Estimation and Forecasting of Contaminant Plumes

The estimation and forecasting of multi-scale uncertain flow systems is one of the most visible, scientifically challenging, and society-relevant computational grand challenge problems of our generation. A collaborative UCSD/LANL team at the Engineering Institute has focused on key aspects of this interdisciplinary problem. The specific application driving this investigation is the forecasting of the movement of contaminant plumes released, either accidentally or maliciously, in both urban and battlefield environments for coordinating emergency response and troop movements, respectively. Related applications include, short-term weather forecasting, long-term ocean current forecasting (for El Nino and climate prediction), and magnetohydrodynamic plasma forecasting (for supersonic flight and solar flare trajectories).

The team specifically focuses on observations derived from a dozen small unmanned aerial vehicles (UAVs) flying in and around the plume, gathering data about the extent and concentration of the plume, the magnitude, direction, and variability of the winds driving its evolution, and the stratification of the atmosphere which limits or drives its vertical mixing. Each of the UAVs is equipped with GPS and sophisticated avionics and sensors, and is assumed to be in intermittent radio contact with a powerful supercomputer back home which both synchronizes the computational model of the plume with the measured data and coordinates the future trajectories flown by the sensor-equipped UAVs. Prof. Thomas Bewley (UCSD) in collaboration with Prof. Daniel Tartakovsky (UCSD) and Dr. Frank Alexander (LANL), is working together with UCSD students Joseph Cessna, Christopher Colburn, and David Zhang to rethink the fundamentals of this UAV-based plume forecasting problem from the ground up. In addition to improved simulation tools for atmospheric flow systems (a problem already receiving substantial research attention), there must be a concomitant emphasis on improved data assimilation and adaptive observation algorithms to address this problem properly; these algorithms thus form the focus of the team’s research.

Data assimilation refers to the synchronization of the supercomputer simulation with existing flow conditions in real time. There are two existing viable methods for accomplishing this: Ensemble Kalman methods, which march sequentially in time and, subject to linear/Gaussian assumptions, well summarize the principle direction of uncertainty, space/time variational methods, which well handle nonlinear/non-Gaussian systems by revisiting past measurements in light of new data but, on their own, do not well summarize uncertainty. The UCSD/LANL team has proposed, developed, and implemented the first consistent, tight hybrid of these two methods, dubbed Ensemble Variational Estimation (EnVE), and is currently evaluating this method using synthetic data. Adaptive observation refers to targeting the sensor motion. This problem is subtle; one gains inadequate information to forecast the plume movement simply by sending sensors towards local maxima in the plume concentration profile, or by orbiting portions of the plume at various isocontours. Rather, it is highly preferred to tailor the upcoming sensor motions to provide measurements which target and minimize the forecast uncertainty. Building squarely on the theoretical framework of EnVE, the UCSD/LANL team has developed a new, elegant algorithm for achieving exactly this, dubbed Ensemble Variational Observation (EnVO).

As the EnVE and EnVO algorithms are being further developed and refined, other members of the interdisciplinary team are assembling a fleet of UAVs and developing the concomitant sensing and communication hardware and software in order, ultimately, to perform a full-scale flight test in which a large-scale atmospheric plume is sampled, estimated, and forecasted in real time, thereby demonstrating the valuable new technological capability which is facilitated by this exciting line of research.
A laser focusing and optimization problem for the next Mars Rover

Walter Barkley (AET-2) has recently received his MS degree from UCSD through the institute.

My colleague told me about the live classes being taught via videoconference at the Engineering Institute in 2004 so I enrolled in the Fall to enhance my credentials and sharpen my mind. With a Bachelor’s of Science in Mechanical Engineering and a Professional Engineering license, I began the pursuit of a Master’s in Mechanical Engineering. My course work included three quarters of Digital Signal Processing, four quarters of linear and non-linear Controls Engineering and two quarters of Structural Engineering (9 total courses, 36 units). UCSD allows up to 24 units of graduate course work through UC extension, which, at the time, was only $300 per quarter. My thesis was a laser focusing and optimization problem for the next Mars Rover, originally scheduled to launch in the Fall of 2009 but now delayed until 2011.

Overall, my experience with the Engineering Institute and UCSD was outstanding. The challenges were in the work scheduling to attend the classes, the time management to complete the course work, and in the support and understanding required by my family. A special thank you to my wife, Allison Majure, for her support and encouragement. Also, thank you to Mike Borden at LANSCE and Raj Vaiyda at AET-2, my group leaders, for supporting this achievement and to Toby Vigil for funding the tuition, books, and occasional trips to UCSD.

Students Highlights

Eric Flynn, a UCSD graduate student shown in the right, won a ‘Best Student Paper’ Award at the ASME 2008 Conference on Smart Materials, Adaptive Structures, and Intelligent Systems, held in Ellicott City, Maryland, October 2008. The paper, entitled “Optimal Sensor Placement for Active Sensing,” describes a new approach for determining the optimal layout for arranging sensors on a structure in order to make appropriate measurements. The work is sponsored as part of the EI research projects. Eric is a graduate student of 2005 Los Alamos dynamics summer school (LADSS) and is currently advised by Prof. Michael Todd in the Department of Structural Engineering.

Molly Nells, one of 2008 LADSS students, won the 3rd Place in Material sciences & Engineering at the 2008 DOE Science & Energy Research Challenge Poster Competition. This prestigious national competition, which took place at ORNL in November, was open to all undergraduate students who conducted DOE related science research during this academic year. The poster, entitled “Use of a Collocated Sensor Actuator for Vibration Suppression and Structural Health Monitoring,” was her research work conducted as part of 2008 LADSS and mentored by Gyuhae Park (INST-OFF).

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The solicitation for the 10th edition of the Los Alamos Dynamics Summer School (LADSS) has recently sent out, and the EI is currently accepting student applications. In short, the goal of the LADSS is to get US citizens to attend graduate school. Students will participate in weekly tutorials and guest lectures from distinguished personnel on various aspects of engineering dynamics, and be placed into 3 person teams to do a research activity in 9 weeks that can be presented in an internal conference. The more information you can find at http://institute.lanl.gov/edynamics-summer-school/ projects. The EI staffs will assist the projects by co-mentoring the research team for the duration of the school. The quality of the LADSS students are excellent and the outcome of their research work usually exceeds the expectations.

Image courtesy of NASA JPL.

10th Los Alamos Dynamic Summer School (June-August 2009)

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We are also currently seeking research projects for LADSS. If you feel you have an interesting research topic that can be completed in a 9 week time frame, please contact Gyuhae Park <gpark@lanl.gov> or Matt Ement <bement@lanl.gov> for further discussion. The research projects in the previous years are listed in the following link (<http://institute.lanl.gov/edynamics-summer-school/projects>). The EI staffs will assist the projects by co-mentoring the research team for the duration of the school. The quality of the LADSS students are excellent and the outcome of their research work usually exceeds the expectations.