The following pages contain the bibliographical information and a brief abstract of additional papers that have been formally published by Draper engineers during the 1999 calendar year.

Ash, M.E.; Trainor, C.V.; Elliott, R.D.; Borenstein, J.T.; Kourepenis, A.S.; Ward, P.A.; Weinberg, M.S.

Micromechanical Inertial Sensor Development at Draper Laboratory with Recent Test Results

Symposium Gyro Technology 1999, Stuttgart, Germany, September 14-15, 1999, Proceedings (A00-17839 03-35), Stuttgart/Bonn, Universitaet Stuttgart/Deutsche Gesellschaft fuer Ortung und Navigation, 1999, pp. 3.0-3.13

A Coriolis Vibratory Gyroscope (CVG) detects inertial rotation by means of the Coriolis effect acting on a vibrating mass. The Draper Microelectromechanical Systems (MEMS) CVG design uses two silicon proof masses that are capacitively comb-driven to vibrate 180 deg out of phase suspended over a glass plane substrate to which the silicon structure is anodically bonded. Angular motion about an axis perpendicular to the velocity vector causes out-of-plane motion of the proof masses, which is capacitively read out and amplified to give a measure of the inertial angular velocity. Through a continuing process of design improvements, the Draper CVG bias stability now surpasses 10 deg/h in temperature-controlled (±0.25°C) 6-h drift tests. Temperature-compensated performance over -40°C to +85°C is 50 deg/h and 200 ppm for bias and scale factor, respectively. Angle random walk of 0.25 deg √h is typical, with best-to-date performance of 0.05 deg √h observed. A companion MEMS torque-rebalance accelerometer has also been developed with an unbalanced silicon teeter-totter proof mass suspended over a glass ground plane that is provided with pickoff and electrostatic torquing capacitors. It has demonstrated sub-milli-g performance in temperature-controlled (±0.25°C) 6-h drift tests.

Barton, G.H.; Tragesser, S.G.

Autonomous Intact Abort System for the X-34

Atmospheric Flight Mechanics, held in Portland, OR. Sponsored by: AIAA, August 9-11, 1999

Autonomous algorithms are developed that provide trajectory guidance for horizontally landing vehicles such as the X-34 under a variety of abort conditions. The nominal guidance system of the X-34 is incapable of directing the vehicle to a safe landing for many possible situations in which the trajectory is far away from nominal conditions (as in the case of an engine failure). To minimize the risk of losing the vehicle, the autonomous intact abort system considers multiple landing sites and redesigns certain guidance inputs in order to adapt to the new conditions presented by the abort. The abort system design is demonstrated in a high-fidelity simulation to prove the feasibility of the concept for various engine-out scenarios. These abort algorithms are being incorporated into the X-34 vehicle to flight test this new technology as a part of the Future-X Pathfinder Flight Demonstration Program.

Bedrossian, N.S.; McCants, E.

Space Station Attitude Control During Payload Operations

Astrodynamics Specialist Conference, Anchorage, AK

Evaluating the feasibility of planned robotic operations requires an analysis methodology and tools that can assess proposed attitude control strategies quickly. In this paper, an efficient approach to model the attitude dynamics of the Space Station during payload motion is presented. This formulation was then used to develop momentum optimal attitude command trajectories for the Space Station Control Moment Gyroscope (CMG) attitude hold controller for use during robotic payload operations. This methodology was 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.

Bernstein, J.J.; Xu, B.M.; Ye, Y.H.; Cross, L.E.; Miller, R.

Dielectric Hysteresis from Transverse Electric Fields in Lead Zirconate Titanate Thin Films

Applied Physics Letters, V74, N23, pp. 3549-3551

Excellent symmetric dielectric hysteresis is observed from lead zirconate titanate (PZT) thin films using transverse electric fields driven by interdigitated surface electrodes. The 1-μm-thick PZT films with a Zr/Ti ratio of 52/48 are prepared on ZrO_2 buffered, 4-in diameter silicon wafers with a thermally-grown SiO_2 layer. Both the ZrO_2 buffer layer and PZT film are deposited by using a similar sol-gel processing. Remnant polarization of about 20 $\mu C/cm^2$ with a coercive field less than 40 kV/cm is obtained as measured using a triangle wave at 50 Hz. Thicker films are being developed, and retention for the transversely polarized state is currently under study. One of the objectives of this study is to develop a large array of d_{33}-driven unimorph-sensing elements for a high-resolution acoustic imaging system.

Bernstein, J.; Miller, R.; Kelley, W.; Ward, P.

Low-Noise MEMS Vibration Sensor for Geophysical Applications

Journal of Microelectromechanical Systems, Vol. 8, No. 4, December 1999, pp. 433-438

The need exists for high-sensitivity, low-noise vibration sensors for various applications such as geophysical data collection, tracking vehicles, intrusion detectors, and underwater pressure gradient detection. In general, these sensors differ from classical accelerometers in that they require no dc response, but must have a very low noise floor over a required bandwidth. Theory indicates that a capacitive micromachined silicon vibration sensor can have a noise floor on the order of 100 nano g/ over a 1-kHz bandwidth while reducing size and weight tenfold compared with existing magnetic geophones. With early prototypes, we have demonstrated a Brownian-limited noise floor at 1.0 g/, orders of magnitude more sensitive than surface micromachined devices such as the industry standard ADXL05.

Billingsley, G.O.; Kuchar, J.K.; Jacobson, S.W.

Head-Up Display Symbology for Ground Collision Avoidance

Gateway to the New Millennium; Proceedings of the 18th Digital Avionics Systems Conference (DASC), Saint Louis, MO, October 24-29, 1999, Vol. 1 (A00-21178 04-01), Piscataway, NJ, Institute of Electrical and Electronic Engineers, Inc., 1999, pp. 4.D.1-1 to 4.D.1-8

Four ground collision avoidance displays were tested using a fixed-base T-38 simulator with a projection screen and simulated Head-Up Display (HUD). When given a standard Break-X, pilots were able to spend only 40 percent of the flight time between desired altitudes and crashed in 20 percent of the runs. Horizontally- and vertically-moving chevron symbols allowed 70 and 80 percent of the flight time to be spent at the desired altitude, respectively, and resulted in a crash in 8 percent of the runs. A preview depiction using a perspective elevated surface at the desired attitude was the best display for the task investigated, allowing 90 percent of the time to be spent at the desired altitude with a crash rate of 2 percent.

Boccuzzi, R.; Brown, T.; Cook, B.; Dodds, L.; Kochocki, J.; LeBlanc, M.; Robillard, M.; Stadelmann, E.; Stewart, W.; O'Brien, W.; Hudson, P.; Bracewell, T.; Farmer, K.; Gaborno, N.; Kono, K.; Vassar, E.

A Simulation-Based Test and Evaluation Capability

55th Institute of Navigation, Annual Meeting, Cambridge, MA, June 28-30, 1999, Proceedings (A00-18180 03-32), Alexandria, VA, Institute of Navigation, 1999, pp. 567-572

A Simulation-Based Test and Evaluation Capability (SiBaTEC) provides a user with the ability to perform real-time Hardware-in-the-Loop (HIL) simulations. For a system under investigation, SiBaTEC permits design verification, testing of potential components, and subsystem modifications before commitment to a prototype, and testing of modified prototypes in simulation. Furthermore, SiBaTEC provides a means of performing system surveillance through repeatable monitoring and margin testing of hardware and embedded software, and hypothesis testing of potential aging and wear-out phenomena. SiBaTEC accomplishes these activities by means of a real-time simulation host supported by a network-based suite of tools and custom I/O capabilities. This paper describes these capabilities of SiBaTEC, as well as the current system integration testing on a MK 6 guidance system.

Boelitz, F.W.

Kistler Launch Assist Platform (LAP) Return Burn Control

Guidance, Navigation, and Control Conference, Portland, OR. Sponsored by: AIAA, pp. 1289-1299

The Thrust Vector Control (TVC) design for the Return Burn segment of the Kistler K-1 Launch Assist Platform (LAP) is presented. The design features a two-mode controller that initially provides state-dependent pre-ignition orientation of the rocket engine, and on ignition, rapid orientation of the vehicle x-axis back toward the launch zone. Following this pitch reversal, the controller seamlessly switches to a second mode that features integral control with acceleration direction estimation. This second mode provides the fine pointing required by guidance to ballistically loft the LAP back to the launch zone. Control gains for the design are precomputed prior to launch through an automated design procedure that searches over a broad family of gains. The automated design tool simultaneously applies frequency domain and time domain constraints, which results in a controller that achieves stable response with adequate margin and minimal settling time.

Borenstein, J.T.; Gerrish, N.D.; Currie, M.T.; Fitzgerald, E.A.

New Ultra-Hard Etch-Stop Layer for High-Precision Micromachining

12th IEEE International Conference on Microelectromechanical Systems (MEMS), Orlando, FL, 1999, pp. 205-210

In the current work, we describe a high-precision fabrication method for silicon micromachining based on a newly developed epitaxial etch-stop. This etch-stop, composed of a silicon-germanium alloy with no boron doping, outperforms traditional boron-doped etch stops in several important and fundamental ways. Etch selectivities in a variety of standard etchants compare favorably with those obtained using high-concentration boron-diffused and epitaxial layers. Microstructural analysis of the new etch-stop layer demonstrates a significant reduction in defect density relative to boron-doped counterparts. Tuning-fork gyroscopes built with the new etch-stop show build dimensions comparable to those fabricated with conventional methods. We propose a band structure model for the etch-stop mechanism that mimics the hole-injection phenomenon often invoked for boron doping, and conclude with a brief discussion of the advantages of this new fabrication technology.

