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Title: New Cyber-Physical Systems Education Activities at Los Alamos National Laboratory

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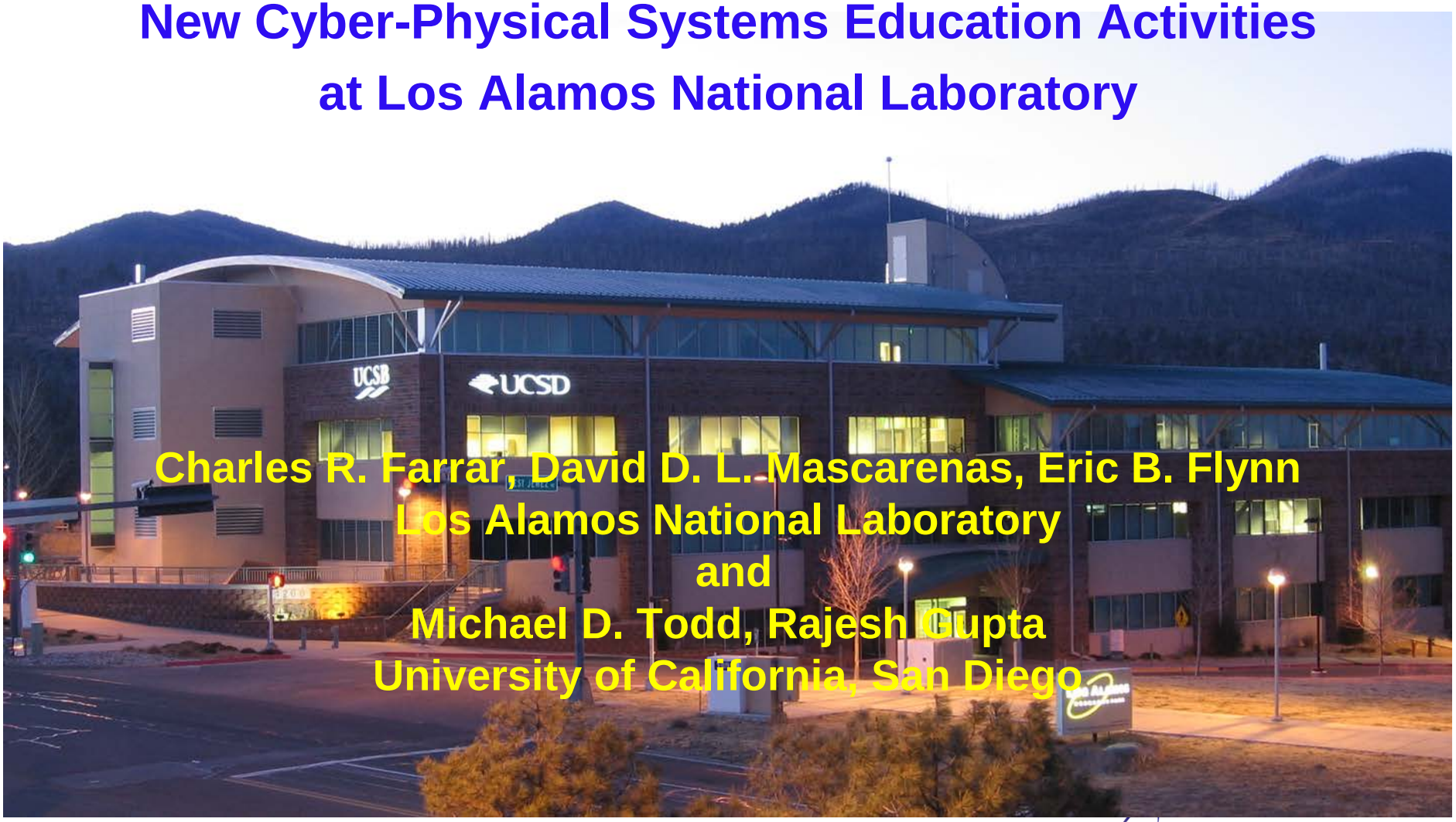
The Engineering Institute

New Cyber-Physical Systems Education Activities at Los Alamos National Laboratory



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Los Alamos National Laboratory
and
Michael D. Todd, Rajesh Gupta
University of California, San Diego

Abstract

Los Alamos National Laboratory (LANL) has been hosting the Los Alamos Dynamics Summer School (LADSS) since 2000. This program is an undergraduate research and education program designed to motivate top U.S. citizen engineering students to attend graduate school. Beginning in 2002 the LADSS concept was expanded into a more comprehensive education and research collaboration with the University of California, San Diego (UCSD), which is referred to as The Engineering Institute (EI). Working jointly with engineering faculty at UCSD the EI's research has focused on integrating advanced predictive modeling capabilities with novel sensing systems and new developments in information technology. Our Institute has evolved to include a formal international partnership, The Engineering Institute-Korea, and we are now hosting Ph.D. students and postdoctoral fellows from several European and Asian countries.

Realizing that a lot of research activities at LANL fall under the general heading of cyber-physical systems, in 2013 we plan to revamp the LADSS to focus on this topic in an effort to maintain LANL mission relevance. Similarly, many of the collaborative research projects with UCSD also can be classified as research related to cyber-physical systems and we plan to continue with this focus into the foreseeable future. This talk will summarize the Engineering Institute's education and research activities with particular emphasis on their relation to cyber-physical systems. In addition to the LADSS we have developed a multi-disciplinary graduate degree program at UCSD that we believe trains students in a manner that better prepares them to address CPS research problems. As an example, in this program structural engineering graduate students are taking more than half of their classes in electrical engineering and computer science. Additionally, the collaborative research projects that we sponsor require faculty and students from electrical, mechanical, and structural engineering and computer science to work jointly on a project. All of these activities are motivated by our belief that the engineering leaders of the future will necessarily have to be more multi-disciplinary and there are currently a dearth of programs that train graduate students in this manner. Also, included in this talk will be issues related to the understanding of cyber-physical systems as a research focus at LANL and new programs we are starting that will directly focus on cyber–physical systems research (e.g. our new Advanced Scholars Program). I will conclude the talk with a summary of challenges we have faced implementing these ideas, some of which we have not fully overcome.

