
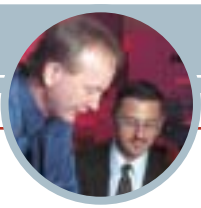

2000 Published Papers


The following pages contain the bibliographical information and a brief abstract of additional papers that have been formally published by Draper engineers during the 2000 calendar year.

Abramson, M.
Intelligent Autonomy for Small Throwable Land Robots
Photonics East, Boston, MA, November 5-8, 2000. Sponsored by: SPIE

DARPA's Tactical Mobile Robot (TMR) program includes a Throwable Robot (Throwbot) designed to be thrown into buildings, then teleoperated for surveillance purposes. Use by ground troops imposes significant size and weight limits, as does the requirement that it survive ballistic delivery. The current program stresses the state-of-the-art in robotics and packaging, but further challenges exist. Future Throwbots would benefit from significant increases in autonomy to deal with RF communications difficulties in buildings and to allow simultaneous operation of multiple vehicles by one person. This describes both currently planned and advanced autonomous capabilities. Draper's flexible autonomous systems architecture provides the structure for these current and advanced capabilities. Limited autonomy functions are currently being designed to guard the operator's teleoperation of the vehicle, to quickly hide when danger threatens, to maneuver to improve communications when they are disrupted, and to right itself should it tumble. Advanced capabilities would include autonomous mapping with ranging and imaging sensors, exploration to map communications within the building, and searching for particular targets within the building.

Adams, M.; Deutsch, O.; Hall, W.; Hildebrant, R.; Kreamer, W.; McConley, M.; Vuong, H.F.
Closed-Loop Operation of Large-Scale Enterprises Application of a Decomposition Approach
Advances in Enterprise Control, Minneapolis, MN, July 10-11, 2000. Sponsored by: DARPA

Real-time, closed-loop optimal control of large-scale dynamic systems (enterprises) remains a challenging problem. We have been developing an approach to problems of this class that employs a distributed, multilevel control architecture wherein planning and execution are decomposed to accommodate the near-and far-term impacts of plant disturbances and modeling uncertainties. The decomposition is based on the theory of multilevel optimization for large-scale systems. The structure of the decomposed solution to the optimization problem obtained from this theory forms a basis for our controller architecture as well. In addition to planning, the controller architecture includes execution management, monitoring, and diagnosis at each level. A previous paper described a decomposed formulation for a large-scale military air operations optimization problem. This paper presents the results of the application of this approach to the control of large-scale military air operations in a simulation-based context. Simulation results indicate that a significant reduction in the time required to achieve specified campaign objectives can be realized by closing the control loop at higher rates facilitated by controller automation. This reduction pertains to the base case and to cases with modeling errors and disturbances, and can be quantified as a savings of 0.5 to 2 days for the moderate-intensity, 7-day scenario under study.

Anderson, J.A.; Kerrebrock, P.A.
Biomimetics in Action: Design and Performance of an Autonomous Robotic Fish
Neurotechnology for Biomimetic Robots, Nahant, MA, May 14-16, 2000

Unmanned Undersea Vehicle (UUV) technologies have evolved in recent years to produce highly functional and capable platforms for a wide variety of undersea missions. As the supporting technologies have progressed, so have the mission requirements. Today's UUV missions require a variety of capabilities that can be mutually exclusive: high transit speed, long range and duration, maneuverability, and station-keeping ability. Fish and marine mammals have captured the interest of vehicle designers as they are able to cruise great distances at significant speed, maneuver in tight spaces, and accelerate/decelerate quickly from rest or low speed with the same integrated propulsion and steering system. Recent research in the flow mechanisms used by fish and marine mammals for propulsion and maneuvering has demonstrated the utility of biopropulsion for undersea vehicles. This paper presents the results of the first engineering demonstrations of the Draper Laboratory prototype flexible-hull UUV that propels and maneuvers like a tuna. Named after the vorticity control flow control mechanisms employed by fish to propel and maneuver, the Vorticity Control UUV (VCUUV) mimics the form and kinematics of a large yellowfin tuna. The fish propulsion paradigm offers order of magnitude improvement in the maneuvering capability that is required for today's challenging UUV missions in dynamic, cluttered environments. The VCUUV prototype proves the concept while serving as a research testbed. Lessons learned from the VCUUV can be applied to new vehicles mechanically optimized to achieve fish-like capabilities in engineered vehicles. Further work will demonstrate that this novel propulsion mechanism can be incorporated into vehicles capable of practical missions that are sufficiently compelling to justify the risk of their development. This effort will include demonstrating the scalability of VC propulsion (both up and down) and developing more stealthy actuators, three-axis maneuvering capability, and sensors and control systems to support fully closed-loop propulsion and maneuvering control.

Atkins, S.C., Hall, W.D.
A Case for Integrating the CTAS Traffic Management Advisor and the Surface Management System
AIAA Guidance, Navigation, and Control Conference and Exhibit, Denver, CO, August 14-17, 2000

Arrival and departure capacities are interdependent at many high-traffic airports. At these airports, total capacity may be dynamically reallocated between arrivals and departures in response to the time-varying demands for both types of operations. Moreover, controllers appear to use a working understanding of the trade-off between arrival and departure capacities in daily practice. This paper investigates how capacity allocation decisions are currently made, the degree to which and the mechanisms by which arrival and departure capacities are controllable, and whether automation could help controllers better match arrival and departure capacities to time-varying demands. Furthermore, this paper studies how the interdependence of capacities affects decision support tools, such as the Traffic Management Advisor (TMA), which schedules arrivals subject to the arrival capacity, and the Surface Management System (SMS), which manages departures on the surface. To this point, TMA and SMS have been developed independently. However, at airports where capacities are interdependent, significant benefit may be achieved by integrating TMA and SMS to coordinate how limited airport resources will be shared. A decision aid to help controllers dynamically reallocate total airport capacity between arrivals and departures may achieve TMA-SMS interoperability. Two possible decision aids are suggested.

Balboni, E.; Ford, J.; Tingley, R.; Toomey, K.; Vytal, J.J.
An Empirical Study of Radio Propagation Aboard Naval Vessels
Antennas and Propagation for Wireless Communications, Waltham, MA, November 6-8, 2000. Sponsored by: IEEE

Most existing studies of indoor radio wave propagation have addressed operation in common commercial environments such as warehouses, office buildings, and factories. These studies show typical path loss gradients ranging from 3-5 and rms delay spreads ranging from 10-40 ns. This paper reports the results of research conducted to characterize microwave radio propagation aboard navy ships. Because of its principally steel construction, the ship environment displays significantly different characteristics from commercial environments. In particular, rms delay spreads ranging between 70 and 90 ns are common. Likewise, path loss gradients are observed to range from slightly greater than inverse square to smaller than unity. These effects of path loss and delay spread are found to be independent of frequency, over the range from 800 MHz to 2.6 GHz.

Barbour, N.
MOD G Hemispherical Bearing Qualification Review
Presented at TRW, Ogden, UT, March on 24, 2000

This presentation provides a summary of design qualification data, life test data, manufacturing readiness data, preproduction qualification

data, and field data from a total of 39 0.375-in hemispherical gas bearings developed as an alternative to the spool bearing in the Peacekeeper SFIR and Minuteman MOD G accelerometers.

Baty, G.; Ganz, M.; Kelley, M.
NTV Briefing to Draper Staff
November 4, 2000

This briefing presents an overview of Navigator Technology Ventures (NTV), a subsidiary of Draper that will focus on identifying investment opportunities in revolutionary technologies and the formation of new companies to commercialize them. Venture Capital (VC) is described: how it differs from other forms of financing; stages of VC funding and expected risks, rewards, and success rates; what technologies are currently attractive to VCs; and what VCs look for in startup companies. NTV's mission and its interaction with Draper, available resources and investment criteria, the commercialization process, as well as an example startup are described.

Bedrossian, N.S.
International Space Station Assembly and Operation Control Challenges
23rd Guidance and Control Conference, Breckenridge, CO, February 3-6, 2000. Sponsored by: AAS

For the International Space Station program to be successful, mission requirements must be robustly met in the presence of uncertainties. Changing Station characteristics during assembly, such as variability in structural flexibility and mass properties, pose unique control challenges. Three examples of control challenges are reviewed in this paper. The first two arise out of variability in flex structure, and the last one is due to mass property variation. Controller/flex structure interaction issues and their origins are reviewed, as well as representative examples. CMG momentum desaturation issues during robotic operations are addressed, and an operational solution is reviewed. Finally, CMG attitude control issues during payload robotic operations are presented, as well as an issue resolution technique.

Bedrossian, N.S.
International Space Station CMG Momentum Desaturation Design
23rd Annual AAS Guidance and Control Conference, Breckenridge, CO, February 2-6, 2000
Modeling and Simulation Technologies, Denver, CO, August 14-17, 2000

The CMG momentum desaturation method developed by Draper Laboratory for the International Space Station for use during robotic payload operations is presented. A frequency optimal feed-forward thruster pulsing strategy that is independent of plant description is developed to minimize structural excitation. It is shown that the appropriate optimization criterion is to minimize the maximum amplitude of the pulsing strategy power spectral density. The flight software implementation details are also presented. Simulation results for Space Station CMG desaturation thruster firings are used to demonstrate the effectiveness of the proposed methodology.

Bernstein, J.; Bottari, J.; Houston, K.; Kirkos, G.; Miller, R.; Xu, B.; Ye, Y.; Cross, L.
In-Plane Polarization for High Sensitivity Ferroelectric MEMS Ultrasound Transducers
International Symposium on the Application of Ferroelectrics. 12th, Honolulu, HI, July 30-August 2, 2000. Sponsored by: IEEE

This paper discusses the design of advanced micromachined ferroelectric ultrasound transducers for use at 3 MHz. 16 x 16 arrays of resonant monomorph sensors have been constructed with sol-gel PZT as the active ferroelectric layer deposited on insulating layers of ZrO_2 and SiO_2. A novel in-plane polarization of the PZT is used to maximize sensitivity, while trading off reduced output capacitance to match the CMOS buffer electronics. This results in about 30 dB improved sensitivity compared with conventional polarizing across the thickness of the PZT layer. An equivalent circuit model as well as finite-element results are presented. Test results are reported, including transmit response and receive sensitivity.

Bibeau, R.T.; Rubenstein, D.S.
Trajectory Optimization for a Fixed-Trim Reentry Vehicle Using Direct Collocation and Nonlinear Programming
Guidance, Navigation, and Control Conference. Held in Denver, CO, August 14-17, 2000 Sponsored by: AIAA

This work examines the feasibility of using a direct solution method to the fixed-trim reentry vehicle optimal control problem as part of a reentry guidance scheme. A procedure was developed to calculate locally optimal trajectories for fixed-trim atmospheric reentry vehicles. A four degree-of-freedom vehicle model was introduced, and appropriate environmental models were chosen and implemented. Software was developed to discretize the optimal control problem using a direct collocation method. The resulting parameter optimization problem was solved using the MINOS nonlinear programming software package. The resulting collocation guidance software was tested using data for the Kistler K-l vehicle system and an independent vehicle simulation. Mass, wind, density, and entry angle dispersions were considered, as were various strategies for updating the trajectory during flight. The results demonstrated that the collocation method is a viable approach to the reentry vehicle guidance problem. The collocation method enforced the vehicle equations of motion to a useful degree of accuracy using as few as 10 nodes, and the resulting control histories yielded acceptably small final position errors.

Borenstein, J.T.; Currie, M.; Gerrish, N.D.; White, R.; Fitzgerald, E.A.
Silicon Germanium Epitaxy: A New Material for MEMS
Published 2000

A wide array of materials have been investigated as candidate fabrication templates for precision microelectromechanical structures. While ceramics, plastics, and polymers have distinct advantages for specific applications, silicon continues to be the mainstay for precision commercial and military applications. Both polycrystalline and highly boron-doped, single-crystal silicon are used successfully to build gyroscopes, accelerometers, pressure sensors, and other high-volume products. However, each presents its own set of limitations, related to ultimate thickness capability, prospects for integration with electronics, and material quality considerations. Recent emphasis has shifted to Silicon-on-Insulator (SOI) technology, which presents new challenges for plasma etching and other fabrication processes.

Brock, L.D.
Transition to an Open-System Architecture
IEEE 19th Digital Avionics Systems Conference (DASC), Proceedings, Vol. 1, Held in Philadelphia, PA, October 7-13, 2000, pp. 4.D.5-1-4.D.5-8

The DoD has directed that an open-system approach be used to the maximum extent practical as one approach to achieving superior war fighting capability with reduced total operating costs. Open systems are expected to reduce development costs and, more importantly, the costs to maintain and upgrade weapons systems over ever-increasing lifetimes. The acquisition requirements for open systems, however, are often expressed in broad and general terms that may not be specific enough to achieve the results desired. One problem is the lack of a clear and common understanding between the government and its supplier on just what open systems are and how they will be used. The purpose of this paper is to contribute to a better understanding. In particular, different levels at which open-system architectures can be implemented are described, and the alternatives available to system managers are outlined. Finally, the increased advantage of open-system architectures when used in coordinated acquisition of multiple systems is suggested.

