1999

SMART STRUCTURES

Brij N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: Air Force/SRDO

OBJECTIVE: The goal of this project is to support SRDO Smart Structures Program by conducting active control of structures with emphasis on modeling, fabrication techniques, sensor and actuator characteristics, and space applications. This is a continuing project.

SUMMARY: Research was performed in two areas: active vibration isolation and shape control of inflatable structures. Active vibration isolation of sensitive payloads, such as imaging sensors, from periodic disturbances caused by devices such as reaction wheels, cryogenic coolers, and vibration of flexible appendages was research. A popular control choice is feed forward control using Multiple Error Least Square (LMS) algorithm, which requires a separately measured disturbance correlated signal for its implementation. A new technique called Clear Box provided system identification of the spacecraft and the disturbance. It allows ability to control unanticipated disturbance without the need for a separately measured disturbance-correlated signal. A new technique, Adaptive Basis Method, is developed which allows isolation from disturbance with rapidly varying frequencies. These control techniques were evaluated experimentally on Ultra Quiet Platform. These methods are found to be very effective and provide on the order of 36 dB vibration reduction. Clear Box is found to be superior method for vibration isolation. Shape control of inflatable structures focuses on the use of piezoelectric film to change the shape of a deployable membrane to correct surface errors and avoid wrinkling effects.

SPACECRAFT SYSTEMS

Brij N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: Space and Navy Warfare System Command

OBJECTIVE: The goal of this project is to develop and operate four spacecraft laboratories: Fltsatcom Laboratory, Spacecraft Test Laboratory, Spacecraft Dynamics and Control Laboratory, and Spacecraft Design Laboratory to support the Space Systems Engineering Curriculum in instruction and experimental research. This is a continuing project.

SUMMARY: During 1999, there has been a major setback to the three spacecraft laboratories and a major upgrade in Spacecraft Design Laboratory. On January 4, 1999, Spacecraft Attitude Dynamics and Control Laboratory, Smart Structures Laboratory, and Fltsatcom Laboratory suffered a major water damage. Since then, the major task under this project has been to rebuild these laboratories. The Spacecraft Design Laboratory had a major upgrade in software and hardware. GENSAT, general-purpose software for spacecraft design, has been implemented. GENSAT integrates currently used software tool, such as STK, AutoCad, Matlab/Simulink, into a single software applications. A three-axis-simulator for research in attitude control has been designed. The simulator platform will be mounted on a spherical air bearing and will have reaction wheels and thrusters as actuators and sun sensors, magnetometers and rate gyros as sensors.

1998
SMART STRUCTURES

Brij N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: Air force/SRDO

OBJECTIVE: The goal of this project is to support SRDO Small Structures Program by conducting active control of structures with emphasis on modeling, fabrication techniques, sensor and actuator characteristics, and space applications. This is a continuing project.

SUMMARY: Research was performed in several areas related to vibration isolation, active vibration control and shape control by using smart sensors and actuators. Active vibration isolation of a 6-degree of freedom Stewart Platform was investigated by using smart struts consisting of geophone sensors and piezoelectric actuators. Adaptive feed forward control was implemented to isolate narrow band disturbances. Active vibration controls were implemented on a space truss by using force transducer as a sensor, piezoelectric strut as actuator and a proof mass actuator as a disturbing source. Techniques for the control of precision space structures by using shape memory alloy (SMA), Nickel Titanium, were developed. The experiment consisted of a composite beam with embedded SMA wires. A feed forward control was implemented to provide a control accuracy of 0.1 mm.

SPACECRAFT SYSTEMS

Brij N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: Space and Navy Warfare System Command

OBJECTIVE: The goal of this project is to develop and operate four spacecraft laboratories: Fltsatcom Laboratory, Spacecraft Test Laboratory, Spacecraft Dynamics and Control Laboratory, and Spacecraft Design Laboratory to support the Space Systems Engineering Curriculum in instruction and experimental research. This is a continuing project.

