Dynamics Modeling And Attitude Control Of A Flexible Space

Satellites are used increasingly in telecommunications, scientific research, surveillance, and meteorology, and these satellites rely heavily on the effectiveness of complex onboard control systems. This 1997 book explains the basic theory of spacecraft dynamics and control and the practical aspects of controlling a satellite. The emphasis throughout is on analyzing and solving real-world engineering problems. For example, the author discusses orbital and rotational dynamics of spacecraft under a variety of environmental conditions, along with the realistic constraints imposed by available hardware. Among the topics covered are orbital dynamics, attitude dynamics, gravity gradient stabilization, single and dual spin stabilization, attitude maneuvers, attitude stabilization, and structural dynamics and liquid sloshing.
This book discusses all spacecraft attitude control-related topics: spacecraft (including attitude measurements, actuator, and disturbance torques), modeling, spacecraft attitude determination and estimation, and spacecraft attitude controls. Unlike other books addressing these topics, this book focuses on quaternion-based methods because of its many merits. The book lays a brief, but necessary background on rotation sequence representations and frequently used reference frames that form the foundation of spacecraft attitude description. It then discusses the fundamentals of attitude determination using vector measurements, various efficient (including very recently developed) attitude determination algorithms, and the instruments and methods of popular vector measurements. With available attitude measurements, attitude control designs for inertial point and nadir pointing are presented in terms of required torques which are independent of actuators in use. Given the required control torques, some actuators are not able to generate the accurate control torques, therefore, spacecraft attitude control design methods with achievable torques for these actuators (for example, magnetic torque bars and control moment gyros) are provided. Some rigorous controllability results are provided. The book also includes attitude control in some special maneuvers, such as orbital-raising, docking and rendezvous, that are normally not discussed in similar books. Almost all design methods are based on state-spaced modern control approaches, such as linear quadratic optimal control, robust pole assignment control, model predictive control, and gain scheduling control. Applications of these methods to spacecraft attitude control problems are provided. Appendices are provided for readers who are not familiar with these topics.
This book presents the dynamic modeling and attitude control of flexible spacecraft with time-varying parameters. The dynamic characteristics, vibration control methods and attitude stabilization methods for spacecraft are systematically studied in respects of the theoretical modeling, numerical simulation and the ground experiment. Three active control theories in complex mode space are presented for flexible space structures. Optimal slew strategies based on variable

amplitudes input shaping methods and coupling control methods are proposed for stabilization of flexible spacecraft. The research provides an important way to solve the problem of high-precision attitude control of flexible spacecraft with time-varying parameters. This book is appropriate for the researchers who focus on the multi-body dynamics, attitude and vibration control of flexible spacecraft.

Written for aerospace engineering courses of senior undergraduate or graduate level, this work presents basic concepts, methods and mathematical developments in spacecraft attitude dynamics and control. Topics covered include rigid body dynamics, environmental effects and linear control theory.

Spacecraft Modeling, Attitude Determination, and ControlQuaternion-Based ApproachCRC Press

This volume contains the invited papers presented at the IUTAM Symposium on Multibody Dynamics and Interaction Control in Virtual and Real Environments held in Budapest, Hungary, June 7?11 2010. The symposium aimed to bring together specialists in the fields of multibody system modeling, contact/collision mechanics and control of mechanical systems. The offered topics included modeling aspects, mechanical and mathematical models, the question of neglections and simplifications, reduction of large systems, interaction with environment like air, water and obstacles, contact of all types, control concepts, control stability and optimization. Discussions between experts in these fields made it possible to exchange ideas about the recent advances in multibody system modeling and interaction control, as well as about the possible future trends. The presentations of recent scientific results may facilitate the interaction between scientific areas like system/control engineering and mechanical engineering. Papers on dynamics modeling and interaction control were selected to cover the main areas: mathematical modeling, dynamic analysis, friction modeling, solid and thermomechanical aspects, and applications. A significant outcome of the meeting was the opening towards applications that are of key importance to the future of nonlinear dynamics.

