Air Force systems have become increasingly dependent upon precision navigation systems that incorporate the strengths of both GPS and Inertial Navigation System (INS) systems. Ultra-tightly coupled (UTC) GPS/INS systems are being developed as an enhancement over conventional "loosely coupled" and "tightly coupled" systems currently in our inventory, primarily because of their inherent higher degree of anti-jam operation capability. This is essential to future weapon systems, particularly for miniaturized air-to-ground munitions for precision strikes on targets protected by a GPS jamming field environment.

Recent thesis research work conducted by Maj. Meidel addressed just that, and was chosen from among the AFIT Dean's Award winners as the 2005 AFIT Commandant's Award winner. The Commandant's Award is presented to the graduating student, or team of students, who produces the most exceptional master's thesis.

In his thesis entitled "GPS Signal Jamming Mitigation Through Multiple Model Adaptive Estimation Applied to Ultra-Tightly Coupled GPS/INS Architecture," Maj. Meidel designed an adaptive GPS/INS to demonstrate the capabilities of multiple model adaptive estimation (MMAE) techniques to identify and mitigate the effects of jamming, providing as accurate a navigation solution as possible in the presence of heavy jamming. Moreover, in accomplishing this research, many modifications and enhancements have been incorporated into the existing modular UTC simulation software to yield a new and thoroughly validated system simulator that is stable (over orders of magnitude greater time and more highly dynamic vehicle trajectories than previously attainable) and flexible enough to enable meaningful research into the performance and robustness of future precision navigation systems for the Air Force.

Dr. Peter S. Maybeck from the Department of Electrical and Computer Engineering served as thesis advisor for Maj. Meidel's project. Says Dr. Maybeck, "Kurt's research efforts will have far-reaching impact on UTC GPS/INS systems, of critical importance to the effectiveness of future miniaturized munitions weapon systems. This is a very challenging arena in which his substantial contributions will provide the basis of truly breakthrough performance."

The Munitions Directorate of the Air Force Research Laboratory, which sponsored Maj. Meidel’s research, reports an estimated $150 thousand R&D savings as a result of the project.

A multiple model adaptive estimator (MMAE) is composed of a set of J parallel “elemental” Kalman filters, each designed to estimate the state of a dynamic system (of signals and parameters associated with navigation for this problem context), assuming a particular value for a parameter to which adaptation is required (jamming strength in this case), $a_j$, $j=1,2,...,J$. Each filter generates both a state estimate, $x_j^\text{e}$, and a residual (the difference between the current measurement and the best prediction of it computable within the filter before that measurement arrives), $r_j$. If the assumed parameter value in a specific "elemental" filter is correct, its residuals will be small and of predictable size; if the assumed value is erroneous, the residuals will be large. Based on the properties of the residuals from all of the elemental filters, the MMAE computes the probabilities $p_j$ that each elemental filter is the right filter to be using at the current time. As the real world parameter (jamming level in this case) varies, the probability-weighted average estimate of the parameter of concern (jamming level in this case), $\hat{a}$, can also be produced as a useful output.
The AFIT Commandant’s Award is chosen from the Dean’s Award winners. The AFIT Dean’s Award is given in recognition of the most exceptional master’s thesis by a graduating student in each academic department of the Graduate School of Engineering and Management. This year’s group of outstanding projects, highlighted here, demonstrates the scope of AFIT’s research programs, impacting the development of munitions and aircraft for the warfighter, antiterrorism efforts, arms control, homeland security, and environmental remediation.

