical mechanisms responsible for blast mitigation using water, and design/demonstrate a new small-scale experiment to characterize non-ideal explosives using a microwave interferometer.

Approach:

- We are systematically studying the effectiveness, and developing a fundamental understanding, of the interaction of blast waves with water (sprays, sheets, etc.). Laboratory-scale characterization of non-ideal explosives is needed for improved understanding and models. Key technical innovations are using controlled laboratory-based experiments with dynamic time measurements at realistic blast profiles from a unique explosively-driven shock tube to study water mitigation, and the development of an entirely new small scale detonation failure experiment of non-ideal explosives.

Overview of completed/iterative outcomes:

- Systematic data sets have been obtained for water barriers, sheets and sprays. Initial modeling has been performed.
- An unique small scale experiment to characterize non-ideal explosives was designed, built & initial data taken for baseline materials.

Overview of future work:

- Modeling of water mitigation systems will be extended and the second phase of experiments will be performed. Small-scale characterization of additional explosives beyond initial base case materials will be performed, as well as parametric studies of particle size and stoichiometry of mixtures. Detonation failure modeling will be performed.

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Blast Attenuation by Water Barriers & Small-scale Characterization of Non-ideal explosives– Top Level

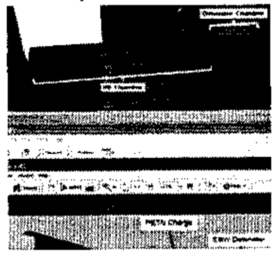
PURDUE UNIVERSITY

Purpose: Activity 1 - Blast Attenuation by Water Barriers are being studied to to elucidate physical mechanisms responsible for blast mitigation using water.

- Current Work: Water barriers, water sheets, and sprays are being experimentally studied.
- Future Work: Modeling will be used to better interpret mechanisms and experimental results

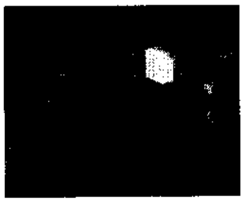
Purpose: Activity 2 – Small Scale characterization of non-ideal explosives.

- Future Work: Design and intial tests completed of new experiment. Refinement of experiment and application to various materials will be made. Modeling will be applied.

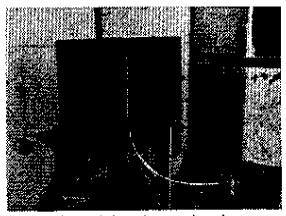


Explosive driven shock tube

Spray mitigation experiment



Water barrier experiment



Non-ideal explosive experiment

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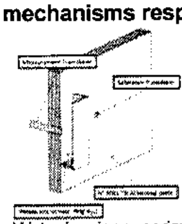
Blast Attenuation by Water Barriers & Small-scale Characterization of Non-ideal explosives-Details

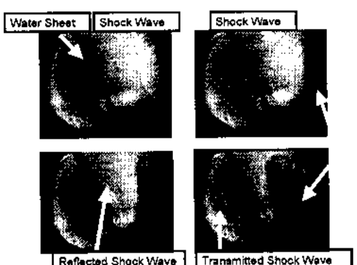
PURDUE UNIVERSITY

Purpose: Activity 1 - Blast Attenuation by Water Barriers are being studied to to elucidate physical mechanisms responsible for blast mitigation using water.

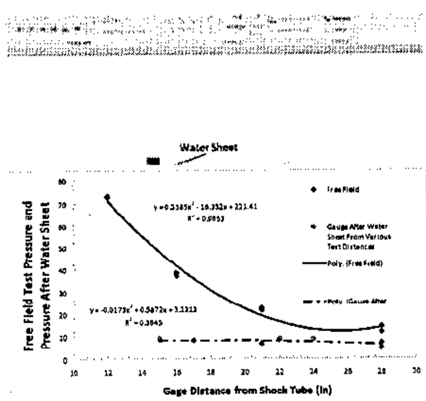
Spray characterization



Water barrier experiment



Blast-water sheet interaction shadowgraph

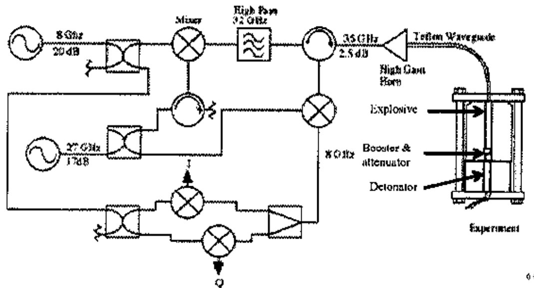


Water sheet shown to be very effective at blast mitigation. Higher volume loading sprays will not be considered. Water barriers are not effective.

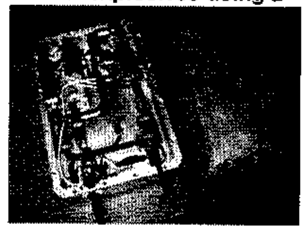
200

Blast Attenuation by Water Barriers & Small-scale Characterization of Non-ideal explosives– Details, cont'd

Purpose: Activity 2 - Small Scale characterization of non-ideal explosives using a novel small-scale transient experiment.

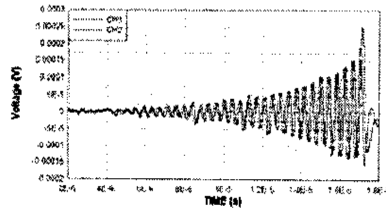


Schematic of experiment



Photograph of microwave interferometer
4.283 grams of Primasheet

Test setup



Baseline microwave interferometry result

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Blast Attenuation by Water Barriers & Small-scale Characterization of Non-ideal explosives

PROJECT METRICS: Mathew Alley (MS), currently NSWC Crane; Ben Schimizze (current M.S.), Eric Miklaszewski (finishing MS), Robert Janesheski (current M.S.), David Reese (M.S.), and Stephen Strinka (U.G. student)

PUBLICATIONS

"Dynamic Blast Testing," invited presentation to Force Protection Industries Workshop; "Dynamic Material Characterization of Brain Tissues," 2nd DoD Brain Injury Modeling Expert Panel Meeting; "Water Blast Mitigation," abstract submitted to APS Shock Compression meeting and journal paper in preparation; "Detonation Failure Characterization of Non-Ideal Explosives," abstract submitted to APS Shock Compression meeting.

Transition to Industry or Collaboration with Industry:

Participation in "Force Protection Industries Workshop."

2

F4-B: Novel Composite Materials & Structures for Blast Mitigation: Arun Shukla, URI

Dynamic PhotoMechanics Laboratory

Purpose/ Relevance:

- Conduct fundamental experiments to elucidate physical mechanisms responsible for damage in novel composite materials & structures subjected to extreme environments associated with blast & fragment loading, thus leading to new more efficient materials & structures with excellent blast mitigation capabilities to safeguard human life and property.

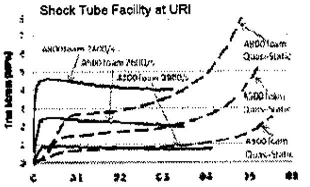
Shock Tube Facility at URI

Innovation:

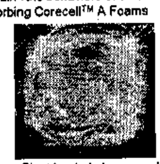
- Highly controlled experiments with real time measurements at extremely high loading rates to give full field load-deformation & damage information at materials & structural level. DPML team at URI has unique capabilities and long experience for such experimentation.

Overview of Completed Work:

- A comprehensive series of experiments were conducted to evaluate blast mitigation response of sandwich panel consisting of composite face sheets and several different energy absorbing/mitigating core materials.
- Numerical expressions were developed to understand the energy redistribution associated with shock loading.
- A comprehensive series of experiments were conducted under controlled blast loading conditions using the shock tube facility to understand damage mechanisms in structural glass panels. A new type of glass panel was designed which restraints the shattered pieces of glass from flying off and causing damage and injuries.
- The response of sandwich composites with existing damage to blast loading was successfully investigated in order to determine how such pre-damage affects the blast response of the specimens.



Quasi-static and high strain-rate behaviors of different types of Energy absorbing Corecell™ A Foams



Blast loaded glass panel with no shattered pieces flying off

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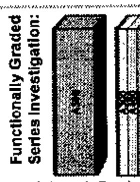
Novel Composite Materials & Structures for Blast Mitigation: Details...

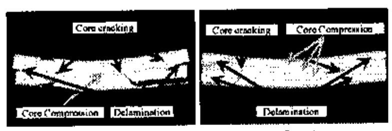
Dynamic PhotoMechanics Laboratory

Task 1:

- A series of shock tube experiments were conducted on sandwich panels consisting of composite facesheets and graded core materials in order to evaluate the overall blast response and mitigation capabilities



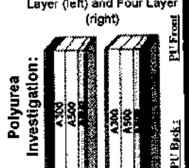
Schematic Drawing: One Layer (left) and Four Layer (right)



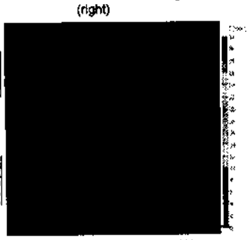
Post Mortem Images: One Layer (left) and Four Layer (right)

Current Work:

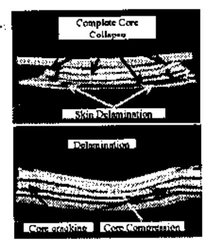
- Investigating the dynamic response of sandwich structures with composite facesheets and various energy absorbing core materials when subjected to high intensity blast loading. Investigations include increasing the number of monotonically graded core layers (1 – 4 layers), as well as the addition of polyurea to the core (in front of/behind foam)



Schematic Drawing: PU Front (left) and PU Back (right)



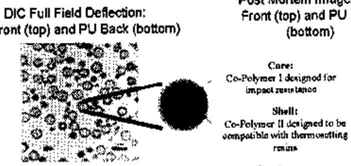
DIC Full Field Deflection: PU Front (top) and PU Back (bottom)



Post Mortem Images: PU Front (top) and PU Back (bottom)

Technical Collaboration and Future Work:

- Future work will include the addition of nano-scale Coreshell Rubber (CSR) to the resin system of the sandwich composites. Gurit, Specialty Products Incorporated (SPI), and TPI Composites will help in facilitating sample preparation. This will also fulfill the main goal of DHS and allow for a unified effort to protect our homeland.



Coreshell Microstructure and Design

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Novel Composite Materials & Structures for Blast Mitigation: Details

Dynamic PhotoMechanics Laboratory

TASK 2:

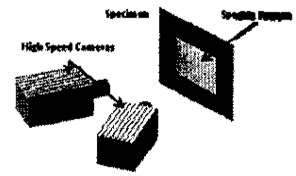
- A comprehensive series of experiments were conducted under controlled blast loading conditions using the shock tube facility to understand damage mechanisms in structural glass panels. A new type of glass panel was designed which restraints the shattered pieces of glass from flying off and causing damage and injuries.

Current Work:

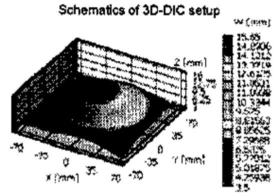
- Five different kinds of glass panels were tested using the shock tube facility at URI. Sandwiched glass panel with XO-Armor® protective coating on both front and back face was found to mitigate the blast loading. 3D- Digital Image Correlation techniques was used to better understand the fracture and damage development in the panels.

Future Work and Technical Collaboration:

- Further investigation will be carried to understand the blast mitigation of non-conventional material and their use as windows glass panels. Technical collaboration with XO-Armor, Texas and PPG Industries will help in sample preparation. This effort also aligns with the mission of DHS to transition technology and allow for a unified effort to protect our homeland.



Schematics of 3D-DIC setup



Deflection contour for sandwiched glass panel using 3D-DIC analysis

Postmortem images for (a) sandwiched glass and (b) laminated sandwiched glass panel

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Novel Composite Materials & Structures for Blast Mitigation: Future Work Continued

Dynamic PhotoMechanics Laboratory

Task 3: Effect of curvature on blast mitigation property

- The work on understanding the effect of curvature on blast mitigation properties of a structure will be continued with metals and then extended to composites. Panels, having three different radii of curvature, will be subjected to same shock loading level to understand their blast mitigation properties. Two different panels will be made; one using Aluminum 2024 T3 (in progress) and one using layered Carbon fibers. An understanding of failure mechanisms and energy redistribution properties will be developed.

Task 4: Effect of face sheet on the blast mitigation property of structure

- Two types of sandwich composites with different face sheets (one metallic and other being the glass fiber face sheet) and same core material will be subjected to a shock wave loading generated by a shock tube. The specimen will be simply supported on the back side to implement the simplest boundary condition and the overpressure of the incident shock wave will be the same. Real time shock wave pressures will be measured to provide accurate input and output parameters and average shock wave front velocities. This data will also be used to evaluate the energy mitigating properties of the sandwich composites.