Roger D. Werking Head, Attitude Determination and Control Section National Aeronautics and Space Administration/ Goddard Space Flight Center Extensiye work has been done for many years in the areas of attitude determination, attitude prediction, and attitude control. During this time, it has been difficult to obtain reference material that provided a comprehensive overview of attitude support activities. This lack of reference material has made it difficult for those not intimately involved in attitude functions to become acquainted with the ideas and activities which are essential to understanding the various aspects of spacecraft attitude support. As a result, I felt the need for a document which could be used by a variety of persons to obtain an understanding of the work which has been done in support of spacecraft attitude objectives. It is believed that this book, prepared by the Computer Sciences Corporation under the able direction of Dr. James Wertz, provides this type of reference. This book can serve as a reference for individuals involved in mission planning, attitude determination, and attitude dynamics; an introductory textbook for stu dents and professionals starting in this field; an information source for experimen ters or others involved in spacecraft-related work who need information on spacecraft orientation and how it is determined, but who have neither the time nor the resources to pursue the varied literature on this subject; and a tool for encouraging those who could expand this discipline to do so, because much remains to be done to satisfy future needs.

The purpose of this book is to assist analysts, engineers, and students toward developing dynamic models, and analyzing the control of flight vehicles with various blended features comprising aircraft, launch vehicles, reentry vehicles, missiles and aircraft. Graphical methods for analysing vehicle performance Methods for trimming deflections of a vehicle that has multiple types of effectors Presents a parameters used for speedily evaluating the performance, stability, and controllability of a new flight vehicle concept along a trajectory or with fixed flight conditions

This book is written for aerospace engineers who have completed their BS degree and are interested in the design and analysis of rocket attitude control systems. It introduces a new approach to the design, characterized by its robustness. Current LV attitude control systems are designed based on classical SISO control theory, and they lack robustness. The theory used here truly offers a technique that enables us to design control systems that are reasonably insensitive to math modeling errors and can withstand disturbances such as gust, and in addition it doesnâ€™t need external states estimator, such as Kalman filtering. Extensive simulation results, which demonstrate the effectiveness of this approach, are presented in this book. Basic rocket theory and a concept of H-infinity control system design technique are explained for those who are new in these fields of study.

This book presents the best contributions of the the Third International Symposium on Solar Sailing Glasgow, 11 – 13 June 2013. It is a rapid snap-shot of the state-of-the art of solar sail technology in 2013 across the globe, capturing flight programs, technology development programs and new technology and application concepts. The book contains contributions from all of the leading figures in the field, including NASA, JAXA, ESA & DLR as well as university and industry experts. It therefore provides a unique reference point for the solar sail technology. The book also includes key contributions from the prospective users of solar sail technology, which will allow the technology to be considered by the user in this unique context.

"Space Vehicle Dynamics and Control provides a solid foundation in dynamic modeling, analysis, and control of space vehicles. More than 200 figures, photographs, and tables are featured in detailed sections covering the fundamentals of controlling orbital, attitude, and structural motions of space vehicles. The textbook highlights a range of orbital maneuvering and control problems: orbital transfer, rendezvous, and halo orbit determination and control. Rotational maneuvering and attitude control problems of space vehicles under the influence of reaction jet firings, internal energy dissipation, or momentum transfer via reaction wheels and control moment gyros are treated in detail. The textbook also highlights the analysis and design of attitude control systems in the presence of structural flexibility and/or propellant sloshing. At the end of each chapter, Dr. Wie includes a helpful list of references for graduate students and working professionals studying spacecraft dynamics and control. A bibliography of more than 350 additional references in the field of spacecraft guidance, control, and dynamics is also provided at the end of the book. This text requires a thorough knowledge of vector and matrix algebra, calculus, ordinary differential equations, engineering mechanics, and linear system dynamics and control. The first two chapters provide a summary of such necessary background material. Since some problems may require the use of software for the analysis, control design, and numerical simulation, readers should have access to computational software (i.e., MATLAB) on a personal computer.

This book describes recent studies on modern control systems using various control techniques. The control systems cover large complex systems such as train operation systems to micro systems in nanotechnology. Various control trends and techniques are discussed from practically modern approaches such as Internet of Things, artificial neural networks, machine learning to theoretical approaches such as zero-placement, bang-bang, optimal control, predictive control, and fuzzy approach.