SUMMARY: During 1998, significant progress has been achieved in several areas. On the Fltsatcom telemetry and command system the VAX/VMS6.2 OS and C complier version 5.5 were installed and implemented and COMET and ISICS were tested. The Flexible Spacecraft Simulator (FSS) was made operational. A Pulse Width Pulse Frequency (PWPF) modulator controller was implemented for thruster control, and compared with bang bang control. A new control technique (neural network control) for attitude control of flexible spacecraft was implemented. A spacecraft design project for a space-based radar spacecraft constellation was completed. The mission requirements were two 1000km x 1000km regions of interest, with a maximum 30 minutes revisit gap, direct theater downlink/crosslink, and compatible with AFCN/SGLS&CDL.

1997

SMART STRUCTURES

B.N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: Air Force/SRDO

OBJECTIVE: The goal of this project was to support SRDO Smart Structures Program by conducting active control of structures with emphasis on modeling, fabrication techniques, sensor and actuator characteristics, and space applications.

SUMMARY: The major efforts were in the development of Smart Structures Laboratory and the validation of MRJ piezoelectric finite element model. The Ultra Quiet Vibration Isolation Platform, developed by CSA Engineering, is operational. System identification of the platform was completed. Coupling between smart struts was significant. NPS space truss was assembled and modal testing of the truss was also completed. Proof mass actuators and piezoelectric struts were procured. Active vibration control of a flexible beam using Modular Control Patch was performed. The investigation included single-mode and multi-mode vibration suppression and Positive Position Feedback control robustness. An experiment using a beam with shape memory alloy wires, fabricated by Lockheed Martin, was developed to demonstrated the active shape control. A Fiber Bragg Grating Optic sensor, manufactured by Bragg Photonics, was tested for the applications to vibration control and shape control. MRJ piezoelectric finite element model was implemented with the user-modifiable NASTRAN V.69. TRW Composite Smart Strut was used as a test article to validate the model. Experimentally, free displacement and blocked force were measured and compared with the analytical predictions from the model. Free displacement measurements were in good agreement with the analytical predictions. However, there was a significant difference between the blocked force measurements and the analytical predictions. Part of the difference is attributed to the flexibility of test fixture, resulting in not providing ideal boundary condition for the blocked force measurements.

SPACECRAFT SYSTEMS

B.N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: Space and Navy Warfare System Command

OBJECTIVE: The goal of this project was to develop four spacecraft laboratories at NPS: Fltsatcom Laboratory, Spacecraft Test Laboratory, Spacecraft Dynamics and Control Laboratory, and Spacecraft Design Laboratory. It is a continuing project.

SUMMARY: During the reporting period, significant progress has been made in several areas. In the Spacecraft Attitude Dynamics and Control Laboratory, implementation of the dSPACE Real Time Control System on the NPS Flexible Spacecraft Simulator (FSS) has been successfully completed and the FSS has been made operational. The Computational Spacecraft Design Laboratory was upgraded both in hardware and software, including Pro/ENGINEER,

Pro/Mechanica, MSC/Nastran and COSMOS/M Engineer. Three spacecraft design projects were completed. The mission for the first project was to investigate three asteroids in the main belts. The project was done under AIAA/Lockheed Martin graduate Competition and won second position. The second project was on a medium earth orbit UHF satellite constellation. This project was sponsored by the Naval Space Command and was in direct support of DoD's effort to analyze alternative solutions for the replacement of the UHF Follow-on (UFO) constellation. The third project was EHF satellite with a classified payload.

MILITARY USE OF COMMUNICATIONS SATELLITE SYSTEMS

B.N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: Institute of Joint Warfare Analysis, NPS

OBJECTIVE: The goal of the project was to aid the military communications planners in the challenging task of providing enhanced communications capacity in the environment of shrinking budgets.

SUMMARY: During the reporting period, the NPS research team, including four students, has worked very closely with DoD Mobile User Study Joint Integrated Teams. The objectives of these Joint Integrated Teams are to define the requirements for Mobile Users, system engineering, and acquisition strategy for the future DoD UHF satellite system. The NPS team had taken an important role on two major tasks. First task was the primary responsibility for the preliminary design of MEO UHF Spacecraft system. The second task was the payload design for GEO UHF Spacecraft System. Both tasks have been completed.