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Novel Composite Materials & Structures for Blast Mitigation: Publications

Dynamic PhotoMechanics Laboratory

- N. Gardner, E. Wang, P. Kumar and A. Shukla, "Blast Mitigation in a Sandwich Composite using Graded Core with Polyurea interlayer" Experimental Mechanics, Accepted for Publication
- E. Wang, N Gardner and A. Shukla, "The blast resistance of sandwich composites with stepwise graded cores", International Journal of Solid and Structures, 46, 3492-3502, 2009.
- E. Wang and A. Shukla, "Analytical and Experimental Evaluation of Energies during Shock Wave Loading", International Journal of Impact Engineering, 37, 1188-1196, 2010.
- M. Jackson and A. Shukla, "Performance of sandwich composites subjected to sequential impact and air blast loading", Composites: Part B (2010), doi:10.1016/j.compositesb.2010.09.005.
- E. Wang, N. Gardner and A. Shukla, "Experimental study on the performance of sandwich composites with stepwise graded cores subjected to a shock wave loading", SEM Annual Conference and Exposition on Experimental and Applied Mechanics, Albuquerque, New Mexico , June 1-4, 2009.
- N. Gardner, "Blast performance of sandwich composites with discretely layered core", SEM Annual Conference and Exposition on Experimental and Applied Mechanics, Student Paper Competition, Albuquerque, New Mexico , June 1-4, 2009.
- S.A. Tekalur, E. Wang, M. Jackson and A. Shukla, "Failure Behavior and energy absorption of sandwich composites under dynamic loading", SEM Annual Conference and Exposition on Experimental and Applied Mechanics, Albuquerque, New Mexico , June 1-4, 2009.
- E. Wang and A. Shukla, "Evaluation of Incident, Reflected and Deformation Energies During Blast Experiments", SEM Annual Conference and Exposition on Experimental and Applied Mechanics, Albuquerque, New Mexico, June 1-4, 2009.
- N. Gardner and A. Shukla, "The Blast Response of Sandwich Composites with a Functionally Graded Core", SEM Annual Conference and Exposition, Indianapolis, Indiana, June 7-10, 2010.
- N. Gardner and A. Shukla, "The Blast Response of Sandwich Composites With a Functionally Graded Core and Polyurea Interlayer", SEM Annual Conference and Exposition, Indianapolis, Indiana, June 7-10, 2010.
- E. Wang and A. Shukla, "The Blast Response of Sandwich Composites with In-Plane Pre-Loading", SEM Annual Conference and Exposition, Indianapolis, Indiana, June 7-10, 2010.
- P. Kumar and A. Shukla, "Blast Loading response of Glass Panels", SEM Annual Conference and Exposition, Indianapolis, Indiana, June 7-10, 2010.
- E. Wang and A. Shukla, "Core Deformation of Sandwich Composites under Blast Loading", SEM Annual Conference and Exposition, Indianapolis, Indiana, June 7-10, 2010.

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Publications, Students Supported and Industry Collaborations

Dynamic PhotoMechanics Laboratory

- E. Wang and A. Shukla, "Blast Response of Sandwich Composites using Digital Image Correlation Technique", 9th International Conference on Sandwich Structures (ICSS9), Caltech, Pasadena, California, June 14 - 16, 2010.
- E. Wang and A. Shukla, "Performance of Pre-Stressed Sandwich Composites Subjected to Shock Wave Loading", 14th International Conference on Experimental Mechanics (ICEM 14), Poitiers, FRANCE July 4-9, 2010.
- P. Kumar and A. Shukla, "Dynamic Response of Glass Panels Subjected to Shock Loading", IMPLAST 2010, SEM Fall Conference, Providence, October 12-14, 2010.
- E. Wang and A. Shukla, "Energy and Impulse Evaluation during a Shock Tube Experiment", IMPLAST 2010, SEM Fall Conference, Providence, October 12-14, 2010.
- N. Gardner and A. Shukla, "The Blast Resistance of Sandwich Composites with a Functionally Graded Core and Polyurea Interlayer", IMPLAST 2010, SEM Fall Conference, Providence, October 12-14, 2010.
- Four Papers are being submitted for the upcoming 2011 SEM Conference and 3 Papers are under preparation for Journal publication.

Graduate Students Supported

1. Puneet Kumar
2. Matthew Jackson
3. Erheng Wang
4. Jefferson Wright
5. Nate Gardner

Undergraduate Students Supported

1. Daniel Gracia
2. Alexander Escher
3. Andrew Krystnewicz

Consulting with industry

1. 3 Tex, 109 Mackenan Dr., Cary, NC 27511
2. XO-Armor, 7812 Melrose Street, Houston, TX 77022
3. Webcore, 8821 Washington Church Road, Miamisburg, OH 45342
4. TPI Composites, Inc., 373 Market Street, Warren, RI 02885

Collaboration with National labs

Blast Mitigation of Cast Iron in collaboration with Lawrence Livermore National Laboratory, Livermore, CA

Collaboration with other DHS Center

Blast Mitigation of Corrugated Core Samples in collaboration with DHS Center at University of Connecticut

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Novel Composite Materials & Structures for Blast Mitigation: Students preparing for experiments

Dynamic PhotoMechanics Laboratory

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F4-C: Stress Attenuation by Means of Particulates and Inclusions

Carl-Ernst Rousseau - University of Rhode Island

Purpose/relevance: To enhance the mitigation of propagating stress and shock waves by strategically interposing inclusions within shielding materials

Approach:

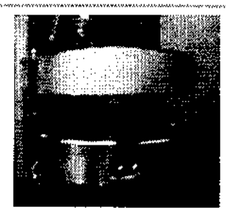
- **Non-destructive ultrasonic and impact testing of model materials.**

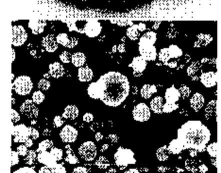
Overview of completed/iterative outcomes:

- **Completion of the study of syntactic foam used as core of shielding materials. The study focussed on how pore size and on frequency of voids influence the wave speed through the material, and more importantly, the attenuation attenuation of the wave during propagation.**
- **The vacuum system of our impactor has been refined and is now fully implemented. Through ports have been set in place to receive fiber optic cables for future implementation of a Doppler velocimeter.**

Overview of future work:

- **Implementation of Doppler velocimetry system, for real-time particle velocity evaluation (in-progress, continues).**
- **Extension of ultrasonic work on syntactic foams to include solid particulates. (in-progress, continues).**





Compressive evaluation of syntactic foam

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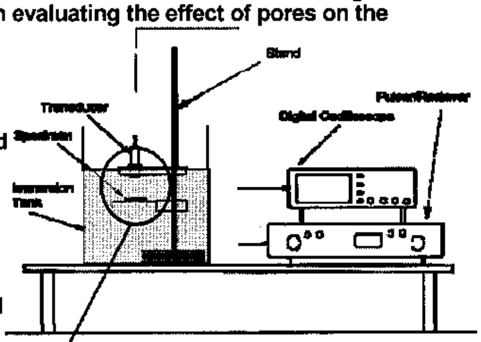
Stress Attenuation by Means of Particulates and Inclusions

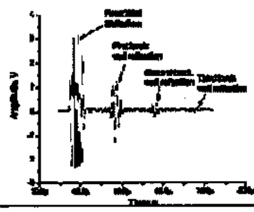
Carl-Ernst Rousseau - University of Rhode Island

Purpose: Activity 1 - Optimize dynamic properties of shielding materials and understand particulate to matrix interaction that will elicit efficient mitigation characteristics. The focus here is on evaluating the effect of pores on the attenuation of propagating waves.

Current Work:

- Porosity achieved by introduction of hollow microballoons within a matrix. Experiments were conducted for 3 sizes, and various concentrations of the voids. Wave speeds are shown to decrease with increasing pore size. Wave attenuation increases with increasing pore size. The effect of volume fraction of voids is beneficial only in some cases, and cannot be generalized.





Future Work:

- Investigate the influence of curing temperature of syntactic foams, as present, this is done primarily at room temperature. The study will also introduce solid particulates in the stead of voids.

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Stress Attenuation by Means of Particulates and Inclusions

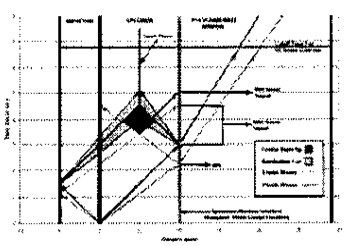
Carl-Ernst Rousseau - University of Rhode Island

Purpose: Activity 2 - Pursuance of mitigating capabilities of various composites, with the aim of identifying basic characteristics that contribute to the mitigation process.

Current Work:

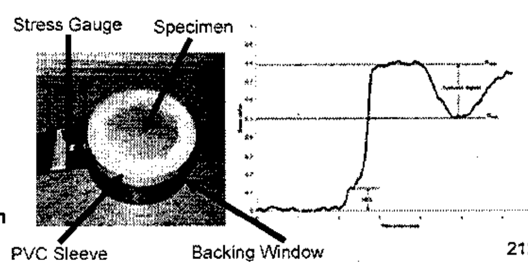
- Specimens are impacted and the generated stress waves propagating through them are monitored. Particulate composites and structural steel have thus been tested.
- Spalling is induced by the same methodology, and the material resistance to failure are thus determined

Wave interaction process



Future Work:

- Fully implement a Doppler velocimetry system that will capture particle velocities along with the stress signatures.
- Fabrication of materials with particulate arranged in specific patterns. Testing will help elucidate the complex interaction process and reveal patterns that enhance attenuation.



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Stress Attenuation by Means of Particulates and Inclusions

Carl-Ernst Rousseau - University of Rhode Island

PROJECT METRICS:

<u>Undergraduate students</u>: Integrated techniques of the project into the Mechanical Engineering Capstone design course. 5 undergraduate students (Andrew Wild, Nicholas Heeder, Dennis Heaphy, Will Whitman, Whit Duncan) received 6 credits for studying the principles of impact engineering, then designed and built a vacuum chamber for the impactor used in the research project. They also delivered 4 formal 1/2 hr presentations to the graduating senior class of 72 students.

<u>Graduate students</u>: B. Ale, M.S. 2011, G. Plume, Ph.D. 2012.

PUBLICATIONS

B. Ale, & C.-E. Rousseau, 2010, "Dynamic attenuation properties of syntactic foams," IMPLAST 2010, Providence, RI.

G. Plume, & C.-E. Rousseau 2010, "A preliminary investigation into the spall strength of cast iron," IMPLAST 2010, Providence, RI.

W. Visser, G. Plume, C.-E. Rousseau, & H. Ghonem 2010, "Deformation criterion of low carbon steel subjected to high speed impacts," IMPLAST 2010, Providence, RI.

B. Ale, & C.-E. Rousseau 2011, "Dynamic attenuation properties of syntactic foams," Int. J. Polymer Science, submitted.Construction, Draft Complete, To Be Submitted, 2011.

TECHNOLOGY TRANSFER: No direct transition to industry yet. However, collaboration has been initiated with the Lawrence Livermore National Lab due to their interest in the porosity study, and its possible effect on the dynamic response of cast iron.

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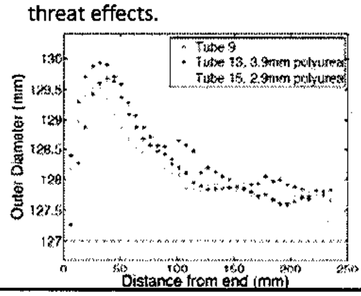
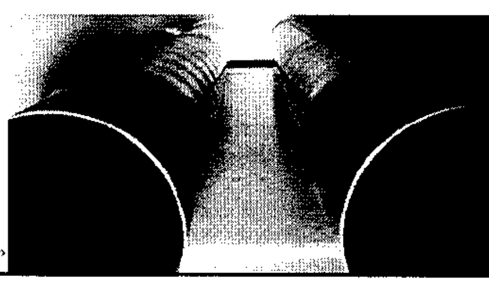
F4-D: Structural Response to Nonideal Explosions

JE Shepherd (PI), JS Damazo, Caltech

- **Purpose/ Relevance**: Determine plastic deformation and rupture thresholds of structures with internal nonideal explosions, specifically gaseous detonation. Fundamental knowledge is needed to design protective structures and evaluate response to threats.
- **Innovation**: Gaseous detonation loading fixture to produce high-strain rate (600 s^{-1}) loading and large (18% strain) plastic deformation of thin-wall structures.
- **This Year outcome**: Measurements on 304 stainless steel tubes demonstrated strain reduction up to 20% with polyurea coatings. Rippling effect due to wave interference was observed on the tube walls, confirming previous results with mild steel specimens.
- **Long-range impact**: High-quality data for developing and testing models of plastic deformation and polymer response. Improved methods of mitigation and prediction of threat effects.





