1998 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 1998 calendar year.

Adams, Neil J.; Sargent, Darryl G.

GN&C development for the K-1 launch vehicle

Guidance and Control 1998; Proceedings of the 21st Annual AAS Rocky Mountain Guidance and Control Conference, Breckenridge, CO, 4-8 February 1998 (A98-42527 11-12), San Diego, CA, Univelt, Inc. (Advances in the Astronautical Sciences, vol. 98), 1998, pp. 225-241.

The K-1 vehicle is a new commercial two-stage launch system currently under development; this fully reusable and autonomous vehicle design's stages fly back to the launch site without the benefit any aerodynamic control surfaces, and land on a dry lake bed near the launch site. Draper Laboratory is responsible for the design and implementation of the guidance, navigation, and control (GN&C) algorithms and software required for autonomous flight, as well as the integrated testing of the GN&C hardware and software. The on-board GN&C system is being designed to accommodate a variety of unique flight characteristics, including nearly full autonomy of the vehicle from the ground, low on-orbit power consumption, and fail-safe operations. We summarize the approach being taken to satisfy these unique GN&C design requirements.

Agustin, Ramses M. (MIT; Draper);
Mangoubi, Rami S.; Hain, Roger M.; Adams, Neil J. (Draper)

Robust failure detection for reentry vehicle attitude control systems

AIAA Guidance, Navigation, and Control Conference and Exhibit, Boston, MA, 10-12 August 1998

This paper presents a robust failure detection methodology for the attitude control system of reusable launch vehicles (RLVs). In particular, we consider the problem of estimating the thrust from multiple jets firing from the Reaction Control System (RCS), as well as the related problem of distinguishing between failures in the RCS and the aerosurfaces. For accurately known vehicle and sensor models, the Kalman filter provides the optimal estimate for the jet thrust, in the least-squares sense. During reentry, however, plant model uncertainties are a major problem for the filter, as the vehicle's aerodynamics vary widely with rapidly changing Mach number, making gain scheduling impractical. Consequently, the Kalman filter's performance degrades. Even if the Mach number were accurately known, rapid gain scheduling may not be desirable or even possible, due to the large data storage requirements it entails. Transient, robust H-infinity or game-theoretic filters are designed for the Space Shuttle Orbiter's attitude determination system. Simulation results demonstrate that the robust filters can be insensitive to plant model uncertainties over a wide range of Mach numbers, while remaining sensitive to failures in the aerosurfaces and the RCS jets.

Allinger, D.F.; Rosch, G.; Kuchar, J.K.

An integrated safety-analysis methodology for emerging air-transport technologies

1998 Proceedings of the International Symposium on Product Quality and Integrity, Anaheim, CA, 19-22 January 1998, pp. 260-267

We demonstrate an approach to integrating reliability, performance, and operational procedures modeling into a system safety analysis. Our methodology is distinguished by its ability to merge system design information with the dynamic parameterization of a system's situation in order to measure accident statistics and reliable system operation. As an application of this methodology, we have considered the problem of simultaneous, but independent approaches of two aircraft on closely spaced parallel runways, Independent Approaches on Parallel Runways, or IAPR. The IAPR concept presumes a flight-deck-based navigation, communication, surveillance, and alerting system. The potential exists for an aircraft on either runway to deviate off course toward another aircraft on the parallel runway. A variety of simulation projects have been undertaken to explore alerting systems for the parallel approach situation, but the major limitation of statistical information generated from these studies is that it represents conditional safety statistics given the flight track simulated. To remove this conditioning, we have shown how to apply the probability of flying the approach with a given flight track using Markov analysis to compute this probability. The results show how each of the probabilities of reliable operation, accidents, and false alarms vary as a function of runway spacing.

Anderson, Jamie

The vorticity control unmanned undersea vehicle - an autonomous robot tuna

AIAA Space Automation and Robotics Technical Committee (SARTC) Robotics Forum, Cambridge, MA, 16-17 July 1998

In recent years, research in the propulsion and maneuvering flow mechanisms used by fish and marine mammals has demonstrated the utility of bio-propulsion for undersea vehicles. Today's underwater vehicle missions demand broad capabilities: high transit speed, long range/duration, maneuverability, and cruising performance without compromising maneuverability. In this paper we present the latest developments in the Draper Laboratory prototype flexible-hull UUV, which 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. Across the broad spectrum of fish form

and movement, tunas are most desirable as a vehicle platform as they are very streamlined, relatively rigid in the forebody, and propel with low-amplitude movements in conjunction with a high-performance hydrofoil (caudal fin). Vorticity control propulsion is well suited to today's underwater missions as it will enable greater transit distances and speeds and order of magnitude improvements in maneuverability, particularly while in close proximity to boundaries and underwater objects.

Anderson, Jamie

The vorticity control unmanned undersea vehicle - a biologically inspired autonomous vehicle

International Symposium on Seawater Drag Reduction, sponsored by NUWC, Newport, RI, 22-24 July 1998, pp. 479-483

Recent interest in improving the operating performance of unmanned undersea vehicles (UUVs) has led to the notion of mimicking the form and function of fish and marine mammals. Often, capabilities of the biological systems far exceed those of modern engineered vehicles with conventional power supplies and propulsors. Of particular interest are the possible energetic benefits and the improved maneuvering characteristics of fish-like propulsion. In this paper we describe the first autonomous mission-scale fish-like vehicle in development at Draper Laboratory, the Vorticity Control UUV (VCUUV). Named after the flow control mechanisms inherent in fish swimming, the VCUUV mimics the form and movement of a large yellowfin tuna. Designed and built as a proof-of-concept test platform, the VCUUV will provide unambiguous measurements of the power required to swim and maneuver like a tuna. Drag reduction will be investigated by comparing the power consumed during swimming and that required for straight coasting at the same speed.

Anderson, Jamie

Vorticity control and maneuvering - an autonomous fish-like underwater vehicle

Proceedings of the 3rd MWA Conference on Technology and the Mine Problem, Monterey, CA, 6-9 April 1998

In recent years, research in the propulsion and maneuvering flow mechanisms used by fish and marine mammals has demonstrated the utility of bio-propulsion for undersea vehicles. Despite advances in unmanned undersea vehicle (UUV) technlogy, little progress has been made in improving propulsive efficiency and maneuverability. Most underwater vehicle designs employ a conventional propeller as the main propulsor and shrouded thrusters and/or control fins for maneuvering. Two types of vehicle designs are prevalent: torpedo-shaped bodies streamlined for speed and range, or box-shaped bodies designed for maneuvering and station keeping. Unfortunately, most UUV missions require all of these capabilities: high transit speed, long range/duration, maneuverability, and station keeping ability. Thus we look to fish as a potentially optimal UUV design in that they are able to cruise great distances at significant speed, maneuver in tight spaces and accelerate and decelerate quickly from rest or low speed. In this paper we present the latest developments in the Draper Laboratory prototype flexible-hull UUV, which 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. Across the broad spectrum of fish form and movement, tunas are most desirable as a vehicle platform as they are very streamlined, relatively rigid in the forebody, and propel with low amplitude movements in conjuction with a high-performance hydrofoil (caudal fin). Vorticity control propulsion is well suited to the underwater mine problem as it will enable greater transit distances and speeds and order of magnitude improvements in maneuverability, particularly while in close proximity to boundaries and underwater objects.

Anderson J.M.; Streitlien K.; Barrett D.S.; Triantafyllou M.S.