Outline

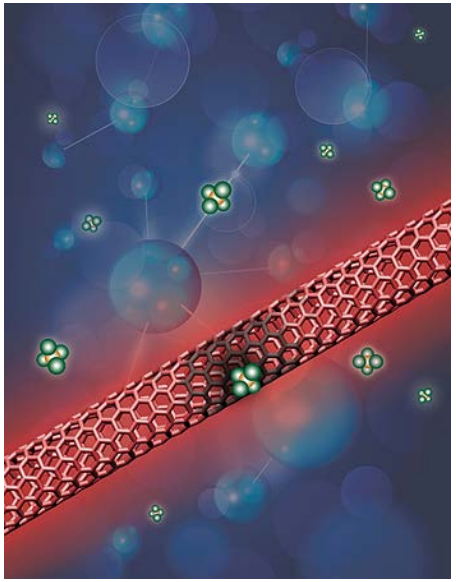
- Why is LANL interested in C-P Systems?
- The Engineering Institute's & its technology focus
- Structural health monitoring
- Education Programs
  - Undergraduate
  - Graduate
  - Graduate/postdoc
- Students are our success! Three structural engineering students
- Cyber-physical security
- Final thoughts on C-P System education

Los Alamos is a national security science laboratory.

- Core mission: ensuring U.S. nuclear deterrent
- Reducing threats of weapons of mass destruction and terrorism:
- Energy security

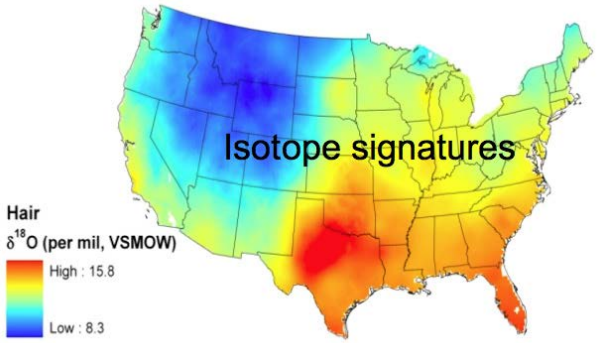
LANL science strategy centers around three pillars

Experimental science
Focused on materials of the future



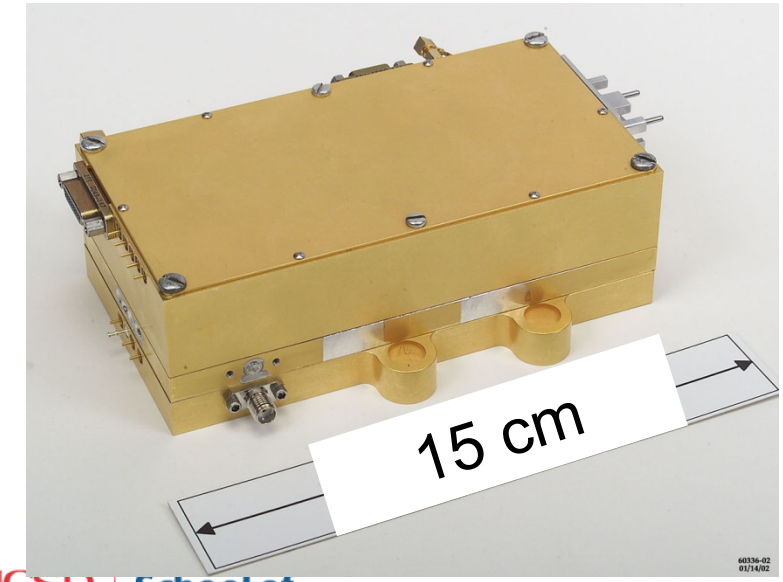
Information science and technology
Enabling integrative and predictive science