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Structural Response to Nonideal Explosions
JE Shepherd (PI), JS Damazo, Caltech

- **Graduate Students**: J. Damazo, J. Karnesky (Graduated June 2010)
- **Undergraduate Students**: K. Chow-Yee, J. Odell
- **Papers/Patents/Presentations**:
- Plastic response of thin-wall tubes to detonation. J. Karnesky, J. Damazo, J.E. Shepherd, A. Rusinek. Proceedings of the ASME 2010 Pressure Vessels and Piping Conference: July 18-22, 2010; Bellevue, USA. (paper and presentation)
- Structural Response to Non-ideal Explosions. J. Karnesky, J. Damazo, J.E. Shepherd. DHS COE Workshop at the University of Rhode Island; March 3, 2010; Kingston, USA. (presentation)
- Investigating Shock Wave—Boundary Layer Interaction Caused by Reflecting Detonations. J. Damazo, J. Ziegler, J. Karnesky, and J.E. Shepherd. 8th ISHPMIE; 2010 September 5-10; Yokohama, Japan. (paper and presentation)
- Mitigating Effect of Polymer Coating on Deformation from Non-Ideal Explosions. J. Damazo, K. Chow-Yee, J. Karnesky, J.E. Shepherd. IMPLAST, SEM Fall Conference, University of Rhode Island; October 14-21, 2010; Providence, USA. (paper and presentation)
- Shock Wave—Boundary Layer Interaction in Reflecting Detonations. J. Damazo, J.E. Shepherd. 63rd Annual Meeting of the APS Division of Fluid Dynamics; November 21-23, 2010; Long Beach, USA.
- **Next Year:**
- **Fluid-Structure Interaction**: Pursue coupled fluid-structure computations to account for the feedback between deformation and gas dynamics.
- **Shock Wave—Boundary Layer Interaction**: Experimentally examine the interaction between the boundary layer induced by the incident detonation with the reflected shock wave using schlieren photography and thermocouple gauges to measure heat transfer.

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F4-E: Self-Healing Materials for Mitigation of Blast Damage
Faculty: N.R. Sottos, S.R. White *Student:* J. Patrick

- **Purpose/Relevance:** To develop self-healing materials capable of autonomous protection and recovery from blast induced damage.
- **Innovation:**
  - Extension of self-healing technology with seamless integration into state-of-the-art composite structural systems.
  - New self-healing materials development for blast damage.

- **This Year's outcome:**
  - Demonstration of self-healing in microvascular PUR foam for sandwich panel core materials
  - Development of vascularized 3D woven fiber-reinforced composite
- **Long-range impact:** New class of self-healing materials developed with specific emphasis on high-energy absorption capabilities for blast infrastructure.
- **Next Year:** System optimization through experimental evaluation. Structural sandwich panel integration. Publish research findings in peer-reviewed journals.

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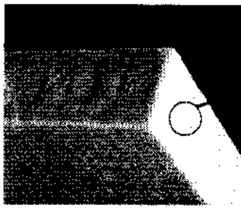
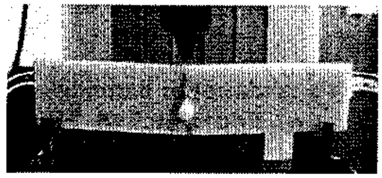
Self-Healing Materials for Mitigation of Blast Damage: Progress to Date

Self-Healing Foam Core for Structural Sandwich Panels

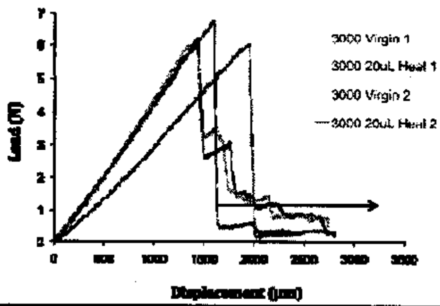
3D Woven Composite Sandwich Structure (3TEX)



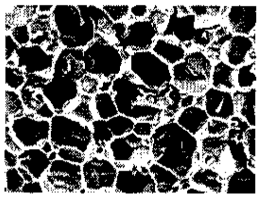
Microvascular Healing



Recovery of Mode I Fracture Toughness



Polyurethane (PUR) foam core material



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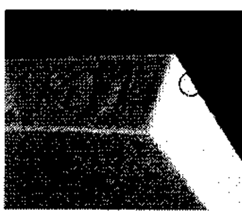
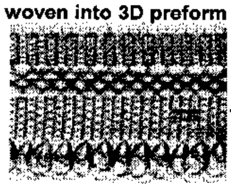
Self-Healing Materials for Mitigation of Blast Damage: Progress to Date

Self-Healing 3D Woven Composite Face Sheets

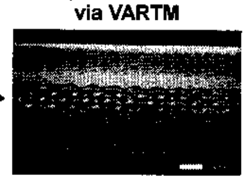
3D Woven Composite Sandwich Structure (3TEX)



"Sacrificial" fibers woven into 3D preform

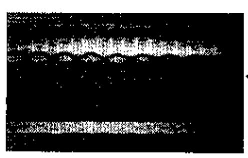


Composite fabricated via VARTM

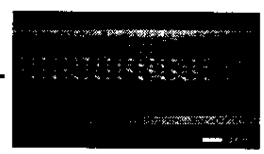


3D Woven Preform

Delivery of healing fluids



Fiber evacuation by heating



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Self-Healing Materials for Mitigation of Blast Damage: Future Work

- Optimize PUR foam healing system through experimental evaluation
- Develop a protocol to damage and heal the woven composite face sheets, e.g. End Notched Flexure (ENF) or Compression after Impact (CAI)
- Demonstrate recovery of mechanical properties in woven fiber-reinforced composites and measure healing efficiency
- Begin integration of self-healing of core and face sheet components into structural composite sandwich panel for eventual blast evaluation

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Self-Healing Materials for Mitigation of Blast Damage: Metrics

- **Project Metrics:** Dr. Nancy R. Sottos (Faculty), Dr. Scott R. White (Faculty) Jason F. Patrick (PhD Student), D.J. Fairfield (Undergraduate Research Assistant)
- **Publications/Patents:**
  - "Three-Dimensional Microvascular Fiber-Reinforced Composites", *submitted for publication (2011)*
  - "A Method for Preparation of Three-Dimensional Microvascular Fiber-Reinforced Composites", *University of Illinois Invention Disclosure (2011)*
- **Presentations:**
  - "Microvascular Based Self-Healing Polymeric Foams", 3rd International Conference on Self-Healing Materials, June 27-29, (2011), Bath, U.K.
- **Technology Transfer:** Collaborated with industrial partner, 3TEX, Inc., to manufacture 3D woven glass-fiber preforms with embedded sacrificial fibers to create microvascular networks for healing. Demonstrated capability for commercialization.

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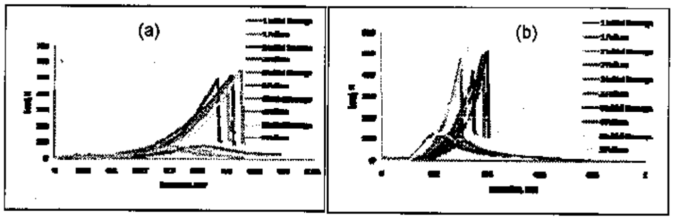
F4-F: Self-healing Concrete

Investigator's Name – Arijit Bose, Students – Michelle Pelletier (G), Triparna Bhattacharya (G), Sam Matus (UG), Amy Gibson (UG); School - URI

- **Purpose/ Relevance**: Develop construction material (concrete) that can recover mechanical strength after initial damage
- **Innovation**: Provide capsules containing healing material within concrete that break when crack passes through it, releasing healing material into crack and partially healing it.
- **This Year outcome**: Demonstrated 25% recovery of maximum loading to failure after initial failure. Controls gave recovery of less than 10%.
- **Long-range impact**: Improved lifetime for concrete; reduced environmental impact as concrete processing releases CO2.



Load versus displacement (extension) for flexural strength characterization of control (a) and capsule-containing (b) samples.

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Self-healing Concrete

Investigator's Name – Arijit Bose, Students – Michelle Pelletier (G), Triparna Bhattacharya (G), Sam Matus (UG), Amy Gibson (UG); School - URI

- **Education Students Present & Graduate**: Michelle Pelletier (MS 2010), Triparna Bhattacharya (MS 2012), Sam Matus (BS/BA 2011), Amy Gibson (BS/BA 2011)

- **Papers/Patents/Presentations**: Self-healing concrete with a microencapsulated healing agent, M. Pelletier, A. Shukla, R. Brown, A. Bose, submitted to Cement and Concrete Research, February 2011.

  Self healing Concrete – Provisional US patent 61358435 filed on June 25, 2010.

  Self healing Concrete, IMPLAST 2010, Providence, RI, October 2010.

- **Transition to Industry or Collaboration with Industry**: Working currently with BASF, W.R. Grace, CEMEX (Switzerland). Foresight Technologies is handling all interactions with industry

- **Next Year:** Role of capsule loading and size on yield strength; characterization of capsule containing sample under dynamic loading conditions; multiple load-release cycle (fatigue) characterization

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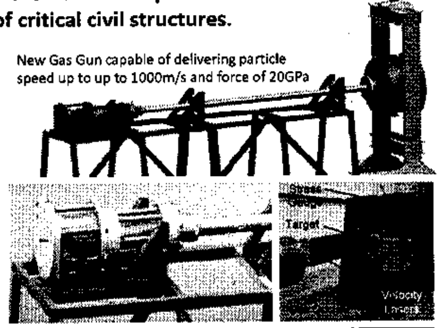
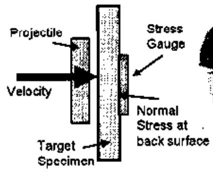
F4-G: Damage and Residual Life of Critical Civil Structures under Blast Loadings

H. Ghonem, O. Gregory, W. Visser, Q. Liu and K. Jeaniouis, U Rhode Island

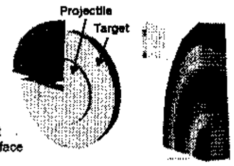
- Purpose/Relevance: **Conduct fundamental experiments coupled with advanced numerical/analytical modeling to determine the relationship between blast loading and residual life of the reinforcing metallic phase of critical civil structures.**
- Approach: **A damage and residual life assessment model incorporating three integrated studies: i- Experimental program utilizing a new gas gun design to deliver TNT equivalent, blast loadings, ii- A mechanistic based deformation criterion associated with high loading rates, and, iii- An experimental methodology to determine post blast residual life in terms of ductility reduction and available fracture energy.**



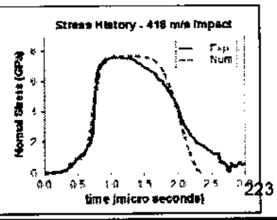
Integrated numerical/ analytical procedure to calculate blast particle speed and stress field within the target. Validation of the approach is shown by comparison of experimental and numerically generated normal stress.



Impact Schematic



Quarter Plate Simulation



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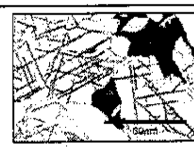
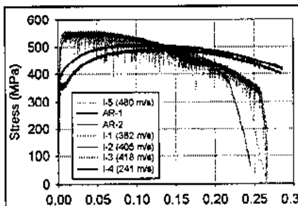
Damage and Residual Life of Critical Civil Structures under Blast Loadings ;

H. Ghonem, O. Gregory, W. Visser, Q. Liu and K. Jeaniouis, U Rhode Island

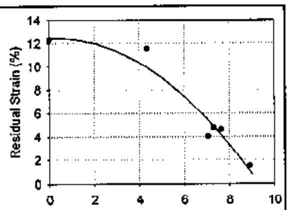
- This Year's Outcome: **A series of blast experiments were carried out to establish a blast deformation criterion for low carbon structural steel based on twin formation. Post-blast residual life has been measured experimentally and correlated with twin volume fraction as a function of impact stress.**



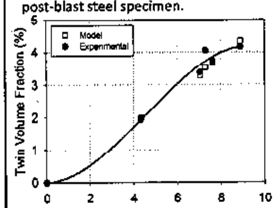
Micrograph of deformation twins in a post-blast steel specimen.



Stress-strain curves of as-received and post-impact steel specimens.



Residual life of post-impact steel specimens as a function of impact stress.



Experimental and analytical twin volume fraction as a function of impact stress.