Oscillating foils of high propulsive efficiency

Journal of Fluid Mechanics, vol. 360, 10 April 1998, pp. 41-72

Thrust-producing harmonically oscillating foils are studied through force and power measurements, as well as visualization data, to classify the principal characteristics of the flow around and in the wake of the foil. Visualization data are obtained using digital particle image velocimetry at Reynolds number 1100, and force and power data are measured at Reynolds number 40,000. The experimental results are compared with theoretical predictions of linear and nonlinear inviscid theory and it is found that agreement between theory and experiment is good over a certain parametric range, when the wake consists of an array of alternating vortices and either very weak or no leading-edge vortices form. High propulsive efficiency, as high as 87%, is measured experimentally under conditions of optimal wake formation. Visualization results elucidate the basic mechanisms involved and show that conditions of high efficiency are associated with the formation on alternating sides of the foil of a moderately strong leading-edge vortex per half-cycle, which is convected downstream and interacts with trailing-edge vorticity, resulting eventually in the formation of a reverse Karman street. The phase angle between transverse oscillation and angular motion is the critical parameter affecting the interaction of leading-edge and trailing-edge vorticity, as well as the efficiency of propulsion.

Antkowiak B.M.; Nelson F.C.

Rotodynamic modeling of an actively controlled magnetic bearing gas turbine engine

Journal of Engineering for Gas Turbines and Power - Transactions of the ASME, vol. 120, no. 3, July 1998, pp. 621-625

This paper summarizes the development of a finite-element rotordynamic solution used in a closed-loop simulation for a magnetic bearing rotor system in a gas turbine engine. A magnetic bearing controlled rotor is analyzed, and the state dynamics matrix [A], the shaft control influence matrix [B], and the sensor matrix [C] are constructed. Bode plots of the state-space transfer function are also constructed and compared to the results of the rotor dynamic model.

Ash, Michael E. (Draper);
Morris, Harold D. (Systron Donner, Concord, CA);
Peters, Rex B. (AlliedSignal Aerospace, Redmond, WA)

Proposed IEEE accelerometer standard and other inertial sensor standards

Collection of Technical Papers, AIAA Guidance, Navigation, and Control Conference and Exhibit, part 2, Boston, MA, 10-12 August 1998, pp. 1322-1330.

A new Accelerometer Specification Format Guide and Test Procedure is being considered by the IEEE for publication as its Std. 1293. It provides guides for specifying accelerometer performance and gives detailed test procedures for verifying compliance with requirements. It also gives the principles of operation of pendulous torque rebalance accelerometers, vibrating beam accelerometers, and open- and closed-loop micromechanical accelerometers on a silicon chip. There are annexes on filtering, noise, and transient analysis techniques, on calibration and modeling techniques (multipoint ramble and vibration and shock test analysis), and on geophysical effects in inertial instrument testing. Also discussed in this paper are the angular-accelerometer, Single- and Two-Degree-of-Freedom Spinning Wheel Gyro, Laser Gyro, and Interferometric Fiber-Optic Gyro standards that have been written by the Gyro and Accelerometer Panel. A new Coriolis Vibratory Gyro document that is being developed by the panel is also discussed.

Bello, M.G.

Comparison of parametric and nonparametric ROC confidence bound construction in the context of acoustic/magnetic fusion systems for mine-hunting

Proceedings of the SPIE - The International Society for Optical Engineering Conference, Orlando, FL, 13-17 April 1998, vol. 3392, part 1-2, pp. 1163-1178

Traditional receiver operating characteristic (ROC) curve confidence bound construction methods are based on the use of asymptotic results or idealized models. In this work, an approach to ROC confidence bound construction is developed for both per-token and cumulative ATR system performance, based on the use of the bootstrap method. This technique is nonparametric, and has been applied to problems in which traditional confidence bounds would be difficult, if not impossible, to construct. In addition, the technique is able to encompass the effects of training data and evaluation data variability in a single unified approach. Results are presented contrasting parametric and bootstrap-based cumulative ROC curve confidence bounds for three distinct sets of side-scan sonar data. Finally, bootstrap-based bounds are developed in the context of acoustic/magnetic fusion systems.

Carman, Gilbert L.; Ives, Dallas G. (NASA, Johnson Space Center, Houston, TX);
Geller, David K. (Draper)

Apollo-derived Mars precision lander guidance

AIAA Atmospheric Flight Mechanics Conference and Exhibit, Boston, MA, 10-12 August 1998

The Earth entry guidance algorithm from the Apollo lunar program has been adapted as a candidate guidance algorithm for Mars precision landing missions. An overview of the Apollo guidance, the modifications for Mars use, and the development of a Mars reference trajectory is given. The derivation of the control equation and gain computations are reviewed in detail. Impacts of the parachute deploy criteria upon guidance accuracy and target selection with respect to the vehicle maneuver capability envelope are discussed. Results are presented for the Monte Carlo footprint resulting from expected dispersions using this algorithm with a preliminary 2001 Mars lander configuration as an example.

Cefola, Paul J. (Draper);
Draim, John E. (Ellipso, Inc., Washington, DC)

Drag reduction in elliptic orbits by controlling solar array aspect

AIAA/AAS Astrodynamics Specialist Conference and Exhibit, Boston, MA, 10-12 August 1998

Communications performance considerations suggest that nontraditional, eccentric orbits with relatively low perigee heights offer economic advantages in the development of global mobile communications systems. However, the low perigee height results in significant atmospheric drag and frequent station-keeping maneuvers. This is particularly the case if the spacecraft is equipped with sizable solar panels. The current paper investigates the possibility of orienting the solar panels parallel to the direction of the motion (in 'trail') in the portion of the orbit near perigee.

Cho, S.T.; Erdmann, F.M.

An on-chip hermetic packaging technology for micromechanical devices

Technical Digest, Solid-State Sensor and Actuator Workshop, Hilton Head Island, SC, 8-11 June 1998, pp. 229-232

A novel on-chip hermetic packaging technology using electrostatic bonding and eutectic sealing is presented. Planarization of the lead transfers is not required since the leads conform to the interfacial layer by forming a eutectic seal with the bonding layer (amorphous polysilicon). The leads also have an isolation resistance of >4 G Omega/sq. This approach requires only one masking step and exhibits low induced stress, high thermal shock resistance, and a leak rate of <10/sup -16/SCCM.

Clough, Anne; Heckathorn, Jasjit

Tailoring the software process: one size does NOT fit all

Proceeding of the SEPG (Software Engineering Process Group) 98 Conference, Chicago, Illinois, 9-12 March 1998

As organizations take steps to increase their capability and efficiency in developing software, one important aspect in improving their software process is to define a standard software development process that will be used by all software projects. In most organizations, however, this standard process needs to be tailored to fit the attributes and characteristics of individual projects. To address this problem, a unique approach to tailoring has been developed at Draper Laboratory that accommodates a wide range of projects. A Project Tailoring Notebook, created to summarize critical Capability Maturity Model (CMM) concepts, includes worksheets, guidelines, and templates that provide a structured way to approach tailoring. The Tailoring Notebook leads task leaders systematically through the decisions that they need to make in the project planning stage. The tailoring worksheets are then evaluated by a process evaluation team to ensure that the level of tailoring is appropriate, given the characteristics of the project. After approval, these worksheets become input to the writing of the project Software Development Plan and are used by Software Quality Assurance to ensure that projects follow the

approved process. In this presentation, we define the components of the tailoring process, look at worksheet and template examples from the Project Tailoring Notebook, and describe how this is applied to a software development project.

