The Bernard M. Gordon Center for Subsurface Sensing & Imaging Systems

Center Overview and Next Steps

Michael B. Silevitch
Director

NSF
Year Nine Site Visit
April 22-23, 2009

http://www.censsis.neu.edu
Outline of the CenSSIS Overview

- Vision and mission
- Research strategy and program
- Achieving Broad Impact
- Education program
- Sustainability Plan
- Summary
The CenSSIS Vision: Diverse Problems– Similar Solutions

Subcellular Biology

100nm - 100 μm

Optics

Underground Diagnosis

1 cm - 100 m

Radar

Tissues & Organs

10 μm - 10 cm

Ultrasound

Underwater Exploration

10 cm - 1 km

Sonar
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A Top Down Approach Motivates Our 10 Year Strategic Plan

**L1** Fundamental Science
- Subsurface Sensing and Modeling
- Physics-Based Signal Processing and Image Understanding

**L2** Enabling Technologies
- Validating TestBEDs
- Engineering System
- Enabling Technologies

**L3** Engineered System
- Bio-Medical Applications
- Environmental-Civil Applications

R1 R2 R3

Image & Data Information Management
A Physics Based Approach Guides Our Fundamental Science Program

Localized Probing & Mosaicing (LPM)

Focused or Pulsed Probe
Focused or Gated Detector

Multi-Spectral Discrimination (MSD)

Wide Band Probe
Narrow Band Detectors

Multi-View Tomography (MVT)

Sources
Object
Detectors
Controlled Environment TestBEDs Help Validate New Fundamental Science Ideas

- **BioBED**: 100nm - 100 μm
- **MedBED**: 10 μm - 10 cm
- **SoilBED**: 1 cm - 100 m
- **SeaBED**: 10 cm - 1 km
MedBED Facilities: Enables Collection of Quantitative High Resolution Data & Images

- Analogic Ultrasound Engine
- Scanning Acoustic Microscope
- Terason 2000 Portable Ultrasound

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MedBED Enables Fundamental Research in R1: Nonlinear and Multi-Mode Sensing and Imaging

- Acousto Optic Imaging
  - Application to breast tumor imaging
  - Application to HIFU lesion imaging
- US and Multi-Mode Therapy

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MedBED: Enables the Validation of New R2 Algorithms and Links to Clinical Applications

- Quantitative Ultrasound
- Multi-Modal Imaging

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Enables Non Medical Extensions: Detecting Buried Objects Using Acoustic Time Reversal

- Acoustically resonant targets
- Buried in sediment
System Applications Are Built Around Important Real World Problems

**Biological-Medical Applications**
- S1 3D Imaging of Cellular Structure
- S2 4D Image Guided Therapy
- S3 3D Multi-Mode Breast Imaging

**Environmental-Civil Applications**
- S4 Remote Assessment of Benthic Habitats
- S5 4D Underground Assessment
The System Applications Require Collaboration With Domain Experts

Important Biological & Medical Problems (S1, S2, S3)

Important Environmental & Civil Problems (S4, S5)
Our Engineered System & Unifying Framework Will Stem from the System Level Applications

““I-PLUS”

Integrated Process for Looking Under Surfaces

- Systems Approach to Articulate both Vertical and Horizontal Integration of Ideas
  - Diverse Problems- Similar Solutions
- Incorporates Solutionware Toolboxes for End-To-End Modeling & Processing
- Enables Rapid Prototyping
- Impact on Education
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The 3D Fusion Microscope A CenSSIS Developed Instrument to Enable New Biological Insights

Important Societal Problems:
Mouse Embryo Viability, Skin Cancer Diagnosis,.....

Optical Quadrature Microscopy (OQM) Patented new modality

Sensor Fusion

Multiple Microscopes in one instrument
Keck Microscope Imaging for the Discovery of Lipid Rafts and Thy-1 in Mouse Embryos

- Use of the Keck + quantum dot technology
- These signaling molecules are markers of embryo health

Distributed Scattering Models: Advances the Imaging Capabilities of the Keck Microscope

New R2 Imaging Tools Will Enhance the Keck: Example Large 3-D Mosaicing of Brain Tissue

Active mitochondria have a different distribution and morphology than inactive mitochondria in ES cells
Mitochondrial localization and activity affect development and impact the therapeutic potential of ES cells