A large-angle, flexible, multibody, dynamic modeling capability has been developed to help validate numerical simulations of the dynamic motion and control forces which occur during berthing of Space Station Freedom to the Shuttle Orbiter in the early assembly flights. This paper outlines the dynamics and control of the station, the attached Shuttle Remote Manipulator System, and the orbiter. The simulation tool developed for the analysis is described and the results of two simulations are presented. The first is a simulated maneuver from a gravity-gradient attitude to a torque equilibrium attitude using the station reaction control jets. The second simulation is the berthing of the station to the orbiter with the station control moment gyros actively maintaining an estimated torque equilibrium attitude. The influence of the elastic dynamic behavior of the station and of the Remote Manipulator System on the attitude control of the station/orbiter system during each maneuver was investigated. The flexibility of the station and the arm were found to have only a minor influence on the attitude control of the system during the maneuvers. Cooper, Paul A. and Garrison, James L., Jr. and Montgomery, Raymond C. and Wu, Shih-Chin and Stockwell, Alan E. and Demeo, Martha E. Langley Research Center ATTITUDE CONTROL; DYNAMIC STRUCTURAL ANALYSIS; REMOTE MANIPULATOR SYSTEM; SPACE SHUTTLE ORBITERS; SPACE STATION FREEDOM; SPACECRAFT CONTROL; SPACECRAFT DOCKING; COMPUTERIZED SIMULATION; DYNAMIC RESPONSE; ORBITAL MECHANICS; SPACECRAFT MANEUVERS...

Tethered Space Robot: Dynamics, Measurement, and Control discusses a novel tethered space robot (TSR) system that contains the space platform, flexible tether and gripper. TSR can capture and remove non-cooperative targets such as space debris. It is the first time the concept has been described in a book, which describes the system and mission design of TSR and then introduces the latest research on pose measurement, dynamics and control. The book covers the TSR system, from principle to applications, including a complete implementing scheme. A useful reference for researchers, engineers and students interested in space robots, OOS and debris removal. Provides for the first time comprehensive coverage of various aspects of tethered space robots (TSR) Presents both fundamental principles and application technologies including pose measurement, dynamics and control Describes some new control techniques, including a coordinated control method for tracking optimal trajectory, coordinated coupling control and coordinated approaching control using mobile tether attachment points

This report delineates the scope of Jet Propulsion Laboratorys? FY8?3 effort in the attitude control area in support of the SP-100 program. Dynamic modeling of the baseline beam configuration has been conducted and is presented herein. As a first cut, the beam is treated as rigid. Its inherent flexibility is then integrated via the hybrid coordinates method. Using the resulting dynamical equations, a preliminary look at attitude control is taken. Only one axis of rotational one flexible mode are included. An alternative to the beam configuration is one that envisions connecting basebody to user via a long, lightweight, flexible tether. A literature search has been conducted in this area and the resulting bibliography is presented. The tether option is not considered viable near term. However, it offers several potentially significant advantages and thus deserves serious consideration for the next generation space power system. This report also treats attitude control constraints imposed by the high temperature and radiation environment and addresses the issue of hardware requirements and availability. Recommendations for FY8?4 tasks include assembling and exercising a simulation program for the beam configuration dynamic model and conducting a technology assessment in the area of tether dynamics and control.

Proceedings of the 2013 Chinese Intelligent Automation Conference presents selected research papers from the CIAC’13, held in Yangzhou, China. The topics include e.g. adaptive control, fuzzy control, neural network based control, knowledge based control, hybrid intelligent control, learning control, evolutionary mechanism based control, multi-sensor integration, failure diagnosis, and reconfigurable control. Engineers and researchers from academia, industry, and government can gain an inside view of new solutions combining ideas from multiple disciplines in the field of intelligent automation. Zengqi Sun and Zhidong Deng are professors at the Department of Computer Science, Tsinghua University, China.

