Spacecraft Attitude Determination And Control

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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

this is the biggest most comprehensive and most prestigious compilation of articles on control systems imaginable every aspect of control is expertly covered from the mathematical foundations to applications in robot and manipulator control never before has

such a massive amount of authoritative detailed accurate and well organized information been available in a single volume absolutely everyone working in any aspect of systems and controls must have this book

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

all spacecraft missions require accurate knowledge of attitude which is derived from on board sensors using attitude determination algorithms the increasing demands for attitude accuracy high performance and low cost spacecraft are driving designers to change from available attitude determination methods to those that are more robust and accurate however the cost the processor workload and the time constraints in spacecraft development and deployment projects curtail the opportunity for developing new

on board attitude determination methods especially with regards to the development of more precise sensors therefore it is always desired to achieve the required attitude accuracy with the existing set of on board sensors but using effective attitude determination methods and sensor fusion algorithms developing such algorithms starts on the ground and is subject to verification and tuning with real experimental data from telemetry moreover the on ground mission control center has to evaluate the attitude accuracy calibrate sensors and performance motivated by these needs the main objective of this thesis is to develop novel attitude determination algorithms combining several sensors and attitude estimation methods for ground based attitude estimation gbae with telemetry data the gbae formulation will be based on a guaranteed ellipsoidal state estimation for acquisition mode and a modified kalman filter for pointing mode to provide optimal attitude estimates of the spacecraft the gbae has to be evaluated both in the simulation environment and in the flight environment in the simulation environment the evaluation of the gbae rests on the availability of an accurate dynamical model for the spacecraft however spacecraft dynamics are complex with multiple modes of operation moreover the nonlinearities in the actual system make the spacecraft dynamics more complex this motivates the use of switching between a global nonlinear controller for acquisition mode and a local linear controller for pointing mode which can guarantee performance and is less computationally intensive for implementation in an on board microprocessor in this thesis novel attitude determination and control algorithms are evaluated in the flight environment for a case study in collaboration with the canadian space agency for the scisat 1 satellite

small satellites use commercial off the shelf sensors and actuators for attitude determination and control adc to reduce the cost these sensors and actuators are usually not as robust as the available more expensive space proven equipment as a result the adc system of small satellites is more vulnerable to any fault compared to a system for larger competitors this book aims to

present useful solutions for fault tolerance in adc systems of small satellites the contents of the book can be divided into two categories fault tolerant attitude filtering algorithms for small satellites and sensor calibration methods to compensate the sensor errors matlab will be used to demonstrate simulations presents fault tolerant attitude estimation algorithms for small satellites with an emphasis on algorithms practicability and applicability incorporates fundamental knowledge about the attitude determination methods at large discusses comprehensive information about attitude sensors for small satellites reviews calibration algorithms for small satellite magnetometers with simulated examples supports theory with matlab simulation results which can be easily understood by individuals without a comprehensive background in this field covers up to date discussions for small satellite attitude systems design dr chingiz hajiyev is a professor at the faculty of aeronautics and astronautics istanbul technical university istanbul turkey dr halil ersin soken is an assistant professor at the aerospace engineering department middle east technical university ankara turkey

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

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

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

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

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

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