- Long-Range Impact: **(i) Develop a numerical tool to predict the survivability of structures subjected to blast loading. This tool will be used to identify the force limit for blast mitigation designs suitable for resistance to single and multiple blasts. (ii) Provide the material dynamic deformation flow characteristics required for the microstructure development of a blast resistant reinforcing metal phase.**

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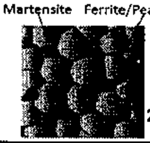
Damage and Residual Life of Critical Civil Structures under Blast Loadings ; H. Ghonem, O. Gregory, W. Visser, Q. Liu and K. Jeaniouis, U Rhode Island

- **Education Student Present & Graduate: D. Barr, Fall River High School Teacher, K. Jeaniouis, Undergrad Student, W. Visser, Masters Student, Q. Liu, PhD Student**
- **Papers/Patents/Presentations:**
  - Microstructural Characterization of Pipe Bomb Fragments, O. Gregory, J. Oxley, J. , M. Platek, J. Smith, M. Downey, C. Cummiskey, E. Bernier , H. Ghonem, *Materials Characterization*, Vol.61, No. 3, p.347-354, March 2010.
  - Deformation Criterion for Blast loading in Low Carbon Steel, W. Visser, Y. Sun, O. Gregory and H. Ghonem, *Int. J. Material Science and Engineering*, submitted December 2010.
  - Time-Dependent Deformation of Low Carbon Steel at Elevated Temperatures, K. Maciejewski, Y. Sun, O. Gregory and H. Ghonem, *Int. J. Steel and Iron Research*, in press March 2011.
  - Numerical Applications of Viscoplastic Deformation of Structural Steel, Y. Sun, K. Maciejewski, O. Gregory and H. Ghonem, *J. Materials Engineering and Performance*, submitted January 2011.
  - Deformation Criterion of Low Carbon Steel Subjected to High Speed Impacts, W. Visser, G. Plume, Y. Sun, C. Rousseau, O. Gregory, H. Ghonem, IMPLAST, Providence, October 14, 2010.
  - Twin Formation and Influence on Deformation Characteristics of Low Carbon Steel, W. Visser, Y. Sun, O. Gregory , H. Ghonem, 2011 SEM Annual Conference on Experimental and Applies Mechanics, Mohegan Sun, Uncasville, CT, June 13, 2011.
- **Collaboration with Industry: National Institute of Standards and Technology, FM Global**
- **Next 2 Years: 1- Extend the impact load experiments to a range beyond that of conventional TNT blast energy in order to examine effects of single and multiple blast events on residual life of structural steel and cast iron materials, and 2- Develop and examine a new low carbon steel capable of absorbing high energy impact loads**



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F4-H: Optimal Design and Use of Advanced Structural Materials to Mitigate Explosive and Impact (Faculty: JJ Myers and J Baird, MST; Students: NL Carey, C Greene, P Mulligan, A. Wulfers, L. Bookout)

Purpose/relevance: To develop advanced materials for multi-hazards including mitigation of explosive and high velocity impacts with reduced fragmentation.

Approach:

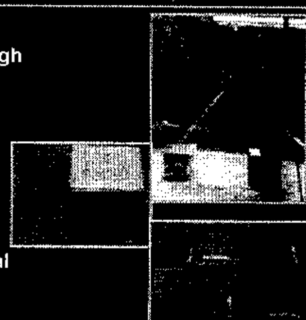
- Physical experimental evaluation of advanced technologies using discrete reinforced polyurea.

Overview of completed/iterative outcomes:

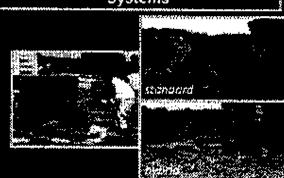
- Optimization of randomly distributed reinforced polyurea coating systems for reduced fragmentation and enhanced blast and impact resistance of structural elements / material characterization (coupon testing), screening and optimization. Flexural, shear, confining RC study on discrete fiber polyurea system.
- Experimental evaluation of beams and cylinders for multi-hazard evaluation.

Overview of future work:

- Panel blast testing using discrete fiber-reinforced polyurea systems, multi-hazard evaluation / testing of structural elements (in-progress, continues).
- Refinement of design protocol for hybrid discrete fiber system. Specification development. Patentability investigation with Line-X (Industry Partner) (in-progress, continues).



Discrete Fiber-Reinforced Polyurea Systems



Protective Coating Systems for Blast Mitigation Barrier Systems

F4-H cont'd: Optimal Design and Use of Advanced Structural Materials to Mitigate Explosive and Impact Threats – Top Level

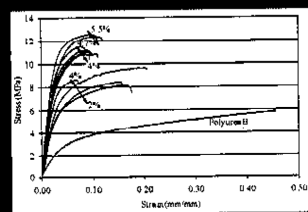
Purpose: Activity 1 -Development /characterization of discrete fiber-reinforced polyurea systems for infrastructural applications, including blast mitigation, fragmentation reduction, hazard mitigation, and repair-retrofit applications.

- Current Work: Five (5) polyureas are being tested reinforced with 6 mm (¼ in.) E-Glass fiber and various fiber content.
- Future Work: Investigate fiber-reinforced polyurea system behavior under blast loading. Numerical investigations and design protocol, specifications.

Purpose: Activity 2 - Evaluation of fiber-reinforced polyurea coating systems for multi-hazard enhancement including column confinement, flexural and shear strengthening for repair-retrofit applications.

- Future Work: Static testing completed. Refinement of design protocols. Cyclic behavior investigated pending future funding.


Tension Test Setup


6 mm (¼ in.) Fiber Length


Ignition Loss Testing


Concrete Cylinders


Steel reinforcement for test beams

F4-H cont'd: Optimal Design and Use of Advanced Structural Materials to Mitigate Explosive and Impact Threats - Details

Purpose: Activity 1 - Development and characterization of different discrete fiber-reinforced polyurea systems for infrastructural applications, including blast mitigation, fragmentation reduction, hazard mitigation, and repair-retrofit applications and their transition of the technology to the field.

Transition of Technology to the Field:

- Current Work Undertaken: The project team has collaboratively worked with LINE-X Protective Coatings Corporation located in Columbia, Missouri (corporate headquarters in Huntsville, AL) in the polyurea formulation studies, fiber development & characterization investigations, and specimen coating. This effort is in a direct alignment with the goal to transition the technological development to the field and satisfy DHS's mission for a unified national effort to secure the country and preserve our freedoms.
- Patent Development: the discrete fiber polyurea system that has been developed will be investigated for patentability during the current funding cycle with the assistance of Missouri S&T's Technology Development and Economic Development Center: http://ecodevo.mst.edu/.


Discrete Fiber Polyurea Application to a Blast Test Panel at LINE-X in Columbia, Missouri

F4-H cont'd: Optimal Design and Use of Advanced Structural Materials to Mitigate Explosive and Impact Threats – Details, cont'd

Purpose: Activity 2 - Evaluation of fiber-reinforced polyurea coating systems for multi-hazard enhancement including column confinement, flexural and shear strengthening for repair-retrofit applications.

Panel Blast Testing

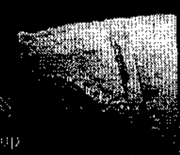
Current Work:

- Two types of panels (plain concrete & concrete with Propex Novocon© 1050 FE steel fibers) with external strengthening systems were evaluated under blast loading.
- Behavior of reduced scale standard reinforced concrete and polyurea coated reinforced concrete panels subjected to blast loading analyzed using LS-DYNA.

Future Work:

- Additional blast testing to complete test matrix.
- Additional behavioral modeling to compare with blast tests.
- Projectile/fragment hazard testing pending funding (leveraged with other Missouri S&T project)

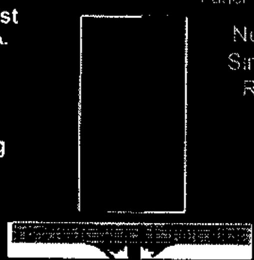
Blast Test Setup



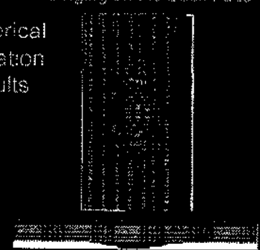
Reinforced Concrete Panel

Polyurea Coated RC Panel, Bulging on the Back Face

Numerical Simulation Results



Reinforced Concrete Panel, Back Face



Polyurea Coated Reinforced Concrete Panel Back Face

F4-H cont'd: Optimal Design and Use of Advanced Structural Materials to Mitigate Explosive and Impact Threats

MYERS ALERT PROJECT METRICS: Dr. John J. Myers (Faculty), Ms. Natalia L. Carey (PhD Student), Mr. Anthony Wulfers (MS Student), Ms. Courtney Greene (MS Student, Grad Dec. 2010), Undergraduate Research Assistants (2)

BAIRD ALERT PROJECT METRICS: Dr. Jason Baird (Faculty), Mr. Phillip Mulligan (MS Student), Ms. Laurin Bookout (MS Student), Undergraduate Research Assistant

PUBLICATIONS

- Carey, N.L., and Myers, J.J., 2010, "Discrete Fiber Reinforced Polymer Systems for Repair of Concrete Structures: Polyurea-Fiber Characterization Results," 10th International Symposium on Fiber Reinforced Polymer Reinforcement for Reinforced Concrete Structures (FRPRCS-10), Tampa, USA.
- Carey, N.L., and Myers, J.J., 2010, "Full Scale Blast Testing of Hybrid Barrier Systems," American Concrete Institute (ACI) Special Publication Journal.
- Carey, N.L., and Myers, J.J., 2010, "Elastomeric Systems with Discrete Fiber for Infrastructure Repair and Rehabilitation," Proceedings for Structural Faults & Repair – 2010, Edinburgh, UK.
- Carey, N.L., and Myers, J.J., 2010, "Discrete Fiber Reinforced Polyurea for Hazard Mitigation," Fifth International Conference on FRP Composites in Civil Engineering (CICE 2010), Beijing, China.
- Myers, J.J., and Carey, N.L., 2010, "Numerical Simulation of Plain Reinforced Concrete and Polyurea Coated Panel Behavior under Blast Loading," Missouri University of Science and Technology, Draft, 2010, 12pp.
- Greene, C., and Myers, J.J. 2011, "Flexural and Shear Behavior of Reinforced Concrete Members Strengthened with a Discrete Fiber-Reinforced Polyurea System," ASCE-Journal of Composites for Construction, Draft Complete, To Be Submitted, 2011, 35pp.

F4-H cont'd: Optimal Design and Use of Advanced Structural Materials to Mitigate Explosive and Impact Threats

TECHNOLOGY TRANSFER

Technology Transfer: Technical Reports

- Myers, J.J., Greene, C. "Glass Fiber-Reinforced Polyurea Strengthening of Reinforced Concrete," Missouri University of Science and Technology, Center for Infrastructure Engineering Studies, Dec. 2010, 231pp.
- Hawkins, J.W., and Baird, J., "Explosives Recognition and Awareness Training: A Psychological Approach to Pre-Blast Mitigation," MS Thesis, Missouri University of Science and Technology, 2010, 85pp.

Technology Transfer: Technical Presentations and Poster Sessions

- Carey, N.L. and Myers, J.J., "Discrete Fiber Reinforced Polyurea Systems for Blast and Hazard Mitigation", American Concrete Institute (ACI) Spring 2011 Convention, April 3-7, 2011, Tampa, FL, USA.
- Myers, J.J., and Carey, N.L., "Full scale blast testing of hybrid barrier systems", ACI Fall 2010 Convention, October 24-28, 2010, Pittsburgh, PA, USA.
- Carey, N.L. and Myers, J.J., "Discrete Fiber Reinforced Polyurea Systems for Infrastructure Repair and Blast Mitigation," Bernard M. Gordon Center for Subsurface Sensing and Imaging Systems (Gordon-CenSSIS) and Awareness & Localization of Explosives-Related Threats (ALERT) 11th Annual Research and Industrial Collaboration Conference (RICC), October 19, 2010, Boston, MA, USA.
- Greene, C. and Myers, J.J., "Flexural and Shear Reinforcement of Reinforced Concrete Beams using Fiber Reinforced Polyurea Coatings," Bernard M. Gordon Center for Subsurface Sensing and Imaging Systems (Gordon-CenSSIS) and Awareness & Localization of Explosives-Related Threats (ALERT) 11th Annual Research and Industrial Collaboration Conference (RICC), October 19, 2010, Boston, MA, USA.
- Hawkins, J.W., and Baird, J., "Explosives Recognition and Awareness Training: A Psychological Approach to Pre-Blast Mitigation," Bernard M. Gordon Center for Subsurface Sensing and Imaging Systems (Gordon-CenSSIS) and Awareness & Localization of Explosives-Related Threats (ALERT) 11th Annual Research and Industrial Collaboration Conference (RICC), October 19, 2010, Boston, MA, USA.
- Mulligan, P., and Baird, J., "The Effects of Run Up on an Explosively Formed Projectile," International Society of Explosives Engineers 36th Annual Conference on Explosives and Blasting Technique, February 6 – 10, 2010, Orlando, FL, USA.