Cook, Brian D.; Lee, Soo-Young

PYRAMID - a hierarchical, rule-based approach toward proximity effect correction - Part II: correction

1996 5th International Symposium on Semiconductor Manufacturing, ISSM, Tokyo, Japan, IEEE Transactions on Semiconductor Manufacturing, vol. 11, no. 1, February 1998, pp. 117-128

One of the major limiting factors with electron beam lithography in the production of high-resolution patterns is the distortion of the exposed region by electron scattering. This distortion (known as the proximity effect) imposes a severe limitation on the ultimate resolution attainable with electron beam lithography. It is therefore important to examine ways in which the proximity effect can be reduced. We are currently developing a novel proximity effect correction scheme called PYRAMID, which takes a hierarchical, rule-based approach toward correction. In Part I, our fast and accurate exposure estimation scheme is presented. In this paper (Part II), we present the correction hierarchy employed in PYRAMID and analyze its accuracy using both simulation and experimental results demonstrating PYRAMID's ability to correct circuit patterns with minimum feature sizes down to 0.1 μm on homogeneous substrates successfully.

Cunningham, B.T.; Bernstein, J.J.; Seltzer, D.; Hom, D.

Micromirror pixel addressing using electromechanical bistability

Technical Digest, Solid-State Sensor and Actuator Workshop, Hilton Head Island, SC, 8-11 June 1998, pp. 285-287

In this work, a novel bistable array of micromirrors (BAMM) has been designed, fabricated, and tested that uses the electromechanical properties of the flexural hinged mirror elements to store the desired individual mirror states. Using the mirror structures as electromechanically bistable storage devices, pixels can be addressed individually without the use of integrated static random access memory (SRAM) cells beneath each element. Through the elimination of integrated RAM circuitry, the mirror array fabrication sequence is greatly simplified, and decreased yielded die costs are expected compared to fabrication that relies on the combined yield of the memory and mirror processes.

Dowdle, John R.; Kourepenis, Anthony; Appleby, Brent

A miniature micromechanical INS/GPS for 5-inch Navy munitions

AIAA Guidance, Navigation, and Control Conference and Exhibit, Boston, MA, 10-12 August 1998

Under the Competent Munitions Advanced Technology Demonstration (CMATD) Program, Draper Laboratory is developing enabling technologies for low-cost miniature guidance systems that will be used in the future to enhance the accuracy of conventional tactical Navy and Army weapons. In particular, a miniature INS/GPS guidance system that occupies approximately 8 cu in. has been developed using a Draper Micromechanical Inertial Sensor Assembly implemented as six laminated multichip modules (MCM-L) and a Rockwell Collins GPS receiver built from two MCM-L modules. The CMATD flight computer combines the GPS pseudo-range and delta-range measurements with micromechanical inertial sensor measurements to produce a 50-Hz navigation solution, and employs the navigation data with a pre-specified aim-point location to generate guidance commands, also at a 50-Hz data rate. An autopilot algorithm computes commands for the canard actuator subsystem to steer the projectile to the desired aim-point. This paper describes the development of the CMATD flight test projectiles, focusing specifically on the miniature INS/GPS guidance system. Results from high-g testing and hardware-in-the-loop simulations are presented, and plans for a December 1998 flight test are discussed

Draim, John E. (Ellipso, Inc., Washington, DC);
Cefola, Paul; Proulx, Ron; Larsen, Duane (Draper)

Designing the Ellipso satellites into the elliptical orbit environment

IAF, International Astronautical Congress, 49th, Melbourne, Australia, September 28-October 2, 1998

The unique three-hour sun-synchronous elliptic orbits associated with the Ellipso constellation present a relatively new space environment in which satellites must operate. At and around perigee, the satellites experience atmospheric drag that tends to decay the orbit; this drag effect is exacerbated by a very large solar array cross-section area. These elliptic orbit satellites also pass through the Earth's orbital debris fields at a higher than normal orbital velocity and thus may encounter more debris in this region. The two orbit planes chosen for the Borealis subconstellations are sun-synchronous and remain 'edge-on' to the sun; thus the Ellipso spacecraft will always be in Earth shadow for a small portion of each orbit. Spending more time near apogee, the satellites experience more solar radiation pressure on the large solar arrays; this can result in significant long-term changes in the semimajor axis (either increase or decrease). The Ellipso designers must also consider the trapped particle radiation experienced while traversing the Earth's electromagnetic field and use components that are radiation-hardened or radiation-resistant. The designer must also consider mission requirements impacted by changing Earth footprint size, varying electronics link margins, etc. The designers of the Ellipso system have analyzed all of the above effects on the Ellipso satellites due to their elliptic orbits, and are incorporating those features deemed necessary to ensure the reliable operation of these satellites during their lifetimes.

Faiz, Robert

Reliable structural integration of micro-devices and electronics used for remote query sensor applications

SPIE Conference on Smart Structures and Materials, San Diego, CA, 1-6 March 1998

This paper addresses the ongoing, internally funded project at Draper Laboratory assessing the robustness and durability of structurally integrated (imbedded) micromechanical and electronic systems (MEMS) technologies when subjected to typical post-processing and operational environments. The MEMS devices evaluated include both proprietary, Draper Laboratory developmental and representative commercial off-the-shelf (COTS) micro-sensor systems. The assessment effort was preceded by summarizing typical potential applications for structurally integrated sensors systems. Applications where the inherent attributes of

structurally integrated, miniature, remote query sensor systems can be effectively used were highlighted. This initial applications assessment provided the focus for the major task assessing the durability of MEMS/MCM devices where integrated into advanced materials (such as composite structures). Data and observations resulting from this assessment is the foundation for addressing all the key design issues encountered when the integration of micromechanical, remote query sensor packages (sensors, microprocessors, power, and telemetry) is included in new engineered structural designs. The preliminary results of this durability assessment effort show that many of the MEMS and MCM technology-based devices can be successfully integrated into advanced material structures with a corresponding increase in reliability. Continuing assessment efforts appear to verify the initial findings.

Fischer, Jack D.; Cefola, Paul J.; Proulx, Ronald J.

Modeling catastrophic decay orbits through perigee

Proceedings of the AAS/AIAA Space Flight Mechanics Meeting, Monterey, CA, 9-11 February 1998, Advances in Astronautical Sciences, vol. 99, part 2, pp. 1215-1234

As highly eccentric orbits decay, their passage through perigee acts as a major perturbation due to highly dynamic atmospheric effects. In order to better model the catastrophic decay these orbits face, the authors briefly analyze modeling errors for various atmospheric effects. Using data from an upper stage SL-6 Molniya rocket body, the errors identified in these analyses are used to define a functional representation of the process noise. The results of incorporating this function into a Kalman Filter are presented.

Gai, Eli

Guiding munitions with a micromechanical INS/GPS system

Proceedings of the Israel Annual Conference on Aerospace Sciences, 38th, Tel Aviv and Haifa, Israel, 25-26 February 1998, pp. S2-1 to S2-7

Micromechanical inertial sensors are the current leading-edge technology in the development of guidance systems. Their small size, low cost, and ruggedness make them excellent guidance, navigation, and control sensors. Combined with miniature GPS receivers, they can provide low-cost guidance for munitions with protection against jamming. This paper reviews the micromechanical sensors and systems programs at The Charles Stark Draper Laboratory, Inc., the developer of the first INS/GPS guidance system for the U.S. Navy 5-inch gun.