Cantwell, R.H.; Ventresca, R.

GPS Continuous Track on a Spinning Vehicle with Multiple Patch Antenna

International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GPS), Nashville, TN. Sponsored by: ION

The objective is to use multiple patch antennas to allow visibility to the Global Positioning System (GPS) satellite vehicles for continuous tracking on a spinning platform without going through the acquisition process. Our methodology is to use patch antennas mounted to allow overlapped visibility coverage of the GPS satellite vehicles. An inertial measurement unit is used to determine the attitude and position or coverage of each antenna. Ephemeris is collected from each visible satellite. Using the GPS receiver's position and the positions of the GPS Satellite Vehicles (SVs), the receiver determines which satellites are in the field of view of each antenna. The overlapped coverage allows an SV to be acquired and tracked on two antennas. At this time, we do a direct track hand-over from the receiver channel whose antenna will be going out of view to another receiver channel using the antenna that has come into view. This eliminates interruption in signal tracking, and thereby results in continuous, accurate navigation solutions. This technique has been demonstrated successfully on multiple spinning vehicles.

Cefola, P.J.; Nazarenko, A.I.; Yurasov, V.

Refinement of Satellite Ballistic Factors for the Estimation of Atmosphere Density Variations and Improved LEO Orbit Prediction

Space Flight Mechanics Meeting, Breckenridge, CO. Sponsored by: AAS/AIAA

In an earlier work, Prof. Nazarenko discussed an atmosphere density tracking process that operates in parallel to the orbit determination process. This atmosphere density tracking process employs ballistic coefficient data observed over short arcs from multiple satellites. The process includes: (1) a procedure for constructing the density variations that operates on a 2- or 3-h grid, (2) a procedure for estimating the true ballistic coefficients of the employed satellites that operates on a 28- or 56-day interval (1 or 2 monthly solar cycles), (3) a procedure for forecasting the atmosphere density at future times. This paper focuses on improving the algorithm for estimating the true ballistic coefficient of the employed satellites. The main aspect of this improvement consists of applying, for updating the ballistic factors of nonstandard satellites, a linear function of altitude to model the systematic

errors. Numerical testing based on simulated data has been undertaken to verify the correctness of the algorithm. The products of the study include a proposal to work with the real data. The possibility of complex utilization of data from both North American Defense (NORAD) and the Russian Space Surveillance System is discussed.

Chaudhry, A.I.; Thele, J.D.; Kang, D.S.

High-Velocity Tele-Operated Rover

13th Aerospace Defense Sensing Simulation and Controls (AeroSense), Orlando, FL. Sponsored by: SPIE

The High-Velocity Tele-operated Rover (HVTR) is motivated by a goal to exceed human physical speed with small ground vehicles for operations in an urban environment. A typical small (man-packable) ground vehicle's speed tops out at 1-2 m/s (2-4 mph). Limited speed is attributed to real-time sensing and processing of the external environment. Low speed makes traversing multiple city blocks taxing on the patience of a human operator. Traversing around a block may take 10-20 min. Even with operator assistance, using video does not significantly increase the speed due to the low perspective of the camera view and camera vibration in an outdoor setting.

Connelly, J.; Kourepenis, A.; Larsen, D.; Marinis, T.F.

Inertial MEMS Development for Space

2nd International Conference on Integrated Micro Nanotechnology for Space Applications, Pasadena, CA

Micromachined silicon inertial sensors offer revolutionary improvements in cost, size, and reliability for guidance, navigation, and control. Inertial sensors represent an important segment of an emerging Microelectromechanical Systems (MEMS) technology, which combines semiconductor materials and processing to create integrated mechanical and electrical systems. Batch manufacturing techniques produce thousands of virtually identical MEMS devices, each a few square millimeters in size, enabling inertial systems at a fraction of the cost, size, and power of any previous technology. Development of MEMS inertial instruments is driven by the high-volume, commercial market that targets modest performance applications at prices below $20 per axis. However, Draper has developed higher-performance, multi-axis systems using commercial processes to ensure their availability and affordability for lower-volume military and space applications. The performance of these new MEMS inertial systems is quickly approaching bias stability of 1 deg/h and 100 µg and scale-factor stability of 100 ppm over -40°C to +85°C. Radiation testing is now underway to evaluate response to predicted space environments. Future MEMS inertial systems will reflect a radical departure from the ways they have been conceived, fabricated, and tested in the past. New inertial devices have been incorporated, enabling multi-axis measurement in a planar array, and development is underway on a new wafer-scale process integrating sensors and Application-Specific Integrated Circuits (ASICs) to create complete systems on a chip. These higher-performance, lower-power, inertial microsystems will be ideally suited for many space applications. This paper addresses Draper's inertial MEMS designs, fabrication methods, instrument and performance progression, and development activities related to space applications. Space radiation issues for MEMS are discussed, expected environments are identified, and radiation testing of MEMS instruments is described. In addition, MEMS packaging development toward high-level multi-axis system integration is reviewed.

Cunningham, B.T.; Regan, R.; Clapp, C.; Hildebrant, E.; Weinberg, M.; Williams, J.

Miniature Silicon Electronic Biological Assay Chip and Applications for Rapid Battlefield Diagnostics

Battlefield Biomedical Technologies, Orlando, FL, April 6, 1999. Sponsored by: SPIE. pp. 26-34; 13th Aerospace Defense Sensing Simulation and Controls (AeroSense), Orlando, FL. Sponsored by: SPIE

Assessing the medical condition of battlefield personnel requires the development of rapid, portable biological diagnostic assays for a wide variety of antigens and enzymes. Ideally, such an assay would be inexpensive, small, and require no added reagents, while maintaining the sensitivity and accuracy of laboratory-based assays. In this work, a MEMS-based biological assay sensor is presented that is expected to meet these requirements. The sensor is a thin Silicon Membrane Resonator (SMR) that registers a decrease in resonant frequency when mass is absorbed onto its surface. By coating the sensor surface with a monolayer of antibody, for example, we have detected the corresponding antigen with a detection resolution of 0.25 ng/ml in a phosphate buffer solution. Micromachining techniques are being used to integrate many (64 elements on the first test chip) identical SMR sensors into a single silicon chip that would be capable of simultaneously performing a wide variety of biomedical assays. The sensors require only a small printed circuit board and an 8-V power supply to operate and provide a readout. The presentation will describe the operation of the SMR sensor, the fabrication of the sensor array, and initial test results using commercially-available animal immunoglobulins in laboratory-prepared test solutions.

de Fazio, T.L.; Rhee, S.J.; Whitney, D.E.

Design-Specific Approach to Design for Assembly (DFA) for Complex Mechanical Assemblies

IEEE Transactions on Robotics and Automation, Vol. 15, No. 5, pp. 869-81

This paper uses Assembly Sequence Analysis (ASA) to explore Design for Assembly (DFA), subassembly partitioning, and assembly sequence choice for two complex assemblies. Complex assemblies have very high parts counts, a final assembly organized as an assembly of subassemblies, and offer limited redesign options. ASA addresses combinatorial aspects of complex assemblies that conventional DFA ignores: choice and partitioning of subassemblies and assembly sequence choice. This paper describes criterion-based searches for favorable subassembly partitioning and assembly sequences that use genetic algorithm techniques to spread assembly move difficulty across entire final assembly sequences while satisfying all logical constraints imposed on the assembly sequence by part geometry. The measure of assembly move difficulty, a count of kinematic degrees of freedom secured during each final assembly step, is measured on an absolute scale. We find that ASA can pinpoint candidate DFA-related redesigns and can suggest assembly issues to designers. Logical assembly issues dominate quantitatively characterized issues when selecting assembly sequence or subassembly partitioning. After logical issues are addressed, the sequence choice criterion defined here often duplicates choices made by experienced analysts. Finally, the sequence choice criterion favors inline over final assembly lines.

Draim, J.E.; Cefola, P.; Proulx, R.; Larsen, D.; Granholm, G.R.

Elliptical Sun-Synchronous Orbits with Line of Apsides Lying In or Near the Equatorial Plane

Astrodynamics Specialist Conference, Anchorage, AK. Sponsored by: AAS/AIAA

This paper explores the characteristics of retrograde, sun-synchronous elliptic orbits with line of apsides lying in or near the equatorial plane. Coverage plots for a five-satellite ring showing the number of satellites in view and elevation angle data versus latitude and local time are presented. Stability of the orbit is discussed. Also analyzed is the effect of the trapped radiation field environment (Van Allen Belts) on these orbits, as well as the exposure to damage by natural and man-made debris. A major advantage seen for these orbits is that they can be used to provide augmented earth coverage for a selected latitudinal zone and a selected time of day (for all longitudes). This feature should prove useful for nongeostationary satellite communications systems where increased capacity is needed during daytime peak-traffic hours in heavily populated latitude bands.

D'Souza, C.; Bogner, A.J.; Brand, T.; Tsukui, J.; Koyama, H.; Nakamura, T.

