Spacecraft Attitude Determination And Control

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Control System Design and Implementation for a 6U CubeSat Proximity Operations Mission
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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

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

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

a flexible robust attitude determination and control adc system is presented for small satellite platforms using commercial off the shelf sensors reaction wheels and magnetorquers which fit within the 3u cubesat form factor the system delivers arc minute pointing precision the adc system includes a multiplicative extended kalman filter for attitude determination and a slew

rate controller that acquires a view of the sun for navigation purposes a pointing system is developed that includes a choice of two pointing controllers a proportional derivative controller and a nonlinear sliding mode controller this system can reorient the spacecraft to satisfy a variety of mission objectives but it does not enforce attitude constraints a constrained attitude guidance system that can enforce an arbitrary set of attitude constraints is then proposed as an improvement upon the unconstrained pointing system the momentum stored by the reaction wheels is managed using magnetorquers to prevent wheel saturation the system was thoroughly tested in realistic software and hardware in the loop simulations that included environmental disturbances parameter uncertainty actuator dynamics and sensor bias and noise

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

fundamentals of space systems was developed to satisfy two objectives the first is to provide

a text suitable for use in an advanced undergraduate or beginning graduate course in both space systems engineering and space system design the second is to be a primer and reference book for space professionals wishing to broaden their capabilities to develop manage the development or operate space systems the authors of the individual chapters are practicing engineers that have had extensive experience in developing sophisticated experimental and operational spacecraft systems in addition to having experience teaching the subject material the text presents the fundamentals of all the subsystems of a spacecraft missions and includes illustrative examples drawn from actual experience to enhance the learning experience it included a chapter on each of the relevant major disciplines and subsystems including space systems engineering space environment astrodynamics propulsion and flight mechanics attitude determination and control power systems thermal control configuration management and structures communications command and telemetry data processing embedded flight software survuvability and reliability integration and test mission operations and the initial conceptual design of a typical small spacecraft mission

attitude determination and control systems adcs are critical to the operation of satellites that require attitude knowledge and or attitude control to achieve mission success furthermore adcs systems only operate as designed in the reduced friction micro gravity environment of space simulating these characteristics of space in a laboratory environment in order to test individual adcs components and integrated adcs systems is an important but challenging step in verifying and validating a satellite s adcs design the purpose of this thesis is to design and develop an adcs testbed capable of simulating the reduced fiction micro gravity environment of space within the massachusetts institute of technology s space systems laboratory the adcs testbed is based on a tabletop style three degree of freedom rotational air bearing which uses four reaction wheels for attitude control and a series of sensors for attitude determination the testbed includes all the equipment necessary to allow for closed loop testing of individual adcs components and integrated adcs systems in the simulated inertial environment of space in addition to the physical adcs testbed a matlab simulink based model of the adcs testbed is developed to predict the performance of hardware components and software algorithms before the components and algorithms are integrated into the adcs testbed the final objective of this thesis is to validate the operation of the adcs testbed and simulation to prepare the tool for use by satellite design teams

adcs spacecraft attitude determination and control provides a complete introduction to spacecraft control the book covers all elements of attitude control system design including kinematics dynamics orbits disturbances actuators sensors and mission operations essential hardware details are provided for star cameras reaction wheels sun sensors and other key components the book explores how to design a control system for a spacecraft control theory and actuator and sensor details examples are drawn from the author s 40 years of industrial experience with spacecraft such as ggs gps iir mars observer and commercial communications satellites and includes historical background and real life examples features critical details on hardware and the space environment combines theory and ready to implement practical algorithms includes matlab code for all examples provides plots and figures generated with the included code

this book gives a basic introduction to navigation from key concepts basic principles main technologies equipment systems to the knowledge frame of navigation the ten chapters fall into three parts chapters i iii introduce the elementary knowledge of navigation chapters iv ix are devoted to the basic principles and the optimization principle of integrated navigation as well and chapter x discusses the application of marine navigation indicating the basic outline of the marine navigation system the book clearly reflects the systematic idea of navigation knowledge from multiple perspectives which is helpful for readers to build a holistic understanding of navigation from the concept principle characteristics technology to the equipment system at the end of each chapter reflections beyond the fundamental knowledge of navigation are included to help readers further develop their scientific thinking and general literacy this book is written primarily for students majoring in navigation and it may also be of interest to researchers and practitioners engaged in navigation