Gibbons, Kevin A. (USAF, Holloman AFB, NM);
Borenstein, Jeffrey T.; Nokes, David S.; Weinberg, Mark S. (Draper);
Trumper, David L. (MIT, Cambridge, MA)

The design, fabrication, and testing of a micromechanical silicon oscillating accelerometer

Collection of Technical Papers, AIAA Guidance, Navigation, and Control Conference and Exhibit, part 2, Boston, MA, 10-12 August 1998, pp. 1296-1306

This paper describes the design, fabrication, and testing of a micromechanical accelerometer. This Silicon Oscillating Accelerometer (SOA) is a micromechanical dual-oscillator system in which each oscillator, composed of two Si masses suspended on Si flexure beams, is electrostatically driven and sensed in an out-of-phase vibrational resonance mode. The oscillators' natural frequencies shift as the accelerometer's seismic mass, which is connected to the vibrating beams, experiences an input acceleration, and thus loads the beams in tension or compression. The input acceleration is proportional to the natural frequency change of the oscillators. A bulk dissolved-wafer on glass micromachining process was used to build the SOA from single-crystal Si. A sharp resonance was achieved by vacuum packaging the SOA in a leadless ceramic chip carrier. The design effort described includes both closed-form and detailed FEM analyses. Test results, including oscillator natural frequency, instrument quality factor, input acceleration sensitivity, and oscillator temperature sensitivity, are presented. Experimental results are in good agreement with closed-form and detailed analytical results.

Goldman, Wade M.

Modified gage repeatability and reproducibility study for measuring ABMA grade 3 bearing balls

American Society for Quality Measurement Quality Division, 6th Annual Measurement Quality Conference, Cambridge, MA, 15-16 September 1998

In the assembly of ultra-high reliable precision bearings for instruments, each bearing ball must be sized so that the variation between balls is less than 5 millionths of an inch. Similarly, the absolute size of the bearing ball is just as important in order to achieve the proper contact angle, running torque and preload for each bearing assembly. A gage repeatability and reproducibility study, slightly modified, was conducted between three separate facilities in order to quantitatively measure equipment differences within and between facilities. The objectives were to determine reproducibility between facilities and repeatability within a facility, and use the data analysis to improve overall inspection methods if required. This paper describes the test plan and summarizes the data analysis techniques and results.

Hammett R.; Coakley M.; Sevigny D.; Zamojski R.

Automatic performance monitoring enhances Seawolf submarine ship control maintainability

Naval Engineers Journal, vol. 110, no. 2, March 1998, pp. 49-59

This paper discusses capabilities built into the Seawolf Ship Control System (SCS) to enhance maintainability and how those capabilities have proved to be effective during development and initial service. These enhancements include automatic Performance Monitoring and Fault Localization (PM/FL) functions and a maintenance computer containing I/O monitoring functionality to troubleshoot the system. The success of this PM/FL approach demonstrates great promise for future submarines and surface ships, allowing for a reduction in the size of the crew needed to operate and maintain the ship control. But this PM/FL functionality does not come without a price; these complex decision-making algorithms required for PM/FL are difficult to specify, develop, and test. It is also important to note that the effectiveness of Seawolf PM/FL is directly attributed to the redundancy inherent in the fault-tolerant design. The paper describes how this approach has evolved from earlier submarines and some of the experiences to date with Seawolf PM/FL testing and Seawolf ship control maintenance. The paper also summarizes the design of the system, discussing the features of the fault-tolerant architecture that facilitate effective maintenance. The difficulties involved in the specification, design, and exhaustive verification of PM/FL will be described. Some speculations as to how future systems might benefit from automated maintenance features are included.

Hammett, Robert C.

Ultra-reliable real-time control systems - future trends

Conference Proceedings of the 1998 17th AIAA/IEEE/SAE Digital Avionics Systems Conference, DASC, Part 1 (of 2), 31 October 1998 - 7 November 1998, Bellevue, WA

Today's aircrafts use ultrareliable real-time controls for demanding functions. Several approaches to a cost-effective realization of these controls are presented. These include the use of low-cost sensors with digital outputs, digitally-commanded fault-tolerant actuation devices, and interconnecting networks of low-cost data buses; integrating the control and distribution of electrical power with the control system; and an all-digital and shared network approach.

Ho, Nhut (MIT; Draper, Cambridge, MA);
Lozano, Paulo; Martinez-Sanchez, Manuel (MIT, Cambridge, MA);
Mangoubi, Rami (Charles Stark Draper Lab., Cambridge, MA)

A model-based vehicle health monitoring system for the Space Shuttle main engine (orbital maneuvering system)

AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, 34th, Cleveland, OH, 13-15 July 1998

A Vehicle Health Monitoring (VHM) system is designed to detect and isolate failures in the engines of Reusable Launch Vehicles (RLVs). This VHM system takes into account engine failures both in sensors and valves, as well as internal components such as turbopumps, injectors, and the combustion chamber. The algorithm of the VHM system is model-based. Specifically, using information from a thermodynamic model of the engine, together with sensor measurements, a Kalman filter is designed to predict sensor outputs. The residual, or the difference between the predicted and actual measurement, is used by several statistical tests to detect the presence of a failure, and to categorize the failure as a sensor/valve failure or an internal component failure. Sensor and valve failures are then isolated using the generalized likelihood ratio test. Internal component failures, on the other hand, are isolated using the multiple model method. The proposed methodology can be used for online failure detection and isolation (FDI) as well as for postflight analysis. At the engine design stage, it can help determine the detectability and distinguishability of failures given a candidate sensor configuration. The FDI algorithms are applied to a simulation of the Space Shuttle Main Engine to demonstrate their performance.

Hsieh, Peter; Cunningham, Brian (Draper)
Reif, Raphael (MIT)

DC magnetron reactive sputtering of low stree AlN piezoelectric thin films for MEMS application

Materials Research Society Fall Meeting, sponsored by MRS, Boston, MA, 29 November-4 December 1998

Many MEMS devices require piezoelectric excitation and readout to actuate and sense motion of mechanical structures. Aluminum nitride is advantageous for MEMS fabrication because it is compatible with silicon integrated circuit foundry impurity contamination requirements, can be deposited at low temperatures, provides a high piezoelectric coefficient, and is easily patterned using conventional photolithographic techniques. In this work, AlN thin films were deposited on silicon substrates for use in a MEMS silicon membrane ultrasonic resonator. The ultrasonic resonator is configured as a gravimetric sensing device for chemical detection. Issues of concern with regard to device performance and yield include the maximization of the electromechanical coupling constant (k^2), film stress control, and film uniformity; these issues were addressed through a central composite design set of experiments to resolve the film property responses as a function of the deposition parameters. Film characterization was conducted with X-ray diffraction, spectroscopic ellipsometry, and surface profilometry. Optimization of film deposition parameters improved sensor performance and enabled further device miniaturization with the use of thinner films.

Jamoom, Michael B.; Feron, Eric; and McConley, Marc W.

Optimal distributed actuator control grouping schemes

IEEE Conference on Decision and Control, Tampa FL, December 1998, pp. 1900-1905

Two methods are presented for grouping actuators while minimizing performance degradation in distributed control systems with saturation constraints. Method one is based on an open-loop performance metric using controllability Grammians. The grouping problem can be converted into a graph partitioning problem that admits a solution via linear matrix inequality (LMI) optimization techniques. Method two is based on closed-loop optimal control performance for saturating control systems. In this case, we find that grouping the actuators allows on-line control design to account for control saturation. It was determined that the grouping problem is insensitive to changes in actuation authority.