Entropy Generation as a Means of Examining Continuum Breakdown

Christopher R. Schrock
Department of Aeronautics and Astronautics

Many of the problems remaining in the field of fluid mechanics deal with non-equilibrium flow phenomena. The governing equations of continuum fluids break down in such regions and a kinetic approach may be required to accurately model such phenomena. In the past, it has been proposed that it may be possible to hybridize continuum and kinetic methods, but difficulty arises in determining when the continuum equations become invalid enough to warrant the higher computational cost kinetic methods as well as when the physics becomes so mild as to make the kinetic approach uneconomical. This research by Mr. Schrock demonstrates entropy generation as such a parameter. Due to a small departure from equilibrium assumption in their derivation, the Navier-Stokes equations tend to delay and diminish predictions of strong non-equilibrium phenomena over what is actually observed. Therefore, any attempt to study the breakdown of these equations must come from a kinetic approach, implying that breakdown parameters computed using continuum data are likely flawed. This project, sponsored by the Air Vehicles Directorate of the Air Force Research Laboratory, is the first work to be published that looks at the use of entropy generation from the DSMC solutions to determine the range of applicability for the Navier-Stokes equations in areas of non-equilibrium. His advisor, Maj. Richard McMullan, says Schrock’s research is changing the way the thermophysics community conducts research in areas of non-equilibrium in a hypersonic flow field, causing them to investigate other alternatives on how to determine where continuum flow solvers are valid. This work will eventually lead to new methods for accurately simulating these flow fields.

Feasibility Analysis of a Compton Spectrometer System for Identification of Special Nuclear Material

Maj. Chad C. Schools, U.S. Army
Department of Engineering Physics

The development of radiation detection systems is a critical part of our national security. Current operational needs require the deployment of radiation detection equipment with the ability to accurately and reliably identify special nuclear materials and their byproducts without dependence on cryogenics. The research conducted by Maj. Schools analyzes the feasibility of using a Compton spectrometer system to determine the isotopic ratio of a plutonium sample. Experimental and computer simulated data show that the system requires fine collimation and alignment to achieve the necessary resolution of 0.5% at 650 keV. The collimation significantly reduces efficiency. The results determine that low count rate applications would not be feasible without multiplexing the system. Further research of the multiplexing of the system may provide the efficiency necessary. Dr. Larry Burggraf was the advisor for this project, which was sponsored by the Defense Threat Reduction Agency.

Modeling Application of Hydrogen Release Compound to Effect In Situ Bioremediation of Chlorinated Solvent-Contaminated Groundwater

First Lt. Ryan C. Wood
Department of Systems and Engineering Management

Chlorinated solvents are the most common groundwater contaminants found at DoD and Superfund sites throughout the U.S. Hydrogen release compound (HRC) is a newly developed technology that is frequently being used to help cleanup these chlorinated solvent-contaminated sites. Currently, design of HRC systems is done using rough “rule-of-thumb” estimates and there is no way to model the impact of an HRC installation on contaminant fate. The model developed in this study by First Lt. Wood incorporates the complex subsurface processes that govern the fate and transport of chlorinated contaminants in the presence of HRC. Using data from a tri Chloroethylene-contaminated field site at Vandenberg AFB, where a pilot test of HRC was being conducted, the newly developed model was tested and validated. The model will allow site remediation managers to design HRC remediation systems, as well as predict whether an HRC system will achieve cleanup goals that are protective of public health and the environment. This model has potential application at literally hundreds of sites nationwide. Lt. Wood’s thesis was described by one leading researcher as “easily the most sophisticated document ever prepared on HRC.” Dr. Mark Goltz was the advisor for this project, which was sponsored by the Air Force Center for Environmental Excellence.

Modeling and Analysis of Clandestine Networks

Capt. Clinton R. Clark
Department of Operational Sciences

This research by Capt. Clark develops a meaningful measure of interpersonal influence within clandestine networks, which considers both the personal characteristics of individuals and the topology of each informal network to which clandestine network members belong. The Discriminant Analysis methodology provides one of the first adequate discussions of the development of a non-network measure of influence compatible with Social Influence Theory. The linear combination of multiple network contexts provides an original yet simple way to simultaneously evaluate influence from multiple network layers. Finally, because the influence measure is a ratio number it can be extended for use in a variety of analysis techniques. The numeric properties of the Holistic Interpersonal Influence Measure (HIIM) are appropriate for use in a variety of analysis tools including Operations Research Network Flow models. Analysis of clandestine networks using Network Flow models enables analysts to provide prescriptive analysis results focused on specific actions and their outcomes, in contrast to traditional Social Network Analysis descriptive results. This work helps address a critical operational need in the Global War on Terrorism, while contributing to the theoretical foundations of Operations Research in the area of Social Network Analysis. The project, advised by Dr. Richard Deckro, was sponsored by the Human Effectiveness Directorate of the Air Force Research Laboratory and the National Air and Space Intelligence Agency.

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