Engineering Institute

UCSD Jacobs | School of Engineering

Los Alamos NATIONAL LABORATORY

this issue

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The Engineering Institute

The Engineering Institute (EI) is a collaboration between LANL and the University of California at San Diego (UCSD) Jacobs School of Engineering whose mission is to develop a comprehensive approach for 1) conducting mission-driven, multidisciplinary engineering research and 2) recruiting, revitalization and retention of the current and future staff necessary to support LANL's national security missions.

The components of the Engineering Institute are 1) the Los Alamos Dynamic Summer School 2) a joint LANL/UCSD degree program, 3) joint LANL/UCSD research projects, 4) annual workshops, and 5) industry short courses.

Contact:

Engineering Institute Leader

Charles R. Farrar, Ph.D. P.E.

farrar@lanl.gov

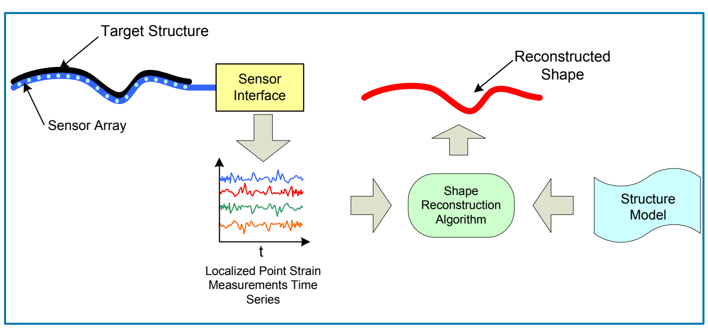
505-663-5330

505-663-5206

Shape Reconstruction Using Novel Fiber Optic Sensing

The U.S. Navy requires an improved capability in monitoring and tracking underwater vehicles and arrays that employ tethered structures, e.g., the USNS Loyal (picture). EI Director Chuck Farrar and EI UCSD Campus Director Michael Todd, along with Brandon Stone (W-13, GRA) and Miles Buechler (W-13, TSM), are collaborating with 3Phoenix Incorporated* on an Office of Naval Research Small Business Technology Transfer (STTR) research and development project to address this goal. The project is entitled "Novel Fiber Optic Methods for Sensing Shape, Orientation, and/or Heading of Undersea Arrays and Tethers," which combines an embedded fiber optic sensing architecture using multiplexed Bragg gratings and novel shape reconstruction algorithms rooted in mechanics-constrained geometric modeling.

The concept (shown in figure 1) is based in the use of fiber optic sensors known as fiber Bragg gratings (FBGs) distributed throughout the tether. FBGs are simple intrinsic periodic structures that are photowritten into silica fiber by ultraviolet radiation, typically over about a 1 cm length. The photowriting process results in a fiber core refractive index modulation that functions like an optical notch filter. Due to interference patterns established within the fiber, most of the wavelengths will be transmitted through the FBG, but a narrow (0.1-0.3 nm wide) band of wavelengths centered at λ_r get reflected, given by $\lambda_r = 2nT$ where n is the effective fiber core refractive index and T is the physical spacing between the refractive index modulations. Because the reflected wavelength is directly proportional to this spacing, any compression or tension in the fiber, such as that due to strain in the local region, results in a shift in the central wavelength. By specifying different unperturbed reflection wavelengths, a practical multiplexing scheme is created allowing serialization of FBGs into a single fiber. Upon launching light around 1.55 μm from a rapidly tunable External Cavity Laser (ECL) into the fiber, each grating will reflect a particular wavelength back to the source. The resulting wavelength shifts due to mechanical strain (approximately 1.33 pm/$\mu\varepsilon$) can then be resolved and sub-microstrain sensitivity can be achieved. This represents approximately two orders of magnitude improvement over conventional gages. The interrogation architecture also provides additional advantages such as self-telemetry, negligible weight and footprint, insensitivity to electromagnetic noise, and low inherent noise performance.



Once distributed, strains are returned by the FBG measurement system and inverse algorithms are applied to convert local strain information into local three-dimensional deformation. These algorithms are based on constrained geometric modeling of tethered structures, employing expected basis functions that map local coordinate information to global coordinate information. EI team members have developed these algorithms to be used with the 3 Phoenix FBG interrogation architecture to create an integrated solution for tether shape reconstruction.