Science of signatures
for nuclear, biological, and chemical threats

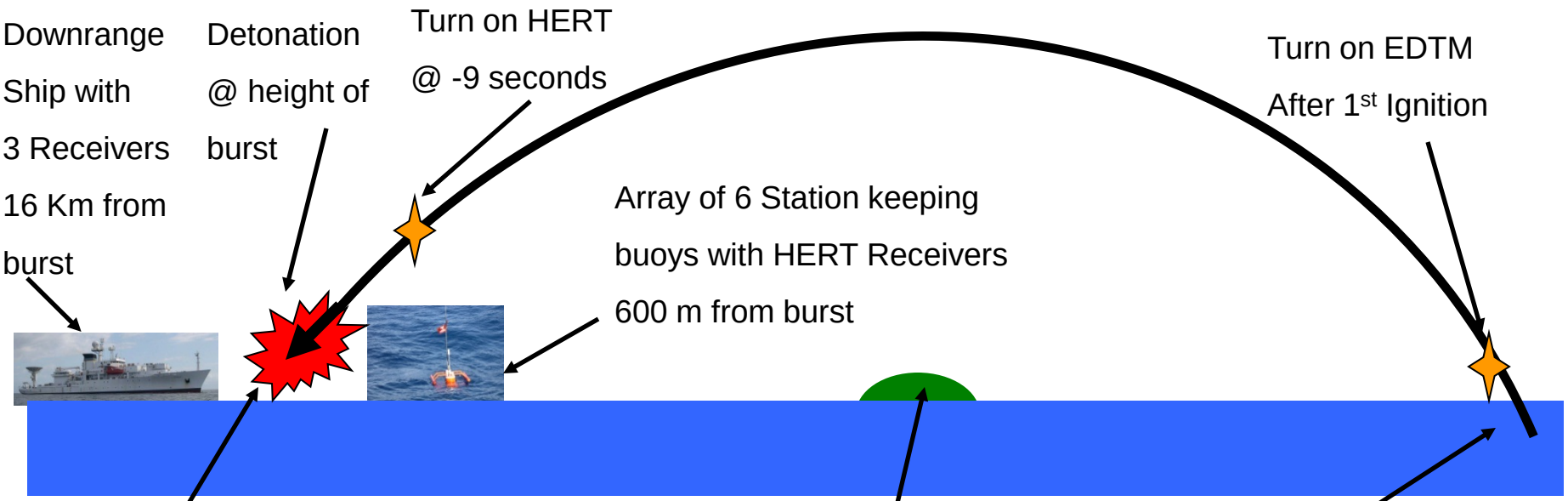


A LANL CPS: High Explosives Radio Telemetry System

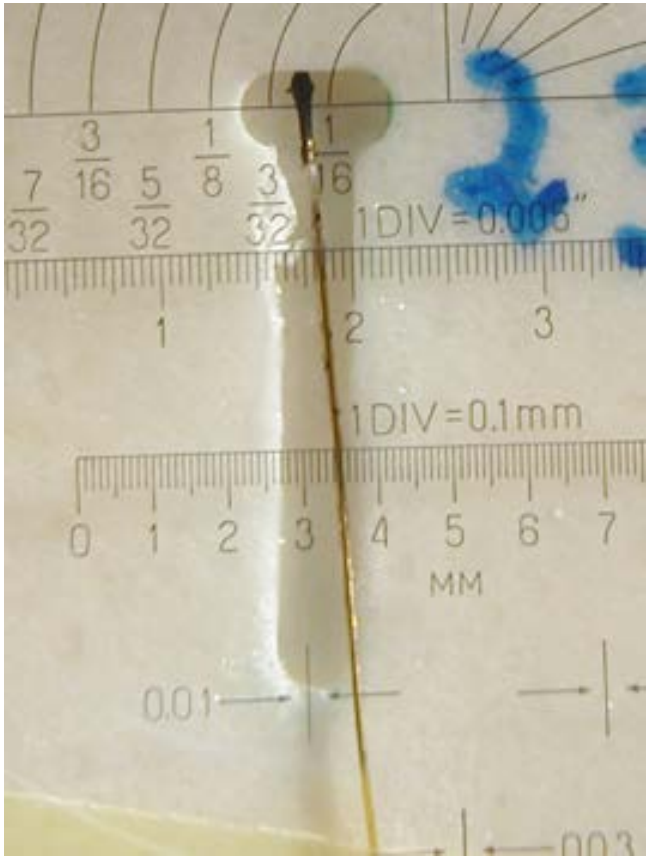
- Develop a system for measuring, transmitting, and receiving data that verifies the in-flight and terminal-event performance of warheads in delivery environments
- This system consists of fiber optic pressure sensors, conventional strain and acceleration sensors, and the High Explosive Radio Telemetry (HERT) system
- 32 fiber optic sensors, 10 ns sampling resolution, 100 Mb/s transmission rate, sensor diagnostic capability, 0.6 kg



Basic Flight Trajectory and Downrange Assets

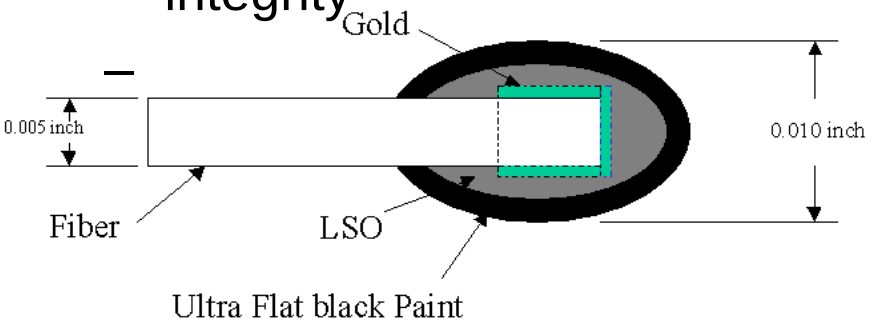


Fiber Optic Shock Sensors with Self-Check



Fiber Sensor

- Fiber Optic Shock Sensor
  - Placed in small machined groove in HE surface
  - Generates light upon arrival of shock wave, blinded from high explosive light
  - Prior to shock arrival all sensors are self-checked for integrity

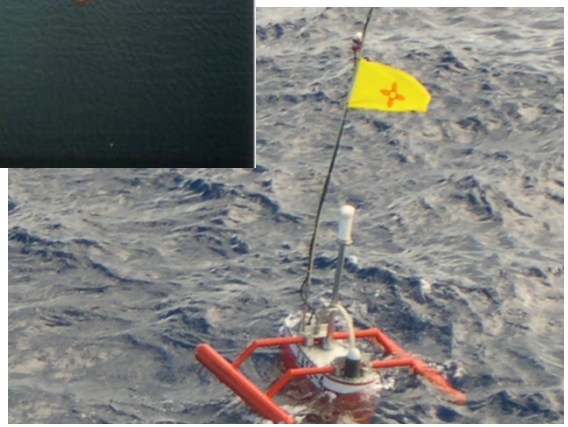


LSO: Cerium-Doped Lutetium Oxyorthosilicate

Ground HERT Explosive Test

Sensor System Loading Environments

HERT Receiver Assets

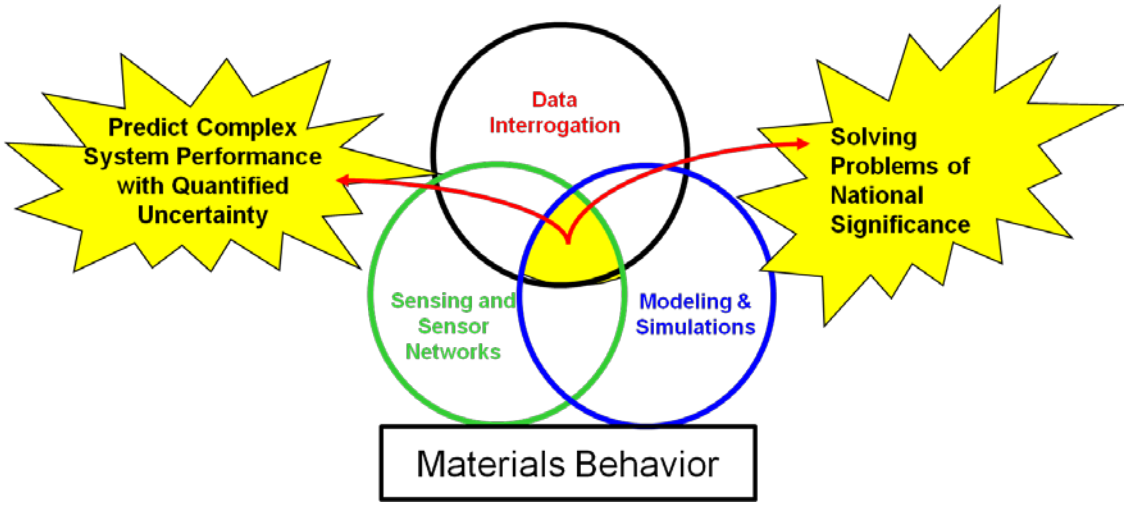


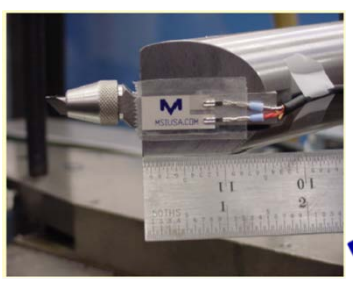
- One each HERT data receivers mounted in six ocean-going Autonomous Surface Craft (ASC) positioned near terminal event location
- Three HERT receivers located on Navy Mobile Instrumentation Ship (NMIS) – one each connected to left and right polarizations of SMART antenna, one to Splash antenna
- Considerable effort made to comply with START Treaty requirements

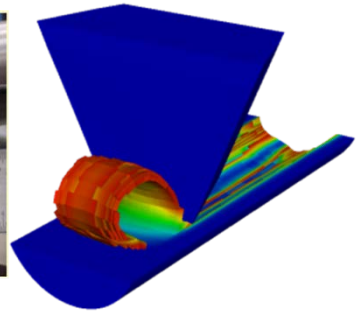
The EI Components

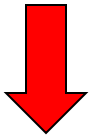
- Since 2002 LANL and UC have invested in the Engineering Institute (EI) to proactively address recruiting, revitalization and retention challenges.
- The EI has evolved to six components
  - Los Alamos Dynamics Summer School
  - Multi-Disciplinary Graduate Degree Program
  - Collaborative Research with UC San Diego
  - Annual Workshops
  - Industry Short Courses (self-sufficient, no LANL or UC resources used to support this activity)
  - **International Collaborations (new in the last two years)**