Chou, P.C.; Haus, H.A.; Brennan, J.F.
Arbitrary Spectral Shaping of an Optical Pulse Stretched with a 4-m Long Fiber Bragg Grating
Published 2000

We demonstrate a method for spectrally shaping optical pulses that is readily reconfigurable and can produce variable filter functions. This practical technique relies on a compact and robust 3.86-m long linearly-chirped fiber Bragg grating that chromatically disperses the pulse to ~30 ns. We then shape the pulse envelope, and thus the pulse spectrum, with a programmable arbitrary waveform generator and an amplitude modulator to yield several filter functions.

Chou, P.C.; Fini, J.M.; Haus, H.A.
Real-Time Principal State Characterization for Feedback-Free PMD Compensation
IEEE Photonics Technology Letters, October 2000

Most polarization mode dispersion (PMD) compensation systems use many feedback parameters that contribute to complexity, instability, and speed limitations. We demonstrate a feedback-free method that quickly and accurately determines the principal states of polarization of a fiber afflicted with PMD.

Chou, P.C.; Haus, H.A.; Brennan, J.F.
Reconfigurable Time Domain Spectral Shaping of an Optical Pulse Stretched by a Fiber Bragg Grating
Optics Letters, Vol. 25, No. 8, April 15, 2000, pp. 524-526

We demonstrate a method for spectrally shaping optical pulses that is readily reconfigurable and can produce variable filter functions. This practical technique relies on a compact and robust 3.86-m long linearly chirped fiber Bragg grating that chromatically disperses the pulse to ~30 ns. We then shape the pulse envelope, and thus the pulse spectrum, with a programmable arbitrary waveform generator and an amplitude modulator to yield several filter functions.

Chou, P.C.; Lee, H.L.T.; Ram, R.J.; Haus, H.A.; Ippen, E.P.; Brennan, J.F.; Kjebon, O.; Schatz, R.
Stable Picosecond Pulse Generation with a Frequency-Modulated DBR Laser and Chirped Fiber Bragg Grating
Conference on Lasers and Electro-Optics (CLEO), San Francisco, CA, May 7-12, 2000. Sponsored by: OSA

We demonstrate a method for generating picosecond pulses at 1553 nm using a passive fiber grating and a semiconductor laser without gain switching, mode locking, or external modulation. With this technique, we make a stable pulse source with an electronically-defined repetition rate and potentially low jitter.

Cleary, M.E.
Hierarchical Decomposition of Autonomy Requirements for Naval UCAVs for The Uninhabited Combat Air Vehicle (UCAV) Demonstrations
Office of Naval Research, July 7, 2000

Logistics resupply can occur in a wide variety of scenarios ranging from ship-to-ship transfers, between automated depots (which are as yet to be designed), and under fire. Vertical Short Take-off and Landing (VSTOL) aircraft can transfer supplies between ships using hooks to carry suspended loads, placing bundles in designated areas on deck. Similarly marked surfaces ashore can be used. There has been discussion of resupplying UCAVs themselves with fuel and munitions using automated depots. UCAVs could provide supplies to embattled troops in situations where the UCAV is expected to not survive the delivery, requiring it to fly so as to maximize the likelihood of delivery despite its damage. Further, such a UCAV might be stripped of self-defense devices so that its cargo capacity or maneuverability could be enhanced. Flying into combat areas will likely require the UCAV to locate badly marked clearings (e.g., forest clearings) and to land on unprepared and uninstrumented "landing pads" (ranging from clearings to low-slope hillsides). Landing near foliage will cause moving objects nearby that must be interpreted properly. For instance, tree branches moving in the rotor wash should not be interpreted as hostile forces and should be evaluated correctly regarding possible interference with landing. Without navigation aids carried by the ground troops being resupplied, the UCAV will require passive landing sensors (e.g., vision) for a variety of environmental conditions (including darkness and heavy weather). UCAV flight control will need to be robust to heavy winds so that they can land reliably in small spots. Approaching a landing spot covertly or below a nearby radar's sight line could require very aggressive terrain-following. The UCAV could use DTED maps and fly at a fixed altitude above the terrain or literally fly at tree-top level, requiring very good foliage sensors. If flying so aggressively, it would need to consider wires, bridges, and towers. (Man-made objects are recorded in separate databases from DTED.)

Cleary, M.E.; Abramson, M.R.
Intelligent Autonomy for Small Throwable Land Robots
Photonics East, Boston, MA, November 5-8, 2000

DARPA's Tactical Mobile Robot (TMR) program includes a Throwable Robot (Throwbot) designed to be thrown into buildings, then teleoperated for surveillance purposes. Use by ground troops imposes significant size and weight limits, as does the requirement that it survive ballistic delivery. The current program stresses the state-of-the-art in robotics and packaging, but further challenges exist. Future Throwbots would benefit from significant increases in autonomy to deal with RF communications difficulties in buildings and to allow simultaneous operation of multiple vehicles by one person. This describes both currently planned and advanced autonomous capabilities. Draper's flexible autonomous systems architecture provides the structure for these current and advanced capabilities.

Limited autonomy functions are currently being designed to guard the operator's teleoperation of the vehicle, to hide quickly when danger threatens, to maneuver to improve communications when they are disrupted, and to right itself should it tumble. Advanced capabilities would include autonomous mapping with ranging and imaging sensors, exploration to map communications within the building, and searching for particular targets within the building.

Cleary, M.E.; Abramson, M.R.
Metrics for Embedded Collaborative Intelligent Systems
Performance Metrics for Intelligent Systems, Gaithersburg, MD, August 14-16, 2000

The intelligence of a network of agents is reflected in the complexity of missions that can be accomplished, the degree of coordination/cooperation among the agents, and the level of uncertainty the system can tolerate and still accomplish its missions. The networked system must be able to evaluate a situation, devise an appropriate response, and act accordingly. Metrics must be devised to capture the complexity and surprises of the real world, and to capture the system's need to reason about its situation to uncover unanticipated problems and opportunities. Inputs for developing autonomous capability specifications (and thus metrics of interest) include (1) descriptions of expected missions, (2) the space of mission parameters, and (3) the cost/benefit ratio for operational concepts. These inputs come from both current and anticipated missions. Several of our recent projects have sought to quantify operational metrics for autonomous ground, air, and undersea vehicles. This paper presents our approach to high-level design of autonomous vehicles that produces the three inputs for metric development. The approach and parameter spaces are illustrated with examples derived from several vehicle projects.

Connelly, J.; Dennehy, N.; Hattis, P.; Johnson, W.; Sargent, D.; Socha, M.
MEMS-Based GN&C Sensors and Actuators for Micro/Nano Satellites
Guidance and Control 2000, *Proceedings of the Annual AAS Rocky Mountain Conference*, Breckenridge, CO, February 2-6, 2000
Advances in the Astronautical Sciences, Vol. 104, San Diego, CA, 2000, pp. 561-576

A new generation of miniature, low/mass/power, high-performance GN&C sensors and actuators will be required for envisioned Micro Satellite and Nano Satellite missions. As satellite volume decreases, correspondingly small sensors and actuators are needed to perform satellite operational functions. Therefore, technology that enables very small devices is quite important for miniature satellite development. Draper, a world leader in MEMS inertial sensing, is currently developing attitude determination and attitude control devices to meet the emerging needs of these new missions. This paper describes designs for both a miniature stellar-inertial attitude sensor package and a MEMS wafer wheel momentum device. The Draper Attitude Sensor Suite (DASS) integrates complementary technologies for Electron-Bombarded Charge-Coupled Device (EBCCD) stellar cameras and MEMS gyroscopes into one miniature package. Both the EBCCD sensor and MEMS gyro technologies have been continuously matured at Draper over the past several years; all major hardware components have been tested successfully in both laboratory and operational environments. The EBCCD stellar camera provides an order of magnitude improvement in S/N ratio (as compared with standard CCD technology) at high bandwidth, allowing detection of faint stars with a relatively small optical aperture. Star detection capability can be improved further by implementing Draper's "drag-back" technique for integrating the star images over periods of several seconds. The back-thinned EBCCD detector is inherently radiation hard. Performance analysis indicates that arcsec accuracy can be accomplished with the DASS. This EBCCD star camera performance is uniquely suited to detect faint stars on highly dynamic micro/nano spacecraft or spin-stabilized satellites. Laboratory testing indicates the ability of the unit to detect stars as faint as magnitude 8 while spinning at 20 rpm. Second-generation MEMS TFGs provide low power/mass/volume, three-axis attitude rate measurements for high-bandwidth updates between stellar fixes. The Draper MEMS Wafer Momentum Device (MWMD) has been designed as a feasible near-term Micro/Nano Satellite attitude control actuator. The wafer rotor in this device is planar and is fabricated as a wafer-thick (500 μm) silicon part. In the current implementation, spin-axis rotational freedom is furnished by a very small, but standard ball bearing cartridge supplied by a commercial vendor. This MEMS wheel has been designed to operate at high speeds of 50,000 rpm and will provide an angular momentum of about 150 dyne-cm-s. This device can be configured to serve either as a momentum wheel, a reaction wheel, or a control moment gyro. As a long-term alternative to the conventional cartridge bearing, Draper is currently investigating a novel ball bearing in which 11-mil steel balls are captured within raceways fabricated into the silicon rotor. This silicon-steel bearing combination is unique and provides a potentially elegant and compact low-cost design. Limited testing has shown the viability of this approach. This very promising investigation showed that silicon mated to steel was potentially a good bearing combination. Looking even further into the future, another suspension concept has been developed for a wafer control moment gyro device with a hemispherical gas bearing. Here, the gas bearing provides the radial and axial stiffness from the boundary layer dynamic forces.

Connelly, J.; Kourepenis, A.; Marinis, T.
Micromechanical Sensors in Tactical GN&C Applications
Guidance, Navigation, and Control Conference, Denver, CO, August 14-17, 2000. Sponsored by: AIAA

Micromachined silicon inertial sensors offer revolutionary improvements in cost, size, and reliability for Guidance, Navigation, and Control

(GN&C). Batch manufacturing techniques produce thousands of virtually identical MEMS devices, each a few square millimeters in size. Development of inertial MEMS is driven by the high-volume, commercial market that targets modest performance applications at prices below $10 per axis. Draper Laboratory has recently demonstrated higher performance, multi-axis systems using commercial processes for lower-volume tactical applications ranging from guided munitions to microsatellites. More accurate sensors enabled by deep reactive ion etch technology and new digital electronics are rapidly approaching bias stabilities of 1 deg/h and 100 µg over -40°C to +85°C. Future architectures under development reflect a radical departure from early demonstration systems. New sensors with complementary input axes have led to multi-axis sensor arrays, and new wafer-scale processes, integrating sensor arrays and ASICs, are creating complete systems on a chip.

Cunningham, B.; Kant, R.A.; Daly, C.; Weinberg, M.; Pepper, J.; Clapp, C.; Bousquet, R.; Hugh, B.
Chemical Vapor Detection Using Microfabricated Flexural Plate Silicon Resonator Arrays
Aerospace Defense Sensing (AeroSense), Orlando, FL, April 24-25, 2000. Sponsored by: SPIE

Draper Laboratory is developing chemical vapor detection arrays based on microfabricated silicon resonators coated with thin-film molecular recognition chemistry. The resonators within the micro-Chemical Analysis Array µCANARY are microelectromechanical flexural plate wave (FPW) sensors that have been miniaturized to allow many independently addressable sensors to be integrated within a single silicon chip. The target analyte of an individual sensor within the chip is selected by placing a microdroplet of the molecular recognition component (or "coating") into a well surrounding the resonating membrane. Detection is performed by monitoring changes in the frequency and damping factor of the resonance as the coating interacts with the environment. In addition to the system capabilities afforded by the ability to monitor many chemical or biochemical interactions simultaneously, the µCANARY operates in air or liquid environments, uses low-cost, low-power address/excitation/readout circuitry, and has demonstrated high detection sensitivity. The presentation will describe the design, fabrication, and testing of 2-element and 8-element µCANARY sensor chips and address electronics. The detailed performance characterization of µCANARY sensors for vapor and liquid phase detection will be presented. For vapor detection, NRL has applied polymer receptor coatings targeted at detection of chemical weapon agents, and has performed extensive chemical vapor exposure tests using two chemical weapon stimulants and four vapor phase interferents. Data describing temperature dependence, long-term/short-term drift stability, detection limits, detection linearity, and vapor selectivity will be presented.