An Evaluation of the GPS Relative Navigation System for ETS VII and HTV

22nd AAS Guidance and Control Conference, Breckenridge, CO. Sponsored by: AAS

The Global Positioning System (GPS) is being used increasingly for spacecraft navigation. Not only is GPS being used in the traditional role of absolute navigation, but it is also playing a role in relative navigation, particularly for spacecraft rendezvous. Two such instances in which relative GPS navigation is playing a key role in spacecraft rendezvous are the Engineering Test Satellite 7 (ETS-VII) and the HII Transfer Vehicle (HTV). ETS-VII is a test satellite developed by the National Space Development Agency of Japan (NASDA) and is designed to test the performance of a relative GPS system. HTV is the Japanese resupply vehicle for the International Space Station (ISS) and is being developed by NASDA. As currently envisioned for HTV, the ISS will send its GPS measurement information over a Radio Frequency (RF) link to HTV, which will simultaneously take GPS measurements to the same satellites. The HTV will difference the GPS measurements in a filter to provide highly accurate relative position and velocity information. NASDA has selected relative GPS navigation to be used for the rendezvous from approximately 23 km from the ISS to 500 m, after which a laser sensor will be used to position the visiting vehicle for grappling by an ISS arm. Draper Laboratory has evaluated the GPS relative navigation system for both ETS-VII and HTV. This paper will describe the testing methodology of the GPS relative navigation system that was used to confirm the tests carried out by Mitsubishi Electric Corporation (MELCO) under contract to NASDA. The testing methodology used by Draper involved the use of an RF satellite signal simulator. In addition to providing a description of the filter architecture, MELCO also provided the trajectory data to drive the satellite signal simulator. A Northern Telecommunications (NorTel) Satellite Signal Simulator (SSS) used the target and chaser vehicle trajectory information to create the RF signal that a GPS receiver would expect to experience along the trajectory. Measurement data, including pseudorange and delta range measurements, were recorded from the GPS receiver, with each trajectory being run separately. The recorded data from the two trajectories was then processed in a filter. Proper merging of the measurement data in the relative navigation filter involved the synchronization of data from the two receivers. Only those measurements that were from common satellites were used in the filter. The measurement data from the target and the chaser GPS receiver were time-tagged with slightly different times. Therefore, in order to difference the measurements, they had to be brought to a common time. This was performed using linear interpolation, with the target measurement being the reference time. The filter was an 8-state linearized Kalman filter. The states included the three relative position states, three relative velocity states, a relative clock bias state, and a relative clock drift state. The position and velocity states were expressed in the Hill frame, which is a curvilinear, rotating frame. The filter dynamics for the position and velocity were described by the well-known Hill-Clohessy-Wiltshire equations. An evaluation was also performed as to whether using the position and velocity for the target and the chaser for the propagation would improve the navigation results, and it was found to improve the results. However, the Hill-Clohessy-Wiltshire equations, which yield a closed-form State Transition Matrix (STM), were still used in the propagation of the covariance matrix. With the use of numerical integration for the state equations and the state transition matrix for the propagation of the covariance matrix, excellent filter performance was obtained. The relative position accuracy was better than 0.4 m and the relative velocity accuracy was better than 6 cm/s. During coasting periods of the trajectory, the velocity accuracy was better than 1 cm/s.

Elwell, J.

Inertial Navigation for the Urban Warrior

The International Society for Optical Engineering Conference, Proceedings, SPIE - International Society of Optical Engineering (USA), Vol. 3709, pp. 196-204

Individual soldier geolocation in situations such as urban warfare where loss of Globl Positioning System (GPS) track can impact mission success has become a critical problem. Concepts such as RF "time difference of arrival" and "dead reckoning" techniques have not demonstrated their ability to support navigation reliably inside buildings on their own. Inertial navigation is the only technology that operates independent of external assets. The advent of micromechanical inertial sensor technology has resulted in low-cost, very small, low-power navigation systems capable of fitting in a soldier's boot. A miniature navigator consisting of three micromechanical gyroscope and accelerometer packages, including supporting application-specific integrated circuit chips, and capable of operating in support of such a mission has been developed. However, because of accelerometer and gyroscope drift, navigating inertially over long time periods, using even the most precise and most expensive inertial sensors available today remains close to impossible. Inertial augmentation techniques are therefore required, and the concept of personal inertial navigation systems aided by zero velocity updating of the accelerometers with each footfall has been examined and shown to be sufficient to determine the location of an individual soldier accurately within a large building complex after hours of operation. In addition to the accelerometer, updates of the gyro via zero attitude rate techniques also enhance position accuracy, as well as provide an attitude reference in support of soldier-carried targeting sensors.

Faiz, R.I.

Net RTM Preforming Process for Cost-Effective Manufacturing of Military Ground Vehicle Composite Structures

"Resin Transfer Molding," SAMPE Monograph, No. 3, pp. 127-138

While the strength, stiffness, and signature advantages of composite materials vs metals are well documented, their application to many military systems has been inhibited by the extreme cost-performance paradigm that has evolved in the industry, the poles

of which are high performance and price-insensitive aerospace components and low-performance and price-sensitive automotive components. Among the key requirements for military automotive composite parts are reasonably high fiber volumes (>40%) using a continuous reinforcement oriented in the production volumes at or less than the 10,000 level. A process that potentially can satisfy the needs of military automotive composites production is Resin Transfer Molding (RTM). Cost studies in the aerospace and automotive industries, and verified by Draper, have indicated that RTM holds great promise for reducing many of the significant cost factors in composites manufacture, especially if the high cost of preform preparation can be reduced. This paper documents the successful definition and demonstration of the enabling technologies used for the development of cost-effective continuous reinforcement, oriented fiber, RTM preforms satisfying all performance requirements.

Feder, H.J.S.; Leonard, J.J.; Smith, C.M. (reprinted)

Adaptive Mobile Robot Navigation and Mapping

International Journal of Robotic Research, Vol. 18, No. 7, July 1999, pp. 650-668

The task of building a map of an unknown environment and concurrently using that map to navigate is a central problem in mobile robotics research. This paper addresses the problem of how to perform Concurrent Mapping and Localization (CML) adaptively using sonar. Stochastic mapping is a feature-based approach to CML that generalizes the extended Kalman filter to incorporate vehicle localization and environmental mapping. The authors describe an implementation of stochastic mapping that uses a delayed nearest neighbor data association strategy to initialize new features into the map, match measurements to map features, and delete out-of-date features. The authors introduce a metric for adaptive sensing that is defined in terms of Fisher information and represents the sum of the areas of the error ellipses of the vehicle and feature estimates in the map. Predicted sensor readings and expected dead-reckoning errors are used to estimate the metric for each potential action of the robot, and the action that yields the lowest cost (i.e., the maximum information) is selected. This technique is demonstrated via simulations, in-air sonar experiments, and underwater sonar experiments. Results are shown for (1) adaptive control of motion and (2) adaptive control of motion and scanning. The vehicle tends to explore selectively different objects in the environment. The performance of this adaptive algorithm is shown to be superior to straight-line motion and random motion.

Flueckiger, K.; Dowdle, J.

A High Antijam INS GPS Navigator

Association of Old Crows, Adelphi, MD. Sponsored by: NAVWAR, April 7-8, 1999

Traditionally, integrated inertial and Global Positioning System (GPS) sensing has been used to provide accurate high-bandwidth navigation solutions. Algorithms designed to integrate these sensors have not used the full sensor data available in a centralized manner. The so-called loosely coupled integration approach assumes that GPS provides a (low-bandwidth) Position, Velocity, and Time (PVT) solution to the navigation algorithm. Traditionally, tight integration approaches demand that GPS provide pseudorange and delta-range measurements. In contrast, the Deep Integration Algorithm, introduced here, uses raw in-phase and quadrature (I and Q) components from the GPS receiver's correlator outputs. By using this full information from the receiver hardware, analysis and hardware results indicate that the Deep Integration Algorithm will improve GPS jamming immunity significantly. A preliminary implementation of the Deep Integration Algorithm for a single SV has been successfully embedded within a commercial-off-the-shelf C/A receiver. Results indicate that the receiver loss-of-lock threshold can be extended by approximately 15 to 20 dB in a sustained jamming environment. Results from two dynamic scenarios are presented here: (1) a velocity step along the SV line-of-sight, and (2) a tactical munition scenario. Both scenarios are presented under a variety of jamming environments. The results are extrapolated to predict the performance of the Deep Integration Algorithm, with full multi-SV tracking capability, using P(Y)-code receiver hardware. This analysis is consistent with performance predictions based on (software-only) simulation.

Fuhry, D.

Adaptive Atmospheric Reentry Guidance for the Kistler K-1 Orbital Vehicle

Guidance, Navigation, and Control Conference, Portland, OR. Sponsored by: AIAA, pp. 1275-1288

The Kistler K-1 is designed to be a fully reusable, two-stage launch vehicle for the economical delivery of small satellite payloads to low earth orbit. Greatest efficiency and, hence, lowest cost are achieved by flyback of both vehicle stages to the near vicinity of the launch site. After deploying the payload and performing the necessary phasing maneuvers, the second stage Orbital Vehicle (OV) performs a deorbit burn to achieve the desired trajectory conditions at atmospheric entry. After entering the atmosphere, the OV is steered aerodynamically until it reaches the deployment point for a stabilization parachute. Subsequently, drogue and main parachutes complete vehicle deceleration for landing on airbags. This paper presents the design of an atmospheric guidance algorithm for bank-to-turn steering of the OV prior to deployment of the stabilization parachute. Reentry guidance targets a desired geographic position for deployment of the drogue parachute. The algorithm employs a numerical predictor/corrector technique to compute the bank angle and the start time of a single bank reversal required to null the predicted target position miss. Aerodynamic loads and heating are limited implicitly by selection of deorbit target conditions for reentry trajectory shaping. Results obtained using the Draper K-1 Integrated Vehicle Simulation illustrates guidance performance under nominal and dispersed conditions.