1996

SMART STRUCTURES

B.N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: Air Forces/SRDO

OBJECTIVE: The goal of this project was to support SRDO Smart Structures Program by conducting active control of structures with emphasis on modeling, fabrication techniques, sensor and actuator characteristics, and space applications.

SUMMARY: The major research efforts were in the antenna shape control using piezoceramic sensors and actuators and development of smart structures laboratory. Analytical techniques were developed for optimal placement of piezoceramic actuators for shape control of a cantilever beam. Experiments were performed to validate the analytical techniques. Experimental results showed that the analysis should include hysteresis, nonlinear behavior and effects of transverse stresses. A finite element model is developed to analyze composite plates with piezoelectric actuators. A simple higher order shear deformation theory was developed to improve prediction of plate deformation in comparison to linear theory. Analytical techniques to determine optimum actuator voltages to minimize surface error were developed. Smart Structures Laboratory will be a state-of-the-art laboratory consisting of vibration isolation platform, space truss, proof mass actuator, fiber optic sensor, shape memory alloy, and piezoelectric actuators.

SPACECRAFT SYSTEMS

B.N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: Space and Navy Warfare System Command

OBJECTIVE: The goal of this project was to develop four spacecraft laboratories at NPS: Fltsatcom Laboratory, Spacecraft Test Laboratory, Spacecraft Dynamics and Control Laboratory, and Spacecraft Design Laboratory. It is a continuing project.

SUMMARY: During the reporting period, significant progress has been made in several areas. In Fltsatcom Laboratory, a Memorandum of Agreement has been signed with NAVSOC to upgrade the Fltsatcom satellite command and telemetry system. In the Spacecraft Attitude Dynamics and Control Laboratory, improved control techniques have been developed for slew maneuvers using the techniques of input shaping in conjunction with PWPF thrusters to minimize structural vibrations. Two spacecraft design projects were completed in response to the request of the sponsor. The mission of the first spacecraft was to demonstrate the ability to passively detect, identify and measure the concentration of atmospheric gas constituents to known location of choice on or above the surface of the earth. The second spacecraft had a classified surveillance mission. The Spacecraft bus was designed to meet the payload requirements and also to space qualify advanced technologies.

MILITARY USE OF COMMUNICATIONS SATELLITE SYSTEMS

B.N. Agrawal, Professor
Department of aeronautics and Astronautics
Sponsor: Institute of Joint Warfare Analysis, NPS

OBJECTIVE: The goal of the project was to aid the military communications planners in the challenging task of providing enhanced communications capacity in the environment of shrink budgets.

SUMMARY: The major effort was to evaluate the ability of the commercial mobile systems (MSS) such as Motorola's Iridium, Loral/Qualcomm's Globalstar, and TRW'S Odyssey to satisfy current and anticipate DOD operational Requirements. Each of these systems was examined in terms of their capabilities, vulnerabilities, and cost. These systems were found to lack many of the characteristics which contribute to survivability on the battlefield and, ultimately, accomplishment of the mission. Given the proliferation of technology, a relatively unsophisticated adversary could disrupt, deny, or exploit DOD communications transmitted via these systems. These systems, however, can be used for logistic support, morale support, peacekeeping and humanitarian operations as well as military support to civilian authorities.

1995

SPACECRAFT SYSEM

B.N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: Space and Navy Warfare System command

OBJECTIVE: The goal of this project was to develop four spacecraft laboratories at NPS: Fltsatcom Laboratory, Spacecraft Test Laobratory, Spacecraft Dynamics and Control Laboratory, and Sapcecraft Design Laboratory. It is a continuing project.

SUMMARY: During the reporting period, the outstanding achievements were making the Vision server optical sensing system operational for Flexible Spacecraft Simulator, development of a new PWPF satellite control algorithms for fine pointing in the presence of structural interactions, integration of FLTSATCOM telemetry and command system, procurement of liquid nitrogen storage tanks for Thermal Vacuum Chamber, and development of the New Computational Spacecraft Design Laboratory and Spacecraft Design Library.