DeBitetto, P.A.; Rasmussen, S.; Plump, J.; Appleby, B.; Piedmonte, M.; Lorusso, T.
Inexpensive Avionics Designs for Small UAVs
AUVSI 2000, Orlando, FL, July 10-13, 2000

Draper Laboratory has developed both inexpensive commercial-off-the-shelf (COTS)-based avionics systems and advanced MEMS multichip module (MCM) electronics packaging-based systems that have been used to automate small aerial vehicles. The COTS-based designs have had sufficient performance and computational flexibility to support advanced guidance, navigation, and control algorithms for relatively small aerial vehicles. The applications have ranged from flight data recording, stability augmentation, controlled hover, waypoint guidance, and autonomous acrobatic maneuvering. The MEMS-based systems have pushed the technology boundaries for extremely small systems. Current prototype MEMS are costly, but the fundamental technology will enable the production of extremely small, inexpensive flight avionics systems in the near future.

Deutsch, O.L.
Guidance Trades for Interceptors not Constrained by Ground-Based Radar
9th Technology Conference and Exhibit, San Diego, CA, July 17-20, 2000. Sponsored by: AIAA/BMDO

Virtually all U.S. ballistic missile interceptor designs under development use terminal seekers that are cued by high-resolution, surface-based radars. The radar is used for target tracking leading to a fire-control solution, for mid-course target state updates, and for end-game target discrimination. New space-based sensor systems such as SBIRS-low are seen as an adjunct that can be used to achieve range extension by cueing radars, and in some concepts, kinematic range extension of interceptors by providing for earlier launch commitments. The availability of global track information from space-based systems, however, coupled with the large design space provided by high throw-weight, retooled SLBM launchers enables an entirely new design concept for national missile defense (NMD). The notional system would use existing infrastructure, minimally modified SLBM launchers, and exoatmospheric kill vehicles currently under development for global coverage from a few sea-based locations against modest-intensity NMD threats. The post-boost "bus" would dispense multiple kill vehicles and would provide a platform to mount communication, sensors, and possibly special "fly-ahead" packages for mechanizing novel approaches to target discrimination. Assuming that antiballistic missile treaty barriers were negotiated successfully, the global coverage of this outermost tier to a layered NMD could simultaneously provide a stabilizing extension of NMD to regional allies.

Deutsch, O.L.
Simulation Analysis of Electronic Attack and Electronic Protection of GPS
Maritime Technology, Washington, DC, December 6-8, 2000. Sponsored by: Office of Naval Intelligence

GPS receivers have an inherent processing gain that allows maintenance of signal tracking through significant levels of interference. The nominal threshold for loss of code lock for the Receiver 3A specification is approximately 54 dB jammer power to signal ratio (JSR). A single jammer with 100-W Effective Isotropic Radiated Power (EIRP) at L1(P) or an array of seven 10-W EIRP jammers at and around a protected point could deny GPS code tracking out to a range of 45 km for a receiver with an isotropic antenna. With more realistic antenna gain patterns and with elevation angle separations between GPS satellite signals and jammer directions, the power levels required to deny tracking rise by about a factor of 10, but are still relatively modest.

Dowdle, J.; Flueckiger, K.
Submeter Navigation Grid System Concept
Position Location and Navigation Symposium (PLANS), San Diego, CA, March 13-16, 2000, pp. 270-276. Sponsored by: IEEE

This paper describes a concept for a system that provides the capability for accurate targeting and within a prescribed geographic context. This system, the Submeter Navigation Grid, defines a geographic region that enables targeting platforms to perform relative navigation to the centimeter level. Ultimately, targeting information is delivered to an appropriate tactical platform, and the system enables the precision guidance of this platform to the identified target coordinates. The Submeter Navigation Grid consists of both airborne and land-based components with communications links between them. Of note is that the Submeter Navigation Grid uses a pseudolite as an electronic counter-countermeasure against a potential jamming threat.

Draim, J.E.; Cefola, P.J.; Castiel, D.
Elliptical Orbit Constellations - a New Paradigm for Higher Efficiency in Space Systems?
IEEE Aerospace Conference, Big Sky, Montana, March 2000

Several systems are being developed for satellite cellular telephone use. Examples are Iridium, Globalstar, ICO, and ELLIPSO. Systems designers seem to prefer subsynchronous multisatellite arrays over geostationary satellites as they can communicate more easily with small low-power handheld cellular telephones, and they also have less signal latency (time delay). The flexibility of the elliptic orbit allows a biasing of earth coverage toward a given latitude. Increased coverage is obtained by placing apogees in a stable orbit over a preferred latitude. If the orbit is both elliptical and sun-synchronous, it can also be biased toward a given (local) time of day. With apogees appearing during daytime, greater capacity is ensured during the peak usage hours for telephone communications. Tailored elliptical-orbit constellations may well become the paradigm for many of these new telecommunications space systems. Lower cost elliptic-orbit constellations with fewer satellites may well prove more profitable than circular arrays for many other space applications as well.

Duffy, R.A.
Robert A. Duffy Memoir ICBMs and Space. Post War II. 1957-1963
Published January 2000

This memoir presents a personal behind-the-scenes glimpse at the early days of space and missile development (1957-1963) and a tribute to the contributions of individuals--both military and civilian. Beginning with the Russian testing of an intercontinental ballistic missile in August 1957 followed by the launching of Sputnik that October, the race was on to develop a strong U.S. strategic space and missile capability. The inception of the Air Force Ballistic Missile Division and the formation of NASA as well as the evolution of missiles systems such as Minuteman and Thor are described.

Edsall, A.C.
Technology Insertion in Health and Usage Monitoring Systems: An Integrator's Perspective
56th American Helicopter Society (AHS) Annual Forum, Virginia Beach, VA, May 2-4, 2000. Sponsored by: AHS

The Joint Advanced Health and Usage Monitoring System (JAHUMS) is a DoD-sponsored initiative to demonstrate advanced HUMS technologies and an open-systems approach to HUMS deployment. The JAHUMS program is currently developing five technology modules to be integrated into the Navy/BFGoodrich Integrated Mechanical Diagnostics (IMD) HUMS for the SH-60 aircraft. These technology modules, from multiple suppliers, will provide new functionality and/or new technology to the HUMS. The open-systems technology insertion process involves both business and technical practices. The business issues involve the clear definition of roles, responsibilities, liabilities, and compensation throughout the HUMS life cycle. The technical issues affect the way that systems engineering, component development, and system integration must be performed. Open standards will facilitate the design of system components by multiple sources, but successful integration of the system requires a thorough up-front systems engineering effort, a well-defined integration and verification process, and life-cycle support to ensure that the system is adequately integrated into the end-users' systems and processes. Development of open architectures and standards is itself a significant process that warrants a systematic approach to ensure that the open-system objectives of all stakeholders are satisfied.

Eiceman, G.A.; Nazarov, E.G.; Miller, R.A.
A Micromachined Radio-Frequency Ion Filter for Mass Spectrometry with Atmospheric Pressure Ionization Sources
Published 2000

The interface between a mass spectrometer and an ion source at atmospheric pressure is best made when a sample can be introduced to the mass spectrometer under controlled gas environments. This is necessary to avoid interferences from the ambient atmosphere. An inlet attachment for a mass spectrometer should be compact in size and suitable for continuous operation. It should also allow the flexibility to use various ion sources and have the facility to handle ions of various kinds and of both positive and negative polarities. Finally, a good inlet should be crafted so that there is high ion transmission to the mass spectrometer. The goal with such an inlet is continuous ion monitoring by APCI-MS with preliminary ion filtering at atmospheric pressure between the ion source and the mass spectrometer. In the approach described here, a small flat micromachined ion filter (total size of 30 x 15 x 2 mm^3) was fabricated with two parallel flat electrodes (12 x 5 mm) and two short electrodes (deflector and focusing electrodes). A carrier gas (flow rate 1- 4 liters/min) carries the ions through a gap (0.5 mm) between these electrodes. When an amplitude-asymmetric radio frequency (1-2 MHz) voltage is applied to the electrodes, the ions oscillate perpendicular to the electrodes. The RF electric field is asymmetric in amplitude, and ion trajectories are proscribed by differences in the high-field dependence of the coefficient of mobility. Only ions whose average velocity in the transverse direction is zero will traverse the drift region. Ions for which this condition is not satisfied can be corrected with an additional dc electric field applied to the electrodes. This dc field can be tuned to select a particular ion species. Consequently, the micromachined IMS can serve as a filter to permit only certain ions to pass into the mass spectrometer (additional electrode is used to record the ion mobility signal.) A focusing electrode with a hole (0.7 mm) at the end of the drift region is located next to the MS orifice; certain potentials on focusing and deflector electrodes make possible the sampling of all ions into the MS. Neutrals are swept from the MS using the carrier gas. This filter was added to the flange of a TAGA 6000 MS/MS, and the entire analyzer and electronics were floated to 30-100 V above the flange potential. Characterizations using benzene and substituted benzenes demonstrate the operation of the RF ion filter. Low cost and reproducibility are provided through microfabrication.

Eiceman, G.A.; Tadjikov, B.; Krylov, E.; Nazarov, E.G.; Miller, R.A.; Westbrook, J.; Funk, P.
A Miniature RF-Mobility Analyzer as a Gas Chromatographic Detector Oxygen-Containing Volatile Organic Compounds, Pheromones and Other Insect Attractants
Journal of Chromatography, 2000

A high electric field, radio-frequency ion mobility analyzer (RF-IMS) was used as a small detector in gas chromatographic separations of mixtures of volatile organic compounds, including alcohols, aldehydes, esters, ethers, pheromones, and other chemical attractants for insects. The detector was equipped with a 2 mCi(63)Ni ion source, and the drift region for ion characterization was 34 mm wide x 20 mm long and 0.6 mm high. The scanning rate for the compensation voltages was 60 V s(-1), and permitted 4 to 6 scans to be obtained across a capillary chromatographic elution profile for each component. The RF-IMS scans were characteristic of a compound and provided a second dimension of chemical identity to chromatographic retention adding in instances of co-elution. Limits of detection were 1.6 to 55 x 10(-11) g with an average detection limit for all chemicals of 9.4 x 10(-11) g. Response to mass was linear from 2 to 50 x 10(-10) g with an average sensitivity of 4 pA ng(-1). Separations of pheromones and chemical attractants for insects illustrated the distinct patterns obtained from gas chromatography with RF-IMS scans in real time and suggest an analytical utility of the RF-IMS as a small, advanced detector for on-site gas chromatographs.

Eiceman, G.A.; Nazarov, E.G.; Takjikov, B.; Miller, R.A.
Monitoring Volatile Organic Compounds in Ambient Air Inside and Outside Buildings Using a Radio Frequency-Based Ion Mobility Analyzer with a Micromachined Drift Tube
Journal of Field Analytical Chemistry, 2000

A radio frequency-based ion mobility analyzer with a micromachined drift tube was operated continuously to monitor volatile organic compounds (VOCs) in ambient air inside a building and in an open space near the intersection of I-10 and I-25 at Las Cruces, NM. Air was drawn directly, without enrichment or preseparation, through the analyzer, which was regulated to 35°C. The ion source was a photodischarge lamp at 10.6 eV, providing a preliminary level of selectivity in response toward chemicals with low ionization potentials. The compensation voltage was scanned continuously from -40 to +20 V at rates of 60-150 V/s, providing profiles of ions obtained from VOCs in air. Solvents were detected at 1-ppm levels as fugitive emissions from other experiments underway in the laboratory from 8 a.m. to 6 p.m. However, patterns in VOCs levels from 1-5 ppb between 6 p.m. and 7 a.m. and on weekends was attributed to air exchange between ambient air and the ventilation system of the building. The mobility analyzer results were consistent with VOCs from traffic on a major city thoroughfare adjacent to the building. In-field studies near two interstate highways demonstrated that analyzer response could be correlated to traffic patterns and exhibited diurnal trends. These findings demonstrate the concept and practice of micromachined mobility analyzers as continuous monitors for VOCs as airborne vapors in buildings and on-site.

Fahroo, F.; Ross, M.
Trajectory Optimization by Indirect Spectral Collocation Methods
Astrodynamics Specialist Conference, Denver, CO, August 14-17, 2000, pp. 123-129. Sponsored by: AIAA/AAS

In this paper, the problem of Bolza arising in trajectory optimization is solved by combining a direct method with an indirect collocation technique. Traditional collocation methods use piecewise continuous polynomials to approximate the time histories of the state and control variables, and then use a numerical integration method to satisfy the dynamic constraints over the subintervals whose endpoints are the collocation points. The pseudospectral methods differ from traditional collocation methods in that global orthogonal polynomials such as Legendre polynomials are used to approximate the state and control variables. The state equations are imposed exactly at the collocation points by a differentiation matrix. In the indirect method, the costate equations are also approximated in the same manner. We show that this method can be used to approximate the necessary conditions derived from the Pontriagin minimum principle in a way that preserves the basic structure of the original equations. Consequently, the Jacobians are sparse and have a well-defined structure that facilitates efficient numerical implementation. This method provides an alternative to traditional indirect methods, and can be used easily in combination with direct methods for solving optimal control problems accurately. A numerical example is presented to demonstrate the effectiveness of this method.