Our Vision for Engineering Research:
Cognitive, Adaptive, Engineering Systems









- **Design system functionality in at the material and manufacturing level**
- **Monitor, Control and assess in-service system condition**
- **Intelligent System Retirement**

Our Vision is about developing new tools and methods

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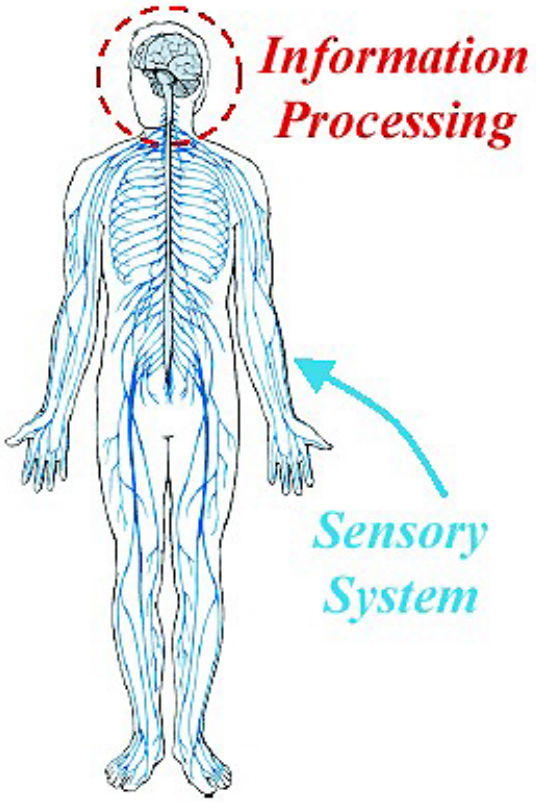
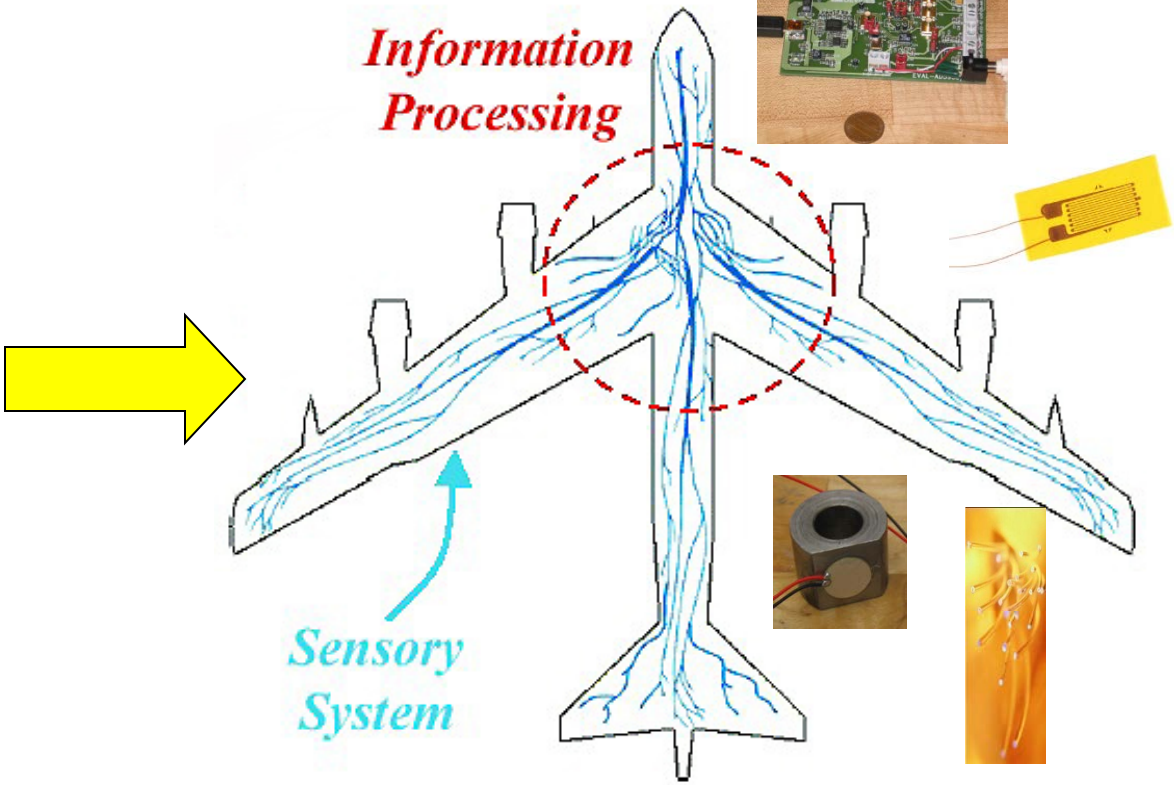
Structural Health Monitoring

Structural Health Monitoring is the process of developing a damage assessment capability for aerospace, civil and mechanical infrastructure



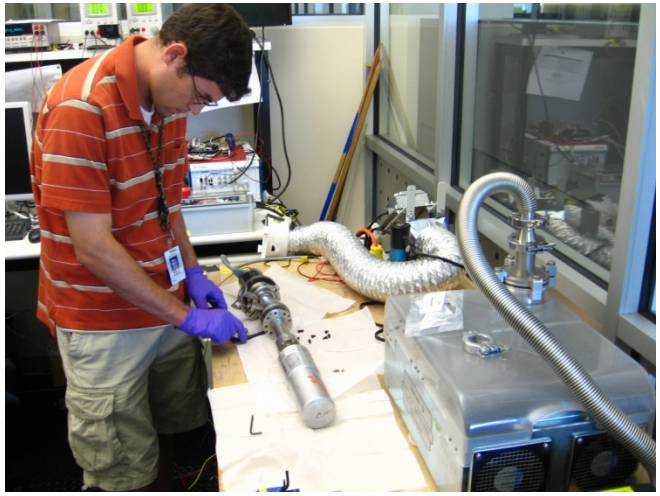


THE LOS ALAMOS DYNAMICS SUMMER SCHOOL

Since 2000, our goal is to get top **US-citizen** undergraduates enrolled in graduate school.

Each year we recruit 15-18 top undergraduate engineering students from around the U.S.