Granholm, G.R.; Proulx, R.J.; Cefola, P.J.

Orbit Determination for Medium Altitude Orbits Using GPS Receivers and Ground-Based Tracking

Astrodynamics Specialist Conference, Anchorage, AK. Sponsored by: AAS/AIAA

The past few years have seen a proliferation of nontraditional medium or high-altitude constellations designed for use in communications. A constellation considered for use in the Ellipso system features ten satellites in highly elliptical Sun-Synchronous Frozen Line of Apsides (SSFLA) orbits. These orbits pose unique challenges to the orbit determination process, including high eccentricity, tesseral resonance, critical inclination, and sensitivity to solar radiation pressure. This paper will compare the effectiveness of Global Positioning System (GPS)-based tracking with ground-based tracking in terms of accuracy of Differential Correction (DC) solutions. A "Truth" orbit will be simulated using a high-precision Cowell numerical integrator. This orbit is then used to create simulated GPS pseudoranges and ground-based Doppler range and range-rate measurements. The GPS constellation is modeled and propagated using analytic J_2-only equations expressed in equinoctial elements. To improve speed and performance, the GPS simulation is coded using a Message-Passing Interface (MPI) parallel implementation. The pseudoranges and

range/range-rate observations are used in a least-square DC process to solve for state parameters, solar radiation and drag coefficients, and ground station biases. Differences between the touch and fit/predict orbits are analyzed numerically and graphically. Cases are run for both atmospherically quiet and perturbed epochs and with atmospheric and gravitational mismodeling. It is found that the accuracy of the solution is strongly affected by atmospheric conditions. Both methods yield similar solutions, but the DC process scan requires more ground-based observations than GPS pseudoranges. Overall, both tracking methods are shown to be viable for these types of orbits.

Guinon, W.; Setterlund, R.H.; Phillips, R.

Reducing the Power Requirements of an Interferometric GPS Receiver for Spacecraft Attitude Determination

Vision 2010: Present and Future: National Technical Meeting, San Diego, CA. Sponsored by: ION, pp. 561-573

The ongoing development of micromechanical inertial systems that require very little power suggests the concomitant development of a low-power Global Positioning System (GPS) receiver. The combination of such an interferometric receiver with inertial instruments would fill the need for a low-cost, lightweight, low-power attitude determination system for use in small, low-cost satellites with modest accuracy requirements (0.1 to 0.5 deg). 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. This study looks at the implications of this strategy on the details of the receiver operation and design including reacquisition, and the trade between pre- and post-detection integration, as well as power consumption. The accuracy of such a system as a function of the interval between GPS measurements was assessed. Depending on this interval and on other parameters, such as IMU quality, antenna baseline, etc., system power consumption on the order of 1 W or less can be achieved. Accuracies in the 0.1- to 0.5-deg regime are readily achievable. Volume, weight, and power projections are based on existing technology and hardware, leading to a system concept for a spacecraft attitude determination that could be of enormous benefit for small satellites.

Gustafson, D.E.

GPS Signal Tracking Using Maximum-Likelihood Parameter Estimation

Journal of the Institute of Navigation, Vol. 45, No. 4, Winter 1998-1999, pp. 287-295

This paper considers the problem of Global Positioning System (GPS) carrier tracking in the presence of spurious modulation components in amplitude and phase caused by rotating antenna elements in a reentry body. The commonly used phase-lock loop approach is not adequate since the disturbances are not modeled specifically. This is a nonlinear estimation problem that is attacked here as a linear estimation problem with an unknown modulation parameter. The modulation parameter is estimated using a maximum-likelihood method in an architecture that uses two Kalman filters of similar structure, one for parameter estimation and one for state estimation. This architecture uncouples the state and parameter estimation processes and reduces the tendency to build up incorrect correlations in the estimator. The performance of the estimator is studied using a Monte Carlo simulation. Maximum likelihood results are found to be superior to those obtained using a second-order phase-lock loop and a nonadaptive fourth-order Kalman filter.

Haley, J.F.; Hanson, D.S.; Marinis, T.F.

Integration of Resistors and Capacitors within MCM-L Substrates

IMAPS (International Microelectronics and Packaging Society) ATW (Advanced Technology Workshop) on Integrated Passives, Denver, CO, April 1999, and IMAPS New England Chapter Annual Symposium, May 1999

The ever-increasing complexity of microelectronics has often resulted in greater overall packaging volumes. Although the Multichip Module-Laminate (MCM-L) has been successful in reducing volume by bringing several types of components together and connecting them on substrates of numerous signal layers, the next step should involve the integration of these advantages. The focus of this research has been on layering passive components within MCM-L substrates. Processes have been developed to integrate two kinds of passive components: resistors and capacitors into the laminate structure of the MCM-L to increase its density and thereby decrease its volume. The resistor integration process has successfully interconnected components embedded through lamination between nonreinforced epoxy resin and copper foil. The capacitor integration process has successfully interconnected components embedded through lamination between nonreinforced epoxy resin and copper foil. The capacitor integration process involved the development of both a material of high dielectric constant, and a means for laminating this material between copper to create very thin parallel plate capacitors. The dielectric material developed consisted of a low viscosity thermoset polymer mixed with a high-permittivity ceramic powder. A detailed description of each of the two processes is presented, including difficulties encountered in interconnecting the embedded resistors and mixing phenomena observed for the polymer/ceramic dielectric composite.

Hammett, R.C.

Ultra-Reliable Real-Time Control Systems – Future Trends

IEEE Aerospace and Electronic Systems Magazine, Vol. 14, No. 8, pp. 31-36

Today's aircraft use ultra-reliable real-time controls for demanding functions such as Fly-by-Wire (FBW) flight control. Future aircraft, spacecraft, and other vehicles will require greater use of these types of controls for functions that currently are allowed to fail, fail to degraded operation, or require human intervention in response to failure. Fully automated and autonomous functions will require ultra-reliable control. But ultra-reliable systems are very expensive to design and require large amounts of onboard equipment. This paper will discuss how the use of low-cost sensors with digital outputs, digitally commanded fault-tolerant actuation devices, and interconnecting networks of low-cost data buses offer the promise of more affordable ultra-reliable systems. Specific technologies and concepts to be discussed include low-cost automotive and industrial data buses, "smart" actuation devices with integral fault-masking capabilities, management of redundant sensors, and the fault detection and diagnosis of the data network. The advantages of integrating the control and distribution of electrical power with the control system will be illustrated. The design, installation, and upgrade flexibility benefits provided by an all-digital and shared network approach will be

presented. The economic benefits of systems that can operate following failure and without immediate repair will be reviewed. The inherent ability of these redundant systems to provide effective built-in test and self-diagnostics capabilities will be described. The challenges associated with developing ultra-reliable software for these systems and the difficulties associated with exhaustive verification testing will be presented, as will additional development hurdles that must be overcome.

Hattis, P.; Bailey, R.

Overview of the Kistler K-1 Guidance and Control System

Guidance, Navigation, and Control Conference, Portland, OR. Sponsored by: AIAA. pp. 1247-1254

Draper Laboratory, under contract to Kistler Aerospace Corporation, is developing the complete flight guidance and control software for the K-1 launch vehicle. The K-1 is a fully reusable two-stage vehicle. The entire K-1 flight is performed autonomously except for one uplink of expected landing site winds before landing. The Launch Assist Platform (LAP) first stage flies a nearly open-loop three NK-33 engine boost phase, and subsequently reignites the center engine after staging to enable return to the launch site in a controlled coasting flight. The Orbital Vehicle (OV) second stage uses a single NK-43 engine to fly a fully closed-loop ascent to orbit. The LAP trajectory is designed to trade return propellant requirements against OV ascent performance impacts. Orbital maneuvers that are computed onboard the OV are used to circularize its orbit, deploy the payload, rephase the OV orbit for landing after 24 hours, and then deorbit the vehicle. The OV reentry is flown with control thrusters used to bank the vehicle as directed by a predictor-corrector guidance law. Landing of both stages is done with a parachute descent and airbag touchdown, with return trajectories biased to provide correction of expected parachute wind drift effects during descent.

Henderson, T.; Dennehy, N.

Attitude Control and Energy Storage (ACES) Flywheel Demonstration Testbed

17th Space Power Workshop, Long Beach, CA

NO ABSTRACT

Houston, K.M.; Hillman, R.E.; Kobler, J.B.; Meltzner, G.S.

Development of Sound Source Components for a New Electrolarynx Speech Prosthesis

24th International Conference on Acoustics, Speech and Signal Processing (ICASSP), Phoenix, AZ. Sponsored by: IEEE, March 15-19, 1999

For many individuals who lose their voices due to laryngeal cancer or trauma, the only option for speech is to use an Electrolarynx (EL), which is battery-powered vibrator that is held to the throat. Current devices produce speech that sounds very machine-like with low levels of loudness and intelligibility, and which also draws undesired attention to the user. A project at Draper, the Massachusetts Eye and Ear Infirmary, and MIT aims to develop a much improved EL called the Electrolarynx Communication System (ELCS), which is a DSP-based device consisting of sound source, control, and speech enhancement subsystems or modules. This paper introduces the ELCS and discusses developments to date in the sound source module. Specific topics include the design of a new linear EL transducer and investigations into glottal waveform synthesis that should result in much more natural speech output.