Fitzgerald, E.A.; Wu, K.C.; Currie, M.; Gerrish, N.; Bruce, D.; Borenstein, J.
Silicon-Based Epitaxial Films for MEMS
Materials Research Society (MRS) Symposium, San Francisco, CA, April 15-16, 2000. Sponsored by: MRS

The objective of this work was to develop an improved wet etch-stop technology for silicon micromachining. To establish a reference for process improvement, the diffusion process currently used to fabricate p++ Si B etch stops was investigated comprehensively. Subsequently, a novel germanium-based epitaxial etch-stop technology was developed. A range of techniques was used to study p++ silicon layers created by boron diffusion into (001) silicon wafers. The results revealed

gradients in boron and lattice constant, as well as a graded three-dimensional dislocation array from lattice-mismatch stress. The gradients in boron concentration and dislocation density can lead to curl in micromachined structures. Although annealing steps can remove the boron gradient, a flat membrane will be a tenuous balance. Epitaxial films of p++ Si B and strain-compensated p++Si(1-x)Ge(x) B can remove composition gradients and improve process control. However, it is undesirable to depend on p-type layers doped at levels near the solubility limit to prevent etching. We have therefore developed a unique etch stop created from relaxed SiGe alloys. Etch-stop behavior quite similar to heavily boron-doped silicon has been demonstrated in undoped silicon-germanium. Neither strain nor defects are responsible for the etch-stop behavior. A model is proposed based on energy band structure and a SiO(x) passivation mechanism.

Gai, E.
The Century of Inertial Navigation Technology
Aerospace Conference, Big Sky, MT, March 18-25, 2000, pp. 59-60. Sponsored by: IEEE

In the early 1930s, visionary engineers and scientists began thinking about practical self-contained systems for the guidance, navigation, and control of aerospace vehicles in inertial space. Starting with the development of the first gyrocompass in 1908, this technology was perfected in the race for improved intercontinental ballistic missile accuracy. Since the end of the Cold War, the technology has continued to advance with a focus on systems of lower size, weight, and power for a given accuracy. Future systems promise to revolutionize guidance, navigation, and control with complete low-cost inertial measurement units as small as 0.03 in^3. This paper reviews the history of the innovations and achievements in inertial guidance technology in the 20th century and projects the possibilities into the 21st century. The development of inertial guidance technology is traced from its birth to its current broad-base application status in aircraft, strategic missiles, satellites, and undersea vehicles.

George, V.; Jenkins, T.F.; Phelan, J.M; Leggett, D.C.; Oxley, J.; Webb, S.W.; Miyares, P.H.; Cragin, J.H.; Smith, J.; Berry, T.E.
Progress on Determining the Vapor Signature of a Buried Land Mine
5th Detection and Remediation Technologies for Mines and Mine-like Targets, Orlando, FL, April 24-28, 2000, pp. 590-601. Sponsored by: SPIE

The purpose of the Explosives Fate and Transport (EF&T) experiments is to define in detail the accessible trace chemical signature produced by the explosives contained in buried landmines. We intend to determine the partitioning (soil, air, water), composition, and quantity of explosive-related chemicals (ERC) that emanate from different kinds of land mines (predominantly plastic-cased with TNT as the main charge) buried in multiple soil types and exposed to various climatic events. We are also developing a computer model that will enable us to predict the composition and quantity of ERC under a much wider range of environmental conditions than we are able to measure experimentally. We have divided our efforts into the following categories: (1) chemical analysis of the main explosive charge from several spaces of TNT and the equilibrium vapor composition from these sources; (2) the amount and composition of ERC that are found on the exterior of landmines; (3) determination of the flux at which ERC evolves from both plastic and metallic land mines; (4) the effect of environmental factors on ERC, i.e., climate, time since burial, depth of burial, soil properties, sunlight, near surface air movement, and vegetation; (5) the characteristics of past-blast residue as compared with the trace ERC signatures produced by buried landmines; and (6) the development and validation of a predictive model to estimate the soil transport of ERC from buried land mines. This model will take into account all the experimental data collected in items 1-6. This paper summarizes the findings and progress made in each of these categories. In addition, it reports on the performance of trained canines at the Fort Leonard Wood research minefield.

Girerd, A.; Barton, G.
Next-Generation Entry Guidance - Onboard Trajectory Generation for Unpowered Drop Tests
Guidance, Navigation, and Control Conference, Denver, CO, August 14-17, 2000. Sponsored by: AIAA

Autonomous algorithms are developed for the real-time onboard design of guidance trajectories for horizontally-landing reusable launch vehicles such as the X-34. Onboard generation obviates the need for shuttle-era preloaded trajectories, resulting in a host of performance and economic improvements. The general problem is one of energy management of an unpowered low lift-over-drag (L/D) vehicle subject to dynamic constraints. The approach takes full advantage of the vehicle's flight capability, generates guidance profiles that are intrinsically flyable and controllable, and allows an inherent abort capability. Automatic trajectories are generated successfully for a variety of flight conditions based on nominal and atypical initializations for subsonic drop tests under 40,000 ft. Furthermore, the guidance output is optimized with respect to robustness. To prove feasibility, the computer-designed trajectories will be flown in a 6-DOF X-34 simulator.

Granholm, G.R.; Proulx, R.; Cefola, P.; Nazarenko, A.I.; Yurasov, V.
Near-Real Time Atmospheric Density Correction Using NAVSPASUR Fence Observations
10th Space Flight Mechanics Meeting, Clearwater, FL, January 23-26, 2000, pp. 1219-1234. Sponsored by: AAS/AIAA

Mismodeled drag effects are one of the most significant sources of error for low-altitude and highly eccentric orbits. It is currently estimated that predicted densities can differ by as much as 30% from real-world conditions, even using the best exosphere/thermosphere models (such as MSISE-90 or Jacchia-Roberts '71). However, we can use observations from frequently tracked objects in the space catalog to provide an "atmosphere correction service" to users desiring more precise orbit determination for a given target orbit. Observations will be in the form of direction cosines from the NAVSPASUR Fence, a multistatic radar system deployed across the southern United States. Using high-precision special perturbation techniques, orbital elements and ballistic factors will be estimated for 200-300 space objects with perigee heights distributed between 200 and 600 km. The difference between the locally estimated ballistic factor and the time-averaged or "true" ballistic factor can be taken as a measurement of the difference between the modeled and true atmospheric densities. These density variation measurements are used to construct a time and altitude-dependent density correction model. The model coefficients can be treated as samples of a stochastic process and predicted using linear stochastic filtering methods. A thorough mathematical description of density variation estimation, forecasting algorithms, and the NAVSPASUR Fence is presented, along with a detailed outline of operational considerations for an atmosphere correction service.

Granholm, G.R.; Proulx, R.J.; Cefola, P.J.; Nazarenko, A.I.; Yurasov, V.
Requirements for Accurate Near-Real Time Atmospheric Density Correction
Astrodynamics Specialist Conference, Denver, CO, August 14-17, 2000. Sponsored by: AIAA/AAS

Several theories have been presented with regard to creating a neutral density model that is corrected or calibrated in near-real time using data from space catalogs. These theories are usually limited to a small number of frequently tracked "calibration satellites" about which information such as mass and cross-sectional area is known very accurately. This work, however, attempts to validate a methodology by which drag information from all available low-altitude space objects is used to update the given density model on a comprehensive basis. The given density model is the model that was used to generate the space catalog. A technique to estimate true ballistic factors is derived in detail. The performance of the method is investigated via an independent simulation capability constructed at Draper Laboratory. The process is initially demonstrated using simulated range, azimuth, and elevation observations so that issues such as required number and types of calibration satellites, density of observations, and susceptibility to disturbed atmospheric conditions can be examined.

Gustafson, D.; Dowdle, J.; Flueckiger, K.
A Deeply Integrated Adaptive GPS-Based Navigator with Extended Range Code Tracking
Position Location and Navigation Symposium (PLANS), San Diego, CA, March 13-16, 2000, pp. 118-124. Sponsored by: IEEE

This paper presents a new approach to GPS-based navigation, which offers significant improvement in antijam capability over traditional designs. The algorithms may be implemented at low cost in software in existing and future GPS receivers using, as inputs, post-correlation I and Q data and, optionally, raw data from other sensors. Traditional systems are not optimal at high jammer-to-signal (J/S) ratios as a consequence of modular design, use of traditional fixed-gain or gain-schedule tracking loops, and use of artificial moding logic. The approach described here employs a nonlinear filter that operates efficiently at all J/S levels. Filter gains continuously adapt to changes in the J/S levels. Filter gains continuously adapt to changes in the J/S environment, and the error covariance propagation is driven directly by measurements to enhance robustness under high jamming and dynamics conditions. Extended-range correlation may be included optionally to increase the code tracking loss-of-lock threshold under high jamming scenarios. Computational complexity is comparable to

an extended Kalman filter. Results of hardware-in-the-loop simulations are presented, which demonstrate improvements of 15 dB or more in antijam capability relative to traditional designs.

Gustafson, D.; Dowdle, J.; Flueckiger, K.
A High Antijam GPS-Based Navigator
26th Joint Services Data Exchange (JSDE), Ventura, CA, October 22-26, 2000. Sponsored by GPS/JPO/EGI

Institute of Navigation National Technical Meeting, pp. 495-503, Anaheim, CA, January 26-28, 2000. Sponsored by: ION

Current GPS-based navigation system performance is marginal in high interference environments in both civilian and military applications. This paper presents a new approach to solving these problems using a design that may be implemented at low cost in software in existing and future GPS receivers. The design approach includes GPS-only navigation capability; however, other sensors may be employed, such as inertial instruments (gyros and accelerometers), radars, altimeters, etc. A multidimensional state is estimated recursively in real time using raw measurement data, which includes (1) in-phase and quadrature data from a bank of correlators, and (2) raw measurements from other sensors. The data are processed in a single processor that produces the desired navigation system outputs (e.g., position, velocity, time, and attitude). In addition, the GPS measurements may be used to calibrate correlated errors in the other sensors. Traditional systems are not optimal at high jammer-to-signal (J/S) ratios as a consequence of modular design, use of traditional fixes–gain or gain-scheduled tracking loops–and use of artificial moding logic. In contrast, the approach described in this paper employs a nonlinear filter that operates efficiently at all J/S levels. The design incorporates traditional code loop functions. Filter gains continuously adapt to changes in the J/S environment, and the error covariance propagation is driven directly by measurements to enhance robustness under high jamming conditions. Extended-range correlation may be optionally included to increase the code tracking loss-of-lock threshold under high jamming scenarios. Computational complexity is comparable to an extended Kalman filter. The system has been tested via simulation and in the laboratory using a Nortel GPS simulator and Plessey receiver. Results indicate a consistent improvement in C/A code tracking of at least 15 dB in wide-band antijam capability relative to traditional designs. This improvement can be traced to several factors: (1) elimination of moding logic, resulting in seamless operation at all values of J/S; (2) continuous adaptive estimation of J/S using measurements from the full correlator bank; and (3) effective handling of measurement nonlinearities. This technology is being developed currently for use in next-generation, deeply integrated INS/GPS navigation systems employing system (MEMS) sensors with a near-term goal of a single package consuming less than 3 W in a 3-in^3 volume.

Hattis, P.D.; Fill, T.J.; Rubenstein, D.S.; Wright, R.P.; Benney, R.J.
An Advanced Onboard Airdrop Planner to Facilitate Precision Payload Delivery
Guidance, Navigation, and Control Conference, Denver, CO, August 14-17, 2000. Sponsored by: AIAA

Precision airdrop from high altitude is increasingly important for delivery of military and humanitarian supplies. A personal computer (PC)-based, C-language, advanced airdrop planner is being developed as part of the New World Vistas Precision Aerial Delivery program in parallel with an advanced PC-based wind modeling tool. The combined operation of these two new tools onboard airdrop carrier aircraft will enable more accurate delivery of high-altitude airdrop payloads by accounting for actual flight circumstances, by using forecast and in-flight environmental measurements, and by providing timely, high-value airdrop advisory information to the carrier aircraft crew. Embedded in the planner is a 6-DOF simulation of ballistic parachutes that has already been developed and tested. The planner software architecture as well as its user and carrier aircraft interfaces have been defined with implementation planned by 2001. The planner and wind modeling tool will be demonstrated together onboard a C-130 aircraft in 2001. The features and design of the planner are discussed, some example ballistic airdrop simulation results are presented, and the operational procedures for using the planner in combination with the wind modeling tool are reviewed.