This thesis investigates a new concept for the flexible design and verification of an ADCS for a nanosatellite platform. In order to investigate guidelines for the design of a flexible ADCS, observations of the satellite market and missions are recorded. Following these observations, the author formulates design criteria which serve as a reference for the conceptual design of the flexible ADCS. The research of the thesis was carried out during the development of TU Berlin's nanosatellite platform TUBiX20 and its first two missions, TechnoSat and TUBIN. TUBiX20 targets modularity, reuse and dependability as main design goals. Based on the analysis of design criteria for a flexible ADCS, these key design considerations for the TUBiX20 platform were continued for the investigations carried out in this thesis. The resulting concept implements the ADCS as a distributed system of devices complemented by a hardware-independent core application for state determination and control. Drawing on the technique of component-based software engineering, the system is partitioned into self-contained modules which implement unified interfaces. These interfaces specify the state quantity of an input or output but also its unit and coordinate system, complemented by a mathematical symbol for unambiguous documentation. The design and verification process for the TUBiX20 ADCS was also elaborated during the course of this research. The approach targets the gradual development of the subsystem from a purely virtual satellite within a closed-loop simulation to the verification of the fully integrated system on an air-bearing testbed. Finally, the concurrent realization of the investigated concept within the TechnoSat and TUBIN missions is discussed. Starting with the individual ADCS requirements, the scalability of the approach is demonstrated in three stages: from a coarse, but cost- and energy-efficient configuration to realize a technology demonstration mission with moderate requirements (TechnoSat) to a high-performance configuration to support Earth observation missions (TUBIN). Diese Dissertation untersucht ein neues Konzept zur flexiblen Entwicklung und Verifikation eines Lageregelungssystems für eine Nanosatellitenplattform. Als Grundlage für die Erarbeitung eines Leitfadens für die Entwicklung werden zunächst Beobachtung des Satellitenmarkts sowie konkreter Missionen zusammengetragen. Darauf aufbauend formuliert der Autor Entwurfskriterien für die Konzipierung eines flexiblen Lageregelungssystems. Die Dissertation wurde im Rahmen der Entwicklung der TUBiX20 Nanosatellitenplattform und ihrer ersten beiden Missionen, TechnoSat und TUBIN, an der TU Berlin durchgeführt. TUBiX20 verfolgt Modularität, Wiederverwendung und Zuverlässigkeit als Entwicklungsziele. Diese werden unter der Verwendung der vom Autor hergeleiteten Entwurfskriterien in dieser Arbeit im Kontext des Lageregelungssystems verfeinert. Das resultierende Konzept setzt dieses als verteiltes System von Geräten und einem hardware-unabhängigen Software-Kern um. Der Software-Entwurfstechnik Component-based software engineering folgend ist das System in unabhängige Module unterteilt, welche wiederum einheitliche Schnittstellen implementieren. Diese Schnittstellen spezifizieren die Zustandsgrößen für die Ein- und Ausgänge der Module inklusive Einheit, Koordinatensystem und mathematischem Symbol für eine eindeutige Darstellung. Der Entwurfs- und Verifikationsprozess für das TUBiX20 Lageregelungssystem wurde vom Autor im Rahmen der Arbeit untersucht. Hier verfolgt der Ansatz einen schrittweisen übergang von einem virtuellen Satelliten als Simulationsmodell bis hin zur Verifikation des integrierten Systems auf einem Lageregelungsteststand. Abschließend diskutiert die Arbeit die Realisierung des untersuchten Konzepts im Rahmen der Missionen TechnoSat und TUBIN. Beginnend mit den jeweiligen Anforderungen wird die Skalierbarkeit des Ansatzes in drei Stufen demonstriert: von einer groben, aber kosten- und energieeffizienten Konfiguration für eine Technologieerprobungsmission mit moderaten Anforderungen

(TechnoSat) bis hin zu einer Konfiguration für hochgenaue Lageregelung als Basis für Erdbeobachtungsmissionen (TUBIN).