F4-I: Optimal Design and Development of Advanced Materials and Structures (PI: Choong-Shik Yoo)

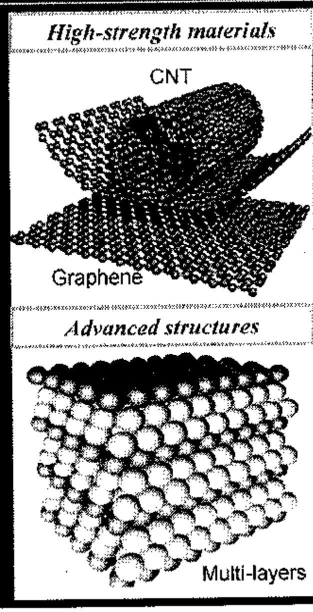
Purpose/relevance: To investigate the shock wave propagation in advanced materials and structures

- Novel materials: high strength Carbon nanotube (CNT) and Graphene with large anisotropy in shock impedance
- Advanced structures: multilayers, amorphous solids, energetic composites

Approach: investigate dynamic responses of materials under large strains, strain rates, and deformations, and develop the effective structures for mitigating blast/shock damages

Significance and relevance:

- Understanding shock-wave interactions with novel materials
- Developing advanced material structures that can dissipate, absorb, or retard the shock-wave propagation
- Mitigating blast damages of thermite mixtures and energetic composites



F4-I: High strength materials: Graphene, CNT, New Diamond-like Carbon

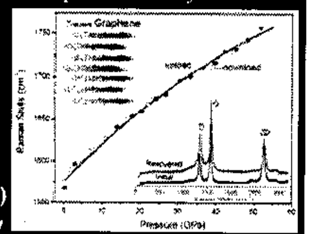
Motivation: Graphene and CNT are novel high-strength materials with high shock anisotropy in nm scales that can dissipate or mitigate strong shock waves and offer a way to reveal how shock wave propagates through in an atomistic scale

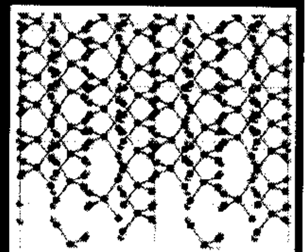
Results:
- Found high structural stability of 7-layered Graphene to 60 GPa, even greater than CNT (35 GPa)
- Found high compressibility on the c-axis, potentially a shock absorbing or self-healing material
- Characterized a new form of diamond-like extended carbon made from CNT in various stress conditions

Significance and relevance:
- Fundamental materials properties critical to basic science of shock-wave propagation in mitigative structures

Next step:
- Investigate Graphene and CNT under dynamic conditions

Graphene under hydrostatic





New diamond-like carbon made from CNT, showing fused layers

F4-I: Advanced Structures – Reactive Multilayers

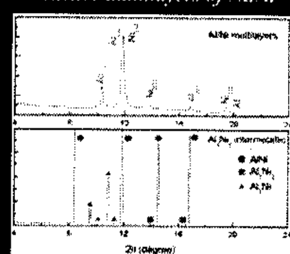
Motivation: Investigate dynamic responses of reactive multilayers – important for understanding mechano-chemical "blast" properties of thermites, energetic composites, nano-energetics

Approach: Subject the reactive multilayer under controlled mechanical (a gas-gun) and thermal (a pulse laser) impacts, and measure the dynamic structural and chemical changes in real-time:
- Mechanical deformation by time-resolved x-ray diffraction (TR-XRD)
- Fracture dynamics by high-speed microscopy
- Chemical reactions: TR-Spectroscopy

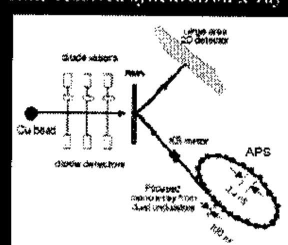
Results:
- Examined XRD of initial and final states of Ni:Al multilayers at Advanced Photon Source (APS)
- Investigated kinetics associated with Ni+Al intermetallic reactions

Next step: First TR-XRD is planned at the APS (March, 2011) to probe the structural evolution during the mechanical deformation and chemical reaction

Reactive multilayers of Ni:Al

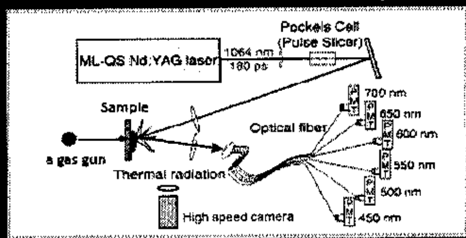


Time-resolved synchrotron x-ray

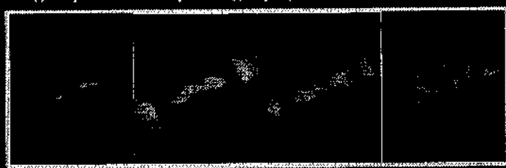


F4-WSU: Investigating Blast Effects of Materials in Controlled Conditions

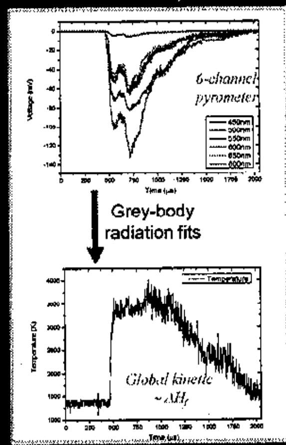
Controlled thermal and mechanical impacts



High speed microphotography



Time-resolved temperatures



Status: Enabling technology developed for blast effects measurements
Next step: Investigate the burn characteristics of thermite mixtures and reactive metals in both aerobic and anaerobic conditions

F4-I: Yr4 Plans and Metrics

Plans :

- Investigate Graphene and CNT under shock compression
- TR-XRD experiments on Ni:Al multi-layers at the APS to probe the structural evolution across the deformation to fracture to chemical changes
- Investigate dynamic mechano-chemical properties of thermite mixtures and reactive metals in controlled aerobic and anaerobic conditions

Metrics:

- 2 GS + 2 PD + 1 Faculty
- 1 in print, 1 in submission, and 2 in preparation
- 1 poster at the 2010 APS_March meetin
- 2 presentations: PacifiChem, GRC-HE

Technology developments: TR-Spec, TR-XRD, TR-Pyrometry for investigation of dynamic responses of solids - leveraged by other DARPA program

Developing enabling collaborations:

- With scientists at APS and LANL, for time-resolved x-ray diffraction for dynamic events

F4-I Publications

Papers:

- Jing-Yin Chen, Minseob Kim, and Choong-Shik Yoo, High Structural Stability of Single Wall Carbon Nanotube under Quasi-hydrostatic High Pressures. Chem. Phys. Lett. 479, 91 (2009)
- Minseob Kim, Jing-Yin Chen, and Choong-Shik Yoo, Formation of New Carbon Structures under Quasi-Hydrostatic Pressures, J. Appl. Phys. (2011) submitted
- Simon Clark, Jing-Yin Chen, and Choong-Shik Yoo, Structure and Stability of Graphene to 60 GPa, in preparation
- Haoyan Wei and Choong-Shik Yoo, Time-resolved Temperatures to Measure Global Kinetics of Reactive Metal Fragments (2010), in prepation

Poster and Abstract:

- Minseob Kim, Jing-Yin Chen, Choong-Shik Yoo, Formation of New Carbon Structure under Quasi-Hydrostatic High Pressures, APS March Meeting, Portland, OR, March 2010
- Choong-Shik Yoo, Advamced Multi-Functional Shock-Resistive Materials and Materials Structures, an abstract submitted to DHS_Summit (2011)

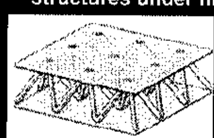
Presentations:

- Choong-Shik Yoo, Monolithic Energetic Materials, an invited talk at the Gordon Research Conference on Energetic Materials, June 13-18, 2010, Tilton School, Tilton, NH
- Choong-Shik Yoo, Novel Solids at Extreme Conditions, an invited talk to PacifiChem, Dec. 15-19, 2010, Honolulu, Hawaii

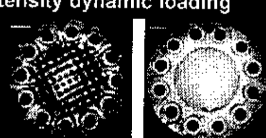
F4-J: Modeling of Explosion – Resistant Structures

(Faculty: A. Vaziri, NU; PhD Student: A. Ajdari, NU, H. Ebrahimi, NU)

- Purpose and Innovative Approach
  - Advanced modeling and numerical simulation of response of structures under blast and shock loading at different scales: from structural components to full-scale structural systems
  - Development of robust failure material models for structures capable of simulating material fracture under dynamic loading
  - Development of novel energy absorbent structural materials based on the concepts of activity, heterogeneity and hierarchy
- Near term and Long range Objectives
  - Achieve fundamental understanding of failure mechanisms of structures under blast and shock loading
  - Develop high-performance explosion-resistant material systems
- Impact
  - Development of novel materials with superior energy absorption characteristics
  - Construction of robust computational platform for simulating the response of structures under high intensity dynamic loading



Sandwich panel with all-metal cores for explosion-resistant structures

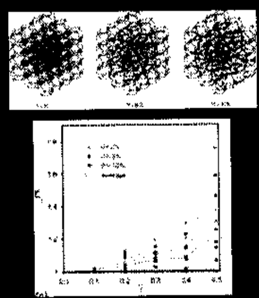


Small-scale structural specimens subjected to shock

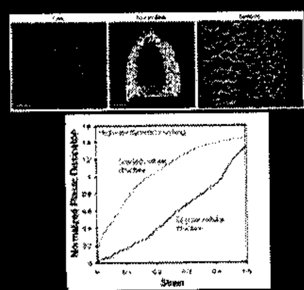
Detailed 3D numerical simulations of structural failure under blast

F4-J cont'd: Modeling of Explosion – Resistant Structures

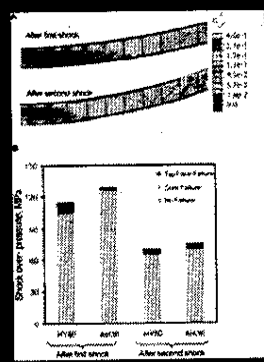
- Year 3 Research Accomplishments (Please see the publications and related award grants)
  - Fundamental study of response of sandwich structures under high intensity dynamic loading
  - Simulation of structures subjected to multiple shocks
  - Studying the energy absorption of heterogeneous and functionally graded materials
  - Research collaboration with Textron and URI through John Adams Foundation



3D irregular cellular structures



Biomimetic cellular structures and their energy absorption



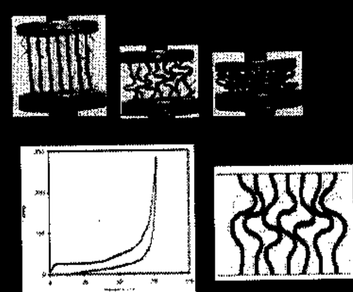
Detailed 3D numerical simulations of structural failure under two consecutive blast loadings

F4-J cont'd: Modeling of Explosion – Resistant Structures

- Year 4 proposed work
  - Investigate the residual structural capacity and safety of shock-loaded structures
  - Investigate the response of structures under fire and at elevated temperature
  - Novel cellular structures with structural hierarchy and biomimetic armored materials with multifunctional advantages and superior mechanical properties

Biological scaled armor systems

Cellular structure of sisal leaf



Crushing of a hybrid cellular structures (experiments and numerical simulations)

F4-J cont'd: Modeling of Explosion – Resistant Structures

- Publications
  - Journal article:
    - A. Ajdari, H. Nayeb- Hashemi, A. Vaziri, "Dynamic crushing and energy absorption of regular, irregular and functionally graded cellular structures", *Int. J. Solids and Structures*, 2011, 48, pp. 506-516.
    - Babee, B. Hapghpanah Jahromi, A. Ajdari, H. Nayeb-Hashemi,& A. Vaziri, "Mechanical properties of open-cell rhombic Dodecahedron cellular structures", *J. Mechanics and Physics of Solids*, under review.
    - A. Vaziri, A. Ajdari, H. Ali., A. Agelaridou Twohig· "Structural analysis of reinforced concrete chimneys subjected to uncontrolled fire", *Engineering Structures*, under review.
    - M. Ashrafi, A. Ajdari, H. Nayeb-Hashemi & A. Vaziri, "Single lap joints with non-flat interfaces", I *Int. J. Adhesion and Adhesives*, in preparation.
  - Conference Abstracts:
    - A. Vaziri, A. Ajdari "Homogenization and failure of metal sandwich panels subjected to air shocks", *IMPLAST 2010*.
    - A. Ajdari, S. Babaeezadeh & A. Vaziri, "Dynamic crushing and energy absorption of cellular structures", *IMPLAST 2010*.
    - S. Babaee, B. Haghpanah, A. Ajdari, H. Nayeb-Hashemi,& A. Vaziri, "Mechanical properties of three-dimensional open, closed and partially-closed rhombic dodecadedron cellular structure", *IMECE 2010*, 2010.