Henderson, T.
Autonomous Systems CSR DFY 2000 Final Review
Published June 16, 2000

The Autonomous Systems CSR developed a modular, reusable software architecture for autonomous air and ground vehicles. This software includes guidance, navigation, and control algorithms on the vehicles and route planning algorithms that account for obstacles and exclusions zones in the intended path. A graphical user interface was also developed that provides a simple means to monitor and control the vehicles. Successful demonstrations of these capabilities were conducted using the Bergen helicopters and the Pioneer ground vehicle.

Hopkins, R.; Borenstein, J.; Antkowiak, B.; Ward, P.; Elliott, R.; Weinberg, M.; DePiero, M.
The Silicon Oscillating Accelerometer: A MEMS Inertial Instrument for Strategic Missile Guidance
Missile Sciences Conference, Monterey, CA, November 7-9, 2000. Sponsored by: AIAA

The ICBM and submarine-launched strategic missiles developed over the past 50 years have employed successive generations of increasingly accurate inertial guidance systems. The comparatively short time of guidance flight and high acceleration levels characteristic of the ballistic missile application place a premium on accelerometer performance to achieve desired weapon system accuracy. Draper Laboratory is currently developing the SOA, a MEMS-based sensor, which has the potential to achieve the ppm/μg performance stability required of the strategic missile application. The SOA belongs to the generic category of accelerometers known as Vibrating Beam Accelerometers (VBA), which sense acceleration by measuring the change in resonant frequency of beam oscillators under the inertial loading of a proof mass. The SOA differs from conventional VBAs in one important respect: the SOA is a silicon MEMS-based device, while VBAs are typically bulk-fabricated quartz devices. The silicon MEMS process offers several advantages from an accelerometer design standpoint: (1) semiconductor-grade, single-crystal silicon is a perfectly elastic, high-strength structural material; (2) the MEMS process enables fabrication of very small (millimeter scale in the case of the SOA) resonator elements that are well isolated from the influence of parasitic instrument package stresses; and (3) capacitively based, electrostatic resonator actuation and sensing that offers great flexibility in designing the SOA resonator elements.

Jackson, M.; Zimpfer, D.; Adams, N.
A Signal Transmission Technique for Stability Analysis of Multivariable Nonlinear Control Systems
10th Space Flight Mechanics Meeting, Clearwater, FL, January 23-26, 2000. Sponsored by: AAS/AIAA

Among the difficulties associated with multivariable, nonlinear control systems is the problem of assessing closed-loop stability. Of particular interest is the class of nonlinear systems controlled with on/off actuators, such as spacecraft thrusters or electrical relays. With such systems, standard describing functions techniques are typically too conservative, and time-domain simulation analysis is prohibitively extensive. This paper presents an open-loop analysis technique for this class of nonlinear systems. The technique is centered around an innovative use of multivariable signal transmission theory to quantify the plant response to worst-case control commands. The technique has been applied to assess the stability of thruster-controlled flexible space structures. Examples are provided for Space Shuttle attitude control with attached flexible payloads.

Jang, J.W.; Bedrossian, N.; Zoss, J.; Templeton, J.; McCants, E.
Draper Station Simulation - A Standard Architecture for Space Vehicle Simulation
Modeling and Simulation Technologies, Denver, CO, August 14-17, 2000. Sponsored by: AIAA

Draper Station Simulation, a COTS-based family of International Space Station on-orbit attitude control system simulations, has been developed and used for flight readiness certification. This architecture allows for both rapid turnaround and wide scope analysis. This high-volume, high-fidelity simulation features the following: (1) by standardizing the simulation architecture, the Draper Station Simulation can be customized easily to simulate most spacecraft attitude control systems; (2) with a well-defined database, it can be reconfigured easily for each Space Station assembly stage; (3) the compiled version increases the simulation speed significantly.

Kaihara, S.; Borenstein, J.; Koka, R.; Lalan, S.; Ravens, M.; Pien, H.; Cunningham, B.; Vacanti, J.
Silicon Micromachining to Tissue Engineer Branched Vascular Channels for Liver Fabrication
Tissue Engineering, Vol. 6, No. 2, April 2000, pp. 105-117

To date, many approaches to engineering new tissue have emerged and they have all relied on vascularization from the host to provide permanent engraftment and mass transfer of oxygen and nutrients. Although this approach has been useful in many tissues, it has not been as successful in thick, complex tissues, particularly those comprising the large vital organs such as the liver, kidney, and heart. In this study, we report preliminary results using micromachining technologies on silicon

and Pyrex surfaces to generate complete vascular systems that may be integrated with engineered tissue before implantation. Using standard photolithography techniques, trench patterns reminiscent of the branched architecture of vascular and capillary networks were etched onto silicon and Pyrex surfaces to serve as templates. Hepatocytes and endothelial cells were cultured and subsequently lifted as single-cell monolayers from these two dimensional molds. Both cell types were viable and proliferative on these surfaces. In addition, hepatocytes maintained albumin production. The lifted monolayers were then folded into compact three-dimensional tissues. Thus, with the use of microfabrication technology in tissue engineering, it now seems feasible to consider lifting endothelial cells as branched vascular networks from two dimensional templates that may ultimately be combined with layers of parenchymal tissue, such as hepatocytes, to form three-dimensional conformations of living vascularized tissue for implantation.

Kang, D.S.; Anderson, J.M.; DeBitetto, P.A.
Draper Unmanned Vehicle Systems
Robotica, Vol. 18, Pt. 3, UK, May-June 2000, pp. 263-72

The Draper Small Autonomous Aerial Vehicle (DSAAV), MITy, and SMART micro-rovers, companion mini-rover, and Vorticity Control Unmanned Undersea Vehicle (VCUUV) are highlighted. The DSAAV demonstrated autonomy with GPS/INS integration and vision processing. The micro- and mini-rovers investigated ground-based autonomy with extensive mapping and planning integration. The VCUUV is a flexible-hull UUV that propels and maneuvers like a tuna.

Kessler, S.S.; Spearing, M.S, Kirkos, G.A.
Design of a High-g Unmanned Aerial Vehicle Structure
AIAA 2000, SAE 2000

The Wide Area Surveillance Projectile (WASP) is a small autonomous flyer that is launched in an artillery shell, and then deployed over the battlefield to capture images. The focus of this paper is the structural design of the WASP vehicle and the manufacturing of components capable of surviving launch loads of 15,000 g. All these pieces need to be as lightweight and durable as possible; therefore, they are manufactured in advanced composite materials.

Laine, J.P.; Little, B.E.; Lim, D.R.; Tapalian, H.C.; Kimerling, L.C.; Haus, H.A.
Characterization of Microsphere Whispering-Gallery-Mode Excitation by Pedestal Anti-Resonant Reflective Waveguide Coupler
Optics Letters, 2000

The Stripline Pedestal Anti-Resonant Reflective Optical Waveguide (SPARROW) is an efficient and robust coupling device for silica microsphere whispering-gallery-mode excitation. The concept incorporates alternating layers of Si and SiO_2, designed to isolate the mode of the sphere and the waveguide from the dielectric substrate. Experimental characterizations of this coupling technique are presented, including displacement measurements and whispering-gallery-mode intensity mapping. Power extraction efficiencies of over 98% are reported.

Laine, J.P.; Little, B.E.; Lim, D.R.; Tapalian, H.C.; Kimerling, L.C.; Haus, H.A.
Microsphere Resonator Mode Characterization by Pedestal Anti-Resonant Reflecting Waveguide Coupler
IEEE Photonics Technology Letters, Vol. 12, No. 8, August 2000, pp. 1004-1006

The Stripline Pedestal Anti-Resonant Reflecting Optical Waveguide (SPARROW) is an efficient and robust coupling device for silica microsphere whispering-gallery-mode excitation. The concept incorporates alternating layers of Si and SiO_2, designed to isolate the mode of the sphere and the waveguide from the dielectric substrate. Experimental characterizations of this coupling technique are presented, including displacement measurements and whispering-gallery-mode intensity mapping. Power extraction efficiencies of over 98% are reported.

Laine, J.P.; Little, B.E.; Lim, D.R.; Tapalian, H.C.; Kimerling, L.C.; Haus, H.A.
Planar Integrated Wavelength-Drop Device Based on Pedestal Anti-Resonant Reflecting Waveguides and High-Q Silica Microspheres
Optics Letters, Vol. 25, No. 22, November 15, 2000, pp. 1636-1638

Whispering-gallery modes in silica microspheres can be accessed very efficiently with the recently introduced Stripline Pedestal Anti-Resonant Reflecting Optical Waveguide (SPARROW) structure. This integrated-optics coupling technique creates novel application opportunities for the high-Q spherical cavities. We report the demonstration of a narrow-band wavelength-drop configuration using SPARROW waveguides and a silica microsphere.

Laine, J.P.; Little, B.E.; Haus, H.A.; Lim, D.R.; Tapalian, H.C.
Silica Microsphere Resonator and SPARROW Waveguide Coupler Structures
Integrated Photonics Research, Quebec City, Canada, July 12-15, 2000. Sponsored by: OSA

Optical microsphere resonator-based wavelength-dropping and acceleration sensing devices are presented. Both components are integrated on SPARROW waveguide coupler chips.

Mangoubi, R.
Design and Performance Analysis of a Target Geolocation Filter for Autonomous Vehicles
December 29, 2000

This report describes a target geolocation algorithm based on the Extended Kalman Filter (EKF). The algorithm is tested off line using flight data. The flight data results show that for an autonomous vehicle equipped with inexpensive navigation equipment and flying at a range of 70 to 110 ft from the target and at an altitude of about 50 to 60 ft, the target can be geolocated within 9 ft using about 9 measurements. In addition, an analysis is conducted to examine the performance of a geolocation algorithm in more realistic battlefield conditions. It is found that with sensors providing a 0.2-m position error standard deviation and 1-mrad angle measurement error standard deviation, an autonomous vehicle would provide a 1-m target geolocation accuracy when flying at a range of 0.5 km from the target and at an altitude of 165 m above it.

Marinis, T.F.; Fulginiti, D.A.; Clausen, H.G.
Packaging MEM Sensor Arrays
Materials Science of Microelectromechanical Systems (MEMS) Devices II, Boston, MA, 2000

Many MEMS sensor applications require hermetic or high-vacuum packaging of sensor clusters. For example, multiple gyroscopes or accelerometers are fabricated on a single chip to improve alignment and stability of input axes or to increase the dynamic range of instruments. Chemical sensors are fabricated as large arrays to both improve selectivity and increase the number of species that can be detected. Still larger arrays of sensors must be packaged for hydrophone and bolometer imaging devices. All these applications place a demanding combination of requirements on the sensor package. The electrical outputs of the sensor array must be well isolated from each other as well as power and excitation signals, while parasitic capacitance is minimized. The package must also be capable of being evacuated and scaled to achieve a pressure of 5 millitorr with a leakage rate below 10^{-11}[Std cc s^{-1}]. Finally, the package must be compact and low cost to realize these same attributes of the MEMS sensor. This paper describes a packaging approach that is based on low-temperature co-fired ceramic materials. This technology meets the packaging requirements of sensor arrays and is well suited to the research environment in which the sensor design is continually evolving.

McCants, E.; Bedrossian, N.; Ghorbel, F.
Space Station Momentum Optimal CMG Maneuver Logic during Payload Operations
Modeling and Simulation Technologies, Denver, CO, August 14-17, 2000. Sponsored by: AIAA

Evaluating the feasibility of planned robotic operations requires an analysis methodology and tools that can quickly assess proposed attitude control strategies. In this paper, an efficient modeling of the attitude dynamics of the International Space Station during payload motion is used to generate an attitude command history that will minimize the peak CMG momentum use during robotic payload operations. This methodology is applied to a realistic Space Station assembly operation and compared with other alternatives. The results indicate that the optimized attitude command trajectory results in the smallest peak CMG momentum cost.

McConley, M.W.; Appleby, B.D.; Dahleh, M.A.; Feron, E.
A Computationally Efficient Lyapunov-Based Scheduling Procedure for Control of Nonlinear Systems with Stability Guarantees
IEEE Transactions on Automatic Control, Vol. 45., No. 1, January 2000, pp. 33-49. Sponsored by: IEEE

We propose an alternative to gain scheduling for stabilization of nonlinear systems. For a useful class of nonlinear systems, the characterization of a region of stability based on a control Lyapunov function is computationally tractable in the sense that computation times vary polynomially with the state dimension for a fixed number of scheduling variables. Using this fact, we develop a procedure to expand the region of stability by constructing control Lyapunov functions to various trim points of the system. A Lyapunov-based control synthesis algorithm is used to construct a control law that guarantees closed-loop stability for initial conditions in the expanded region of state space. This

control asymptotically recovers the optimal stability margin in the sense of a Lyapunov derivative, which in turn, can be seen as a performance measure. Robustness to bounded disturbances and stabilization under bounded control are easily incorporated into this framework. In the worst case, the computational complexity of the analysis problem that develops in the new method is increased by an exponential in the disturbance dimension. Similarly, we can handle control constraints with an increase in computational complexity of no more than an exponential in the control dimension. We demonstrate the new control design procedure as an example.