Mosaics constructed from 60 multi-spectral confocal stacks of size 1024x1024x50
(upper: 5-color image mosaic, lower: rendered 3-D object mosaic with neurons (purple), vessels (green), astrocytes (red), microglia (yellow))
Reflectance Confocal Microscopy of Skin Cancers: Goal Is Rapid Office Visit Screening

Screening, diagnosis in vivo

Tumor-mapping to guide surgery

Melanoma
Basal cell carcinoma

Vellous Hair and Nanoparticle Interactions: Probing Skin Structures to Inform Diagnostics

Depth Map

Projection from Top

Projection from Left

40-nm Gold Nanoparticles enter skin through vellous hair follicles. Side projection shows nanoparticles in sebaceous gland.

Milind Rajadhyaksha, MSKCC/Dermatology and Charles DiMarzio, NU/CenSSIS
New CenSSIS Tools for Radiation Therapy Planning

- Important Problem: Accurate treatment of cancers in complex sites with intensity-modulated radiation
- Collaboration with strategic partners
  - G. Chen, T. Bortfeld (MGH),
  - M. Lovelock, A. Jackson (MSKCC)
- New tools to automate and accelerate critical processes
  - Deformable 3D/4D Organ Modeling and Segmentation
  - Fast, Accurate IMRT Planning with Constraints

Contouring: minutes → seconds
Planning: hours → minutes
Real Time Imaging and Sensor Fusion: Reliable Breast Cancer Screening

Important Problem
Fast Minimally Invasive High-Resolution (~5mm) Detection of Breast Tumors

MGH-GE Platform
Digital Breast Tomosynthesis (DBT)
- Impedance
- Optical
- Microwave
- Elastography

Sensor Fusion
X-Ray Tomosynthesis Fused with CenSSIS-Developed Modalities: Structure with Function

Digital Breast Tomosynthesis (DBT)

Electrical Impedance Tomography

Diffuse Optical Tomography
Clinical Requirements Drive Fundamental Science: Call Back and Biopsy Reductions

EIT: accrued 72 subjects simultaneous co-registered Impedance and X-ray

CenSSIS R1-R2 Advances

DOT: accrued 120 subjects co-registered X-ray priors constrain DOT reconstruction
Clinical Requirements Drive Fundamental Science: Call Back and Biopsy Reductions

DBT: GPU-based 60x Speedup
From ~ 4 Hours - Single PC
To ~4 Minutes - GPU

DBT 3000 woman NCI Screening trial
-3200 accrued
-reported 38% callback reduction at RSNA

Avoids >1.5 million callback exams annually in US alone

CenSSIS R3 Advances
Large Area Coral Reef Health Assessment: An Important Societal Problem

Satellite And Airbourne Hyperspectral Remote Sensing

Benthic Habitat quantitative imaging needs multimodal/multiplatform capability

SeaBED AUV

Remote Sensing is Limited to 20 meters
Puerto Rico Hyperspectral Data Campaign: Tests Accuracy of Remote Sensing Methods

- Hyperspectral Image Coverage
  - Total coverage = 1740 km² at 4 m spatial resolution
- Multiple Mission Collaborators
  - NASA, NOAA, USGS, Forest Service
  - UPRM (non-CenSSIS), U. Miami, NSU
- Coincident Field Campaign
  - Comprehensive simultaneous field measurements

The SeaBED AUV Enables Quantitative Imaging of Deep Coral Structures (> 200 Meters)

CenSSIS Students Built the AUV

Mosaicing and Registration Algorithms Used in Multiple Applications

Quantitative Assessment Unmixing Algorithms Change Detection Modeling and Inversion

The SeaBED AUV Has been Disseminated Throughout the World

Arctic AUVs
- Benthic Habitat
- Gas Blowout
- NWFSC

Archeology - Med

Aussie/Taiwan Seabed

Chile - Microbial Mats

Deep Coral - Bermuda, Puerto Rico

Multiple AUVs

SMAR
The S5 Area Is Now Focused on Developing New Externally Funded Directions

Experiment-based Sensor characterization

Model-based diagnostics supports sensor fusion

Fundamental Research translates to Industry

NSF Phase I SBIR: Soil Sensing via Impedance
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Curricular Innovations: CenSSIS Education Works at All Levels

Engineering Profession

Continuing Ed.