there has been an increasing interest in multi disciplinary research on multisensor attitude estimation technology driven by its versatility and diverse areas of application such as sensor networks robotics navigation video biomedicine etc attitude estimation consists of the determination of rigid bodies orientation in 3d space this research area is a multilevel multifaceted process handling the automatic association correlation estimation and combination of data and information from several sources data fusion for attitude estimation is motivated by several issues and problems such as data imperfection data multi modality data dimensionality processing framework etc while many of these problems have been

identified and heavily investigated no single data fusion algorithm is capable of addressing all the aforementioned challenges the variety of methods in the literature focus on a subset of these issues to solve which would be determined based on the application in hand historically the problem of attitude estimation has been introduced by grace wahba in 1965 within the estimate of satellite attitude and aerospace applications this book intends to provide the reader with both a generic and comprehensive view of contemporary data fusion methodologies for attitude estimation as well as the most recent researches and novel advances on multisensor attitude estimation task it explores the design of algorithms and architectures benefits and challenging aspects as well as a broad array of disciplines including navigation robotics biomedicine motion analysis etc a number of issues that make data fusion for attitude estimation a challenging task and which will be discussed through the different chapters of the book are related to 1 the nature of sensors and information sources accelerometer gyroscope magnetometer gps inclinometer etc 2 the computational ability at the sensors 3 the theoretical developments and convergence proofs 4 the system architecture computational resources fusion level

the development of a small spacecraft attitude determination and control subsystem is described this subsystem is part of the space flight laboratory s generic nanosatellite bus with a 20cm3 body the bus has an attitude determination and control subsystem capable of full three axis stabilization and control enabling more advanced missions previously only possible with bulkier and more power consuming attitude control hardware specific contributions to the space flight lab s attitude control hardware are emphasised particularly the full development of a 32g three axis nanosatellite rate sensing unit is described this includes embedded software development skew calibration hardware modeling and qualification testing for the unit development work on a three axis boom mounted magnetometer is also detailed a full hardware design is also described for a new microsatellite sized rate sensor larger and more powerful than the nanosatellite rate sensors the design ensures a low noise low drift architecture to improve attitude determination on future microsatellite missions

the purpose of this work is to discuss the attitude determination and control system adcs design process and implementation for a 12 kg 6u 36 6 cm x 23 9 cm x 27 97 cm cubesat class nano satellite the design is based on the requirements and capabilities of the application for resident space object proximity analysis and imaging arapaima proximity operations

mission the satellite is equipped with a cold gas propulsion system capable of exerting 2 5 mn m torques in both directions about each body axis the attitude sensors include an angular rate gyro and star tracker str supplemented by the payload optical array cameras the dynamic simulation of the satellite includes extensive environmental models and analyses that show how the satellite attitude is affected by aerodynamic drag solar radiation pressure gravity gradient torques and residual magnetic moments a mechanical propellant slosh model and a reaction torque analysis of the deployable solar panel hinges approximate the internal dynamics of the satellite a trade study is presented to justify the use of a reaction control thruster actuated system over the more traditional reaction wheel configuration both actuation systems are modeled to hardware specifications and their propellant and energy requirements are examined alongside pointing performance two methods of accounting for sensor noise and sampling rates are presented the first is an extended kalman filter based on the nonlinear model of a rate gyro coupled with quaternion attitude kinematics the second presents a gyro less angular rate observer capable of extrapolating str measurements to the desired frequency an additional method uses images from the payload cameras to perform camera frame centering maneuvers and to address the possibility of bias in the controller reference signal four different controllers are described to reflect the chronological progression of the adcs design the first controller designed to perform long angle maneuvers and target tracking utilizes fixed gain eigenaxis control the same controller is then augmented with a parallel proportional integral derivative pid type control law using scheduled gains this configuration is designed to switch between eigenaxis and pid control during imaging procedures to take advantage of the integral control introduced by the pid algorithm to reduce system complexity a modified eigenaxis control law which incorporates scheduled integral control but does not require a switch to pid control is introduced a discrete time equivalent of the modified eigenaxis control law is also developed additionally a brief description of a detumbling control law is presented each of the four control laws is paired and tested with the different feedback and estimation methods discussed an extensive showcase of numerical simulation results outlines the pointing performance of each system configuration and evaluates their capabilities of meeting a 1 arcmin pointing requirement a comparison of the different properties and performance of each control system configuration precedes the selection of the discrete modified eigenaxis control law as the best alternative

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