- Mean undergrad GPA approx. **3.8/4.0**
- Week long (1.5 hr/day) tutorials (e.g. signal processing),
- Guest lectures on various research topics,
- Numerous tours and a field trip to Sandia Lab.
- Students work on team research projects, produce conference paper, present paper following February at an International Conference.
- **Lectures on applying to grad school and competing for fellowships**.
- **Recruit the best of these to attend grad school at UCSD and fund their graduate studies!**



Student working on vibration control of mechanically-cooled germanium detector

Student presentation at IMAC conference

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2013 LADSS tutorials will focus on CPS

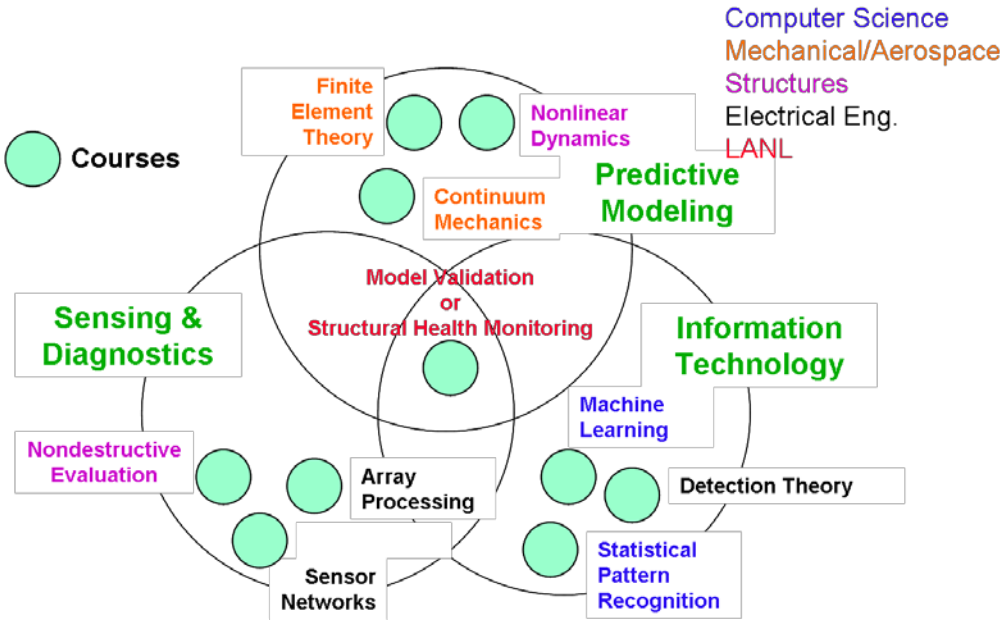
- Better balance of computer science students and engineers.
- Week-long tutorials will be more relevant to CPS:

Week	Past Tutorials	2013 CPS Tutorials
1	Introduction to signal processing and data acquisition	Probability and Statistics including introduction to data acquisition and introduction to detection theory
2	Structural Dynamics	Dynamics Systems (electrical, mechanical, fluid, thermal), conservation laws, emphasize modeling on various length and time scales, different types of models (physics, data-driven (machine learning), statistical)
3	Experimental Modal Analysis	Signal Processing
4	Computational Structural Dynamics	System I.D. (exp. modal as an example) (physics, data-driven (machine learning), statistical)
5	Wave Propagation	Controls & Embedded Systems
6	Nonlinear Dynamics	Nonlinear Dynamics (beyond structural dynamics)
7	Model Validation and Verification	Model Validation and Verification (physics, data-driven (machine learning), statistical)

Multi-Disciplinary Graduate Education Program

Our Tenet: Engineering leaders of the future will need to be much more multi-disciplinary. However, graduate schools focus almost exclusively on training the specialist.

- To address this issue, we have developed a Multi-Disciplinary Graduate Degree program at UCSD
- In the future, a High-Energy, RF Grad. Degree Program will train next generation of pulsed-power EEs to support LANSCE and MaRIE.



Aggressively Promoting Multidisciplinary Research

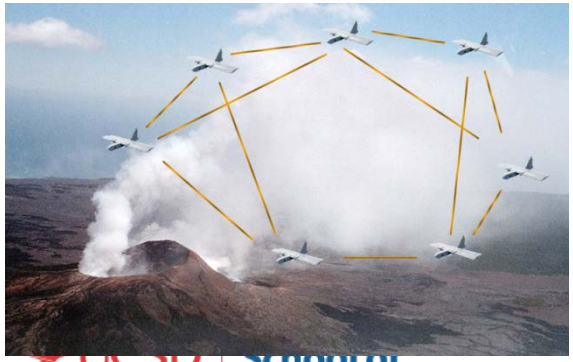
Multi-disciplinary projects involving one UCSD faculty PI and Graduate Student from:

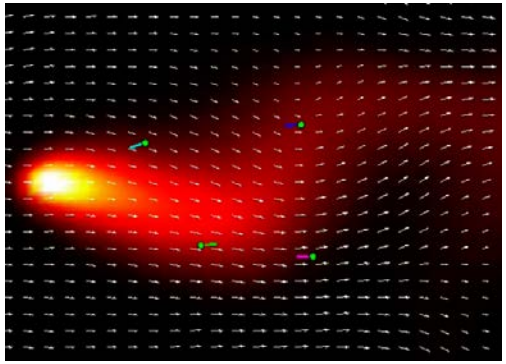
- Computer Science and Engineering,
- Electrical and Computer Engineering,
- Mechanical and Aerospace Engineering, and
- Structural Engineering.

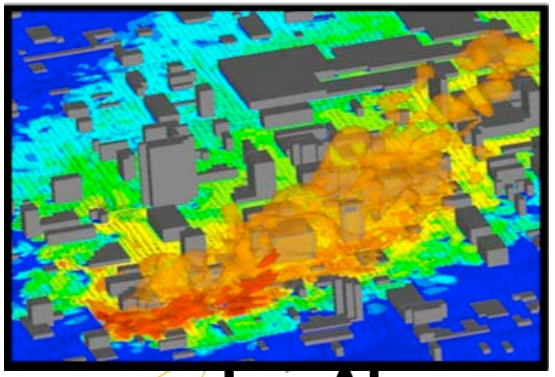
- **LANL staff work jointly with faculty and co-mentor the graduate students**
- **Typically in any year, the EI supports 15-20 Grad Students + 6 more students supported by NSF & NDSEG fellowships**
- **Incentivize LANL and UCSD PIs to submit joint proposals to external funding sources after project's first year!**

Plume Detection, Tracking, Forecasting

- **Multi-disciplinary research example:**
  - **UAVs provide plume concentration and weather information**
  - **HPC predicts dispersion, repositions UAVs**
  - **First demonstration of mobile sensor nodes directly communicating with HPC**