Grad. SSI Topics “Distributed University”

Upper-class Intro to SSI Undergrad Research

Fresh. Hi-Tech Tools&Toys CenSSIS Scholars

K-12 Outreach

NU RPI MGH LLNL MSKCC WHOI INL UPRM BU
There is Active Student Involvement
Over 150 Students in year 9

- Motivated by ERC’s Vision and Mission
- Local Chapters and center-wide Council
- Monthly Meetings and Field Trips
- Students Share Ideas Via Seminars, Posters, ....
Freshman High Tech Tools and Toys Lab: A Common Theme for all CenSSIS Partners

The Intro To SSI Undergraduate Courses Students Work With Real Data

Graduate Courses Are Provided Via the “Distributed University”: Biomedical Image Analysis E-Office Hour

A New Textbook: A Major Goal For Year 9
Diversity is an Essential Element of CenSSIS
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The Future of CenSSIS

**NSF Sunset**
- NSF funding ends 2010
- Center is expected to be self supporting

**Sustainability Plan Elements**
- Gordon $20 Million Gift
  - Sustains R&D Infrastructure
  - Gordon Engineering Leadership Program
- Seamless Collaboration with Industry
- Major Research and Education “Glue” Proposals
- Associated Grants Leveraging the Center
- Intellectual Property Revenue
The $20 Million Gift from the Gordon Foundation: Will Help Sustain the R&D Infrastructure of CenSSIS

Renaming Ceremony
October 2006
There is concern at the highest levels that the US is losing its engineering leadership edge.

The Gordon Engineering Leadership Program: A Response to the “Gathering Storm”

**Impact of the Challenge Project**

- Cutting Edge Research
  - Pioneering Ideas
- Technology Transfer
  - Fresh Applications
- Production
  - Next Generation Systems

**Potential Sponsors Stem From Center Links**

- Textron
- Raytheon
- Analogic
- Siemens
- Lockheed/Martin
- Hologic
- DHS
- Goodrich
- L3
- Analog Devices
- NeuroLogica
- AS&E
- GE
- Air Force Research Lab
- Army NVESD
- IMI

Multi-modal Standoff Explosives Detection

Provide reliable explosive material detection at safe ranges to enable successful diversion of the terrorist threat.
A Key Element of our Sustainability Strategy
Joint R&D Proposals With Industrial Partners
$1.7 M Phase I DHS Project Is An Example of The Center’s Teaming Ability

Northeastern University
Proposal Lead Winning Science
Multi-Mode Video Radar X-Ray THz Sensor Fusion

AS&E
ZBV Van & X-ray Sensor

NU, Raytheon, & PPT
MMW Radar metal detection

RPI
THZ Explosive detection

Siemens & NU
Intelligent Video & Data Fusion

Multi-mode Detection of Suicide Bombers At Distances > 50 Meters
Translational Research Is Not An Easy Task For University Centers

Requires Integration of Fundamental Science and Industrial/Nat’l Lab Collaboration
<table>
<thead>
<tr>
<th>Won</th>
<th>Agency</th>
<th>Collaborators</th>
<th>Title</th>
<th>Funding</th>
<th>Duration</th>
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<tr>
<td>NIH</td>
<td>NIH Biomedical Research Partnership</td>
<td>$3.8M</td>
<td>5 Years</td>
<td>Microscopy Toolsets</td>
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<td>DHS</td>
<td>Bubble Technologies / NU</td>
<td>$5M</td>
<td>10 Months</td>
<td>Nuclear Portal Development</td>
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<td>NIST-TIP</td>
<td>NU-BU-UML-UVM-Witten Technologies VOTERS</td>
<td>$9M + $9M Match</td>
<td>5 Years</td>
<td>Infrastructure Monitoring</td>
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<td>DoD</td>
<td>UPRM</td>
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<td>3 Years</td>
<td>Hyperspectral IED Detection</td>
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<td>NASA</td>
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<td>AUV Arctic Mission</td>
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<td>Raytheon/American Science and Engineering / Siemens Corporate R&amp;D, PPT, RPI, NU</td>
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<td>NU-BU-RPI-UPRM ... ALERT Center of Excellence</td>
<td>$13M</td>
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<td>Army SBIR</td>
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<td>Soil Characterization</td>
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<td>DoD MURI</td>
<td>BU / Other non CenSSIS Collaborators</td>
<td>$1.3M</td>
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<td>Multi-sensor Target Recog.</td>
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Multi-Partner Research & Education Proposals: An Integral Part of our Sustainability Strategy