This book explores topics that are central to the field of spacecraft attitude determination and control. The authors provide rigorous theoretical derivations of significant algorithms accompanied by a generous amount of qualitative discussions of the subject matter. The book documents the development of the important concepts and methods in a manner accessible to practicing engineers, graduate-level engineering students and applied mathematicians. It includes detailed examples from actual mission designs to help ease the transition from theory to practice and also provides prototype algorithms that are readily available on the author's website. Subject matter includes both theoretical derivations and practical implementation of spacecraft attitude determination and control systems. It provides detailed derivations for attitude kinematics and dynamics and provides detailed description of the most widely used attitude parameterization, the quaternion. This title also provides a thorough treatise of attitude dynamics including Jacobian elliptical functions. It is the first known book to provide detailed derivations and explanations of state attitude determination and gives readers real-world examples from actual working spacecraft missions. The subject matter is chosen to fill the void of existing textbooks and treatises, especially in state and dynamics attitude determination. MATLAB code of all examples will be provided through an external website.

Spacecraft Dynamics and Control: The Embedded Model Control Approach provides a uniform and systematic way of approaching space engineering control problems from the standpoint of model-based control, using state-space equations as the key paradigm for simulation, design and implementation. The book introduces the Embedded Model Control methodology for the design and implementation of attitude and orbit control systems. The logic architecture is organized around the embedded model of the spacecraft and its surrounding environment. The model is compelled to include disturbance dynamics as a repository of the uncertainty that the control law must reject to meet attitude and orbit requirements within the uncertainty class. The source of the real-time uncertainty estimation/prediction is the model error signal, as it encodes the residual discrepancies between spacecraft measurements and model output. The embedded model and the uncertainty estimation feedback (noise estimator in the book) constitute the state predictor feeding the control law. Asymptotic pole placement (exploiting the asymptotes of closed-loop transfer functions) is the way to design and tune feedback loops around the embedded model (state predictor, control law, reference generator). The design versus the uncertainty class is driven by analytic stability and performance inequalities. The method is applied to several attitude and orbit control problems. The book begins with an extensive introduction to attitude geometry and algebra and ends with the core themes: state-space dynamics and Embedded Model Control. Fundamentals of orbit, attitude and environment dynamics are treated giving emphasis to state-space formulation, disturbance dynamics, state feedback and prediction, closed-loop stability. Sensors and actuators are treated giving emphasis to their dynamics and modelling of measurement errors. Numerical tables are included and their data employed for numerical simulations. Orbit and attitude control problems of the European GOCE mission are the inspiration of numerical exercises and simulations. The suite of the attitude control modes of a GOCE-like mission is designed and simulated around the so-called mission state predictor. Solved and unsolved exercises are included within the text - and not separated at the end of chapters - for better understanding, training and application. Simulated results and their graphical plots are developed through MATLAB/Simulink code.

Spacecraft with high performance attitude control systems requirements have traditionally relied on imperfect mechanical gyroscopes for primary attitude determination. Gyro bias errors are corrected with a Kalman filter algorithm that uses updates from precise attitude sensors like star trackers. Gyroscopes, however, have a tendency to degrade or fail on orbit, becoming a life limiting factor for many satellites. When errors become erratic, pointing accuracy may be lost during short star gaps. Unpredictable gyro degradations have impacted NASA spacecraft missions such as Skylab and Hubble Space Telescope as well as several DoD and ESA satellites. An alternative source of angular rate information is a software implemented real time dynamic model. Inputs to the model from internal sensors and known spacecraft parameters enable the tracking of total system angular momentum from which body rates can be determined. With this technique, the Kalman filter algorithm provides error corrections to the dynamic model. The accuracy of internal sensors and input parameters determine the effectiveness of this angular rate estimation technique. This thesis presents the background for understanding and implementation of this technique into a representative attitude determination system. The system is incorporated into an attitude simulation model developed in SIMULINK to evaluate the effects of dynamic modeling errors and sensor inaccuracies. Results are presented that indicate that real time dynamic modeling is an effective method of angular rate determination for maneuvering multi-body spacecraft attitude control systems.