Kabir, A.E.; Bashir, R.; Bernstein, J.; DeSantis, J.; Mathews, R.; O'Boyle, J.O.; Bracken, C. (reprinted)

High-Sensitivity Acoustic Transducers with Thin p+ Membranes and Gold Backplate

Sensors and Actuators A-Physical, Vol. 78, No. 2-3, December 14, 1999, pp. 138-142

High-sensitivity acoustic transducers (microphones) have been fabricated on 5-in wafers in a production environment and the experimental results are presented. One main advantage of this microphone design is that it can be fabricated on a single wafer, eliminating the need for the multiple wafers and subsequent wafer bonding steps as in conventional designs. The devices use thin (similar to 3 μm) p+ silicon membranes as the active movable element and a thick perforated plated gold backplate. The p+ membranes are fabricated using an optimized boron solid source diffusion at 1150°C. Ethylene-Diamine-Pyro-Catecol (EDP) etching at 100°C was performed from the backside of double-sided polished wafers to release the thin silicon membranes. The zero-bias capacitance with the air gap was 2.2 pF, and it increased to 2.4 pF at 9 V. The frequency response was measured, and the measured sensitivity of 5.28 mV/Pa at 5 V and 10.77 mV/Pa at 9 V at 1 kHz are among the highest reported in the literature for micromachined acoustic transducers.

Kirkos, G.A.; Jurgilewicz, R.P.; Duncan, S.J.

MEMS Optimization Incorporating Genetic Algorithms

The International Society for Optical Engineering Conference, Proceedings of the SPIE - International Society of Optical Engineering, Vol. 3680, Pt. 1-2, pp. 84-93

Micromechanical sensors are simulated routinely using finite-element software. Once a structure has been proposed, various parameters are optimized using experience, intuition, and trial and error. However, using proven finite-element modeling coupled with a Genetic Algorithm (GA), optimal designs can be "evolved" using a hands-free approach on a workstation. Once a problem is defined, the sole task required of the designer is the specification of a mathematical objective function expressing the desired properties of the sensor; the sensor geometry that maximizes the given function is then synthesized by the algorithm. We have developed an optimization tool and have applied it to the design of Tuning-Fork Gyroscopes (TFGs). In this paper, we demonstrate how a TFG was optimized using GAs. TFG suspension beam lengths were adjusted through the robust search technique, which is resistant to trapping in local maxima. Desired vibration mode order and mode frequency separations were governed by the objective function as specified by the designer. This multidimensional nonlinear optimization problem had a solution space of over 8 million possible designs. Industry-standard mechanical computer-aided engineering tools were integrated along with a GA toolbox and a web-based control interface. Designs offering reduced vibration sensitivity and increased sensor dynamic range have been produced. A tenfold decrease in total sensor optimization time has been documented, resulting in reduced development time.

Kogan, R.G.; Desai, M.; Pien, H.; Grimson, E.

Model-Based Visualization of Ultrasound Images

Battlefield Biomedical Technologies, Orlando, FL. Sponsored by: SPIE, pp. 84-92

Ultrasound imaging is the most pervasive, cost-effective, portable, high-resolution, and nonionizing modality of diagnostic imaging available. The use of ultrasounds, however, has been hampered by the noise properties and poor contrast inherent in such imagery.

A novel processing system is currently being developed that overcomes some of these disadvantages by producing a high-quality rendering of the anatomical structure of interest. In particular, a normal anatomical atlas is used as the starting point; this atlas is produced from either CT or MR imagery. As the ultrasound probe is moved along the body, image registration techniques, as well as external instrumentation that monitors the position and attitude of the ultrasound probe, are used to provide a continuous mapping between the ultrasound observations and the atlas. As discrepancies between the atlas and the observed anatomy occur, the atlas is deformed to reflect actual observations. Operated in this mode, the system displays the deformed high-resolution atlas to the user, providing a high-contrast, low-noise rendering of the patient's anatomy. In scenarios such as battlefield critical care, where large, immobile CT or MR scanners are not feasible, deformation of a high-quality atlas to match real-time ultrasound imagery can provide much improved assessment and treatment possibilities.

Kourepenis, A.

Low-Cost MEMS Inertial Systems for GPS Antijam Applications

Draper Report, April 8, 1999

Microelectromechanical System (MEMS) technologies have the enormous potential to enable the realization of low-cost inertial systems for a myriad of both commercial and military applications. With the large volume needs of the commercial market seeking inertial systems for automotive, camcorder, toys, and other applications, an economical base for the low-cost manufacture of these technologies will be established. These same capabilities can be leveraged to realize low-cost inertial systems critical to the development and deployment of weapons platforms at costs that cannot be matched in other technologies. Current applications being demonstrated with MEMS inertial technologies include competent munitions, autonomous vehicles, robotics, and personal navigation. Many of these applications use MEMS-based Inertial Navigation System (INS)/Global Positioning System (GPS) systems to enable precise guidance, navigation, and control functions at power, volume, and g-survivability levels unattainable by other means. The current performance of these devices is in the 10- to 100-deg/h range and offer marginal improvement in the Antijam (AJ) capability of GPS receivers. Improvements in inertial performance, combined with innovative techniques for coupling the inertial and GPS systems, will result in excellent rejection of intentional and unintentional GPS interference at low cost. This presentation details the state-of-the-art in MEMS technologies, highlighting current levels of performance, and future initiatives that will result in small, low-cost inertial systems that perform at levels in the 0.01- to 0.1-deg/h regime. Operating principles and current levels of performance of Draper's MEMS technologies will be presented, and various applications and demonstrations will be described. Initiatives and roadmaps to higher levels of performance and the applicability to INS/GPS high AJ will be provided.

Kwan, A.; Bedrossian, N.S.; Jang, J.W.; Grigoriadis, K.

Reducing Conservatism of Analytic Transient Response Bounds via Shaping Filters

Astrodynamics Specialist Conference, Anchorage, AK. Sponsored by: AAS/AIAA

Recent results show that the peak transient response of a linear system to bounded energy inputs can be computed using the energy-to-peak gain of the system. However, an analytically computed peak response bound can be conservative for a class of bounded energy signals, specifically, pulse trains generated from jet firings encountered in space vehicles. In this paper, shaping filters are proposed as a methodology to reduce the conservatism of peak response analytic bounds. This methodology was applied to a realistic Space Station assembly operation subject to jet firings. The results indicate that shaping filters indeed reduce the predicted peak response bounds.

McConley, M.W.; Oh J.H.; Jamoom, M.B.; Feron, E.

Solving Control Allocation Problems Using Semi-Definite Programming

Journal of Guidance Control and Dynamics, Vol. 22, No. 3, pp. 494-497

We consider the control surface allocation problem in the case when the surface allocation is limited to be a linear mapping from moment space to control space. We show that an approach to that problem based on ellipsoid volume maximization can be easily recast as a convex optimization problem. This method is applied to a numerical model of the F-18 High-Alpha Research Vehicle (HARV) and has been compared with other approaches. The convex nature of the optimization problem under consideration makes it possible to incorporate the proposed procedure in a real-time aircraft control allocation reconfiguration in the event of damaged control surfaces. The byproducts of the optimization procedure (especially the resulting ellipsoids) may be used in other proposed surface allocation procedures as well.

McGovern, L.K.; Feron, E.

Closed-Loop Stability of Systems Driven by Real-Time, Dynamic Optimization Algorithms

38th IEEE Conference on Decision and Control, Phoenix, AZ. Sponsored by: IEEE

The Receding Horizon Control (RHC) scheme uses on-line optimization to find a finite-horizon control input to a constrained dynamic system. This paper examines the relationship between the optimization algorithm and the closed-loop dynamic system in RHC. Past research on RHC has assumed that the optimization algorithm provides an optimal solution in a fixed time interval. Since RHC typically employs quadratic programming, which is usually solved only approximately, this presupposition is not valid. Instead of making the traditional optimality assumption, this paper supposed that the provided solutions are only suboptimal. A sufficient condition is derived for closed-loop stability given control sequences, which are optimal with tolerance. Also, a bound is derived for the number of computations to find an optimal solution from a warm start using an interior-point method. As long as this number of computations can be carried out in less than the time step of the dynamic system, the closed loop is guaranteed to be stable.

Miller, R.; Eiceman, E.; Alan, G.; Nazarov, E.

A Micromachined Field Asymmetric-Ion Mobility Spectrometer (FA-IMS)

8th International Conference on Ion Mobility Spectrometry, Buxton, Derbyshire, UK

The possibility of creating mobility spectrometers with dimensions under a few centimeters has been considered a next step in reducing the size and cost of Ion Mobility Spectrometry (IMS) analyzers. This would be plausible if the drift tube design could be simplified over traditional configurations and if fabrication methods were amenable to mass production. One drift tube design, which is simplified without ion shutters or voltage dividers and offers extremely high sensitivity, is the asymmetric field analyzer or FA-IMS. The FA-IMS has ion behavior rooted in mobility phenomena, although the details of ion motion are under active investigation. This mobility analyzer offers novelty in ion behavior, which is a secondary consideration, and was selected for the simplicity of a planar micromachined construction. Another factor was the potential for improved detection limits

over conventional analyzers. A planar micromachined field asymmetric-mobility drift tube has been crafted and partly characterized; results of these studies will be described along with certain performance features. The micromachined spectrometer drift tube is ~2.5 x 2.5 x 0.2 cm^3, and is equipped with a 10.6-eV (l=116.5 nm) photo-discharge lamp as the ion source. The flow rate of drift gas is 21 min (-1) of scrubbed air. Results from parametric studies with organic vapors of environmental, medical, or security interests are being used to evaluate the performance of the drift tube. Any compromises in spectral characteristics from reduction in size are still being assessed, but do not appear to be significant. These include detection limits, signal to noise, the effect of moisture, and resolution of ions. Ion identities were confirmed by interfacing the analyzer to a tandem mass spectrometer.