Examples of Current “Glue” Proposal Efforts

- **NSF**
  - IGERT Proposal on Civil Infrastructure Assessment
    - Proposal Funded - Partnership Between NEU and UPRM

- **Department of Homeland Security**
  - Center of Excellence in Explosives Detection, Mitigation and Response: $2.5-4 M/yr for 4 years
    - Proposal Funded - Led by NEU involves all CenSSIS partners
  - Tunnel Detection: $400K for 2 years
    - Funded through Lockheed Subcontract

- **NIH**
  - FARSIGHT BRP: $3.5M for 5 years
    - Proposal Funded - Led by RPI

- **NIST Technology Innovation program**
  - VOTERS (Civil Infrastructure Assessment): $9M for 5 years
    - Proposal Funded - Led by NEU Civil Engineering Dept. Faculty

- **NIEHS**
  - Superfund Cleanup: $2M/yr for 5 years
    - Proposal Re-Submission April 09
Aging Civil Infrastructure

- $1.6 Trillion over 5 years to maintain
- BIG DIG tunnel collapse $1Billion
- 50% potable water loss in Puerto Rico
- Life threatening earthquake damage

Advanced modeling & processing algorithms are needed for high resolution automatic quantitative assessment.
ALERT: Awareness and Localization of Explosives-Related Threats

A Department of Homeland Security Center of Excellence

Funding Awarded
$10 Million for Initial 4 Years

Anticipate 10 Years Of Funding

The ALERT Mission: Comprehensive Solutions to a Complex Threat

Detection | Mitigation

Detection

Effective Response

Education & Outreach

The Three Level Structure Shows The Strategic Interdependency of ALERT Efforts

Level 3
Grand Challenges & Next Generation Systems

C1: Ultra-Reliable Screening
C2: >100 meter Stand-Off Discovery and Assessment
C3: Unequivocal Pre & Post Blast Mitigation
C4: Rapid and Thorough Preparedness and Response

Level 2
Enabling Technology Solutions

T1: Multimode Standoff Detection
T2: Trace Explosives Detection / Screening
T3: Shockless Mitigation Testbed
T4: Multisensor Luggage Scanner
T5: Portable Sniffer

Level 1
Fundamental Science

F1: Physical & Chemical Characterization: Explosives Materials
F2: Novel Sensing Modalities & Sensor Configurations
F3: Multisensor Systems & Alternative Sig: Threat Detection & Identification
F4: Mitigation of Explosives Effects

Fieldable Products

Proof-of-Principle Tests of Research

Research Barriers

Teaming with National Labs & Industry

Research Drivers

$400K-$600K per year for 4 years
Supports MA Industry to Work on Demonstration Projects
1:1 Industrial Matching Funds Required
ALERT will be the Conduit for this pool of funds

John Adams Innovation Institute
The FARSIGHT Project: Multi-dimensional Image Analysis Tools for Microscopy and Neuroscience

- $3.8M 5-yr NIH Biomedical Partnerships Grant, 2008-2013
  - External partners: Wadsworth Center, U. Wisconsin, Kitware Inc.

- Integrates CenSSIS R2 tools:
  - Multi-spectral confocal microscopy
  - Spectral unmixing
  - Automated large-scale 3-D segmentation
  - SVM cell classification, and
  - Joint 3-D image & object-level mosaicing (based on generalized dual-bootstrap registration algorithms)

- Gigavoxel datasets

Image space

Object Feature Space

Common Data

Graph Space

Tabular Space
Our Industrial Relationships Enabled a Potent “Glue” Proposal: Led by NEU Civil Engineering Dept.