McConley, M.W.; Piedmonte, M.D.; Appleby, B.D.; Frazzoli, E.; Feron, E.; Dahleh, M.A.
Hybrid Control for Aggressive Maneuvering of Autonomous Aerial Vehicles
Institute of Navigation 2000 National Technical Meeting, Anaheim, CA, January 26-28, 2000

Operation of future autonomous vehicles in high-stress mission environments, such as air combat, suppression of enemy air defenses, and urban warfare, requires high maneuverability and adaptation to uncertain dynamics and environmental conditions. Traditional control algorithms impose performance limitations that fall far short of what can be achieved by skilled human pilots. New advances in control theory are required to overcome these limitations in order to enable aggressive autonomous vehicle maneuvering, while adapting in real time to changes in the operational environment. Motion planning for a nonlinear high-dimensional system, such as an aerial vehicle, is a highly complex problem. Our approach to reducing this complexity is based on quantization of the system dynamics, leading to a hybrid control architecture. The states of the hybrid automaton represent feasible trajectory primitives for the vehicle. The power of this approach lies in the fact that any sort of feasible trajectories can be incorporated in the primitive list and made available to the automatic control system. In particular, it is possible to include pilot-inspired behaviors by conducting manual flight tests with the vehicle and recording control and state trajectory information while a human pilot executes a desired set of aggressive maneuvers. The behavior library thus constructed can be augmented by generating additional maneuvers to transition among a prescribed set of trim trajectories via analysis of the dynamic model of the vehicle. This paper describes the structure of a robust hybrid automaton that solves a time-optimal, motion-planning problem by sequencing maneuvers in real time from the combined list of pilot-inspired behaviors and model-generated maneuvers. The motion-planning algorithm can be used in a free workspace, or in the presence of fixed or moving obstacles. We present a case study in which we have generated a behavior library via a combination of analysis and live flight tests with a small remote-controlled helicopter. Given this behavior library, we have constructed a robust hybrid automaton for motion planning and a nonlinear control law for maneuver execution. We present simulation results showing the effectiveness of this approach. In addition, we plan to conduct flight tests over the next few months to evaluate this approach in real flight.

Miller, J.L.
Technical Evaluation Report. Information Systems Technology Panel Symposium. New Information Processing Techniques for Military Systems
IST Symposium, Istanbul, Turkey, October 9-11, 2000. Sponsored by: NATO

This paper presents a technical evaluation of the Information Systems Technology Panel Symposium held in Istanbul, Turkey. There is a need for information technology to compensate for the changing nature of recent threats (low-scale operations other than war and counter terrorism). The nature of these threats precludes collecting data over a long period of time prior to engagements and requires the rapid collection, exploitation, and dissemination of tactical information. The changing military operations demand increased deployability, flexibility, interoperability, low collateral damage, and precision targeting. The symposium was intended to provide a overview of information processing techniques; 29 papers were presented covering a wide range of topics. A major disappointment was the lack of papers dealing with new technology that can be applied to military information systems. While it is important to apply existing commercial technology to military applications, we need to recognize the specialized information requirements imposed by warfare. The defense community has the opportunity to regain the lead in information technology through establishing metrics and a theoretical/mathematical basis for information systems. A major development observed is the increasing use of internet-related techniques and client-server computer architectures. A second major trend observed is the increased use of computer graphics and multimedia displays for visualization to the user.

Miller, R.A.; Eiceman, G.A.; Nazarov, E.G.
A MEMS Field Asymmetric-Ion Mobility Spectrometer (FA-IMS) for Chemical Warfare Agent Detection
Published 2000

Time-of-flight ion mobility spectrometry (IMS) is the leading detection technology for chemical warfare agents in the battlefield. Current spectrometers use conventionally machined drift tubes for ion identification, but new drift tube fabrication technologies are needed to realize smaller, lower cost, spectrometers. MEMS technology has been identified as one such key enabling technology. Yet so far, attempts to fabricate miniaturized MEMS IMS drift tubes have lead to spectrometers with poor sensitivity or resolution. A recently developed IMS-based technique that allows miniaturization of IMS drift tubes through MEMS, while preserving sensitivity and resolution, is high field asymmetric waveform-ion mobility spectrometry (FA-IMS). In this paper, we present results from characterization of the first MEMS FA-IMS. The device exhibits excellent performance characteristics with a drift tube ~3 x 1 x 0.2 cm^3 in size. The FA-IMS consists of a micromachined drift tube containing an ionization source, a tunable ion filter, and a detector. A carrier gas (flow rate of 1 - 4 liters/min) transports the ions through the drift region where they are filtered by applying a dc bias voltage and a radio frequency waveform to ion filter electrodes. Adjusting the ratio of dc bias voltage to RF voltage selects the ions that can pass through the filter and be collected at a detector. Characterizations using chemical agent simulants such as DMMP and substituted benzenes demonstrate part-per-billion detection limits and a new mechanism for separating ions in a manner not encountered in traditional ion mobility spectrometers.

Miller, R.A.; Eiceman, G.A.; Nazarov, E.G.; King, T.A.
A MEMS Radio-Frequency Ion Mobility Spectrometer for Chemical Agent Detection
Solid-State Sensors & Actuators Workshop, Hilton Head Island, SC, June 4-8, 2000

A first-of-a-kind MEMS Radio-Frequency Ion Mobility Spectrometer (RF-IMS) with a miniature drift tube of total volume 0.4 cm^3 has been fabricated and tested. The spectrometer has detection limits in the parts-per-billion and the ability to identify chemicals such as isomers of xylene not resolved in conventional time-of-flight ion mobility spectrometry. Spectrometer operation with a miniature 10.6 eV (λ=116.5 nm) UV photodischarge lamp and a 100-pCi radioactive ionization source has been demonstrated. The resultant spectra with both these ionization sources are similar, with several additional peaks evident for the radioactive source. The effect of varying the carrier gas flow rate on the resultant spectra has been investigated, and optimal flow conditions are found at flow rates between 2 and 3 liters/min. The RF-IMS has been interfaced to a mass spectrometer and RF-IMS spectral peaks have been confirmed. The RF-IMS/MS configuration illustrates another use for the RF-IMS as a prefilter for atmospheric pressure chemical-ionization mass spectrometry applications.

Miller, R.A.; Eiceman, G.A.; Nazarov, E.G.
A Microfabricated Radio Frequency Ion Mobility Spectrometer (RF-IMS)
Published 2000

Environmental, medical, and security requirements for on-site chemical screening are motivating the development of low-cost, miniature, detectors with performance comparable to that of larger devices. One leading technology for on-site monitoring is low electric field strengthened IMS, which has been used extensively for detecting chemical weapons and explosives. However, these low-field drift tube designs suffer from reduced resolution or sensitivity when miniaturized. RF-IMS is a recently developed IMS-based technique that allows miniaturization of IMS through microfabrication, while preserving sensitivity and resolution. Here, the production of the first microfabricated RF-IMS with drift-tube dimensions ~2.5 1 0.2 cm^3 will be described. The device exhibits excellent performance characteristics and offers low cost and reproducibility. The microfabricated device consists of a micromachined drift tube containing an ionization source, a tunable ion filter, and a detector. A carrier gas (flow rate of 1-4 liters/min) transports the ions through the drift region where they are filtered by applying a dc bias voltage and an RF waveform to ion filter electrodes. Adjusting the ratio of dc bias voltage to RF voltage selects the ions that can pass through the filter and reach a detector. Characterizations using benzene and substituted benzenes demonstrate the ppb detection limits and new mechanism for separating ions in a manner not seen in low-field traditional mobility spectrometers. The application of this device as an inlet for a mass spectrometer will also be illustrated.

Miller, R.A.; Eiceman, G.A.; Nazarov, E.G.; King, A.T.
A Novel Micromachined High-Field Asymmetric Waveform-Ion Mobility Spectrometer
Sensors and Actuators - B — Chemical, Vol. 67, No. 3, September 2000, Switzerland, pp. 300-306

The fabrication and characterization of a novel micromachined high-field asymmetric waveform-ion mobility spectrometer (FA-IMS) is described. The spectrometer has a 3 x 1 x 0.2 cm^3 rectangular drift tube and a planar electrode configuration. The planar configuration permits simple construction using microfabrication technology where electrodes and insulating regions are made with deposited metal films on glass substrates. The spectrometer is characterized using organic vapors (including acetone, benzene, and toluene) at ambient pressure and with air as the drift gas. Ions are created in air at ambient pressure using photo-ionization with a 10.6-eV photodischarge lamp (λ=116.5 nm). The micromachined FA-IMS exhibited behavior consistent with conventional FA-IMS designs where compensation voltage was effective in discriminating between ion species in high-field RF regimes. Excellent resolution of benzene and acetone ions in mixtures illustrates an advantage of the FA-IMS over low-field ion mobility spectrometry. Detection of toluene at concentrations as low as 100 ppb has been demonstrated. Improvements in detection limits by as much as 100X are anticipated with improved ionization source designs. The ability to transport both positive and negative ions simultaneously through the FA-IMS drift tube is demonstrated here for the first time. Ion intensity is found to be proportional to sample concentration, although clusters of sample ions and neutrals at high concentrations illustrate the need for a drift region that is kept free of sample neutrals. Micromachining promises cost, size, and power reductions enabling both laboratory and field instruments.

Miller, R.A.; Bernstein, J.J.
A Novel Wet Etch for Patterning Lead Zirconate-Titanate (PZT) Thin-Films
Integrated Ferroelectrics, Vol. 29, No. 3-4, pp. 225-231

Little is reported in the literature on the wet etching of PZT, and all wet etch recipes described use high concentrations of hydrofluoric acid (HF). Here, a novel recipe that operates in a new regime of extremely low HF concentration is used to wet etch thin-film PZT. The recipe provides excellent etch control, minimizes undercut, and does not attack photoresist. Unlike most wet PZT etchants, it does not leave a lead-rich residue, and the etchant is selective over SiO_2 and ZrO_2. The recipe and preliminary etching results for 5-μm-thick sol-gel deposited PZT films are described in this paper.

Miller, R.A.; Eiceman, G.A.; Nazarov, E.
Performance of a Micromachined RF-IMS with Non-Rad and Low-Rad Ionization Sources
9th International Conference on Ion Mobility Spectrometry (ICIMS), Halifax, Nova Scotia, Canada, August 13-17, 2000. Sponsored by: ISAS

Radio Frequency Ion Mobility Spectrometry (RF-IMS) is a recently developed IMS-based technique that allows miniaturization of IMS drift tubes through micromachining, while preserving sensitivity and resolution. The micromachined device fabricated at Draper Laboratory exhibits excellent performance characteristics with a drift tube 3 x 1 x 0.2 cm^3 in size. The RF-IMS consists of a micromachined drift tube containing an ionization region, a tunable ion filter, and a detector. A carrier gas (flow rate of 1 - 4 liters/mm) transports the ions through the drift region where they are filtered by applying a dc bias voltage and a radio frequency waveform to ion filter electrodes. Adjusting the ratio of dc bias voltage to RF voltage selects the ions that can pass through the filter and be collected at a detector. This paper compares performance results (e.g., detection limits, reproducibility, and resolution) of the RF-IMS for a range of volatile organic compounds using several nonradioactive and low-activity ionization sources. These ion sources include a UV photodischarge lamp and a 100-curie americium source.

Mofrad, M.R.K.; Kamm, R.D.; Borenstein, J.; Vacanti, J.P.
Optimizing Microvascular Channels for Liver Fabrication
3rd Tissue Engineering Society (TES) Meeting, Orlando, FL, November 30-December 3, 2000. Sponsored by: TES

Conventional approaches in tissue engineering have so far failed to create thick complex tissues for vital organs like the liver, kidney, and heart. In this work, we design and generate optimal microvascular systems using microfabrication technologies on silicon and Pyrex wafers that may be integrated with engineered tissues before implantation in order to allow for successful engineering of the liver.