TOMOGRAPHIC SATELLITE SYSTEM DESIGN

B.N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Security Group

OBJECTIVE: The goal of the project was to design a cost-effective satellite system to support a word-wide network of Computerized Ionosphere Topography (CIT) receiving stations.

SUMMARY: A satellite system was designed to meet the object of this project. The constellation was comprised of twelve satellites in four planes. All orbits are circular with an altitude of 1000 km and inclination of 88^o. The satellite had a rectangular shape (35 cm x 35 cm x 150 cm). The total mass of the spacecraft was 75 kg. The payload consisted of two transmitters, a GPS receiver, a CPU, a frequency standard and two quadrifilar helix antennas. Four body mounted silicon solar arrays, one NiH_2 battery made up of 24 cells and power control circuitry comprised the electric power system. Three hydrazine thrusters and two spherical tanks constituted the propulsion subsystem. The primary attitude control was gravity gradient stabilization. Two magnetic torquers and modulated thruster supported the satellite to keep attitude control during thruster firings. Thermal control is passive.

MILITARY USE OF COMMUNICATIONS SATELLITE SYSTEMS

B.N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: Institute of Joint Warfare Analysis, NPS

OBJECTIVE: The goal of the project was to aid the military communications planner sin the challenging task of providing enhanced communications capacity in the environment of shrinking budgets.

SUMMARY: The major effort was to analyze the issues related to future MILSATCOM architecture by reviewing over thirty five reports and engaging in discussion with the experts. The guiding principles for MILSATCOM architecture were to structure architecture to provide highest capacity and maximum flexibility, acquire military SATCOM only to provide capabilities not available from commercial infrastructure or when cost effective, and use commercial systems and practices whenever they meet needs economically. These principles resulted in several options. A preliminary design was also performed to provide EHF communications for mobile tactical users above 65^o N latitude, the area not covered by geosynchronous satellites, such as UHF-Follow-on. The orbit selected was highly elliptical Molniya orbit with inclination 63.40 and period of twelve hours. The payload was the same as on UHF-Follow-On.

SMART STRUCTURES

B.N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: Air Force/SRDO

OBJECTIVE: The goal of this project was to support the SRDO Smart Structures program by conducting active control of structures with emphasis on modeling, fabrication techniques, sensor and actuator characteristics, and space applications.

SUMMARY: The major efforts were in the survey of the state-of-the-art, vibration suppression and antenna shape control. Several control laws were evaluated to minimize the motion of the tip of the flexible arm of the Flexible Spacecraft Simulator. Multi piezoceramic sensors and actuators were mounted on the flexible beam and a CCD camera was used to measure the motion of the tip of the flexible arm. Analytical model for the shape control of a beam was completed. A finite element model for laminated composite plate with piezoceramic using higher order shear deformation theory was developed. Code for the model were also written and validated.

NASA/USRA ADVANCED DESIGN PROGRAM

B.N. Agrawal, Professor, Department of Aeronautics and Astronautics
Sponsor: NASA/University Space Research Association

OBJECTIVE: The goal of the project was to promote engineering education in space and astronautics through design.

SUMMARY: Two spacecraft system design projects were completed: Topaz II Nuclear Powered SAR Satellite and Design Concept for the Tomographic Satellite System (TOMSAT). The primary specifications for the Topaz II Nuclear Powered SAR Satellite were based on an AIAA Lockheed Corporation graduate Team Space Design Competition data package. The NPS design won second place in this national design competition. The satellite mission was to provide SAR imagery of open ocean and land mass areas over L, C, X frequency bands using dual polarization and using TOPAZ II as electric power source. The mission of TOMSAT was to provide ionosphere mapping of the earth through a process similar to that used in medical CAT scanning technology.

1994

ADAPTIVE SPACECRAFT STRUCTURES

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Sponsor: Naval Postgraduate School

OBJECTIVE: The goal for the project was to improve adaptive structures (smart structures) technologies for spacecraft application.