VOTERS: Versatile Onboard Traffic Embedded Roaming Sensors

$9M in funding from NIST w/ addl cost share

1 of 2 major projects
Funded by NIST TIP

This “Roaming Sensors” Concept Can Extend Well Beyond Civil infrastructure Applications

VOTERS: Versatile Onboard Traffic Embedded Roaming Sensors

- Use of vehicles of opportunity to collect data and report condition to a centralized map
- New innovative technology with high – risk for success
Puerto Rico Test Site for Exploring Contamination Threats (PRoTECT)

Northeastern University
University of Puerto Rico – Medical Sciences Campus
University of Puerto Rico – Mayagüez
University of Michigan

Preterm Birth Rates Have Risen in Puerto Rico


Preterm birth rates in Puerto Rico compared to other US subpopulations (1990 – 2004)

Three-level Implementation

Level 3: Grand Challenge
- PRoTECT - System Based Implementation
- Government Agencies; Academic Institutions; Industry; Organizations; Public

Level 2: Enabling Systems
- Research Translation Core
- Research Project Leaders
- Data Management and Modeling Core
- GIS Maps/Models (Industry + Government)
- Publications/Communication (Broad Audience)
- GeoBed/Demo’s (Industry + Government)

Level 1: Basic Science
- P1: Xenobiotics (Non-targeted Study)
- P2: Oxidative Stress Study
- P3: Epidemiology (Targeted Study)
- P4: Fate/Transport Study
- P5: Green Remediation Study
- Data Management and Modeling Core (Core D)
- Human Subjects and Sampling Core (Core C)

Research results translated to societal impact
Commercialization Of Center Technologies: An Integral Element Of Our Sustainability Plan

- **Emerging Intellectual Property (Examples)**
  - Cell Counting for Reliable In Vitro Fertilization
  - Portable Confocal Microscope for Skin Cancer
    - For Use in the Doctor’s Office
  - Dual Bootstrap Registration Tool
    - Dual Align Spin Off Company
  - Autonomous Underwater Vehicle
  - IR Based Detection of Explosives
  - EIT and DOT Methods for Breast Cancer Diagnosis
  - NVIDIA Chip Acceleration of Tomosynthesis
  - Wooden Piling Decay Assessment for Buildings
    - Initial Focus on Boston’s Back Bay Area
  - New CT Technique to Detect Cardiovascular Blockages

- **A More Powerful Strategic Alliance With MGH**
  - Allied with the Gordon Leadership Program
  - “Engineering Residencies”
  - Emerging Ideas/IP from Hospital Clinicians
### Our Center Is Poised For Sustainability!

<table>
<thead>
<tr>
<th>Source of Funds</th>
<th>Actual</th>
<th>Projections</th>
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<tbody>
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<td></td>
<td>Yr 1</td>
<td>Yr 2</td>
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<td>NSF ERC Program (base &amp; Supplemental)</td>
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<td>(not incl. Leadership Program)</td>
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<td>Industry/Government</td>
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<td>(Cash &amp; Joint Proposals)</td>
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<tr>
<td>Key Associated Contracts &amp; Grants</td>
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<td>$0.55</td>
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<td>(includes ALERT &amp; VOTERS)</td>
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<tr>
<td>Commercialization &amp; Licensing Income</td>
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<td>Total Funds</td>
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Our Long Range Mission - A Systemic Means to Attack Important Subsurface Problems

Applications
- Biological-Medical Applications
  - Breast Imaging
  - Radiation therapy
  - Embryo Viability
  - Retinal surgery
- Suicide Bomb Detection
- ATR
- Radiation therapy
- Littoral Zone Monitoring
- Mine Detection

DOD-DOE-DHS Applications
- Tunnel Detection

Diverse Problems
- Similar Solutions

Physics-Based Signal Processing and Image Understanding
- Subsurface Sensing and Modeling
- Image & Data Information Management
Summary of Accomplishments (March 2009)

- 451 Journal Publications (73 in Yr 9)
- 621 Conference Publications (89 in Yr 9)
- 173 Papers With Multiple Partners (37 in Yr 9)
- 21 Patents Filed (2 in Year 9)
- 20 Licenses and Patents Issued (0 in Year 9)
- 14 New Medical Procedures Adopted (3 in Year 9)

- 181 Yr 9 CenSSIS Students
  86 B.S.   29 M.S.   66 PhD.
- Yr 9 CenSSIS Graduates:
  12 M.S.   9 PhD.
- 37 Courses and Course Modules (5 New in Year 9)

- K-12 Outreach (Year 9): 300 Students and 10 Teachers

- 412 Workshops for Industry and Others (38 in Yr 9)
- 22 Gordon Leadership Students (13 in Yr 9)
Our New initiatives = New Opportunities for Students, Researchers & Industrial Partners
Gordon-CenSSIS: A Vibrant and Sustainable Multisector Partnership!