Muldoon, R.C.; Gill, J.; Brock, L.D.

Integrated Mechanical Diagnostic (IMD) Health and Usage Monitoring System (HUMS) - An Open System Implementation Case Study

Gateway to the New Millennium; Proceedings of the18th Digital Avionics Systems Conference (DASC), Saint Louis, MO, October 24-29, 1999, Vol. 2 (A00-21262 04-01), Piscataway, NJ, Institute of Electrical and Electronic Engineers, Inc., 1999, pp. 9.B.4-1 to 9.B.4-8.

The large number of flight-critical and maintenance-intensive dynamic components in a helicopter has led to the development of diagnostic systems to improve flight safety and reduce operations and support costs. These systems, commonly called Health and Usage Monitoring Systems (HUMS), have been used on large commercial helicopters and are now being developed for military helicopters. In 1997, the U.S. Navy embarked on an innovative approach to fielding an integrated mechanical diagnostic system for Navy helicopters. Sponsored by the Department of Defense's Joint Dual Use Program Office, the Navy and BF Goodrich Aerospace began an accelerated program to field a militarized version of a commercial HUMS for the CH-53E and SH-60B helicopters. An open systems architecture is critical to the military implementation of HUMS technology on multiple platforms. An open system architecture is essential for system upgrades and for introducing the broad range of new technologies as they become available from a number of different sources. Through significant team effort and participation from BF Goodrich, the Navy, Draper Laboratory, the Joint Advanced HUMS (JAHUMS) program team, and the DoD Open Systems Joint Task Force (OS-JTF), the IMD-HUMS program is successfully navigating the often-turbulent waters of open system architecture implementation. This paper will provide details on some of the lessons learned from both an industry and government perspective and provide a program status update.

Nazarenko, A.I.; Cefola, P.; Proulx, R.J.; Yurasov, V.

Neutral Atmosphere Density Monitoring Based on Space Surveillance System Orbital Data

Astrodynamics Specialist Conference, Anchorage, AK, August 16-19, 1999. Sponsored by: AAS/AIAA

One approach for increasing the accuracy of satellite orbit determination and prediction for Low-Earth Orbit (LEO) satellites is the organization of an upper atmosphere monitoring function. This would be the analog of a weather service in the lower atmosphere. Monitoring the upper atmosphere based on the use of the available satellite atmospheric drag data (ballistic factors) on all catalogued LEO satellites offers a low-cost approach to this capability. These data are operationally updated in the Space Surveillance System (SSS) as a result of regular satellite observations. It is concluded that there are actual possibilities for operational monitoring of the global atmospheric density variations at altitudes ranging from 200 up to 600 km. The elaboration of a plan for a real data test of the upper atmospheric monitoring concept is discussed.

Persson, B.A.

Control of the Kistler K-1 First-Stage Reorientation Prior to Entry

Guidance, Navigation, and Control Conference, Portland, OR. Sponsored by: AIAA, pp. 1300-1309

The control design for the Kistler K-1 first-stage reorientation maneuver is presented. The reorientation maneuver follows the main engine burn that places the first stage on a trajectory to return it to the landing site. The design takes advantage of the available aerodynamic moment to accelerate the first stage in the direction of the desired orientation for entry. The maneuver takes place near the apex of the first-stage return trajectory, a region of low dynamic pressure. Small Attitude Control System (ACS) thrusters are used to stabilize the vehicle during the maneuver. The maneuver must therefore complete prior to reentry. This paper also presents a method for incorporating this time constraint into the design.

Proulx, R.J.; Smith, J.E.; Cefola, P.J.; Draim, J.E.

Optimal Station-Keeping Strategies via Parallel Genetic Algorithms

Space Flight Mechanics Meeting, Breckenridge, CO. Sponsored by: AAS/AIAA

In an effort to overcome the limitations of more traditional methods, this paper investigates the use of genetic algorithms in generating nongreedy, global, near-optimal station-keeping strategies. The orbit of an Ellipso™ Borealis satellite is constrained, and the minimum-fuel optimal burn strategy is developed such that the orbit is maintained within the specified constraints over the entire time period of interest. The resulting fuel costs are shown to be lower than costs estimated via previous methods, specifically previous primer vector strategies. Operational and computational limitations of this method are also described.

Rubenstein, D.S.; Carter, D.W.

Attitude Control System Design for Return of the Kistler K-1 Orbital Vehicle

Journal of Spacecraft and Rockets, Sponsored by: AIAA

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. Results indicate that the approach to entry/return control is both fuel efficient and effective from a landing accuracy perspective.

Rubenstein, D.S.; Melton, R.G.

Multiple Rigid-Body Reorientation Using Relative Motion with Constrained Final System Configuration

Journal of Guidance, Control, and Dynamics, Vol. 22, No. 3, 1999, pp. 441-446

Movable appendages in multibody spacecraft can augment or replace the attitude control actuators. In this work, motions of the movable bodies relative to the main body are used to adjust the system's inertial attitude to approach or attain a desired target attitude. A control algorithm designed to generate the maneuver commands that cause the necessary relative motions is tested with several cases representing a variety of dynamic conditions. The control can accommodate many different system configurations and dynamic conditions, such as nonzero system momentum, a problem that historically has proved difficult to solve in a generalized, three-dimensional mode. Additionally, the control can return the system's geometric configuration to its initial state by the conclusion of the reorientation. The results indicate that the control can accomplish nearly complete reorientations in all cases tested while meeting the system constraints.

Sacramone, A.; Desai, M.

Real-Time Detection of Undersea Mines. A Complete Screening and Acoustic Fusion Processing System

13th Aerospace Defense Sensing Simulation and Controls (AeroSense), Orlando, FL, April 5-9, 1999. Sponsored by: SPIE; 4th Detection and Remediation Technologies for Mines and Mine-like Targets, Orlando, FL, April 5-9, 1999. Sponsored by: SPIE, pp. 615-625

A complete mine Detection/Classification (D/C) system has been specified and implemented that runs in real time and has been exercised on the latest available dual-frequency side-scan sonar acoustic image sets. The complete D/C system comprises a collection of algorithms that has been developed and evolved at Draper over the past decade. The detection process consists of image normalization, enhancement, segmentation (blob formation), and feature extraction algorithms. The enhancement algorithm is a variant of a Markov random field-based anomaly screener developed in FY 94. The features that were extracted were those derived in FY 93. A distance constrained matching algorithm, which was developed in FY 95, is used to generate a list of High- and Low-Frequency (HF and LF) fused tokens. The classification process involves the evaluation of a hierarchy of three, multilayer perceptron neural networks: HF, LF, and HF/LF fused. Research performed in FY 95 also concentrated on the development of several variants of information fusion with a hierarchical neural network. The "discriminant-combining" variant of fusion was selected as part of this D/C system. In addition, a classification post-processing and decision node statistic modification step, which was developed in FY 96, was included. This paper will describe the algorithms that were implemented. However, the emphasis will be on the performance results of processing the latest available side-scan imagery, comparison of single sensor vs dual-frequency sensor result, and the issues that were encountered while exercising the D/C system on the new data set.

Scholten, J.R.; Burnes, J.R. III; Gels, R.G.; McKenna, J.F.; Rosenberg, S.C.; Rosenstrach, P.A.

The Smart Intrusion Sensor Alarm

DSP World ICSPAT, Orlando, FL

The Smart Intrusion Sensor Alarm (SISA) is a small (10-cm) battery-powered device with a miniature geophone and microphone sensor, flexible Digital Signal Processor (DSP)-based signal processing, and a short-range radio transmitter. Advanced processing and packaging technologies are used to minimize size and maximize capability. Prototypes have been fabricated and field-tested to detect motorized vehicles and footsteps and to trigger a remote camera. The SISA will operate outdoors unattended for over 2 weeks.

Schwartz, G.; Richter, D.

A Concept for a Survivable Ship Control Computer

12th Ship Control Systems Symposium, The Hague, Netherlands. Sponsored by: SCS

A surface ship can withstand considerable physical damage, but if the ship's control system does not also survive, the ship might still fail to complete its mission, or worse. This is in contrast to an aircraft fly-by-wire control system, where a small amount of damage may well cause loss of the vehicle, and the survivability of the control system is less of an issue. Fault-tolerant computers for real-time applications have typically followed the aircraft model without survivability as a goal. For example, the Ship Control Computer for the Seawolf attack submarine, SSN-21, was designed to be highly fault tolerant, but the redundant computing channels are connected via dedicated communication links and all are located in a single, relatively confined ship space. Even minor damage in that space could cause the loss of all processing channels. Furthermore, regaining capability would require a considerable repair effort. A concept is presented for a control system computer that will survive damage as well as tolerate faults. The concept has been pursued as an Independent Research and Development project at Draper. The concept takes advantage of the redundant paths intrinsic to a mesh network. The computer's redundant computing channels communicate with each other using a connection-oriented protocol over a mesh network, which is automatically reconfigured by the surviving channels after damage has occurred. Thus, a channel cut off by damage to the network could be reconnected instantly, without the delay and expense of installing new cable. In the event of widespread damage, a channel could be plugged into the network in an undamaged part of the ship. The network technology being employed for this project is Asynchronous Transfer Mode, but the concept could be realized with other technologies. It is envisioned that when a fully developed computer is transitioned for shipboard deployment, the redundant computer channels will be nodes on the ship's data network infrastructure.