Spacecraft attitude maneuvers comply with Euler's moment equations, a set of three nonlinear, coupled differential equations. Nonlinearities complicate the mathematical treatment of the seemingly simple action of rotating, and these complications lead to a robust lineage of research. This book is meant for basic scientifically inclined readers, and commences with a chapter on the basics of spaceflight and leverages this remediation to reveal very advanced topics to new spaceflight enthusiasts. The topics learned from reading this text will prepare students and faculties to investigate interesting spaceflight problems in an era where cube satellites have made such investigations attainable by even small universities. It is the fondest hope of the editor and authors that readers enjoy this book.

The oceans are a hostile environment, and gathering information on deep-sea life and the seabed is incredibly difficult. Autonomous underwater vehicles are robot submarines that are revolutionizing the way in which researchers and industry obtain data. Advances in technology have resulted in capable vehicles that have made new discoveries on how th

This book offers a unified presentation that does not discriminate between atmospheric and space flight. It demonstrates that the two disciplines have evolved from the same set of physical principles and introduces a broad range of critical concepts in an accessible, yet mathematically rigorous presentation. The book presents many MATLAB and Simulink-based numerical examples and real-world simulations. Replete with illustrations, end-of-chapter exercises, and selected solutions, the work is primarily useful as a textbook for advanced undergraduate and beginning graduate-level students.

Predictive Filtering for Microsatellite Control Systems introduces technological design, modeling, stability analysis, predictive filtering, state estimation problem and real-time operation of spacecraft control systems in aerospace engineering. The book gives a systematically and almost self-contained description of the many facets of envisaging, designing, implementing or experimentally exploring predictive filtering for spacecraft control systems, along with the adequate designs of integrated modeling, dynamics, state estimation, and signal processing of spacecrafts and nonlinear systems. Unifies existing and emerging concepts concerning predictive filtering theory, state estimation, and signal processing for spacecraft control systems Provides a series of latest results in, including but not limited to, nonlinear filtering, attitude determination, and state estimation towards spacecraft control systems Gives numerical and simulation results in each chapter in order to reflect the engineering practice and demonstrate the main focus of the developed analysis and synthesis approach Covers advanced topics in nonlinear filtering with aerospace application

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The book focuses on new theoretical results and techniques in the field of intelligent systems and control. It provides in-depth studies on a number of major topics such as Multi-Agent Systems, Complex Networks, Intelligent Robots, Complex System Theory and Swarm Behavior, Event-Triggered Control and Data-Driven Control, Robust and Adaptive Control, Big Data and Brain Science, Process Control, Intelligent Sensor and Detection Technology, Deep learning and Learning Control Guidance, Navigation and Control of Flight Vehicles and so on. Given its scope, the book will benefit all researchers, engineers, and graduate students who want to learn about cutting-edge advances in intelligent systems, intelligent control, and artificial intelligence.

Fault-Tolerant Attitude Control of Spacecraft presents the fundamentals of spacecraft fault-tolerant attitude control systems, along with the most recent research and advanced, nonlinear control techniques. This book gives researchers a self-contained guide to the complex tasks of envisaging, designing, implementing and experimenting by presenting designs for integrated modeling, dynamics, fault-tolerant attitude control, and fault reconstruction for spacecraft. Specifically, the book gives a full literature review and presents preliminaries and mathematical models, robust fault-tolerant attitude control, fault-tolerant attitude control with actuator saturation, velocity-free fault tolerant attitude control, finite-time fault-tolerant attitude tracking control, and active fault-tolerant attitude contour. Finally, the book looks at the future of this interesting topic, offering readers a one-stop solution for those working on fault-tolerant attitude control for spacecraft. Presents the fundamentals of fault-tolerant attitude control systems for spacecraft in one practical solution Gives the latest research and thinking on nonlinear attitude control, fault tolerant control, and reliable attitude control Brings together concepts in fault control theory, fault diagnosis, and attitude control for spacecraft Covers advances in theory, technological aspects, and applications in spacecraft Presents detailed numerical and simulation results to assist engineers Offers a clear, systematic reference on fault-tolerant control and attitude control for spacecraft

Presents the established principles underpinning space robotics with a thorough and modern approach. This text is perfect for professionals in the field looking to gain an understanding of real-life applications of manipulators on satellites, and of the dynamics of satellites carrying robotic manipulators and of planetary rovers.