F4-J cont'd: Modeling of Explosion – Resistant Structures

- A. Vaziri, B. Haghpanah & A. Ajdari, "Failure and fracture of shock-loaded sandwich panels", *IMECE 2010*, 2010.
- A. Ajdari, S. Babaee & A. Vaziri, "Dynamic crushing of heterogeneous and functionally graded cellular structures", *New England Workshop on the Mechanics of Materials and Structures*, 2010.
- S. Babaee, A. Ajdari & A. Vaziri, "Heterogeneous and functionally graded three-dimensional cellular materials" , *2011 SEM Annual Conference and Exposition on Experimental and Applied Mechanics.*
- A. Ajdari, S. Babaee & A. Vaziri, "Mechanical properties and energy absorption of heterogeneous and functionally graded cellular structures", *International Conference on the Mechanical Behavior of Materials, 2011.*
- A. Ajdari, S. Babee, H. Nayeb-Hashemi & A. Vaziri, "Cellular structures with irregular structural organization", *Engineering Mechanics Institute Conference (EMI2011).*
- S. Babaee, B.H. Jahromi, A. Ajdari, H. Nayeb-Hashemi, A. Vaziri, "Energy absorption of 2D and 3D Cellular structures", *Sixth MIT Conference on Computational Fluid and Solid Mechanics*, Cambridge, MA 2011.
- A. Ajdari, A. Vaziri, "Structural hierarchy in 2D honeycombs", *USNCCM 11*, Minneapolis, MN 2011.
- A. Ajdari, S. Babaee, A. Vaziri, "Energy absorption of 3D closed-cell rhombic dodecahedron structures", *ASME App. Mech.* Mat., Chicago, IL, 2011.

F4-J cont'd: Modeling of Explosion – Resistant Structures

- Related awarded grants:
  - 2010 AFOSR YIP ($360k)
    Bioinspired surfaces and interfaces for hybrid structures
  - Multi-national grant from QNRF ($910k)
    New approaches for structural protection in oil and gas industry
  - John Adams Foundation Award – in collaboration with Textron and URI ($100k)
    Dynamic mechanical properties of polymers and aluminum alloys
- Pending proposals: 2011 ONR YIP, 2011 DARPA YIP.
- Organizing and Co-organizing symposiums and mini-symposiums in the area of Impact Engineering in the following conferences:
  - 10th US National Congress on Computational Mechanics
  - IV European Conference on Computational Mechanics
  - International Conference on Computational and Experimental Engineering and Sciences (ICCES10)
  - Workshop co-Organizer, The New England Workshop on the Mechanics of Materials and Structures
  - Symposium co-Organizer, Six MIT Conference on Computational Fluid and Solid Mechanics

F4-K: Fundamental Science of Progressive Collapse Resistance of Reinforced Concrete (RC) Structures (Faculty: Mehrdad Sasani, NU; Postdoc: Yaser Mirzaei, NU)

- Purpose and Innovative Approach
  - Advanced modeling and numerical simulation of response of full-scale structural systems following member loss due to explosions
  - Unique and pioneering experimental program on actual structures
  - Complements Joe Shepherd's work on confined structures (pipelines)
- Near term and Long range Objectives
  - Achieve fundamental system-level understating and develop advanced modeling methods of primary collapse resistant mechanics and mechanisms (Catenary & Vierendeel actions)
  - Develop a probabilistic framework for design of innovative structures and evaluation of existing structures against explosion
- Impact
  - Drastic improvement of integrity evaluation of complex RC structures

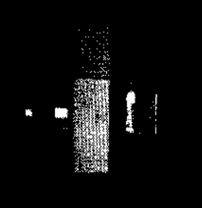
20-Story RC structure slated for demolition used in experiments

1st Floor column before explosion

Post-explosion results used to validate models and ideas

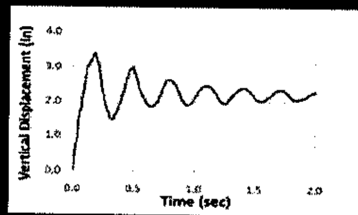
F4-K cont'd: Fundamental Science of Progressive Collapse Resistance of Reinforced Concrete (RC) Structures

- Review of accomplishments in Year 2
  - In order to carry out analytical and experimental studies proposed in year 2 (first slide), we study progressive collapse resistance of flat slabs/plates (i.e. RC slabs without beams) , which are economical structural systems used particularly in parking garage structures and are susceptible to manmade hazards (explosions in parking garages such as 1993 WTC bombing)
  - Response of an actual two-story parking garage with flat slab following column explosion is experimentally evaluated (recorded deformation shown below)



Parking garage 1st Floor column before explosion

Parking garage 1st Floor column after explosion



Vertical displacement of flat slab following explosion versus time

F4-K cont'd: Fundamental Science of Progressive Collapse Resistance of Reinforced Concrete (RC) Structures

Year 3 Plan (From Year Two Annual Report) and current status:

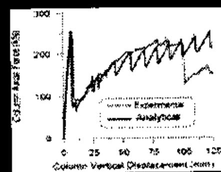
- Development of analytical model for estimating punching shear under unbalanced loads; Completed.
- Development of analytical model consistent with the mechanical model for post-punching shear; Completed.
- Implementation of these models in the analytical software ABAQUS; Completed.
- Evaluating system level response of flat slab structures following loss of a load bearing element and punching shear failure in neighboring columns including large deformation response; Completed.
- Accounting for effects of floor growth and in turn the corresponding axial compressive force in progressive collapse analysis; In Progress.
- Developing a probabilistic framework for design of new structures and evaluation of existing structures against manmade hazards; (Research on a model required in such a framework is in Progress.)
- Further development of the education website to be widely used by high school physics teachers. In Progress.

F4-K cont'd: Fundamental Science of Progressive Collapse Resistance of Reinforced Concrete (RC) Structures

Year 3 accomplishments (In progress)

- A new mechanical-based modeling technique is developed to account for post-punching response of flat slabs, which is verified against experimental data.
- The new modeling technique is used to evaluate progressive collapse resistance of a flat-slab structure following the explosion of a column, in which the collapse was arrested in part due to the proper modeling of the slab post punching response.

Simulated Punching Cone and Supporting Reinforcement



Experimental and Simulated Column Axial Force vs. Vertical Displacement in Punching Shear

Punching Shear in an Actual Slab and Supporting Reinforcement

Vertical Displacement Contours in a Slab with 4 Interior Columns after a Column Explosion and Punching Shear

F4-K cont'd: Fundamental Science of Progressive Collapse Resistance of Reinforced Concrete (RC) Structures

Publications:

- Mirzaei, Y., and Sasani, M., (2010). "Finite Element Modeling of Post-Punching Behavior of Reinforced Concrete Flat Slab Structures," IMPLAST 2010, Society for Experimental Mechanics, Tenth Symposium on large deformations, Providence, RI.
- Kazemi, A., and Sasani, M., (2010). "Effects of Beam Growth and Axial Force in Progressive Collapse Analysis of RC Structures," IMPLAST 2010, Society for Experimental Mechanics, Tenth Symposium on large deformations, Providence, RI.
- Mirzaei, Y., and Sasani, M., (2011). "Punching Shear Failure in Progressive Collapse Analysis," Structures Congress, April 14-16, 2011, Las Vegas, NV.
- Kazemi, A., and Sasani, M., (2011). "Progressive Collapse Analysis of RC Structures Including Beam Axial Deformation," Structures Congress, April 14-16, 2011, Las Vegas, NV.
- Mirzaei, Y., and Sasani, M., (2011). "Progressive Collapse Resistance of Flat Slabs: Modeling Post-Punching Response," Journal Engineering Structures, Submitted.

Year 4 Plan:

- Development of a predictive method for coupled flexural-axial response of beams and slabs accounting for membrane (axial compression), catenary (axial tension) and Vierendeel frame (flexural) actions for the entire range of deformation up to collapse. Such a method is a necessary step in developing early warning systems for progressive collapse evaluation, which will be used for interpreting sensor data in estimating element failure and in turn system level collapse

F4-K cont'd: Fundamental Science of Progressive Collapse Resistance of Reinforced Concrete (RC) Structures

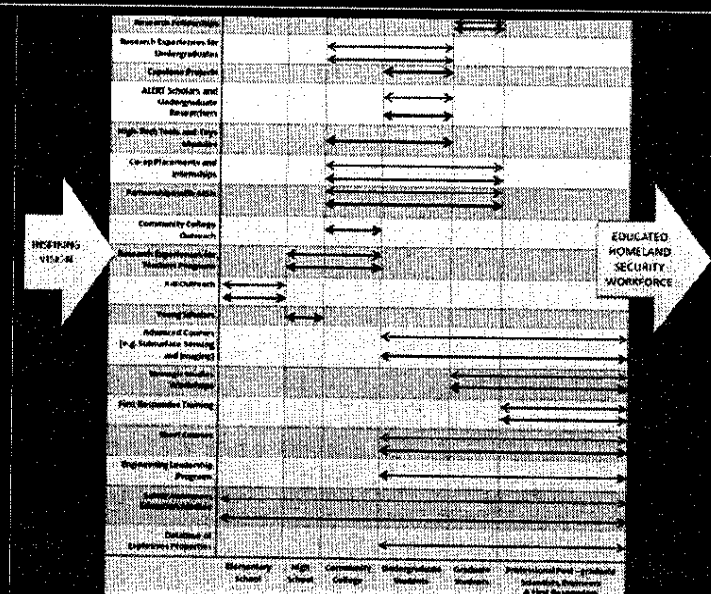
Relevance to DHS Mission

- Developing a predictive method for local failure and global collapse evaluation as a required step towards early warning systems for collapse prediction is directly aligned with the following DHS mission: Enhancing the nation's capabilities to respond to major disasters and emergencies, including catastrophic events, particularly in terms of situational assessment and awareness, emergency communications, evacuations, search and rescue.
- Refining the predictive method (short term) will lead to a collapse warning system (long term) which will help develop an effective evacuation plan and provide first responders with information as to the safety of damaged structures.

Related Activities and Interactions

- Further development of the education website for high school teachers and students: http://collapseresistance.weebly.com.
- Involvement in initiating SEER (Structural Engineers Emergency Response) program in Massachusetts .
- Presentations and discussions with Weidlinger Associates, Inc. (a company extensively involved in blast mitigation projects) to initiate collaboration and a means for transition of outcomes to the field.
- Presentations of research outcomes at ASCE Structures Congress.

The ALERT Education Program Strategic Plan Links a Broad Range of Constituents and DHS Stakeholders



The Key Elements of the Education Program at NU-led ALERT Span from K-12 to Career Professionals

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- Graduate Programs
- Undergraduate Programs
- Initiatives to Increase Diversity
- Community College Outreach
- K-12 Outreach
- Initiatives for First Responders and DHS Stakeholders

The Graduate Program at ALERT: Helping to Prepare a DHS Workforce With Deep Scientific Expertise and Engineering Leadership Capabilities

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Year 3 Results

- ALERT Universities supported 43 PhD and 18 MS Students through 2010
- Thesis topics related to Explosives-Related Threats include:
  - X-ray tomographic image formation and multi-spectral X-ray tomography
  - Diffraction tomography and THz image tomographic image formation
  - Advanced reconstruction algorithms for limited angle, limited dose tomographic image formation
  - Synthetic Aperture Radar Imaging of Improvised Explosives Devices
- Gordon Engineering Leadership Program at NU has enrolled 32 DHS–related Gordon Fellow Graduate students since 2007 sponsored by ALERT, Analogic, Raytheon, Textron Systems, US Army Night Vision and US Air Force

The Graduate Program at ALERT: Helping to Prepare a DHS Workforce With Deep Scientific Expertise and Engineering Leadership Capabilities

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Year Four Plans

- Schedule ALERT "Research to Reality" Webinars for Distance Education (Beginning Spring 2011)
  - ALERT Researchers present projects, goals and expected deliverables
  - Industry, Government, or DHS end-users address how research relates to their needs, opportunities for students in the field upon graduation, and skills that would be useful for people entering this field.
  - Topics may include Security Screening Technologies, Explosive Detection Technologies, and Multisensor Systems
  - Presented live and recorded for future use
- Identify DHS-related Gordon Fellow Candidates for 2011/2012 class
- Launch ALERT Involvement in the ACTION Innovation Ecosystem

The Undergraduate Programs at ALERT: Providing Students With Exciting Research Opportunities and Hands-On Coursework

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Year Three Results

- High Tech Tools and Toys "Hands On" Module Dissemination
  - Undergraduate students developed DAC Interface for CC HTT&TL
  - MATLAB interface for ThorLabs spectrometer developed for IR Spectroscopy module – Distinguishing olive oil from motor oil
  - Undergraduate student developing Acoustic Phased Array Module
- 43 ALERT Scholar and Undergraduate Students involved in research through 2010
  - Projects Include: Radar Construction for suicide bomber detection, Explosive Simulant Characterization, Segmentation of luggage images, whole body imaging testbed construction, and Tunnel Detection
- ALERT Research Experiences for Undergraduates Program
  - 8 students at NU, RPI, and UPRM (Summer 2010)
  - 21 students attended presentations on ALERT research

The Undergraduate Programs at ALERT: Providing Students With Exciting Research Opportunities and Hands-On Coursework

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Year Four Plans

- High Tech Tools and Toys "Hands On" Modules
  - Community College Collaborator, Middlesex Community College, will incorporate HTT&TL (Fall 2011/Spring 2012)
- ALERT Scholar and Undergraduate Research Involvement
  - ~25 ALERT Scholars and undergrads to work on research projects (Fall 2011)
- Research Experiences for Undergraduates
  - 9 undergraduates - 4 from Roxbury Community College (Summer 2011)