Sitomer, J.; Connelly, J.; Kourepenis, A.

Micromechanical Inertial Guidance, Navigation, and Control Systems in Gun-Launched Projectiles

Atmospheric Flight Mechanics, Portland, OR. Sponsored by: AIAA

Micromechanical technology applied to inertial instruments opens up many new applications where cost, size, and power are important. One very important application is the guidance, navigation, and control of gun-launched projectiles. In order to be affordable, these systems must cost less than $2,000, have very low power requirements, and eventually fit into a standard NATO fuze of 9 in^3, including all fuzing and safe and arming functions. Since 1997, when Draper demonstrated the first successful launch from a Navy 5-in projectile, many new applications have been identified and are being pursued. Draper is currently ready to flight test a Micromechanical Inertial Measurement Unit/Global Positioning System (MMIMU/GPS) in a spinning 5-in projectile with the system despun in the nose-mounted fuze assembly. This paper describes the application of this technology to Navy and Army projectiles, both spin stabilized and nonspinning. Some of the projectiles described will be the Navy's Extended-Range Guided Munition (ERGM) Demo, the Army's Precision Guided Mortor Munition (PGMM) 120-mm projectile, and standard NATO fuze applications to spin-stabilized projectiles, such as the existing 5 in, 155 mm, and 120 mm, etc.

Smith, J.; Proulx, R.J.; Cefola, P.; Draim, J.E.

An Operational Approach for Generating Near-Optimal Station-Keeping Strategies via Parallel Genetic Algorithms

Astrodynamics Specialist Conference, Anchorage, AK. Sponsored by: AAS/AIAA

Extending on the results of the authors' previous parallel genetic algorithm optimization approach, this study investigates ways in which the parallel genetic algorithm can be used as the basis for an operational station-keeping system. Specifically, an orbit is defined and parallel genetic algorithms are applied in such a manner that the orbit is maintained within a given set of tolerances. However, unlike the previous study that focuses only on maintaining the orbit within the state constraints, this study focuses on ways to maintain near optimality in the station-keeping maneuvers, while also maintaining the operational characteristics of repeatability, speed of convergence, and ease of implementation. Finally, the use of this operational station-keeping algorithm as a planning tool is discussed.

Soltz, J.A.; D'Souza, C.; Brand, T.J.; Tsukui, J.; Koyama, H.; Nakamura, T.

An Evaluation of the GPS Relative Navigation System for HTV Using a Functional Simulator

AIAA ISS Service Vehicle Conference, Houston, TX.

No Abstract

Staugler, A.; Shepperd, S.W.

Autonomous On-Orbit Targeting and Guidance for a Reusable Launch Vehicle

Guidance, Navigation, and Control Conference, Portland, OR. Sponsored by: AIAA, pp. 1255-1265

Kistler Aerospace is currently developing a two-stage reusable launch vehicle to place payloads in circular low-Earth orbit. This vehicle is unique in that both stages return to the vicinity of the launch site on parachutes and land on airbags. Draper has developed the guidance and targeting algorithms for the on-orbit phase of the Kistler mission. This phase consists of five burns, for each of which targeting supplies the desired terminal conditions by directing the thrust vector during the burn. Targeting is driven by two primary requirements. First, the vehicle maneuver capability on entry is limited. Targeting accuracy is essential for landing in a small zone near the launch site. Second, unlike almost all previous programs, the Kistler vehicle will not communicate with the ground while on orbit, so targeting must be completely autonomous. Guidance draws heavily on algorithm designs from the Space Shuttle, but a new guidance mode developed specifically for the Kistler mission to provide an accurate orbital period for phasing is described.

Tetewsky, A.; Lozow, J.B.; Flueckiger, K.W.

Determining Specifications for an External GPS Reference Oscillator

International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GPS), Nashville, TN. Sponsored by: ION, pp. 289-300

There are many test and development situations in which a Global Positioning System (GPS) receiver is operated with an external frequency reference that is phase locked to a GPS simulator or to a second receiver. Although one might intuitively predict that receiver performance could be enhanced by using a high-quality commercial frequency source, the application of this source can actually degrade performance as evidenced by reduced Signal-to-Noise Ratio (SNR) measurements, increased bit detection errors, and related operational failures. The cause of this degradation may be the frequency synthesizer that converts the reference frequency to the unique master frequency required by a specific receiver. These degradations are generally the result of residual high-frequency phase noise introduced by tunable frequency synthesizers. In this paper, we quantitatively model the effects that reference frequency phase noise has on the receiver's master timing chain, specifically: L-band to baseband down-conversion errors and user clock errors. These timing chain errors then impact GPS receiver phase tracking, bit detection, and SNR estimation. Although a GPS receiver can compensate for "low-frequency" noises by calculating the oscillator's bias and drift rate, it cannot compensate for excess high-frequency phase noise. Using the analysis presented here, we can then understand why high-frequency sideband performance or small time difference Allan variance performance typical of a high-quality reference standard is needed, and why care is needed in selecting a general-purpose synthesizer. Measurements with a MITEL/Plessy GPS Builder-2 kit and P(Y) Commercial off-the-Shelf (COTS) receiver driven by an external oscillator will be presented to illustrate the analysis. The main contributions of this work are to: (1) derive the industry rule-of-thumb of maintaining –80 to –100-dBc sidebands over the GPS front-end bandwidth and the oscillator's bandwidth fh; (2) understand how the upper bandwidth of the oscillator noise spectrum, fh, enters into the problem; and (3) translate oscillator specifications in Allan variance and other domains into the sideband domain that many circuit designers seem to prefer.

Tetewsky, A.K.; Lozow, J.B.

The Effects of Ground Planes on Rotating GPS Antennas

55th Navigational Technology for the 21st Century: Institute of Navigation Annual Meeting, Cambridge, MA, June 28-30, 1999, Proceedings (A00-18180 03-32), Alexandria, VA,1999, p. 289-300.

Time-varying changes in the orientation of a single Global Positioning System (GPS) antenna with respect to the circularly polarized GPS signals in space can produce carrier phase modulation. However, popular GPS references and software tools do not include these terms and typically show only the contribution of translational terms to the GPS group delay and carrier phase measurements. With the emerging Real-Time Kinematic (RTK) differential positioning and attitude fix algorithms requiring cm-level accuracy, coupled with arrays of antennas that are not constrained to be coplanar, orientation effects must be modeled. This paper presents a general theory of the phase effects introduced by changing antenna orientation and extends previous work by allowing ground plane effects to be modeled. Although computer models will ultimately be needed in order to account for ground-plane effects, by working with some simplified coordinate frames and motion models, additional factoring of the polarization functions into a pure orientation term plus a small residual spin modulation function yields valuable insights into the physics and interpretation of the polarization terms. A brief review of the phase wrapup problem and the original derivation based on the Hertzian (infinitesimal) dipole approximation without a ground plane is presented. Next, directivity patterns for a small micropatch antenna with ground planes are evaluated, and the phase wrapup and spin modulation polarization effects are calculated. Because the directivity pattern holds only for the upper half-space, care must be used when calculating element responses to exclude contributions from beneath the ground plane. Due to this additional complexity, only the results for the antenna's boresight aligned with the spin axis will be covered. Although the technique is general, other geometries introduce significant amounts of algebra, and results are not yet available. The impact that the polarization phase has on raw (pseudorange and carrier phase) measurements, navigation fixes, and general receiver operation are also discussed.

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

A Users Perspective on the Continuing Evolution of GPS Simulators

55th Institute of Navigation Annual Meeting, Cambridge, MA, June 28-30, 1999, Proceedings (A00-18180 03-32), Alexandria, VA, Institute of Navigation, 1999, pp. 581-596

A Global Positioning System (GPS) simulator is a valuable piece of test equipment. For the receiver developer, it provides a controllable signal source. For the integrator, it places a receiver (and, often, other navigation sensor) on a movable host platform. For the analyst, it produces an environment to enable studying the operational performance of a system. Over the last decade, we have seen developers' and testers' expectations of simulator capability and technical performance increase in parallel to the evolution and maturing of end-user missions. This paper identifies the trends we have seen and projects their implications on future simulator hardware and software.

Thompson, M.T.; Thornton, R.D.; Kondoleon, A. (reprinted)

Flux-Canceling Electrodynamic Maglev Suspension: Part I Test Fixture Design and Modeling

IEEE Transactions on Magnetics, Vol. 35, No. 3, May 1999, pp. 1956-1963

The design and analysis of a scale-model suspension test facility for magnetic levitation (maglev) is discussed. We describe techniques for the design, construction, and testing of a prototype Electrodynamic Suspension (EDS) levitation system. The viability of future high-temperature superconducting magnet designs for maglev has been investigated with regard to their application to active secondary suspensions. In order to test the viability of a new "flux-canceling" EDS suspension, a 1/5-scale suspension magnet and guideway was constructed. The suspension was tested using a high-speed rotating test wheel facility with a linear peripheral speed of up to 84 m/s (300 km/h). A set of approximate design tools and scaling laws has been developed in order to evaluate forces and critical velocities in the suspension.