Moynahan III, S.A.; Tuohy, S.T.
Development of a Modular On-Orbit Serviceable Satellite Architecture
IEEE Aerospace Conference, Big Sky, Montana, March 2000

This paper describes an avionics architecture that enables the replacement of deficient satellite hardware on-orbit as well as upgrade/adapt on-orbit systems. It is anticipated that routine, safe, and reliable spacecraft servicing will have significant payoff for many future types of science and military missions. The technologies that enable modern satellite servicing will therefore be critical for implementing new space architectures. Satellites that are placed on-orbit and are functionally lost due to simple failures beg for the development of an on-orbit replacement capability. To date, this has been performed by an astronaut. Repair of Intelsat VI and the Hubble Space Telescope during STS-49 and STS-61, respectively, were possible due to the human intervention capabilities provided by the Space Shuttle. Human intervention in space, however, carries risk and cost associated with it that would not be necessary if an autonomous satellite repair capability were developed. The associated capability to perform preplanned upgrades and adaptations to on-orbit space assets also has the potential for architecting high-performance future spacecraft. Such a capability would allow system designers to accommodate differing rates of technology advancement and would minimize the need for prelaunch risk reduction measures. The first step in developing a serviceable satellite is to evolve the tightly integrated satellite architectures of today toward an architecture that supports functional and/or physical replacement of anomalous or failed hardware. Draper Laboratory has performed a trade study to develop a single-point architecture that provides a growth path from the functionally efficient satellite designs of today to a functionally reliable modular architecture that will support the autonomous on-orbit upgrade and functional enhancement of tomorrow's satellites. This paper presents an overview of an architecture that can enable autonomous satellite servicing.

Moynahan III, S.A.; Tuohy, S.T.
Satellite Architecture [for Autonomous On-orbit Servicing]
2000 IEEE Aerospace Conference, Vol.4 , pp. 247-60

This paper describes an effort to develop an avionics architecture that enables the replacement of deficient satellite hardware on-orbit as well as upgrade/adapt on-orbit systems. It is anticipated that routine, safe, and reliable spacecraft servicing will have significant payoff for many future types of science and military missions. Satellites that are placed on-orbit and are functionally lost due to simple failures beg for the development of an on-orbit replacement capability. To date, this has been performed by an astronaut. Human intervention in space, however, carries risk and cost associated with it that would not be necessary if an autonomous satellite repair capability were developed. The associated capability to perform preplanned upgrades and adaptations to on-orbit space assets also has the potential for architecting high-performance future spacecraft. The first step in developing a serviceable satellite is to evolve the tightly integrated satellite architectures of today toward an architecture that supports functional and/or physical replacement of anomalous or failed hardware. Draper Laboratory has performed a trade study to develop a single-point architecture that provides a growth path from the functionally efficient satellite designs of today to a functionally reliable modular architecture that will support the autonomous on-orbit upgrade and functional enhancement of tomorrow's satellites. This paper presents an overview of an architecture that can enable autonomous satellite servicing.

Murphy, M.; Armacost, S.; Barnes, R.; Templin, K.; Krepp, D.
Ballistic Missile Guidance System Test in an Aircraft Pod
Guidance, Navigation, and Control Conference, Denver, CO, August 14-17, 2000. Sponsored by: AIAA

A test pod carried under wing by a high-performance aircraft was developed by the U.S. Navy/SSP and the U.S. Air Force to perform dynamic testing of ballistic missile guidance systems. To date, the Trident MK 6 stellar-aided inertial system and the Litton LN-195 stellar-aided thrust following system have been tested. The aircraft chosen for proof-of-concept testing is an Air Force F-15E. A GPS-based reference system is being used to evaluate the aircraft pod test capability. In testing the MK 6 system, certain performance responses to dynamic conditions were made observable. In addition, stellar sightings were made under dynamic conditions at higher altitudes, allowing evaluation of the stellar sensor under more stressful conditions than in the laboratory or environmental chambers. The LN-195 Pod Test effort was established and coordinated in 1998 between the Air Force and Navy.

Varying trajectories were flown and stellar updates were made on multiple stars to provide observability of LN-195 system performance. Flight navigation was evaluated with various ground initialization modes, while simulated nuclear event interrupts were injected during flight to demonstrate the LN-195 circumvention and recovery mechanization. An Integrated Product Development Team was created by Draper Laboratory, which was supported by a team of industrial subcontractors to procure and integrate equipment, and to perform the tests. This paper describes the details of the current pod design and tests.

Nelson, F.C., Cerminaro, A.M.
An Aircraft Gas Turbine Configured as a Smart Machine
Conference on Structural Dynamics, San Antonio, TX, February 7-10, 2000
Society for Experimental Mechanics, Inc./Society of Photo-Optical Instrumentation Engineering (SPIE), Vol. 4062, pp. 1119-1122

A finite-element method (FEM) rotordynamic model of a high-temperature, high-speed aircraft gas turbine has been coupled through simulated active magnetic bearings (AMB) to a simulated closed-loop PID controller. The FEM model includes the destabilizing effects of internal damping. A FEM model and a computer-based simulation were also developed for a benchtop rotor suspended on purpose-built AMB. The predicted results were then compared with experimental data from the rotor rig in order to establish some level of confidence in the predictions given by the gas turbine simulation. AMB can change their stiffness and damping in response to machine operating conditions and, as such, they offer the potential of converting an aircraft gas turbine into a smart machine, with real-time diagnostics, prognosis capabilities, and the ability to make on-line corrections. This potential will be discussed in light of the challenges of designing aircraft gas turbines that have higher performance, less maintenance, longer lifetimes, and enhanced safety.

Proulx, R.; Castiel, D.; Draim, J.E.; Cefola, P.
Radio Interference Between Nongeostationary Communication Satellite Constellations
10th Space Flight Mechanics Meeting, Clearwater, FL, January 23-26, 2000, pp. 611-637. Sponsored by: AAS/AIAA

Main-beam intrusion between big low-earth orbit (LEO) Global Mobile Communications systems has been identified as an area of concern by the ELLIPSO™ team that must be characterized and quantified. In particular, the team has noted that it shares the C-band feeder downlink spectrum with both Globalstar and ICO, as well as other potential Big-LEO systems. The goal of this study is to determine the severity and characteristics of main lobe RF interference in the C-Band between the ELLIPSO constellation and these competing systems. Only the conjunction geometry (and duration statistics as indicated by the geometry) of intrusion events will be considered in this initial analysis. The relationship of the intrusion duration statistic to the latitude of the ELLIPSO feeder station will be explored. Significant intrusion events occur even for reception beamwidths that are relatively narrow. We will discuss the effectiveness of site diversity to mitigate RF interference events.

Rao, Y. (Reprinted); Qu, J.M.; Marinis, T.; Wong, C.P.
A Precise Numerical Prediction of Effective Dielectric Constant for Polymer-Ceramic Composite Based on Effective-Medium Theory
IEEE Transactions on Components and Packaging Technologies, Vol. 23, No. 4, December 2000, pp. 680-683

Nanostructure polymer-ceramic composite with high-dielectric constant (epsilon (r) similar to 90) has been developed for embedded capacitor application. This polymer-ceramic system consists of lead magnesium niobate-lead titanate (PMN-PT) ceramic particle and modified high-dielectric constant low-viscosity epoxy resin. In order to obtain precise prediction of effective dielectric constant of this composite, an empirical prediction model based on self-consistent theory is proposed. The electrical polarization mechanism and interaction between epoxy resin and ceramic filler has been studied. This model can establish the relevant constitutional parameters of polymer-ceramic composite materials such as particle shape, composition, and connectivity that determine the dielectric properties of the composite. This model is simpler, uses fewer parameters, and its prediction compares better with experiment (error <10 %). The precision and simplicity of the model can be exploited for predictions of the properties and design of nanostructure ferroelectric polymer-ceramic composites. The Effective-Medium Theory (EMT) has been proved a good tool to predict the effective properties of nanocomposites.

Rao, A.V.
Riccati Dichotomic Basis Method for Solving Hypersensitive Optimal Control Problems
Guidance, Navigation, and Control Conference, Montreal, Canada, August 6-9, 2000. Sponsored by: AIAA

The solution of a completely hypersensitive Hamiltonian boundary-value problem (HBVP) arising in optimal control can be approximated accurately by concatenating an initial boundary-layer segment, an equilibrium segment, and a terminal boundary-layer segment. The approximation in the initial boundary layer has no unstable component in forward time, while the approximation in the terminal boundary layer has no unstable component in backward time. Using a dichotomic basis, the Hamiltonian vector field is decomposed into its stable and unstable components. In this paper, it is shown that dichotomic bases can be constructed by solving Riccati differential equations along the approximations in the initial and terminal boundary layers. From the aforementioned properties, successive approximation procedures arise from which the solutions in the boundary layers and the dichotomic bases can be computed. The successive approximation procedures are illustrated as an example, and their range of applicability is assessed.

Ricard, M.J.; Keegan, M.
Intelligent Autonomy for the Manta Test Vehicle
OCEANS 2000 Conference, Providence, RI, September 11-14, 2000, pp. 1265-1271. Sponsored by: MTS/IEEE

The Navy's next-generation Unmanned Undersea Vehicle (UUV) missions include: (1) long-range intelligence, surveillance, and reconnaissance; (2) tactical oceanography; and (3) antisubmarine warfare. To support the vision to perform these missions with unmanned platforms, significant increases in the levels of system autonomy and onboard autonomous processing are required. The Naval Undersea Warfare Center (NUWC), Division Newport, and Draper Laboratory have teamed to perform research and development in the area of autonomy and autonomous processing necessary to support next-generation UUV missions. This paper outlines the autonomy requirements of these missions with respect to the capabilities of UUVs that are fielded or currently under development. The approach taken to develop the autonomous processing capabilities required of these missions will be outlined. Central to this approach is Draper's All-Domain Execution and Planning Technology (ADEPT) architecture for intelligent autonomy. Intelligent autonomy is the ability to provide rapid, effective response to stochastic and dynamic mission events. This provides an unmanned vehicle with adaptive behavior that is currently present in man-in-the-loop systems without requiring operator intervention. The architecture is a hierarchical extension of the sense-think-act paradigm of intelligence and is quite similar to the military's Observe-Orient-Decide-Act (OODA) loop. The key elements of the system are modules for situation assessment, plan generation, plan implementation, and coordination. A reusable, object-oriented software framework has been developed that implements these functions. As the architecture is applied to new areas, only the application-specific software needs to be developed. This paper also discusses the progress that has been made in the development of the Navy's next-generation, autonomous UUV testbed, the Manta Test Vehicle (MTV). The MTV is a nontraditionally-shaped UUV that is being designed and fabricated by NUWC. The vehicle has dimensions of 34 ft x 16 ft x 8 ft, which allows significant payload capability for sensing elements and related processing equipment. MTV was conceived to help push the envelope on what could be achieved in an unmanned system, and will serve as the testbed for Intelligent Autonomy R&D. Draper has also teamed with NUWC to assist in the areas of vehicle design, hydrodynamic modeling, and simulation, along with guidance, navigation, and control software. MTV underwent its second in-water-run series in preparation for payload demonstrations in Fall 00.

Rubenstein, D.S.; Carter, D.W.
Attitude Control System Design for Return of the Kistler K-1 Orbital Vehicle
Journal of Spacecraft and Rockets, Vol. 37, No. 2, March-April 2000, pp. 273-282

An attitude control system design is presented that provides the maneuver capability and aerodynamic angle maintenance necessary for the atmospheric reentry and return to launch site of an unmanned reusable launch vehicle. The primary functions are categorized into those that perform bank maneuvers about the air-relative velocity vector and those that are responsible for the tracking and control of the vehicle aerodynamic trim conditions. The control system is supported by an onboard aerodynamic estimation function. The estimator uses

measurements of vehicle states from navigation in combination with analytic models in a gain-scheduled filter environment to provide control with current trim angle information. The control system uses this information to minimize actual vehicle deviations from the trim. Also, control is provided with bank commands from a guidance function. As this paper is concerned only with the control and estimation functions, the guidance strategies are discussed only to the extent that is necessary to justify/clarify control or estimator designs. The algorithms developed here are applied to the Kistler K-1 Orbital Vehicle and tested in the Kistler Integrated Vehicle Simulation at Draper Laboratory. Results indicate that the approach to entry/return control is both fuel-efficient and effective from a landing accuracy perspective.

Schmidt, G.
Inertial Sensing - Where To Now?
Russian Academy of Navigation & Control, St. Petersburg, Russia, May 31, 2000
No Abstract.

Schwartz, G.
Integrated Communication Specification for the Reduced Ships-Crew by Virtual Presence (RSVP) Advanced Technology Demonstration (ATD)
Published 2000
This document describes data communication throughout the Reduced Ships-Crew by Virtual Presence (RSVP) system.