Kang, David; Anderson, Jamie; DeBettito, Paul

Draper unmanned vehicle systems

IFAC Intelligent Autonomous Vehicles, Madrid, Spain, 25-27 March 1998

The Draper Small Autonomous Aerial Vehicle (DSAAV), MITy and SMART micro-rovers, Companion mini-rover, and Vorticity Control Unmanned Undersea Vehicle (VCUUV) are highlighted. 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. VCUUV is a flexible-hull UUV that propels and maneuvers like a tuna.

Kantsiper, Brian; Weiss, Stanley

An analytic approach to calculating Earth coverage

Advances in the Astronautical Sciences, volume 97, part I, pp. 313-332, March 1998

One of the primary metrics used to describe a constellation is its percent coverage, i.e., what percent of the surface of the Earth can be seen by the satellites at any given time. This parameter is typically evaluated numerically, requiring the use of a very dense grid. When there are a large number of satellites or fine precision requirements, this method can be rather slow and becomes even slower if one is interested in multiple satellite coverage. This paper discusses an alternate approach to dramatically decrease the calculation time. The new approach is an analytical method using the inclusion-exclusion principle of set theory. It is found that the area of the region on a sphere defined by the overlap of circles on that sphere is integrable. A spherical Earth and nadir-pointing satellites are assumed. The new method shows a significant improvement in accuracy over traditional numerical integrations for similar execution times.

Kauppinen, John; Williams, John

Development and implementation of an accelerometer slip ring lubricant

24th Joint Services Data Exchange (JSDE) Symposium, Anaheim, CA, 16-19 November 1998

High-performance floated accelerometers use slip rings to transfer power and signals from a stable member to a rotating member. These slip rings operate while submerged in a fluorocarbon, which provides accelerometer flotation, damping, and thermal transfer. A typical accelerometer employs a slip ring having about 20 circuits with only ~0.020 in between circuits. This close proximity between circuits can result in electrical shorts from conductive wear debris bridging circuits or shorting to case. For these reasons, Draper Laboratory sought to develop and implement a fluorocarbon-soluble gold lubricant to eliminate slip ring wear and the accompanying electrical shorts. A halogenated aryl ester, Br_3E_2, was developed at Draper Laboratory that eliminates electrical shorts associated with slip ring wear. The additive also greatly diminishes the wear of the slip ring component (rings) responsible for generating the debris capable of causing electrical shorts. The resultant increase in slip ring reliability will greatly increase and extend the accelerometer and IMU reliability.

Kerrigan D.C.; Roth R.S. (Draper); Riley P.O.

The modeling of adult spastic paretic stiff-legged gait swing period based on actual kinematic data

Gait & Posture, vol. 7, no. 2, March 1998, pp. 117-124

With the ultimate goal to better demonstrate the biomechanics of spastic paretic stiff-legged gait, we simulated the motion of this gait disability, based on actual kinematic gait data. We created and applied a seven-link-segment forward dynamic model to the gait kinematics of five adult subjects with this gait disability as a result of stroke. Trunk and limb segment torques developed during the affected limb's swing period of gait were calculated via inverse dynamic techniques from the measured kinematic data and incorporated into the forward dynamic model to simulate motion. In each case, the simulated motion corresponded to the directly measured kinematics. The hip and knee torques were then altered to predict potential resultant changes in knee flexion. Preliminary results suggest a stronger effect of hip torque than knee torque on knee angle, which also qualitatively corresponded with clinical data. This study demonstrates the feasibility of forward dynamic modeling based on actual clinical data and provides a further means to analyze potential mechanisms of this gait disability.

Klumpp, A.R. (JPL, Pasadena, CA); Smithwick, R.M.; Eyles, D.E. (Draper); Jordan, J.F. (JPL, Pasadena, CA); Woeltjen, L.H.

Concepts for Project Galaxy

Collection of Technical Papers, AIAA/AAS Astrodynamics Specialist Conference and Exhibit, Boston, MA, 10-12 August 1998, pp. 57-62

Project Galaxy, proposed at JPL, will enable students, mission planners, and astronomy buffs to fly to any modeled planet, satellite, solar system, or black hole in the galaxy or beyond. The Galaxy flight simulator will enable its pilots to observe modeled objects true to life, including their surfaces, motions, and behavior. Clicking on modeled objects produces multimedia displays of background data. Pilots can ride along on missions currently in progress, future missions now being designed, and missions that they design themselves. Relativistic effects will be modeled so that pilots can fly near light speed on round-trip missions to other stars while observing the effects on clocks, constellation shapes, etc. Users can modify and extend Galaxy's capabilities to incorporate their own flight software and hardware models, and even their own celestial bodies. Project Galaxy will provide educational partnerships, including thesis opportunities for developing new software components. The simulator is expected to serve as a repository for scientific models of celestial objects indefinitely.

Kondoleon, Anthony S.; Kelleher, William P.

High-bandwidth, low-loss magnetic suspension system for turbomachinery

Proceedings of the 1998 International Gas Turbine & Aeroengine Congress & Exhibition, 2-5 June 1998, Stockholm, Sweden

Magnetic bearings, unlike traditional mechanical bearings, consist of a series of components that, when mated together, form a stabilized system. The correct design of the magnetic bearing actuators will provide a cost-effective device with low power requirements. The necessity of stability, which a magnetic suspension control system requires in both gain and phase margin, demands the actuators have sufficient bandwidth over the operating range. This paper presents designs for both radial and axial actuators that have attained both high bandwidth and low loss in operation. Test data that verifies the actuator models are presented. Applications of this technology for turbomachinery are described. These include fully magnetically levitated rotor systems, tip clearance control systems, and noise and vibration control systems.

Kourepenis, A.; Borenstein, J.; Connelly, J.; Elliott, R.; Ward, P.; Weinberg, M.

Performance of MEMS inertial sensors

IEEE 1998 Position Location and Navigation Symposium, Palm Springs, CA, 20-23 April 1988, pp. 1-8

Advanced microfabrication techniques have produced small, low-cost silicon inertial sensors of high performance, ruggedness, and inherent symmetry. When integrated with applications specific integrated circuits (ASICs), the sensors fit in a 3-cm-per-side flat pack and operate from a single 5-Vdc supply. They have been evaluated in automotive antiskid and traction control systems, and in guided munitions. Multichip module (MCM) versions instruments enable guided munitions to improve the accuracy of the Navy 5-in/54 gun platform. These sensors are fabricated using a dissolved wafer process that features single-crystal silicon anodically bonded to a glass substrate, resulting in a sensor die size approximately 1 mm. Uncompensated bias and scale factor performance of 0.5 degrees/s and 1.0% for the gyroscope, and 30 mg and 0.5% for the accelerometer are nominally demonstrated over the temperature range of -40 degrees C to +85 degrees C. Stability over smaller temperature ranges of 0.5 degrees C has surpassed 10 degrees/h (0.003 degrees/s) in overnight (6-h) tests, while the companion accelerometer nominally demonstrates sub milli-g performance. Angle random walk of 0.25 degrees/$\sqrt{h}$ is typical for the gyros with best to date performance of 0.05 degrees/$\sqrt{h}$ observed, while the accelerometers provide

velocity random walk of 5 cm/s/√h. When compensated for performance across the temperature range of -40 degrees C to +85 degrees C, instrument scale factor performance surpasses 200-ppm stability, and bias uncertainty is less than 50 degrees/h and 1 mg for the gyro and accelerometer, respectively. The robustness of these is demonstrated in the ability to survive air guns tests in excess of 60000 g. This paper discusses measured performance, with the principal focus on recent gyro and accelerometer instrument test results. Associated electronics, controls, and applications issues are also addressed.