Tingley, R.; Pahlavan, K.

Propagation Measurement Using Antenna Array

Electronics Letters, Vol. 35, No. 15, pp. 1211-12

The design and construction of a 2.4-GHz antenna array suitable for measurement of the time, angle, and complex amplitude of path arrivals in an indoor radio channel are described. Calibration of the array is facilitated with the aid of an anechoic chamber. An optimal least-squares processor is derived, which compensates for systematic calibration errors. Early measurement results are presented, and the future direction of the research is indicated.

Toomey, K.; Seman, A.

Enabling Technologies for Cost-Effective Shipboard Situational Awareness - Reduced Ships Crew by Virtual Presence (RSVP) - 1999 Advanced Technology Demonstration (ATD)

12th Ship Control Systems Symposium, The Hague, Netherlands. Sponsored by: SCS

Current U.S. Navy technology development thrusts and ship designs are being driven by pressures to reduce the costs of acquisition and cost of ownership (life-cycle costs). As identified in the 1995 NRAC Study on "Life-Cycle Cost Reduction" and reiterated in a 1996 NRAC Summer Study on "Damage Control and Maintenance for Reduced Manning," a majority of the total cost of ownership of a ship is operation and support costs. Of these costs, manning is identified as the predominant cost driver. As stated in the 1995 NRAC study, reducing manning is not straightforward, and "impacts the complex relationship of manpower requirements for operating, maintaining, supporting, fighting, and saving the ship. A rational approach to reducing manning requires a systems engineering approach with in-fleet demonstrations of proof of principle." To address this problem, the Navy is pursuing changes in doctrine and insertion of cutting edge technology aboard selected commissioned ships. Technology insertion will include advanced sensors, wireless networking, distributed monitoring, processing, and advanced reasoning capabilities. Current systems such as the Damage Control System (DCS), automated Machinery Control System (MCS), and the Integrated Condition Assessment System (ICAS) provide some level of this capability. However, the full level of automated monitoring and situational awareness/assessment required to safely reduce manning does not exist in these systems today. Reliable, accurate, and timely automated ship system assessment and awareness is required to support ship operation in a reduced crew environment. The Office of Naval Research-funded RSVP approach and demonstrated technologies capture the life-cycle cost reduction objectives and will form the basis of a ship-wide systems approach capable of providing situational awareness of ship's systems and compartments necessary for ship operation in a reduced manning environment. This paper will explore the necessary system architecture trade-offs of capability, cost, power consumption, reliability, and commercialization associated with the elements of the RSVP approach.

Vytal, J.

Shipboard EMI/EMC Test Report for the Reduced Ships-Crew by Virtual Presence (RSVP) Advanced Technology Demonstration (ATD)

Journal Announcement: USGRDR0004

Electromagnetic Interference/Electromagnetic Compatibility (EMI/EMC) testing was conducted on board the USS Normandy (CG-60), a Ticonderoga Class Aegis Cruiser, in early April 1999. The tests were made to determine a typical electromagnetic operating environment for the RSVP RF communications system and to perform propagation measurements in the proposed 2.4-GHz ISM band. The scope of the testing included measurements of the electromagnetic environment from 10 kHz to 3 GHz in three different spaces aboard the ship, and 2.4-GHz propagation measurements in those spaces. The spaces chosen were Main Engine Room 2, Auxiliary Machinery Room 1 and Engineering Crew Quarters. Of particular interest for the EM measurements was the band at 2.4 GHz and those surrounding 100 MHz and 10.7 MHz, the proposed first and second Intermediate Frequencies (IFs) for the RSVP receiver. While the testing revealed no serious problems, it must be remembered that these measurements are only a snapshot in time aboard a single ship. Testing onboard different ships may reveal significantly different results.

Weigold, J.W.; Juan, W.H.; Pang, S.W.; Borenstein, J.T. (reprinted)

Characterization of Bending in Single Crystal Si Beams and Resonators

Journal of Vacuum Science & Technology B, Vol. 17, No. 4, July-August 1999, pp. 1336-1340

Optical interferometry has been applied to determine the displacement of p(++) Si beams. Clamped-clamped Si beams and cantilevered beams were fabricated with short and long B diffusion processes and characterized. Measurements of beam bending for released Si structures with length varying from 50 to 1000 μm, width varying from 5 to 15 μm, and thickness varying from 6 to 37 μm were obtained. By taking advantage of an etch-diffusion process, thicker beams can be fabricated that have less bending due to stress gradients. A 6.0-μm-thick cantilevered beam had a deflection of 11.2 μm due to stress gradients, while a 36.7-μm-thick beam had a deflection of only 0.3 μm. Beams fabricated

using a dissolved wafer process with a 12-h B diffusion were found to bend the same amount as those fabricated with a 4-h diffusion. This indicates that bending in doped Si beams not only depends on the gradients in the B concentrations, it could also be related to the distribution of dislocations. Using the deep-etch shallow-diffusion process, resonating elements that are 20 µm long, 4 µm wide, and 28 µm thick were found to be perfectly flat without any bending.

Xu, B.M.; Ye, Y.H.; Cross, L.E.; Bernstein, J.J.; Miller, R. (reprinted)

Dielectric Hysteresis under Transverse Electric Fields in Sol-Gel Lead Zirconate Titanate Films Deposited on ZrO_2 Passivated Silicon

Integrated Ferroelectrics, 1999, No. 1-4, pp. 19-31

Lead zirconate titanate (PZT) thick thin films with a Zr/Ti ratio of 52/48 have been prepared on ZrO_2-passivated, 4-in diameter silicon substrates with a thermally-grown SiO_2 layer. Both the ZrO_2-passivated layer and PZT film are deposited through a similar sol-gel process that can be used to make PZT films with thicknesses up to 5 µm. Using interdigitated electrode arrays on the upper surface, the dielectric and ferroelectric properties of PZT films are characterized, with emphasis on 1-µm thick films. Dielectric constant of over 1000 with dielectric loss of about 0.01 is achieved for the films. Excellent symmetric hysteresis loops are also obtained with the apparent remanent polarization of around 20 $\mu C/cm^2$ and coercive field of 20 to 30 kV/cm. The results demonstrate that the properties of these PZT films on ZrO_2-passivated silicon substrates are comparable to that of the PZT films on Pt-buffered silicon substrates, and they can be used to fabricate micromachined, d(33)-mode unimorph bending transducers that are expected to have much better performance than the conventional, d(31)-mode bending transducers.

Xu, B.M. (reprint); Polcawich, R.G.; McKinstry, S.; Ye, Y.H.; Cross, L.E.; Bernstein, J.J.; Miller, R.

Sensing Characteristics of In-Plane Polarized Lead Zirconate Titanate Thin Films

Applied Physics Letters, Vol. 75, No. 26, December 27, 1999, pp. 4180-4182

The sensing characteristics of in-plane polarized lead zirconate titanate (PZT) thin films were studied and compared with the through-thickness polarized PZT films. The in-plane polarized PZT films were deposited on ZrO_2-passivated silicon substrates and had interdigitated electrode systems on the top surface; hence, they can be polarized in the film plane. This in-plane polarization configuration separates the electrode spacing and film thickness as independent variables; thus, the voltage sensitivity can be increased by using wider electrode spacing even for fixed film thickness. The results show that for films with a thickness of 1 µm, the voltage sensitivity of in-plane polarized PZT films can be more than 20 times higher than that of the conventional, through-thickness-polarized PZT films that were deposited on Pt-buffered silicon substrates.

Zarchan, P.; Gratt, H.

Adaptive Radome Compensation Using Dither

Journal of Guidance, Control, and Dynamics, Vol. 22, No. 1, January-February 1999, pp. 51-57

A technique is presented for estimating a radar homing missile's radome slope by using a nondestructive dither signal on the acceleration command. A planar example is presented in detail showing how bandpass filtering is used to extract the radome slope estimate and then to compensate for unwanted radome aberration angle effects. A second example is presented showing how Kalman filtering techniques can also be used for the same planar example to estimate the radome slope. Although the Kalman filter approach does not yield superior radome slope estimates, it does provide a solid framework so that the radome slope estimation technique can be extended to the more realistic three-dimensional case where cross-plane slopes are important.

Zimpfer, D.J.

On-Orbit Flight Control Design for Kistler K-1 Reusable Launch Vehicle

Guidance, Navigation, and Control Conference, Portland, OR. Sponsored by: AIAA, pp. 1266-1274

This paper describes the on-orbit control design for the Kistler K-1 Reusable Launch Vehicle Orbiting Vehicle (OV) stage. To meet the K-1 design goals, the control must provide fully autonomous operation with minimal preflight reconfiguration. The on-orbit guidance, navigation, and control targets, guides, and controls the vehicle to and from orbit, maintains orientation to adequately deploy payloads, separates from the payloads to avoid collision, and provides spin-stabilization prior to long periods of orbital "sleep" operations. For control, the OV relies on a gimbaled Orbital Maneuvering System (OMS) and cold-gas thrusters. The flight control algorithms are derived from the U.S. Space Shuttle and Russian Mir Space Station Control algorithms. This paper overviews the on-orbit mission operations for the K-1 vehicle, presents the control algorithms developed, and summarizes predicted on-orbit control performance.