SUMMARY: The focus of the research was to minimize the vibration at the end of flexible arm supporting an antenna by using piezo-ceramic sensors and actuators. H-infinity wave absorbing controller for vibration suppression of the arm was analyzed. A new control technique for selecting gains for multi-sensors and actuators was developed. It was based on optimization approach to minimize the cost function representing the vibration at the end of flexible arm. These control laws were implemented on AC-100 for experiments. The new control laws provided good performance.

SPACECRAFT SYSTEMS

B.N. Agrawal, Professor, Department of Aeronautics and Astronautics
Sponsor: Space and Navy Warfare System Command

OBJECTIVE: The goal of this project was to develop three spacecraft laboratories at NPS: Fltsatcom Laboratory, Spacecraft Test Laboratory, and Spacecraft Dynamics and Control Laboratory. It is a continuing project.

SUMMARY: The Ling vibration control system became operational. A new switching function was developed for robust control of slew maneuvers using thruster. The switching function provided the capability to make trade-offs between slew maneuver time and propellant consumption. An adaptive control law was developed for a space based two-link robotic manipulator. The adaptive controller is found to be superior to the non-adaptive controllers for a high level of system parameter uncertainty. Pulse-width-pulse-frequency (PWPF) modulator thruster control methods over conventional bang-bang thruster control methods were analyzed. Simulations were performed for flexible spacecraft using a describing function model of the modulator. Stability margin with respect to the structural mode limit cycle is predicted and verified.

1993

ATTITUDE CONTROL OF FLEXIBLE SPACECRAFT

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Sponsor: Naval Postgraduate School

OBJECTIVE: The goal of this project was to develop improved control techniques for flexible spacecraft and space robotic and validate them by experimental tests. It was a continuing project.

SUMMARY: A new closed-loop switching function for on-off thruster firing is developed to provide a good attitude control performance in the presence of modeling errors for single-axis slew maneuver of a rigid spacecraft. The switching function also provides capability of a trade-off between slew maneuver time and fuel expenditure. The analytical simulations and experimental results demonstrate that the new switching function provides significant improvement in the slew maneuver performance. In the area of space robotic, Lyapunov method was used to develop cooperative control of multiple space manipulators. A fifth order polynomial reference trajectory was selected. The control torque consists of reference torque and a torque related to tracking errors and rates. The system consisted of two dual link manipulators with a common payload. The analytical and experimental results demonstrated good performances of the control laws.

1992

ATTITUDE CONTROL OF FLEXIBLE SPACECRAFT

B.N. Agrawal, Professor, Department of Aeronautics and Astronautics
Sponsor: Navy Center for Space Technology
Funding: Naval Postgraduate School

OBJECTIVE: The goal of this project was to develop improved control techniques for flexible spacecraft and space robotic and validate them by experimental tests. It was a continuing project.

SUMMARY: The application of piezoelectric actuators and sensors in the vibration suppression of flexible space structures was demonstrated experimentally. Damping of the first structural mode was increased by a factor 4 by using this active control. Several control techniques, proportional-derivative control, reference trajectories, and optimal control were evaluated analytically and experimentally for the slew maneuver of a flexible spacecraft simulator. Reference trajectory using sinusoidal torque profile provided the best performance. Thruster control was also studied for slew maneuver. The analytical and experimental results are in good agreement.

SPACECRAFT SYSTEMS

B.N. Agrawal, Department of Aeronautics and Astronautics
Sponsor: Space and Navy Warfare Systems Command
Funding: SPAWAR

OBJECTIVE: To develop improved spacecraft system design techniques and continue development of spacecraft laboratories to perform research in spacecraft systems. It is a continuing project.

SUMMARY: Fltsatcom satellite was moved into a newly constructed room. A joint project was initiated with the Navy Satellite Operation Center (NAVSOC) to test command software using Fltsatcom at NPS. Piezoelectric actuators and sensors, thruster system, and a two-link manipulator were added to the flexible spacecraft simulator. Two spacecraft system design projects were completed. Development of a general purpose spacecraft design computer program was initiated.