The team recently completed a Phase I simulation/study effort to demonstrate feasibility and has applied for both a Phase I option, where a demonstration test of this concept will be conducted at LANL, and a Phase II contract, where a prototype system will be developed, tested, and demonstrated.

** http://www. 3phoenix.com/*

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UCSD Course Sequences

Signal Processing
Digital Signal Processing
Array Processing
Detection Theory
Parameter Estimation
Stochastic Processes
Sensor Networks
Random Processes

Embedded Systems
Introduction to Embedded Systems
Software for Embedded Systems
Validation and Testing of Embedded Systems
Design Automation and Prototyping for Embedded Systems

Parallel Computing
Large Scale Computing
Parallel Computation

Controls
Linear Systems Theory
Nonlinear Control Systems
Approx Identification and Control
Applied Structural Control

NDE/SHM
Experimental Mechanics and NDE
Structural Health Monitoring

Structural Dynamics
Structural Dynamics
Advanced Structural Dynamics
Nonlinear Mechanical Vibration
Random Vibrations
Wave Propagation in Elastic Media
Wave Propagation in Continuous Structural Elements

Applied Mechanics
Theory of Elasticity
Theory of Plasticity/ Viscoelasticity
Structural Stability
Solid Mechanics for Structural and Aerospace Engineering
Mechanics of Laminated Composite Structures

Computational Mechanics
Numerical Methods
Finite Element Analysis I & II
Computational Fluid Dynamics
Model Verification and Validation

If you are interested in having any of these classes or a class sequences offered at LANL, please contact Kathie Womack (Womack@lanl.gov, 663-5206)

Towards Structural Health Monitoring System Design: A Bayesian Approach to Optimization

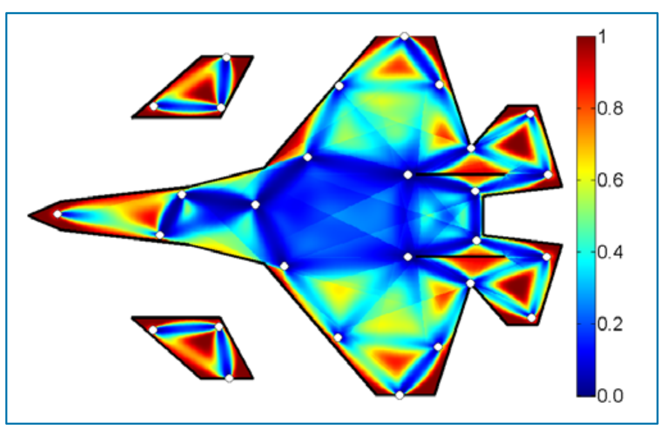
Structural Health Monitoring (SHM) involves a paradigm of in-situ data acquisition/sensing, data feature extraction, and data feature classification as a means of appropriately assessing the condition of a structure. With ongoing advances in SHM-supporting technologies, formal optimization of the SHM system design process is becoming a key step to transforming SHM from laboratory development to field deployment. Researchers at EI, led by UCSD Ph.D. student Eric Flynn, are developing and implementing a framework to tackle the optimization problem in a way that reflects practical application goals, distributed costs, and the utility of SHM systems.