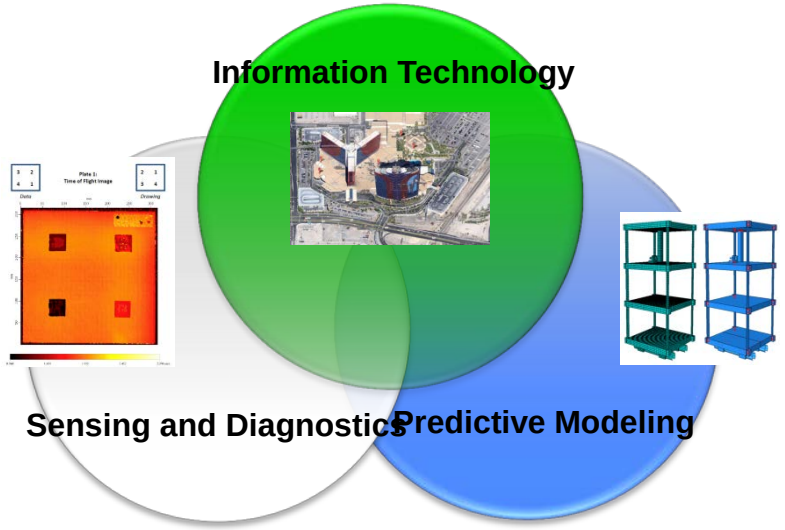






EI Advanced Studies Institute Concept

- Invite innovative graduate student and postdoctoral researchers from around the country for 3 week intensive program
- Arrange into small teams of 2-4 researchers and write proposals on challenging Science of Signatures problems.



- In some cases try to develop prototype, proof-of-concept demonstrations or models.
- Technical lecture series (e.g. electric grid dynamics)
- Professional development lecture series (e.g. proposal writing)

Students are Our Success Story!

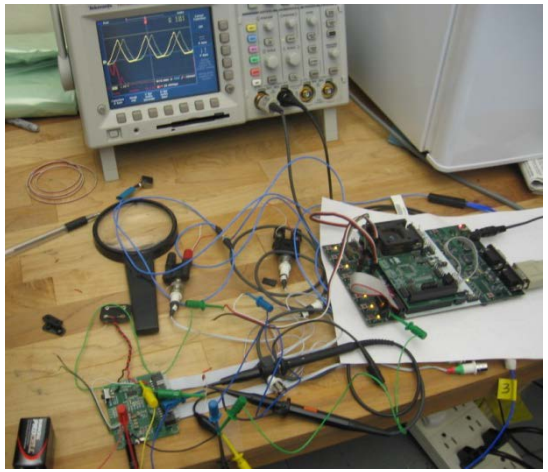
David Mascarenas, LANL Staff

- Attended 2003 LANL Dynamics Summer School
- Enrolled in graduate school at UCSD
- Ph.D. research (@ Cal-IT2) focused on wireless energy delivery to embedded sensor nodes for structural health monitoring
- LANL Director's Funded Postdoc
- Became LANL staff member in 2012

David's project

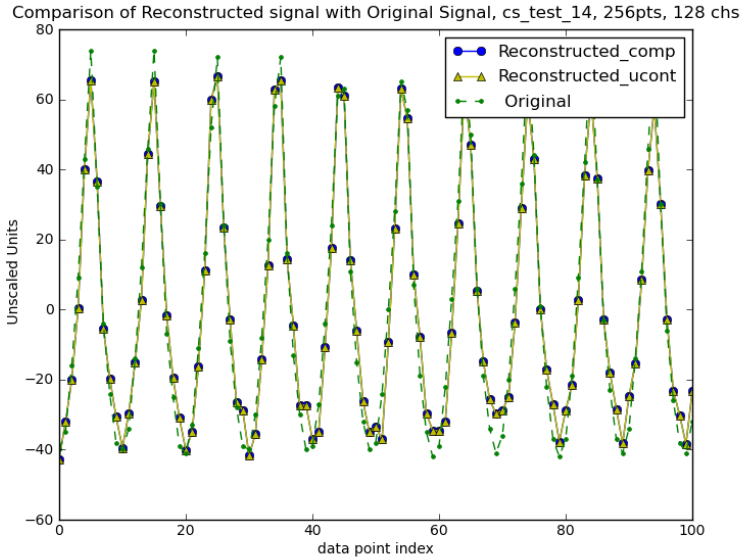
Embedded Compressed Sensing

- Proof of concept study developing low-power embedded sensor nodes implementing compressed sensing.
- Implemented a digital version of the “smashed filter.” (a “matched filter” in the compressed domain).



Prototype compressed sensing hardware

Test structure



Signals reconstructed using L1 norm minimization on compressed coefficients.