Diversity Initiatives at ALERT Enable Meaningful Participation of Underrepresented Groups

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Year Three Results

- 2010 Research Experiences for Undergraduates Program
  - 8 undergraduate students participated in research projects at ALERT partner locations (NU, RPI, and UPRM) including 3 Hispanic students, 1 African-American students and 4 female students
  - Summer 2010 UPRM REU participant, Gabriel Perez-Acosta is engaged in an internship with Pacific Northwest Laboratory in Spring 2011
- ALERT University Partner, UPRM, is a major engineering institution serving a primarily Hispanic population – UPRM faculty and students are part of our diverse community
- HBCU Collaborations –Morehouse and Spelman Colleges
  - Prof. Zhang (RPI) / Prof. Rockward (Morehouse College): "CW Terahertz Imaging"
  - Morehouse undergraduate, Joshua Burrow returned to RPI for his second summer engaged in the REU experience with Prof. Zhang's lab (Summer 2009, 2010)
  - Prof. Hernandez (UPRM) / Prof. Peter Chen (Spelman): "Coherent Raman Detection"

Diversity Initiatives at ALERT Enable Meaningful Participation of Underrepresented Groups

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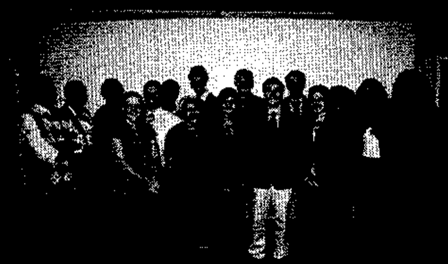
Year Four Plans

- ALERT Scholars and REU Programs
  - Provide Encouragement for Underrepresented minority and female students to apply
- DHS Scientific Leadership Bridge Award with Roxbury Community College
  - Underrepresented minority students are invited to attend ALERT-related events during the school year and participate in research experiences during the summer (Began in Spring 2011)
- Continuing Research Collaborations with Morehouse College and Spelman College



The Community College Outreach Programs at ALERT Enable Connection With A Largely Untapped Population of Students and Faculty

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Year Three Results

- Research Experiences for Teachers- NU STEM Center
  - Four Community College Faculty were recruited (Summer 2010)
- Community College Outreach
  - Two-Week HTT&T Workshop for CC faculty working with NU (Summer 2010)
  - Received DHS Scientific Leadership Bridge Award for Minority Serving Community Colleges between ALERT at NU and Roxbury Community College
  - Shared ALERT/DHS research through CC STEM Seminars and Clubs (Summer 2010/Fall 2010)

The Community College Outreach Program Will Continue to Flourish in Year 4

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Year Four Plans

- **Research Experiences for Teachers- NU STEM Center**
  - Up to four Community College Faculty will be recruited (Summer 2011)
- **Community College Outreach**
  - Expanded Two-Week HTT&T Workshop for 16 CC faculty at NU (Summer 2011)
  - DHS Scientific Leadership Bridge Award for Minority-Serving Community Colleges - NU/Roxbury Community College (Spring 2011 and Summer 2011)
  - ALERT/DHS CC STEM Seminars and Clubs (Summer 2011/Fall 2012)
  - Three CCs to offer HTT&TL courses (Spring 2011 – Spring 2012)
  - Pending NSF Proposal to expand HTT&TL modules in Partner Community Colleges

K-12 Outreach at ALERT: Involvement of Pre-College Teachers and Students

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Year Three Results

- Research Experiences for Teachers – NU STEM Center
  - 6-week research and professional development experience for secondary teachers and Community College Faculty
  - High School Teacher Mark Casto worked with Prof. Mehrdad Sasani on the "Progressive Collapse of Reinforced Concrete Structures" project
  - 23 STEM Teachers and Community College Faculty participated in a workshop to facilitate implementation of ALERT-related lesson plans
- Young Scholars Program (High School) – NU STEM Center
  - 18 students participated in 6 weeks of research at NU and 2 participated in ALERT-related research
  - All 18 students attended ALERT-related seminars
- Other K-12 Outreach
  - Exxon Mobil Bernard Harris Summer Science Camp – 48 Rising 6th, 7th, and 8th grade students were introduced to research work of DHS field testing of "Lookout!"magazine
  - ALERT students assisted with university field trips and summer camps at NU

New Curriculum Modules Created by High School Teacher Mark Casto Are Being used To Excite Students About DHS Related Research

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Collapse Resistance in Reinforced Concrete Beams

http://collapseresistance.weebly.com/

An Inside Look at How Civil Engineers are Reinforcing Structures to Build a Safer Tomorrow

RESEARCH ABSTRACT:

The extent of initial damage to the World Trade Center Towers and the Pentagon during the September 11, 2001 terrorist attacks was beyond what was perhaps practical to be considered for progressive collapse resistant design. The extreme assaults and the tragic outcomes have initiated wide spread interest and research in progressive collapse of structures under more moderate initial damage scenarios. As part of an on-going research on progressive collapse of structures at Northeastern University, experimental and analytical studies are being conducted on potential collapse of reinforced concrete structures due to loss of columns. Following loss of columns, the beams bridging over these columns will need to dynamically redistribute the gravity loads to other parts of the structures. In order to better model the behavior of these critical beams and its effect on the response of the buildings and for educational purposes, small scaled models of RC systems are being tested.

Progressive Collapse of Reinforced Concrete Structures, Research Experience for Teachers @ Northeastern University

The K-12 Outreach Programs at ALERT Will Be Gaining More Momentum in Year 4

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Year Four Plans

- Research Experiences for Teachers- NU STEM Center
  - Program to continue and expand to include additional teachers (Summer 2011)
  - Host 4 Teachers through ALERT Funding and up to 4 from the NU-ALERT partnership with Roxbury Community College (Summer 2011)
  - All RET participants will participate in ALERT-related seminars
- Young Scholars Program (High School)- NU STEM Center
  - Program to continue with 24 students participating in ALERT-related seminars with a high priority of placement in ALERT-related research labs (Summer 2011)
- Pending DoD Proposal for Center of Excellence for Science, Technology, Education and Math at UPRM

ALERT Involves First Responders and DHS Stakeholders in Conferences, Training, Workshops and Innovative Technology Transition Programs

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Year Three Results

- Research to Reality Conference October 2010
- Explosives Training Short Course (MS&T)
  - 30 Ft. Leonard Wood Personnel - (Feb 22, 2010)
- "Hands-on Explosives Training" for Midwest Research Inst. (TTU)
  - Four-day on-site course for US Government Personnel (Summer 2010)
  - Over 45 attendees: Students Police, FBI, US Marshall Office, bomb squad & fire dept
- Held 2 Algorithm Development (ADSA) Workshops for DHS Stakeholders
  - AIT & CT Screening Themes- Over 150 attendees from Government, Industry & Academia
- Submitted $2M 2 Year Proposal to NSF to create an Innovation Ecosystem Alliance to Cultivate Technological Innovation for Our Nation (ACTION)

Year Four Plans

- Continue Research to Reality Conference
- Continue Explosives Awareness Training for law enforcement (MS&T)
- Continue "Hands-on Explosives Training" for MRI (TTU)
  - Proposal pending with CTTSO to develop video versions of this, and similar courses
  - One day refresher course is being developed
- Launch ACTION and Continue ADSA Workshops

ALERT-Linked Events Reach a Wide Audience

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Research to Reality (R2R) Conference

- A New Theme for Annual Research and Industrial Collaboration Conf (RICC)
- Held October 2010
- Overviews from NSF, DHS and DARPA
- Three Parallel Strands
  - Biomedical (PROTECT Included)
  - Homeland Security and Defense (ALERT focus)
  - Civil Infrastructure Assessment
- ~ 400 Attendees
  - Students, Researchers, Industry, Government, People in the Field

RICC 2010

Research to Reality R R

Conferences and Workshops are Integral to the ALERT Educational Effort

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- THz Workshop (October 30, 2008)
- Algorithm Detection for Security Applications (ADSA) Workshop 1 (April 23-24, 2009)
- ADSA Workshop 2 (October 7-8, 2009)
- ADSA Workshop 3 (April 27-28, 2010)
- ADSA Workshop 4 (October 5-6, 2010)
- ADSA Workshop 5 (May 3-4, 2011)
- ADSA Workshop 6 (planned November 2011)
- VBIED Scenarios & Signatures Workshop (Dec 2009 – Jan 2010)
  - Collaboration with PNL
  - Involves both NEU and URI teams

Long Range ADSA Strategy: Creation of Next-Generation Explosives Detection or Imaging Algorithms Leveraging Advances in Areas such as Medical Imaging

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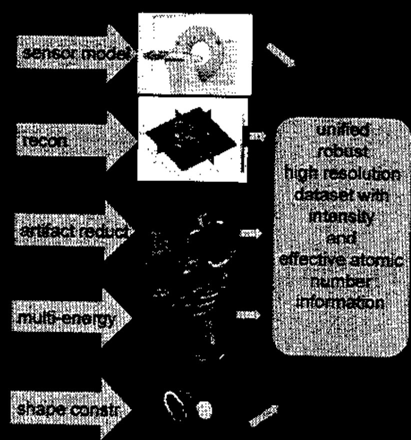
- Purpose
  - Substantially improve the image quality available in a CT image for security screening
- Innovation & Approach
  - Demonstrated novel iterative recon algorithms
  - Concurrently couple estimates of material property and shape constraints with reduced-artifact reconstruction algorithm to facilitate multi-modality target assessment
- Short Term Objectives
- develop advanced reconstruction algorithms to improve image quality
- Long range objectives
- improved scanner design and support of multi-energy



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ACTION Will Enable ALERT Researchers to Innovate

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"ACTION"

Alliance to Cultivate Technological Innovation for Our Nation

ACTION *Research to Reality*

- ✓ $2M Proposal Submitted to NSF February 2011
- ✓ Jointly led by COE-CBA, 1:1 match from VC NU alumnus
- ✓ Engage Industry, Research labs and Students
- ✓ Real-World Impact of Center Research Ideas
- ✓ Linked to Gordon-CenSSIS, ALERT and PROTECT

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ALERT Safety Program

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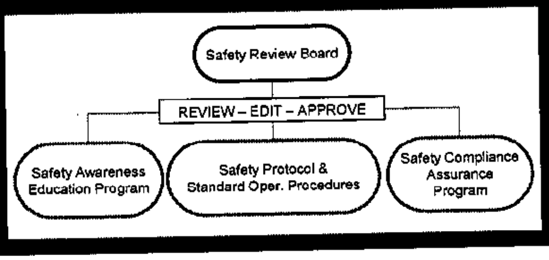
- **ALERT Safety Program**
  This slide outlines the components of the ALERT Safety Program:
  1. Safety Review Board,
  2. Safety Awareness Education Program,
  3. Safety Protocols and Standard Operating Procedures,
  4. Safety Compliance Assurance Program.
- By taking the time to educate, review safe operating procedures, measure compliance, and make Safety a focus practitioners will have a heightened awareness of the hazards and take care.



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ALERT Safety Review Board

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- The functions of the ALERT Safety Review Board are to provide input and review:
  1. Safety Protocol and Standard Operating Procedures
  2. Safety Awareness Education Programs
  3. Safety Compliance Assurance Plan (SCAP)
  4. Other ongoing safety issues
  5. Safety incidents (annual SCAP audit results) and approve corrective action plans.

Bill Koppes (Chair)	Synthetic Chemist	Navy, Indian Head <ret>
Andrew Clapham	Chemistry Dept Safety Officer	University of Rhode Island
Mike Coburn	Synthetic Chemist	Los Alamos National Lab <ret>
Jimmie Oxley	Explosive Research	University of Rhode Island
Alex Schuman	Explosive Safety	Navy, Indian Head
Ronald Willey	University Safety Officer	Northeastern University

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Safety Awareness Educational Program

Northeastern

- Drawing on the resources of our own ALERT researchers and those of the Department of Defense (DoD) and National Laboratories, a Safety Awareness Education Program was created to supplement the safety education in partner institutions. The Safety Program has been provided every 6 months. Each course will be held a different partner institution.
- Topics will include:
  1. Basic laboratory best practices
  2. DoD contractor safety manuals and storage regulations
  3. Required testing and the meaning of test results
  4. Handling requirements specific to each explosive
  5. Historic explosive accidents for a "lessons learned"
- Safety Courses Given and Scheduled
  1. 4/23/10 Northeastern Jimmie Oxley, Andy Clapham
  2. 10/27/10 Texas Tech Jared Martin, Jimmie Oxley, Bill Koppes
  3. 4/7/11 Missouri S&T Jason Baird, Jimmie Oxley

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Safety Compliance Assurance Program

Northeastern

- Safety Review Board Visited Partners
  - Safety Program
  - Safety Protocol
  - Standard Operating Procedures
- NEU Partners Handling Explosives:
  - Texas Tech University
  - Washing State University
  - Missouri Science and Technology
  - University of Puerto Rico, Mayaguez
- Approved Each Partner

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The ALERT Education Program Enables the Center to Impact a Broad Spectrum of Students & Stakeholders

Northeastern

Education: the University Community

THE UNIVERSITY OF RHODE ISLAND

18 PI's in 8 universities- URI, NMSU, CalTech, Purdue, UIL, FIU, HUJI, BGU with 52 Graduate & 35 Undergraduates students. Undergraduates work along side graduates and often have their names on publications.