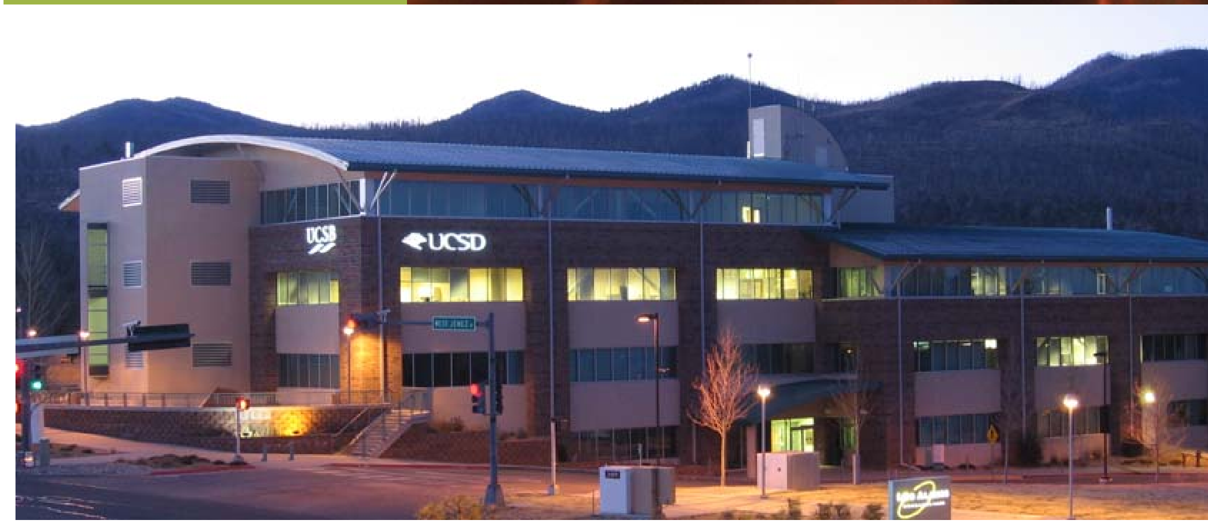
Optimal SHM design works to maximize some chosen system performance metric given constraints on required resources such as system cost and power consumption. Many optimization attempts to date have been *ad-hoc*, with little consideration of the system's ultimate intended purpose. The more established metrics are generally adaptations of information-based approaches taken from the estimation theory and NDE fields. One such common performance metric is the determinant of the Fisher information matrix, which statisticians refer to as the D-optimality criterion. As an example in the field of structural dynamics, for linear structural vibrations, the Fisher information matrix reduces to the product of the subset of the structural modal matrix and its transpose.

The D-optimality criterion and other information-based criterion work to optimize problems of inference. The fundamental goal of SHM, however, is not solely inference, but rather the reduction of the life cycle cost of a structure through both inference and proper decision-making. The SHM optimization problem, therefore, is most suitably approached through a more general framework rooted in the theory of Bayesian experimental design, which seeks to minimize (maximize) the total expected loss (utility) of the SHM system. As a result, researchers at EI have adapted this framework to the unique objectives of the SHM problem.

This framework enables the optimization of SHM system designs with respect to unequal economic costs and likelihoods of the potential damage modes and severities. With performance measured in terms of actual economic cost, the SHM system's cost of installation, operation, and maintenance are naturally tied into the problem as well in order to achieve full system optimization.

One area of particular focus in which to apply this optimization paradigm is the placement of actuation/sensing networks for active-sensing-based SHM using ultrasonic guided waves. In this problem, the expected risk calculation is made tractable by dividing the structure into discrete regions of interest with individual likelihoods and costs of damage. The optimal arrangement of actuators and sensors is then that which minimizes the total expected cost of detection (Bayes risk) across all region plus the cost of instrumentation. The detection performance of a given arrangement is determined through a meta-model of the feature extraction process derived from analytical wave scattering theory. Figure 2 shows the application of this approach for a hypothetical airframe skin with symmetric potential defects (only one side is depicted). The figure shows the 28-transducer optimal arrangement with a map of the resulting normalized distributed Bayes risk.





Student Highlight

Greg Jarmer, formerly an undergraduate summer student with W-7, recently completed his M.S. degree in UC San Diego's Department of Structural Engineering. Greg's thesis, entitled "Crack detection diagnostics using ultrasonic insonification," considered data-driven modeling approaches with ultrasonic interrogation to detect fatigue cracks in metallic structures, a research area relevant to W-7. W-7 funded Greg's research through the Engineering Institute's graduate degree program in structural health monitoring, damage prognosis, and validated simulations. Greg, advised by Prof. Michael Todd, plans to continue Ph.D. research through the EI in conjunction with W-7 focusing on integrating data-driven diagnostic techniques with predictive models in an effort to create a fatigue crack prognostic capability. When not buried in research, Greg enjoys either exploring a nearby state park, cooking a new recipe from the Food Network, or working on his '66 Mustang fastback.

(Greg after his defense with Chuck Farrar, left and Michael Todd, right)

Advisory Board for EI

The EI has formed an internal advisory board to help guide its educational and research activities. The purpose of this Board is to maximize the positive impact the EI's recruiting, training and retention activities have on LANL engineers and maximize the number of line organizations impacted by these activities.