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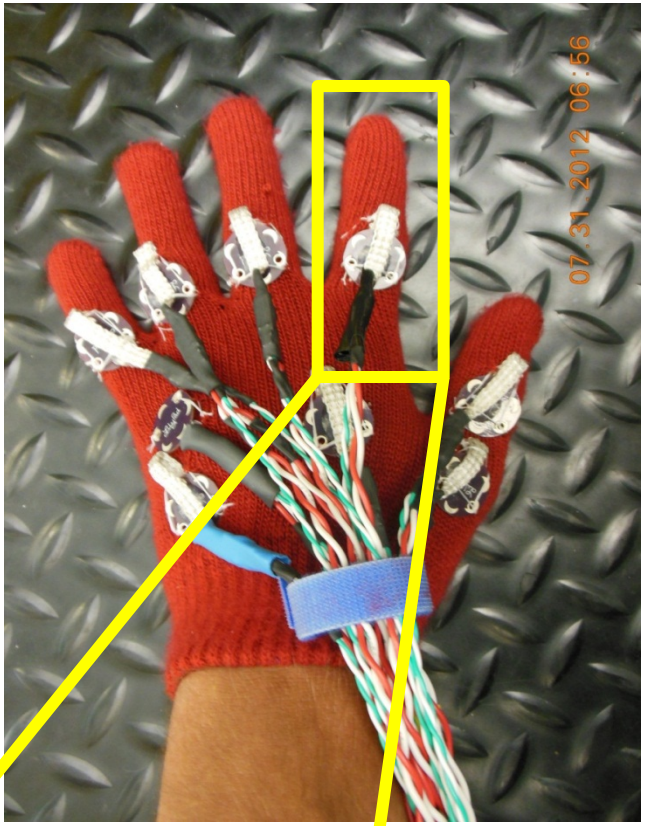
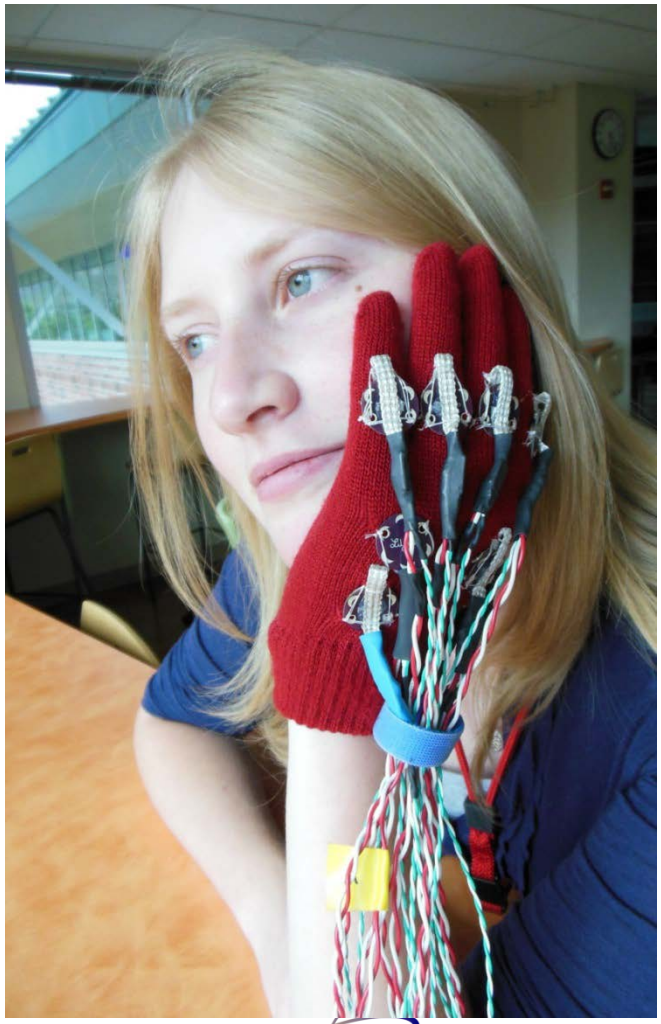
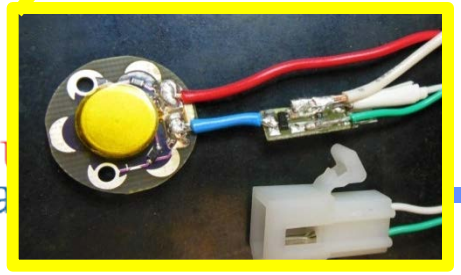
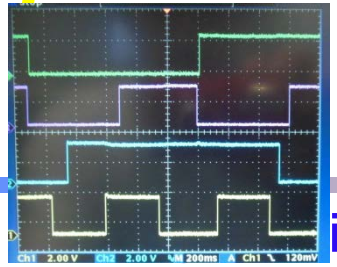
Vibro-Tactile Haptics for Human-Machine Interface





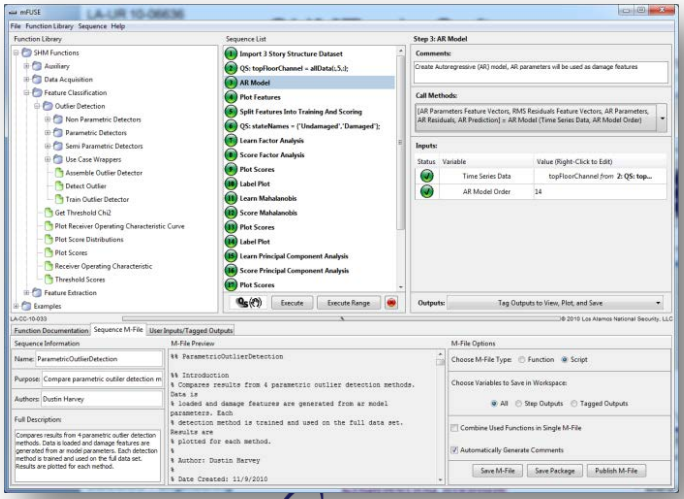




Students are Our Success Story!

Eric Flynn, LANL Director's Funded Postdoc

- Attended 2006 LANL Dynamics Summer School
- Selected for NSF graduate fellowship
- Attended other top engineering grad school
- Enrolled in graduate school at UCSD
- Ph.D. research (@ Cal-IT2) focused on optimal sensor/actuator placement for guided-wave structural health monitoring
- Led team of CS & structural engineering students that produced SHMTools software(downloaded 1000+ times)



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Eric is extending his work to HPC

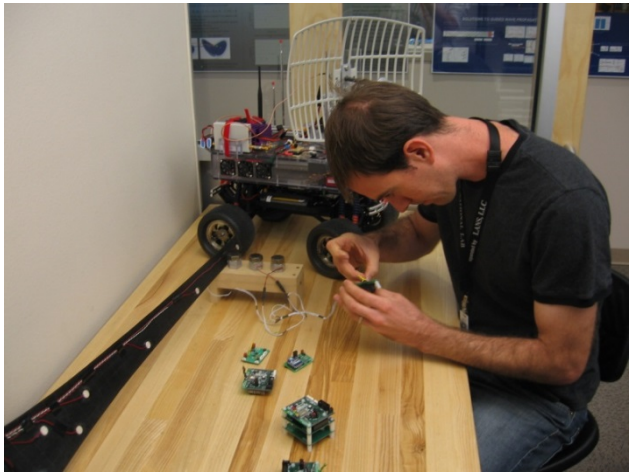
- LANL HPCs (e.g. Roadrunner) cost 100s of millions of dollars.
- Air conditioning bill is more than $20 million/yr
- Not enough power coming into Los Alamos county for an exascale HPC

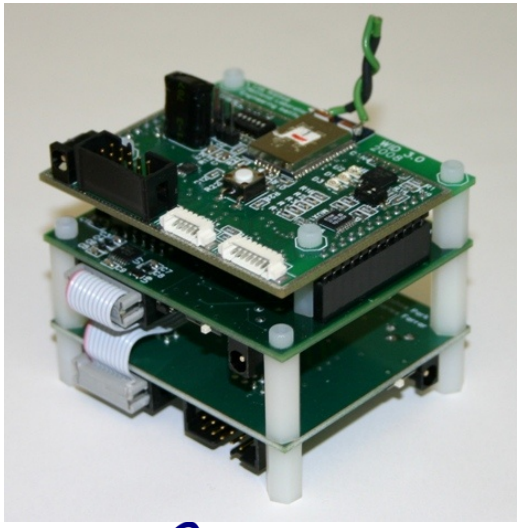
- Eric is developing visualization tools for data flow through nodes
- Addressing resilience of HPC (SHM concepts applied to HPC)

Students are Our Success Story!