Smith, S.R. Jr.
Draper Technology for the Second-Generation Reusable Launch Vehicle
Published July 2000
This paper describes how specific elements of Draper-developed technology might be applied to NASA's Second-Generation Reusable Launch Vehicle (RLV) program, which aims to support the development of a commercially-operated RLV capable of delivering dramatic improvements in safety, reliability, and cost to orbit. Specific applicable technologies include autonomous space vehicle operation, fault-tolerant computing, high-reliability avionics architectures, low-cost vehicle health management, and miniaturized electronics. The paper demonstrates how these technologies contribute to achieving significant improvement in safety, reliability, fault diagnosis and system reconfiguration, and economic operation of the new RLV.

Stocker, D.A.; Goepfert, I.D.; Schubert, E.F.; Boutros, K.S.; Redwing, J.M.
Crystallographic Wet Chemical Etching of P-type GaN
Journal of the Electrochemical Society, Vol. 147, No. 2, February 2000, pp. 763-764
We demonstrate crystallographic wet chemical etching of p-type GaN with etch rates as high as 1.2 mum/min. Etchants used include molten KOH, KOH dissolved in ethylene glycol, aqueous tetraethylammonium hydroxide, and phosphoric acid (H_3PO_4), at temperatures ranging from 90 to 260°C. The observed crystallographic p-GaN etch planes are (0001), left brace 101 over bar 0 right brace, and left brace 101 over bar 2 right brace. The etch rates follow an Arrhenius characteristic with activation energies varying from 21 kcal/mol for KOH-based solutions to 33 kcal/mol for H_3PO_4. The etch rate and crystallographic nature for the various etching solutions are independent of conductivity, as shown by seamless etching of a p-GaN/undoped, high-resistivity GaN homojunction and by comparison of the etch rates of p-GaN with n-GaN.

Soucy, J.W.; Haley, J.F.; Marinis, T.F.
An Approach to MEMS Sensor Array Packaging
Advancing Microelectronics, Vol. 27, No. 6, November-December 2000, pp. 16-18
Low-temperature co-fired ceramic (LTCC) technology has been used to fabricate a substrate for packaging MEMS sensor arrays. These sensors place a demanding combination of requirements on the package. The electrical outputs of the sensor array must be well isolated from each other, as well as power and excitation signals with minimal parasitic capacitance. The package must be capable of being evacuated and hermetically sealed to achieve a pressure of 5 millitorr with a leakage rate below 10^{-11}[Std cc s^{-1}]. Finally, the package must be compact and low cost to realize these same attributes for the MEMS sensor. A 13-mm 143-pin BGA package format was selected for the MEMS gyroscope sensor array application. The package consists of a metal Kovar cover brazed to the LTCC multilayer substrate with an array of solder balls on the bottom. The MEMS sensor device is flip-chip mounted using gold bumps to connect the many pairs of bond pads on the substrate and sensor array. After sensor mounting, the lids and substrates are loaded into fixtures that hold them in alignment while they are outgassed, joined, and brazed under vacuum. Solder balls are applied to the sealed package with the use of a Draper-designed fixture that locates a 60 Sn/40 Pb solder ball to each pad on the bottom of the package.

Terai, H.; Tanksley, S.G.; Koka, R.; Borenstein, J.; Vacanti, J.P.
Microfabricated Channels in Degradable Polymer Films
3rd Tissue Engineering Society Meeting, Orlando, FL, November 30-December 3, 2000. Sponsored by: TES
The use of biodegradable polymer scaffolds with cell culture has led to advances in the field of tissue engineering. However, the growth of thick, complex tissues that require high oxygen and nutrient supply–such as vital organs including the liver, kidney, and heart–has not been accomplished. To solve this critical problem, we have studied microfabrication in biodegradable polymer films as a method to engineer a branched tubular system.

Tetewsky, A.K.
GPS Simulators. What They're Good For, How To Use One, How To Pick One
Presented at ION, January 12, 2000
This presentation focuses on the issues involved in selecting the appropriate GPS simulator for specific applications. Features/selection questions are discussed, including: hardware accuracy vs dynamics, hardware expandability, software flexibility/company support, and synchronism capability for GPS plus other sensors. An overview of typical GPS simulator operation is presented: how the physical system translates into a simulated system and how the scenario is specified. Typical GPS navigation tests are discussed, as well as highlighted features to look for, e.g., integrated GPS/INS/other sensor simulations, jamming, and multi-antenna systems.

Tumminelli, R.; O'Sullivan, M.; Ayers, E.; Sutherland, R.E.; Gay, D.; Marinis, T.
Die Recovery for Prototype Applications
International Microelectronics & Packaging Society (IMAPS), Boston, MA, September 20-22, 2000. Sponsored by: IMAPS
Bare die are used extensively in the fabrication of multichip-modules (MCM), using either MCM-L (-laminated) or MCM-D (-deposition) technologies. For MCM prototyping, the availability of bare die can present somewhat of a problem. In some cases, die may be available in wafer form, but require a large one-time purchase when only tens of dies are needed. Usually, only the older generations of a particular device are available in bare die form, while the latest technology is available only as a packaged part. Finally, some die are simply not available in bare die form at all. At Draper Laboratory, we have developed a process that uses a combination of acid etching and mechanical lapping to recover die from epoxy encapsulated packages. The die is left in a form that can be easily incorporated into embedded MCM-D configurations or surface mounted as a flip chip or wire bone device.

Tuohy, S.T.
Concept Evaluation through Simulation: Rapid Acquisition of System Knowledge
February 14, 2000
All projects use simulation, whether it is in the form of advanced virtual prototyping or using spreadsheets. But are projects using simulation to the greatest benefit? How should simulations be constructed to get the greatest benefit? This presentation will define this issue and suggest avenues of exploration. The presentation will begin with a definition of the purpose of simulation: to provide the "prototype" from which we can extract performance measures and evolve the design. It will describe simulation requirements for different design phases of a program and show examples of each. From these requirements, a methodology will be developed to provide rapid prototype development at the beginning of a program, and for the communication of requirements and of the design through subsequent program phases.

Turkovich, J.
The Draper C^4I Laboratory--Command, Control, Communications, Computers, and Intelligence
May 15, 2000
This presentation provides an overview Draper's Command, Control, Communications, Computers, and Intelligence (C^4I) Laboratory. C^4I is the coordinated operation of numbers of assets to accomplish a set of objectives in an uncertain environment subject to sets of constraints: observations are made, orientation is assessed, decisions are made, and actions are taken (OODA). DoD has a significant C^4I problem; prior to 1986, the roles of all services (Army, Navy, and Air Force) enabled them to operate independently. In 1986, the Commanders in Chief (CINCs) became responsible for wartime operations with joint

forces. However, the service C^4I systems are not designed to be interoperable. Draper has facilities to host the development of solutions to DoD's C^4I problems and the potential to lead the future of C^4I for joint forces interoperability. Draper's GN&C expertise is directly applicable to the roles of OODA. Draper can continue to solve C^4I problems by engaging in joint experiments through the U.S. Joint Forces Command, applying ASD C^3I standards, and maintaining user contract through the services and CINCs. Draper is currently involved in a number of C^4I-related programs, including the BC2A Information Management System, Information Dissemination Management (IDM), and Joint Forces Air Component Command (JFACC).

Weinberg, M.S.; Cunningham, B.T.; Clapp, C.W.
Modeling Flexural Plate Wave Devices
Journal of Microelectromechanical Systems, Vol. 9, No. 3, September 2000, pp. 370-379

A lumped parameter model is derived for flexural plate wave (FPW) devices that are rectangular plates or diaphragms with structural layers, a piezoelectric layer, and with interdigitated conducting combs for driving and sensing. This configuration is often used in micromechanical chemical sensors. The model is based on a closed-form solution of a resonating beam; however, the results are applicable to plates supported on four edges. The model gives a voltage or charge output from the sense combs as a function of voltage applied to the drive combs. The analysis predicts the response of the multiple plate modes to axial tensions and to comb finger dimensions and position relative to the diaphragm eigenfunctions. These models are much more detailed than those described in the literature on acoustic chemical sensors and are difficult to obtain by finite-element solutions. Frequency responses of FPW devices constructed from silicon with deposited aluminum nitride as the piezoelectric compared well with analytic results. The effects of boundary conditions on the plate's lateral edges are discussed in both the analysis and testing.

Xu, B.M. (Reprinted); Cross, L.E.; Bernstein, J.J.
Ferroelectric and Antiferroelectric Films for Microelectromechanical Systems Applications
Thin Solid Films, Vol. 377, December 1, 2000, pp. 712-718

In this paper, we have introduced several types of ferroelectric and antiferroelectric thin (thickness <1 mum) and thick (thickness >1 mum) films developed in our group for sensor, actuator, and transducer applications in MEMS. Ferroelectric lead zirconate titanate (PZT) films of up to 12 mum in thickness have been prepared on Pt-buffered silicon substrates, which allows for the conventional, through-thickness polarization, and of up to 5 mum in thickness on insulating layer (ZrO_2) passivated silicon substrates, which allows for the novel, in-plane polarization. The in-plane poled films make it possible to develop d(33)-mode rather than d(31)-mode bending devices, which immediately leads to two-times improvement in device performance because d(33) approximates to 2 d(31). It also can greatly increase the voltage sensitivity of bending devices because the film thickness and electrode spacing are separated as independent variables, and thus, smaller film capacitance can be obtained by using wider electrode spacing even for fixed-film thickness. In addition to PZT ferroelectric films, we have also developed antiferroelectric films as an alternative for high-strain microactuators. The strain level of the antiferroelectric films can reach more than 0.4%, and both digital and analog actuation can be realized by modifying the compositions of the films. As an example for MEMS applications, micromachined, unimorph-type two-dimensional transducer arrays have been fabricated based on both the through-thickness and in-plane polarized PZT films, which can be used for miniaturized, high-resolution acoustic imaging such as a hand-held diver's sonar system, medical ultrasound imaging, and nondestructive testing.

Zarchan, P.; Lianos, D.
Filtering Strategies for Spiraling Targets
9th AIAA/BMDO Technology Conference and Exhibit, San Diego, CA, July 17-20, 2000. Sponsored by: AIAA/BMDO

Intentional or unintentional spiraling maneuvers on the part of a tactical ballistic missile target can make it particularly difficult for a pursuing missile to hit. The paper first reviews why it is difficult to hit a spiraling target with proportional navigation guidance. It is then shown that by using a special-purpose linear Kalman filter that is specifically tuned for a spiral maneuver in conjunction with an advanced guidance law, it is possible to dramatically improve system performance over that of a proportional navigation guidance system. However, in order for the necessary filtering and guidance to work properly, the target's spiraling frequency must be known. If the spiraling frequency is unknown, other methods must be used. The paper investigates two schemes for deriving the spiraling frequency of the target. The first scheme involves using a bank of Kalman filters, each of which is tuned to a different spiraling frequency. Various schemes for identifying which filter in the filter bank is tuned to the actual target frequency are investigated. The second method for deriving the target frequency involves using a single extended Kalman filter that explicitly estimates the target spiraling frequency. It is shown that such an extended Kalman filter when used in conjunction with an advanced guidance law can dramatically improve system performance.

Zarchan, P.; Musoff, H.
Fundamentals of Kalman Filtering: A Practical Approach
Progress in Astronautics and Aeronautics, AIAA 2000

This book is a practical guide to building Kalman filters and shows how the filtering equations can be applied to real-life problems. Numerous examples are presented in detail showing the many ways in which Kalman filters can be designed. Computer code written in FORTRAN, MATLAB, and True BASIC accompanies all the examples so that the interested reader can verify concepts and explore issues beyond the scope of the text. Sometimes mistakes are introduced intentionally to the initial filter designs in order to show the reader what happens when the filter is not working properly. The text spends a great deal of time setting up a problem before the Kalman filter is actually formulated in order to give the reader an intuitive feel for the problem being addressed. Real problems are seldom presented in the form of differential equations and they usually do not have unique solutions. Therefore, the authors illustrate several different filtering approaches for tackling a problem. Readers will gain experience in software and performance trade-offs for determining the best filtering approach for the application at hand.

Zarchan, P.
Tracking and Intercepting Spiraling Ballistic Missiles
Position Locations and Navigation Symposium Conference. Sponsored by IEEE, Aerosp. & Electron. Syst. Soc. Conference Date: March 13-16, 2000, San Diego, CA

Intentional or unintentional spiraling maneuvers on the part of a tactical ballistic missile target can make it particularly difficult for a pursuing missile to hit. The paper first presents normalized miss distance curves, showing how the target spiraling frequency and amplitude along with the interceptor guidance system time constant determine the miss distance for a proportional navigation guidance system. It is then shown how more advanced guidance techniques can be used to improve system performance against spiraling targets. The advanced guidance techniques require knowledge of various target states plus the target weave frequency. Various Kalman filtering options for estimating the states required for the advanced guidance law are presented. Preliminary miss distance results are presented with each of the candidate filtering options.