The roles and responsibilities of the EI Advisory Board include

- Represent their respective line organization's needs in terms of recruiting, training and retention to the EI staff.
- Guide the collaborative research projects and educational activities of the EI
- Help to define other EI activities such as workshops and development of proposal writing teams
- Bridge a gap between line organization and EI for summer internships, for post-doctoral research appointments, or for staff hiring.

The following members will serve on this advisory board for a two-year period,

Frank Addessio (T-3)
Don Hush (CCS-3)
Doug Kautz (WCM-2)
Thomas Mason (W-6)
Evelyn Mullen (IAT-DO)
R. Alan Patterson (MST-DO)
Ray Guffee (AET-1)
Daniel Rees (AOT-RFE)
Angela Mielke (ISR-3)

EI Training Seminar

Engineering Institute starts a new quarterly training seminar series for staff members across the Laboratory. First two seminars are planned.

- "Kalman Filtering Tutorial," June 24th 1:00 -5:00 (Matt Bement, X-3)
- "Optimization," September 23rd 8:00 – 5:00 (lecturer TBD)

EI is currently soliciting other topics for future seminars. If interested, please contact Chuck Farrar, farrar@lanl.gov. The training seminar may be used to meet Professional Engineering License Continuing educational requirement. Certificates will be provided for attending the seminar.

New Courses in Fluid Mechanics

From fall 2009, EI offers new sequential classes in fluid mechanics taught by UCSD faculty in distance learning mode. Classes may be taken in "concurrent enrollment mode," by which the student does not have to be in a degree program. The offered classes are

- 210A. Fluid Mechanics I, Fall 2009
  Conservation laws. Flow kinematics. The Navier-Stokes equations and some of its exact solutions. Non-dimensional parameters and vorticity dynamics
- 210B. Fluid Mechanics II, Winter 2010
  Potential flows, boundary layers, low-Reynolds number flows
- 223. Computational Fluid Dynamics, Spring 2010
  Numerical methods in fluid dynamics and convective transport processes. Numerical solution of the Euler and Navier-Stokes equation. Additional topics will vary according to instructor. Examples include eigenvalue problems in hydrodynamic stability, vortex methods, spectral and panel methods.

We are also planning on offering Dynamic Behavior of Materials and FE Methods in Solid Mechanics. For more information, contact EI.

EI Annual Workshops

EI hosts an annual workshop with focus on the broad areas of predictive modeling, advanced sensing and information technology. The reports from these workshops are available on our website. We also work with other LANL organizations to co-host workshops. For more information, please contact Chuck Farrar at farrar@lanl.gov, 663-5330.

Events

- **Los Alamos Dynamic Summer School Lecture Series**
  - **Tutorials**
    - July 6-9th: **Computational Structural Dynamics**, D.J. Luscher (W-13)
    - July 13-16th: **Wave Propagations**, Anthony Puckett (W-13)
    - July 21-24th: **Nonlinear Dynamics**, Doug Adams (Purdue University)
    - July 20, 22, 27th: **Model Validation**, Francois Hemez (X-3)
  - **Guest Lectures**
    - July 7th: **Extended Regeneration Testing of the Tritium Waste Treatment System**, Mark Bibeault (AET-1)
    - July 9th: **Sport Equipment Dynamics**, John Kosmatka (UCSD)
    - July 14th: **Aerospace Structural Dynamics**, Nick Lieven (U. of Bristol, UK)
    - July 16th**: Air Force Space Program**, Brandon Arritt (AFRL, Kirtland)
    - July 21st: **Modal Analysis and FE Modeling of Engineering Structures**, Gretchen Ellis (AET-1)
    - July 23rd: **Boeing Aerospace Applications**, Steve Griffin (Boeing)
    - July 28, 30th: **Alexis and Forte Satellite**, Tom Butler (INST-OFF)

These lectures are open to all LANL staff and students. Staff members can use the tutorials and guest lectures to meet the continuing education credit requirements needed to maintain a professional engineer's license. We will issue certificates of attendance to staff for the purpose of documenting attendance in order to verify PE continuing education requirements.
For more information, contact Kathie Womack, 663-5206.

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MS T001
Los Alamos, NM 87545
505.663.5206 ph
505.563.5225 fax
http://institute.lanl.gov/eiei