Lawton J.A.; Jesionowski R.J.; Zarchan P.

Comparison of four filtering options for a radar tracking problem

Journal of Guidance, Control, and Dynamics, AIAA, vol. 21, no. 4, July-August 1998, pp. 618-623

Four different filtering options are considered for the problem of tracking an exoatmospheric ballistic target with no maneuvers. The four filters are an alpha-beta filter, an augmented alpha-beta filter, a decoupled Kalman filter, and a fully coupled extended Kalman filter. These filters are listed in the order of increasing computational complexity. All of the filters can track the target with some degree of accuracy. Although the pure alpha-beta filter appreciably lags the other filters in performance for this problem, its augmented version is very competitive with the extended Kalman filter under benign conditions. Perhaps the most surprising result is that under all conditions examined, the decoupled (linear) Kalman filter, which is at least an order of magnitude less computationally complex than the fully coupled extended Kalman filter, performs essentially the same as the extended Kalman filter.

Laznicka, Oldrich

Micro-Optical Mechanical Fiber-Optics Sensor (MOMFOS)

Trends in Optics and Photonics, sponsored by Optical Society of America, 1998, vol. 23, pp. 84-88.

Over the past 15 years, fiber-optic sensor technology evolved around components that were significantly larger than the wavelength of an optical source. Those restrictions imposed a size limit on a fiber-optic sensor and associated optical processing components. By reducing an optical component's dimensions to that of an optical wavelength, new devices can be envisioned. Recently, Brent E. Little from an MIT group under Prof. Haus' leadership has proposed a new type of displacement readout sensor based on the combination of the Whispering Gallery Modes (OGMs) in a microsphere and a Mach-Zehnder (MZ) interferometer. This approach is an excellent candidate for a high-performance readout for a micromechanical sensor without the limits imposed by a current capacitive readout. Initial theoretical and experimental basis shows that displacement resolutions on the order of 0.01 picometer can be achieved with available technology. For example, initial calculation shows that a micromechanical gyroscope readout limit below 0.01 deg/h is attainable with this type of readout. This paper introduces a new approach for a multiplexed sensor combining micromechanical and fiber-optic technology.

Lozano, Paulo; Martinez-Sanchez, Manuel (MIT, Cambridge, MA);
Ho, Nhut (MIT; Draper, Cambridge, MA);
Mangoubi, Rami (Draper)

The use of vibration data for liquid rocket health monitoring

AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, 34th, Cleveland, OH, 13-15 July 1998

An approach is presented to the construction of a liquid rocket health monitoring system capable of using both vibratory and thermodynamic data. Preliminary results are obtained in the area of vibration data tracking/identification, using as a testbed a low-order linear dynamic model of the Space Shuttle main engine high-pressure fuel turbopump. Limitations and future extensions are discussed.

Marchand, Francis P., Jr.

CVD TiC coated balls in bearing applications

24th Joint Services Data Exchange (JSDE) Symposium, Anaheim, CA, 16-19 November 1998

This paper discusses the use of a chemically vapor deposited (CVD), titanium carbide (TiC) coating on a 440C stainless steel substrate ball in bearing applications. Ball design and quality requirements and coating process definitions will be provided for background into the selection of a CVD TiC ball. The theory for the use of these balls in bearing applications is discussed. Industry has used these balls in both high-speed bearings as well as in slow-speed operation. Both applications have benefited from higher yields and longer reliability, which offset the initial higher cost of the CVD TiC balls. Performance data of a very slow-speed bearing comparing the use of CVD TiC coated balls and standard 440C balls is furnished.

McConley, M.W. (Draper);
Dahleh, M.A.; Feron, E. (MIT, Cambridge, MA)

Polytopic control Lyapunov functions for robust stabilization of a class of nonlinear systems

Journal: Systems & Control Letters, vol. 34, no. 1-2, 25 May 1998, pp. 77-83

We develop a method for computing a region in state space over which a nonlinear system is guaranteed by a given polytopic control Lyapunov function to be stable in closed loop under some appropriate control law. For systems that are nonlinear in only a few state variables, the procedure is computationally tractable. The computation time required to evaluate stability over each cone comprising a level set of the Lyapunov function is exponential in the number of "nonlinear states" but otherwise polynomial in the dimension of the full state space. Control constraints and robustness to bounded disturbances are easily incorporated.

Nazarenko, Andrey I. (Center for Program Studies, Moscow, Russia);
Cefola, Paul J. (Draper);
Yurasov, Vasiliy (Space Research Center 'Kosmos', Moscow, Russia)

Estimating atmosphere density variations to improve LEO orbit prediction accuracy

Proceedings of the AAS/AIAA Space Flight Mechanics Meeting, Monterey, CA, 9-11 February 1998, Advances in Astronautical Sciences, vol. 99, part 2, 1998, pp. 1235-1264

An atmosphere density tracking process that operates in parallel to the orbit determination process is introduced. The atmosphere tracking process employs data from

multiple satellites. The atmosphere tracking process includes separate procedures for constructing the atmosphere density variations and for estimating the true ballistic coefficient of the satellites employed. The process also includes procedures for forecasting the atmosphere's density at future times. Practical implementation of this process allows construction of a unique system for upper atmosphere state monitoring.

Neelon, Joseph G. Jr.; Cefola, Paul J.; Proulx, Ronald J.

Current development of the Draper semianalytical satellite theory standalone orbit propagator package

Advances in the Astronautical Sciences, vol. 97, part II, pp. 2037-2051, March 1998

Early development of the Draper Semianalytical Satellite Theory (DSST) was motivated by the goal of a nonsingular, semianalytical theory that combined the best characteristics of existing Numerical and Semianalytical Satellite Theories. By early 1983, the Draper Goddard Trajectory Determination System (GTDS) implementation of the DSST included the major physical models: higher-order geopotential, atmospheric drag, lunar-solar point masses, and solar radiation pressure. To provide greater access to the DSST, a standalone version that operated separately from GTDS was constructed. GTDS and the standalone each developed through incremental changes, but in different directions. Currently, an effort is in progress to improve the accuracy and maintainability of the standalone. The improvements include new models for the coordinate system reference (J2000), geopotential (50 x 50), and solid Earth tides, and modifications to the short-periodic model. The most recent application of this standalone is the Automated Station-Keeping Simulator (ASKS) tool for satellite constellations.

Phillips, Richard; Guinon, Walter; Setterlund, Roy (Draper);
Giustino, Antonio (Draper; MIT, Cambridge, MA; USAF, Washington, DC)

A low-cost low power INS/IGPS spacecraft attitude determination system

ION GPS-98, Proceedings of the 11th International Technical Meeting of the Satellite Division of the Institute of Navigation, Nashville, TN, 15-18 September 1998, pp. 1819-1829

The anticipated proliferation of small low-cost communication and science satellites with modest pointing requirements and correspondingly limited power, mass, and cost budgets calls for a very low-volume, -mass, -power, and -cost attitude determination system. Micromechanical inertial sensors and an interferometeric GPS (IGPS) attitude determination receiver potentially offer such a system. Power consumption by the GPS receiver can be reduced by turning off the RF front end, the frequency synthesizer, the reference oscillator, and the digitizer for brief intervals of time while using the inertial system to maintain adequate attitude knowledge and to simplify obtaining subsequent IGPS attitude updates without time-consuming integer ambiguity resolution. The study predicts the accuracy of such a system as a function of inertial instrument quality, antenna array geometry, and the interval between IGPS measurements. Depending on the exact values chosen, system power consumption on the order of one watt or less can be achieved. Accuracies in the 0.1- to 0.5-deg regime are readily achievable. Results are presented using actual IGPS measurements blended with actual micromechanical gyro data. Modeling assumptions and filter tuning are discussed as well as the importance of 'model-based' estimation techniques to further improve system performance. Volume and weight projections are based on existing technology and hardware.