Stuart Taylor, LANL Postdoc

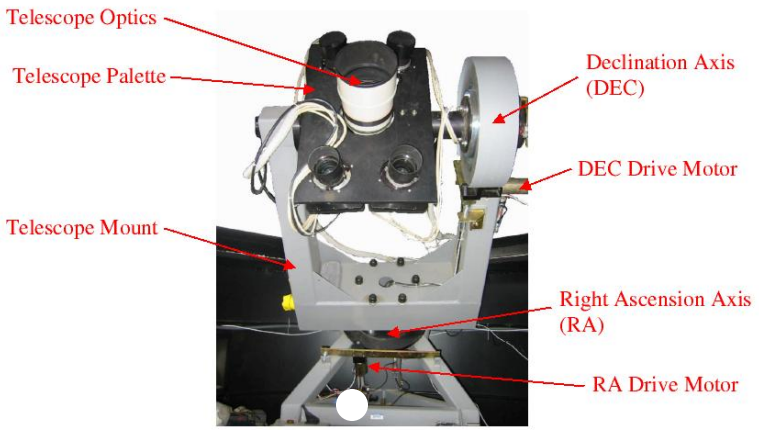
- Attended 2003 LANL Dynamics Summer School
- Selected for NSF graduate fellowship
- Enrolled in graduate school at UCSD
- Ph.D. research (@ LANL) focused on wireless sensor nodes for structural health monitoring (LANL pursuing patent)
- Spent six month working for N-2 in the role of a terrorist designing NW components





Condition Assessment of RAPTOR Telescope: Sensing the sensor

Project Goal: Develop an embedded, autonomous monitoring system that provides RAPTOR operators with real-time telescope mechanical condition data facilitating improved maintenance schedules and system reliability.



Data Collection / Analysis

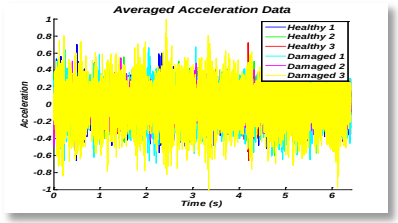
⇩

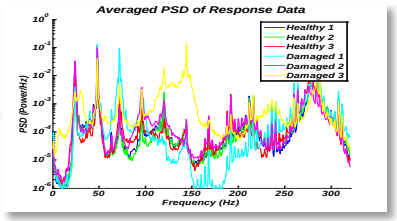
Statistical Pattern Recognition

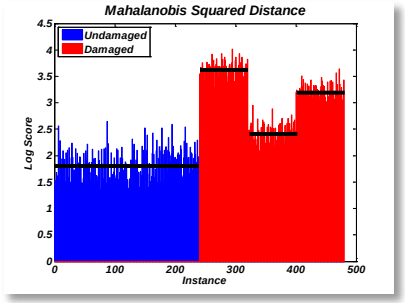
⇩

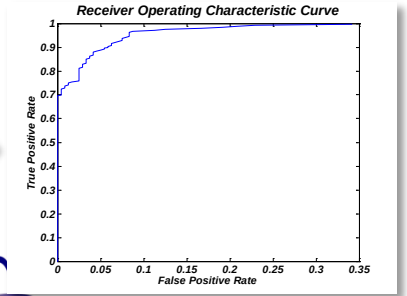
Damage Model Validation

SHMTools + mFUSE Function Sequencer for MATLAB









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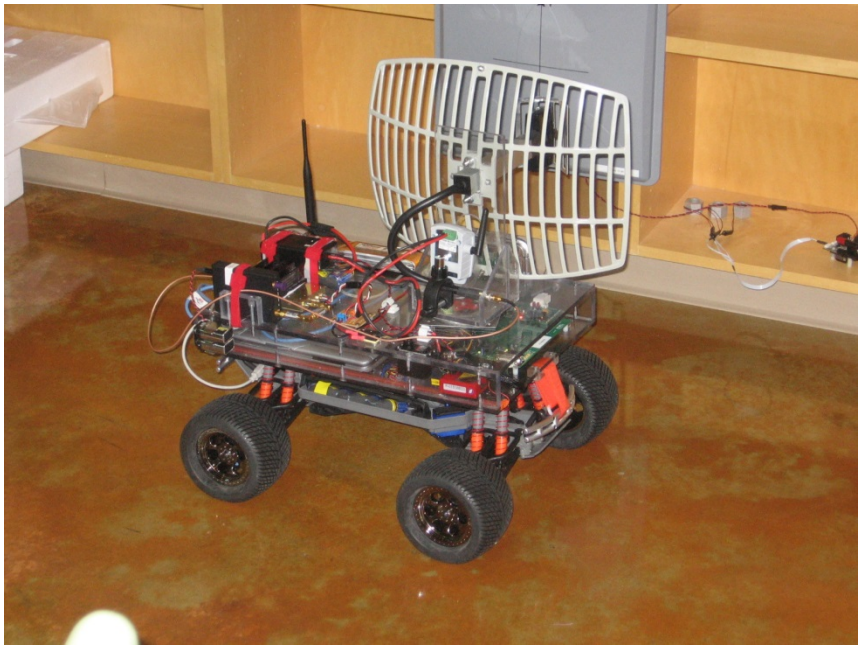
Cyber-physical security

- **C-P System concepts will not transition from research to practice without Cyber-Physical Security.**
- **Robot operating system vulnerability "honeypot" study at DEFCON 2012**
  - Chemistry Ph.D. student,
  - Civil Eng. Postdoc,
  - Mechanical Eng. Staff
- **Is C-P security part of the education process?**



Some Final Thoughts on C-P System Education

- **The Good News!**
  - Students educated through our multi-disciplinary graduate program at UCSD are in demand at LANL!
  - They are recognized by our senior staff & management as the next generation of engineering innovators and leaders
  - They are viewed on par with the best early career physical scientists.
- **Tenure and Promotion is hurting us**
  - Rewards the individual investigator; does not reward team efforts, does not reward curriculum development
- **Is education evolving to address the more multi-disciplinary technology needs of CPS?**
  - Need to start this multi-disciplinary education at the undergrad level.
- Are we educating the practicing engineers and educators?
- **The role of the technology integrator is crucial to C-P System technology! Does our education address this issue?**

Additional Metrics of Success

- Publications: 31 journal papers, 52 conference proceedings, and 3 book chapters in FY-10 &11.
- 19 invited lectures at Research Institutes & International Conferences in FY-10 &11
- Korean Government developing the Engineering Institute-Korea that is modeled after LANL's EI.
- Industry, Government Agencies and Universities pay to learn about our research through our short courses
  - Boeing, United Space Alliance, FAA, American Shipping Bureau, Princeton, Stanford, Sandia, Naval Surface Warfare Center, Disney
- International Collaborations
  - Institutions from around the world send their graduate students and postdocs to the EI at their expense
  - Japan, Korea, Portugal, Italy, Poland, Ireland, Germany, Greece, Turkey
  - Univ. of Bristol (UK), Univ. of Sheffield (UK), AGH Univ (Poland), Chonbuk National Univ. (Korea), **AWE**