Summer programs bring in more undergraduates and foreign interns.

Examples of Thesis Topics

Study of weak detonation.
HME Detonation & Properties
Simulation of Liquid Explosives.
Peroxide Explosives
Characterization of Non-Ideal Explosives
Measurements of Adhesion Forces between Energetic Materials and Solids
Decomposition Kinetics of Gas Phase Ions in Differential & Ion Mobility Spectrometer
Robust Gas Sensors
Optical Chemical Sensors using Nanocomposites from Porous Silicon Photonic Crystals & Sensory Polymers
Structural Response to Non-ideal Explosions
Novel Composite Materials & Structures for Blast
Three-Dimensional Microvascular Fiber-Reinforced
Self-healing Concrete
Deformation Criterion for Blast Loading in Low Carbon Steel

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Education: Collaboration with Industry & National Labs

THE UNIVERSITY OF RHODE ISLAND

PI's collaboration with industry makes for internships, co-ops, and job offers for graduate & undergraduate students.

AS&E
Ahura (now ThermoFisher)
BASF
CEMEX (Switzerland)
DetectaChem
Draper Labs
Eastman Chemical
Emitech
Exxon
Field Forensics Inc
Foresight Technologies
FM Global
Haifa Chemicals (Israel)
ICx Nomadics (now FLIR)
Implant Science
Lindon Group
Lawrence Livermore National Lab
Los Alamos National Laboratory

National Institute of Standards & Technology
Naval Undersea Warfare Center
PPG Industries
Rafael Advanced Defense Systems LTD (Israel)
Raytheon IDS
SensorTech, Inc.
Smiths Detection
Specialty Products Inc
SQM Corp. (Chile)
Triton Systems
UOP
XO-Armor (TX)
W.R. Grace
TPI
3TEX, Inc

Students working with Detectachem (top) & AS&E (bottom) at URI

Education for the Education Community

Summer programs bring in teachers and professors & students from MSI.

Research Experiences for Teachers:
- 2 teachers in summer 2008
- 7 teachers in summer 2009
- 7 teachers in summer 2010
- 1 teacher will go to URI grad school Fall 10

Teachers' research was presented at Oct 2009 URI Detection Workshop

Teachers in summer 2010

Richard Marrese	Pilgrim High School
Mary Stoukides	Mount St Charles Academy
David Barr	Cranston High School West
Mark Bartley	Exeter-West Greenwich Senior HS
Robert Springer	Coventry High Schools
Emily Winsor	Newport High School
Jefferson Wright	transitioned to grad student

MSI Professor (Dr. Bu) & grad student Laureen London from Clark Atlanta U were in Oxley-Smith URI lab for summer 2010

Education

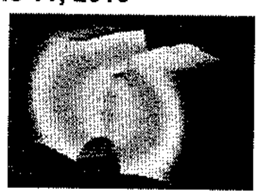
Lego Robots WBCA 2nd year 5th place; Narragansett Middle School—4 teams

Education: magic shows - grade schools & retirement homes

Education: Briefings & Workshops for Professions

Homeland Security S&T Advisory Committee **Jan 28, 2010**
Delta Airline security **Jan 29, 2010**
URI Foundation Board **Jan 30, 2010**
Lt. Governor Robert's Emergency Management Advisory Council Feb. 9, 2010
RI Higher Education Preparedness **Mar 3, 2011**
TSWG Homemade Explosive educators **Mar 10, 2010**
Briefing to Under Secretary O'Toole **June 11, 2010**

RI Lt Governor with Prof Oxley



Teaching Workshops for Professionals
Vendors & Users Explosive Detection (URI) Oct 2009
American Assoc. of Forensic Scientists Feb 23, 2010
North American Thermal Analysis Society Sept 2009 & August 2010
Blast Mitigation Workshop April 2009
IMPLAST 2010 Providence Oct 12-14, 2010

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Education: Short Courses for Professionals

Class	DATES	#students
Fundamentals Edwards AFB	Jan 19-21	26
Fundamentals	Feb 1-3	26
Hazards Ottawa, CA	Feb 3-5	13
Fundamentals, Sandia NL	Feb 17-19	9
Hazards, Sandia NL	Feb 17-19	11
Warheads	Feb 24-26	26
Materials Response, Canada	Mar 22-23	15
Air Blast Ottawa, Canada	Mar 24-26	13
Terrorism Issues,	April 25-26	40
Safety Protocols,	Ap 28-29	25
Fundamentals, URI	May 4-6	26
Nanomaterials,	May 25-26, 2010	20
Pyrotechnics,	June 7-11	28
Fundamentals,	July 26-28	28
Materials Characterization	Sept 16-18	19
Unintended Ignition,	Oct 20-22, 2010	19
Materials Response,	March 10-11, 2011	
		344

About 350 professionals in 17 classes.

Five new classes this year

Warhead Mechanics Feb 23-25, 2010 Picatinny, NJ	Detonation wave interactions and effects on metal Shaped charges and jet penetration Fuzes, esp. in-line electronic safing, arming & firing (ESADs)
Nanomaterials March 8,9 2010; Picatinny, NJ	Combustion propagation in pyrotechnics Thermites & metastable interstitial compositions (MIC)
Air Blast & Structural Response Mar 24-26, 2010 Ottawa, Canada	Blast wave from high explosives - scaling laws Coupling to structures Stress & strain, single-degree-of-freedom systems Pressure-impulse failure estimates Blast from deflagration Thermobarics
Pyrotechnics June 7-10, 2010 Picatinny, NJ	General principles and chemistry of pyrotechnics Roles for pyrotechnics: heat, ignition, light, thrust producers Pyrotechnic devices Flares & luminosity Manufacturing, incl. twin-screw extrusion
Terrorism Issues April 26,27, 2010 April 26,27, 2011	Terrorist Threats: Peroxide Explosives-preparation, performance & s Pre-blast / Detection of Explosives Fragment hazards Performance codes by law enforcement Case Studies

New concept:
Fundamentals of Explosives for EOD

Open for Registration

Fundamentals of Explosives	May 3-5, 2011 URI
Explosive Operations: Safety & Protocol	May 10-11, 2011
Propellants & Combustion	May 9-10, 2011
Detonation & DDT	June 8-9, 2011
Materials Response under Impulsive Loading	March 10-11, 2011
Terrorism Issues	April 26,27, 2011
Laboratory Analysis & Forensics	Apr 27,28, 2011

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Other Educational Events

Grad students Ryan Rettinger & Pat Bowden (top) & Pat & Jon Canino (bottom) make devices at MA bomb squad field day May 2010

Prof Smith helps Prof Oxley into boots while grad student Lucius Steinkamp watches at 1st responders meth lab training Aug 2009

Other Educational Events
URI "Characterization Team" Participates in two TSA VIPER exercises Port of Davisville Aug 7 & (shown) RI Block Island ferry) Aug 14, 2009

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Education: Safety in the University Community

Creating a Culture of Safety
Overarching Safety Protocol and SOP
Semi-annual safety classes by webinar CoE participants,
- **Ap 23, 2010;**
- **Oct 27, 2010**
- **Ap 7, 2011**

Manual & Multiple SOP's
Participate in MIT's Safety Roundtable July 21, 2010

CSHEMA webinar for 62 universities
Jan 19, 2011

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Campus Safety Health & Environmental Management Assoc. (CSHEMA) requested webinar. 62 university safety officers attended (1/21/11)

Auburn University
Boston College
Boston University
Buffalo State College
California Institute of Technology
California State University Chico
Carnegie Mellon University
Eastern Kentucky University
Elizabethtown College
Farmingdale State College
Georgia Institute of Technology
Harvard University
Johns Hopkins University
Massachusetts Institute of Technology
Michigan State University
Missouri State University
Northwestern University
Pennsylvania State University Main Campus
Scripps Research Institute
Stanford University
Stony Brook University
SUNY at Buffalo
Syracuse University
Texas A&M University
Texas Tech University Health Science Center
University of Alabama
University of California Berkley
University of California Davis
University of California Los Angeles
University of Colorado Boulder
University of Delaware
University of Hawaii
University of Idaho
University of Illinois Chicago
University of Iowa
University of Louisville
University of Manitoba
University of Maryland Baltimore
University of Memphis
University of Minnesota Crookston
University of Minnesota Duluth
University of Minnesota Twin Cities
University of Minnesota-Morris
University of Missouri Columbia
University of Nevada, Reno
University of North Carolina Charlotte
University of Pennsylvania
University of Texas Arlington
University of Texas at Austin
UTexas Southwestern Medical Center Dallas
University of the Sciences Philadelphia
University of Utah
University of Vermont
Vanderbilt University
Villanova University
Wake Forest University Health Sciences
Washington State University
Washington University in St. Louis
Weill Cornell Medical College
West Virginia University
Western Washington University
Yale University

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EXPLOSIVES DATABASE

Physical properties of ~75 explosives & precursors

University of Rhode Island

WELCOME

The University of Rhode Island's Explosives Database, a project funded through the auspices of the National Memorial Institute fo the Prevention of Terrorism, is an interactive library of analytical data for explosive and energetic compounds. The quick links to the right will help to get you started using this sytem.

Take some time to read about the contents of the database, and when your ready, click the **Register** button to sign up for an account. Once your account has been confirmed, you can use the **Login** button to access the database.

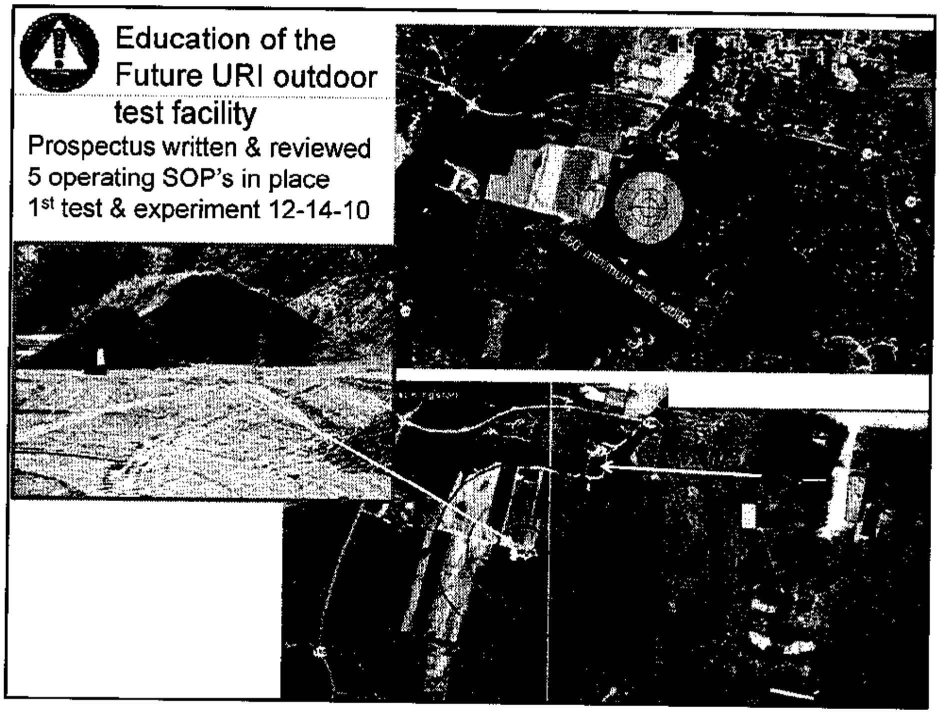
If you have any questions or encounter any problems while using the site, please don't hesitate to **Contact Us**.

Home
Database Info
Register
Login
Contact Us

Funded By:
MIPT

2007-2010 ~250 applications
Jan- Feb 17, 2011 92 new applications!

Home Database Info Register Login Contact Us


Education of the
Future URI outdoor
test facility
Prospectus written & reviewed
5 operating SOP's in place
1st test & experiment 12-14-10
minimum safe radius

Record Number	Number of Pages	Title of Record	Record Date	Exemption
12	50	Center for Awareness and Localization of Explosives-Related Threats (ALERT), A DHS Center of Excellence for Explosives Detection, Mitigation and Response, Preliminary Year Two Workplan	1/28/09	6
13	76	ALERT Workplan	2/8/10	
14	149	Center for Awareness and Localization of Explosives-Related Threats (ALERT), A DHS Center of Excellence for Explosives Detection, Mitigation and Response, Year Three Progress and Preliminary Year Four Workplan	3/2/11	
15	162	BomDetec--Wide Area Surveillance and Suicide Bomber Detection at >10M: Phase 1 Preliminary Design Review (PDR) Report	N/A	4,6
TOTAL	437			