Piedmonte, M.D.; Meckl, P.H.; Nwokah, O.D.I.; Franchek, M.A.

Multivariable vibration control of a coupled flexible structure using QFT

Journal: International Journal of Control, vol. 69, no. 4, 10 March 1998, pp. 475-498

Quantitative feedback theory (QFT) is a valuable control strategy for multivariable systems that contain parametric uncertainty. This paper uses multivariable QFT to design an internal model reference loop (IMRL) controller. The QFT IMRL method allows a single controller to be designed for large time-invariant parameter variations by forcing the system transfer function matrix to be diagonally dominant. The controller architecture causes the coupled system to behave like the uncoupled system with proper choice of reference model. The design method is extended to discrete time by using a pseudo-continuous time (PCT) approach. The control application is extended to robust disturbance rejection rather than robust tracking by designing an outer-loop controller to reduce the sensitivity of each diagonal element. The structure to be controlled is a two-degree-of-freedom flexible beam with variable coupling. The result of the control method is one single discrete decentralized controller able to robustly reject disturbances with nearly identical performance for a large variation in coupling and inertia.

Proulx, Ronald; Cefola, Paul (Draper);
Smith, James (USAF, Washington, DC);
Draim, John (Ellipso, Inc., Washington, DC);

Ellipso Gear Array coordinated elliptical/circular constellations

AIAA/AAS Astrodynamics Specialist Conference and Exhibit, Boston, MA, 10-12 August 1998

This paper analyzes the development of a hybrid elliptical/circular equatorial constellation concept, the Gear Array (patent pending). In this hybrid constellation, the relative motion between satellites from the two subconstellations is commensurable. In this paper, we survey the construction, stability, maintainability, and usefulness of the Gear Array concept.

Rozelle, David (Litton Guidance and Control, Woodland Hills, CA);
Carson, Robert (Draper);
Krepp, Dennis (USAF, Systems Program Office, Hill AFB, UT)

IFOG technology development for strategic guidance applications (interferometric fiber-optic gyro)

AIAA Guidance, Navigation, and Control Conference and Exhibit, Boston, MA, 10-12 August 1998

This paper documents the ongoing effort to develop IFOG (interferometric fiber-optic gyro) technology, within a five-year time frame, capable of supporting strategic guidance applications (SCIFOG). Program goals are to develop key technologies in critical IFOG components and identify high-risk areas for strategic-grade IFOG development. Three major objectives have been successfully achieved: the preparation of a program plan for IFOG technology development; the design, fabrication, and test of three 3.2-km proof-of-concept fiber-optic gyros; and the design, fabrication, and developmental test of two 3.2-km full environment

technology-demonstration fiber-optic gyros (TDFOGs) with system brassboard electronics. Significant achievements include the successful wind, build, and test of CFOG and TDFOG 3.2-km fiber coils exhibiting excellent performance characteristics (ARW = 0.00029 deg √h, bias stability = 0.00035 deg/h, scale factor stability = 0.4 ppm, and input axis stability = 0.04 arcsec).

Shah, Naresh H.; Proulx, Ronald J.; Kantsiper, Brian; Cefola, Paul J. (Draper)
John Draim (Mobile Communications Holdings, Inc.)

Automated station-keeping for satellite constellations

Advances in the Astronautical Sciences, vol. 97, part I, pp. 357-385, March 1998

The on-orbit control of future satellite constellations poses a great challenge. New approaches are required that result in viable control systems that are flexible, reliable, and efficient. This work develops new methods for the maintenance of satellite constellations. Strategies that employ these methods are applied to analyze the control and coverage characteristics of the Ellipso constellation. The Automated Station-Keeping Simulator (ASKS), a software package developed for this project, is employed.

Smith, C.M.; Leonard, J.J.; Feder, H.J.S.

Making difficult decisions autonomously: the impact of integrated mapping and navigation

Proceedings of the 1998 Workshop on Autonomous Underwater Vehicles, IEEE, Cambridge, MA, 20-21 August 1998, pp.123-32

The role of navigation is changing. The forces of increased autonomy, less prior knowledge, and larger missions are extending the navigation problem from the requirement of absolute localization to the larger question of context determination. Current technologies are inadequate in the face of such circumstances. The key to an evolved navigation technology begins with the ability to reason, in an integrated way, about the models used to determine vehicle context: physical models, dynamic models, sensor models, and behavior models. The integrated mapping and localization (IMAN) algorithm provides a hybrid estimation scheme to integrate decision-making about navigation events with navigation and mapping. An overview of IMAN is presented, along with an initial analysis of its performance. While IMAN is sensitive to the complexity of ambiguous situations, the algorithm demonstrates superior performance when complexity does not lead to failure. These results are used to examine the emerging set of technological needs for advanced navigation and mapping applications, including map representation, multiscale modeling, map fusion, and cross-model correlation.

Szulewski, Paul A.; Budlong, Faye C.

Metrics for visual software development, initial research and findings

CrossTalk (Journal of Defense Software Engineering), November 1998, pp. 21-25, p. 30

This article provides a summary of recent research that investigated the use of visual languages (VLs) and visual programming environments (VPEs). The study reviewed the state of the practice for developing software using VLs and managing these development activities. The study concluded that there is little evidence of the use of mature practices and recommends candidate metrics for VLs and VPEs as a first step toward a method to estimate the effort required to develop software using VLs and VPEs.

Tetewsky, A. K.; Youngberg, J. W.; Soltz, J. A.

The effects of phase ripple on GPS receivers - sources and solutions

ION GPS-98; Proceedings of the 11th International Technical Meeting of the Satellite Division of the Institute of Navigation, Nashville, TN, 15-18 September 1998, pp. 221-232

We have identified a mechanism that causes certain GPS receivers to lose lock at times when the carrier-to-noise-power density ratio (NPDR) and vehicle dynamics should support continuous tracking. This loss of lock is caused by the receiver manager acting upon erroneously low estimates of the carrier-to-noise-power density output by the receiver's NPDR estimator. We have found that a popular NPDR estimator is sensitive to small deviations in carrier phase that can be imparted by vehicle rotation or by flexure of an offset antenna. We also note a surprising result that GPS simulators can produce unexpected phase deviations when a high-dynamics trajectory file is converted within the simulator. The challenge for developers and test engineers is to diagnose the correct cause when a receiver fails a performance test. We review a particular NPDR estimator and identify its sensitivity to phase deviations and recommend a means for testers to avoid the problem when testing receivers that use that NPDR estimator.

Thele, John; Kang, David S.

Micro-rover operator station

SAE International Conference on Environmental Systems, Danvers, MA, 13-16 July 1998

Micro-rovers are small, lightweight, robotic vehicles, often less than a meter in length. They provide a highly mobile platform for mounting a variety of sensors such as cameras, sonars, or atmosphere/soil-sampling devices. For many applications that only require small, lightweight sensors, a micro-rover is a cost-effective alternative to more traditional, larger vehicles. This paper reviews implementations of interfaces developed for Draper micro-rovers. The current interface under development uses a top-down image provided by an aerial vehicle to allow control of a micro-rover at high speed.

Tragesser S.G.; Longuski J.M.

Analysis and design of aerocapture tether with accounting for stochastic errors

Journal of Spacecraft and Rockets, AIAA, vol. 35, no. 5, September-October 1998, pp. 683-689

As an alternative to conventional aerocapture spacecraft, a system comprising two vehicles (a probe and an orbiter) connected by a long thin tether has been proposed. In this tethered system, the probe provides the necessary atmospheric drag while the orbiter remains high above the sensible atmosphere. The results of a sensitivity analysis of the aerocapture tether are presented. Errors in knowledge of the atmosphere and in control of the initial conditions are considered. A result of the analysis is the discovery that the tethered system possesses a self-correcting mechanism that partially compensates for these errors. This intrinsic characteristic can be enhanced with a simple guidance algorithm that implements a change in the tether length to minimize the effect of off-nominal conditions. Design rules

are developed to accommodate stochastic errors without violating the constraints, i.e., breaking or compressing the tether, subjecting the orbiter to atmospheric effects, crashing, or failing to capture. The final design consists of a 68-km tether with a mass of 381 kg and a probe and orbiter of 1000 kg each. It is capable of achieving a 99% success rate for aerocapture at Mars.

Tuohy, Seamus T.

An integrated vehicle simulation for the development and validation of a commercial reusable launch vehicle

Collection of Technical Papers, AIAA Modeling and Simulation Technologies Conference and Exhibit, Boston, MA, 10-12 August 1998, American Institute of Aeronautics and Astronautics, pp. 138-146

An overview of the Integrated Vehicle Simulation (IVS) being developed to support the Kistler Aerospace K-1 reusable launch vehicle is presented. IVS is a 6-degree-of-freedom, variable-mass, high-fidelity simulation that will support the entire project development, including GN&C algorithm development, ON&C software development, functional testing and mission validation, and hardware-in-the-loop avionics and vehicle integration and validation. IVS is being developed in Draper's Simulation Framework. The Framework provides a standard set of tools (such as data visibility, plotting, and recording) and also a methodology in which flight software can be developed, integrated, and tested. Then, since the code is in ANSI C, it can be ported directly to the target hardware. In addition, once the code is cross-compiled onto the target platform, the hardware can then be integrated back into the simulation through hardware-in-the-loop interfaces. In this manner, one simulation can support project development from conception through flight testing and into operational deployment.

Weinberg, Marc; Borenstein, Jeff; Connelly, James; Kourepenis, Anthony; Ward, Paul (Draper)
Heiertz, James (Boeing North American)

Applications of Draper/Boeing micromechanical inertial instruments

Sensors Expo '98, sponsored by Advanstar, Communications Chicago, IL, 6-8 October 1998

Draper Laboratory and Boeing North American have built several generations of micromechanical gyroscopes and accelerometers. The instruments are fabricated using a dissolved-wafer process that results in single-crystal silicon anodically bonded to a glass substrate 2 mm on each side. The performance of these instruments will be summarized. The following applications will be described: (1) competent munitions where artillery shells incorporate six-axis inertial guidance systems; (2) vestibular prostheses, an assist to balance-impaired patients; (3) automotive applications/traction control and roll-over sensing; (4) tractor-trailer control; and (5) the instrumented baseball bat, a sports application.

Wender, Peter; Trainor, Christopher

Gerontology issues in missile guidance

24th Joint Services Data Exchange (JSDE) Symposium, Anaheim, CA, 16-19 November 1998

Financial and political pressures on strategic weapons programs are pushing equipment to longer service lives than planned by designers. In addition to expected wear-outs in extended service, degradation of components due to time-related changes in bulk or surface material properties will be increasingly evident. Unfortunately, aging degradation may not be discernible in reliability data until a significant fraction of the deployed systems are about to simultaneously reach end of life. Engineering solutions necessary to keep the weapon system operational, if implemented in response to such a crisis discovery would be much more costly than if advanced warning had been available. This paper highlights three options for equipment gerontology or the study of aging phenomena in mechanical systems that can help identify issues in an orderly way. The first approach, called 'spares-based,' is a comprehensive expert review in which an aging team examines all of the parts, compares inventory size with use rate, considers likely future availability, factors in fundamental materials information, and identifies parts of highest concern for further inquiry. The second approach, called 'performance-based,' establishes an ongoing evaluative effort that examines field self-test data plus results of special engineering tests to identify performance shifts that give early indication of impending end-of-life. The third approach, a conceptual ideal for age management, uses a fully analytical approach to predict component reliability into the future based on design, materials, and use environments.

Williams, John; Kauppinen, John; Ricker, Joseph

Development and implementation of an accelerometer slip ring lubricant

24th Joint Services Data Exchange (JSDE) Symposium, Anaheim, CA, 16-19 November 1998

The purpose of this program was to develop an accelerometer slip ring that would prove to be reliable and free from failure for 20,000 running hours. The specific driver for this effort was failures due to electrical shorts caused by slip ring wear debris. Toward this end, an aryl ester, Br_3E_2, was developed at Draper, which, when added to Krytox, showed significantly less wear than Krytox alone.

Williams, Julie

Collaborative information, acquiring & managing intranet content

Internet Librarian, sponsored by Information Today, Monterey, CA, 1-5 November 1998

Finding information within a company, in its various formats and locations, and making use of it has always been a difficult task. The Web and the rise of the Intranet has revolutionized the way we access information. Draper Laboratory's Technical Information Center (TIC) has been instrumental in the development of Intranet web-based services within our company. This paper discusses the establishment of our Intranet and its evolution from a mere listing of services to a truly centralized information resource.

Zarchan, P.

Midcourse guidance strategies for exoatmospheric intercept

Journal Announcement: GRAI9905

This paper considers the interception of an exoatmospheric target with a ship-based interceptor that employs both midcourse and terminal guidance. Before and during the midcourse phase of flight, the target is tracked with a ship-based radar. With target state estimates derived from the radar measurements, the interceptor is launched at the expected intercept point. The inevitable intercept point

prediction errors are reduced during the interceptor's flight with midcourse guidance updates from the ship. When the interceptor's seeker acquires the target, noise-free terminal guidance information is assumed for guiding on the actual target. The purpose of this paper is to briefly investigate various midcourse guidance strategies that will influence the missile's terminal performance.

Zimpfer, D.J.; Shieh, L.S.; Sunkel, J.W.

Digitally redesigned pulse-width modulation spacecraft control

Journal of Guidance, Control, and Dynamics, AIAA, vol. 21, no. 4, July-August 1998, pp. 529-534

A new method is presented for the design of control laws for systems with on-off nonlinear actuators. The new methodology improves the design of control laws for pulse-modulated systems by allowing the use of continuous time, MIMO design procedures. Discrete-time state feedback control gains are developed from the digital redesign of continuous-time feedback gains, based on a geometric series approximation, to closely match the states of the closed-loop hybrid system to those of the original designed closed-loop, continuous-time system at each sampling instant. A delay is then incorporated into a pulse-width modulator design to closely match the states of the modulated system to those of the discrete-time, pulse-amplitude modulated system. The new control law design is applied to the problem of attitude control of the Space Shuttle Orbiter with the Hubble Space Telescope deployed on its remote manipulator.