Fundamentals Of Spacecraft Attitude Determination And Control

Fundamentals Of Spacecraft Attitude Determination And Control Fundamentals of spacecraft attitude determination and control Spacecraft attitude determination and control are critical aspects of modern space missions, ensuring that satellites and spacecraft can accurately orient themselves in space to perform their intended functions. Whether it's pointing a telescope toward a distant galaxy, aligning antennas for communication, or executing precise scientific measurements, understanding the fundamentals of attitude determination and control is essential for mission success. This article provides a comprehensive overview of these core concepts, exploring the principles, components, sensors, actuators, and control algorithms involved. Understanding Spacecraft Attitude and Its Importance What is Spacecraft Attitude? Spacecraft attitude refers to the orientation of a spacecraft relative to an inertial frame of reference, such as the stars or Earth. It determines how the spacecraft's axes are aligned with respect to external reference points. Why is Attitude Control Important? Proper attitude control allows a spacecraft to: - Point instruments, sensors, or antennas accurately. - Maintain stability during operations. - Execute maneuvers like orbit adjustments or station-keeping. - Ensure safety and proper functioning of onboard systems. Fundamentals of Attitude Determination Attitude determination involves estimating the spacecraft's orientation in space using various sensors and algorithms. Accurate attitude knowledge is fundamental to effective control. Sensors Used in Attitude Determination The primary sensors include: Star Trackers: High-precision optical devices that identify star patterns to determine orientation with accuracy up to a few arcseconds. Inertial Measurement Units (IMUs): Consist of gyroscopes and accelerometers measuring angular velocity and linear acceleration, providing rapid attitude change 2 detection. Sun Sensors: Detect the position of the Sun relative to the spacecraft, useful for coarse attitude estimation. Magnetometers: Measure Earth's magnetic field vector, aiding in orientation estimation, especially in low-precision applications. Earth Sensors: Detect Earth's limb to determine the spacecraft's position relative to Earth. Attitude Representation Representing spacecraft attitude mathematically is crucial for computation and control. Common methods include: Euler Angles: Three angles defining orientation, but prone to singularities (gimbal1. lock). Rotation Matrices: 3x3 orthogonal matrices representing rotation, robust but2. computationally intensive. Quaternions: Four-element vectors providing a compact, singularity-free3. representation ideal for real-time calculations. Attitude Estimation Algorithms Algorithms process sensor data to produce accurate estimates of the spacecraft's orientation: Kalman Filter: Combines sensor measurements optimally in the presence of noise. Extended Kalman Filter (EKF): Handles nonlinear measurement models, widely used in practice. Complementary Filters: Blend high-frequency IMU data with low-frequency star tracker data for stable attitude estimation. Fundamentals of Spacecraft Attitude Control Attitude control involves adjusting the spacecraft's orientation to match desired attitudes using actuators based on the estimated attitude. Control Objectives The main goals are: - Achieving and maintaining a specific orientation. - Executing precise maneuvers. - Damping unwanted motions or oscillations. 3 Actuators for Attitude Control Types of actuators include: Reaction Wheels: Spin up or down to produce torque via angular momentum conservation, enabling precise control. Control Moment Gyroscopes (CMGs): Use gimbal-mounted spinning rotors to generate large torques efficiently, suitable for large spacecraft. Magnetorquers: Electromagnetic coils that interact with Earth's magnetic field to produce torque, useful for momentum dumping and coarse control. Thrusters: Small propulsion systems that produce force and torque through controlled propellant expulsion, often used for larger maneuvers. Control Algorithms Implementing effective control requires algorithms that translate attitude errors into actuator commands: Proportional-Derivative (PD) Control: Uses attitude error and its rate to generate torque commands. Optimal Control: Minimizes energy or time to reach desired attitude, often employing Linear Quadratic Regulators (LQR). Quaternion Feedback Control: Uses quaternion error metrics to avoid singularities and gimbal lock issues. Attitude Control System Architecture A typical attitude control system integrates sensors, estimators, controllers, and actuators in a closed-loop configuration: Sensing: Sensors collect data on the current attitude.1. Estimation: Algorithms process sensor data to estimate the current attitude2. accurately. Error Calculation: Difference between desired and estimated attitude is3. computed. Control Law Application: Control algorithms determine the required actuator4. commands based on the attitude error. Actuation: Actuators generate the necessary torques or forces to correct the5. attitude. A key aspect of system design is redundancy and robustness, ensuring the system can handle sensor failures or external disturbances. 4 External Disturbances and Compensation Spacecraft experience various external disturbances that affect attitude stability: Gravity Gradient Torque: Due to Earth's non-uniform gravity field, especially for elongated spacecraft. Magnetic Torques: Interactions with Earth's magnetic field. Solar Radiation Pressure: Photons exerting force on the spacecraft surface. Atmospheric Drag: For low Earth orbit spacecraft, residual atmosphere can induce torque. Attitude control systems incorporate disturbance rejection strategies such as active compensation via control algorithms and momentum management with reaction wheels or magnetorquers. Design Considerations and Challenges Designing an attitude determination and control system involves balancing various factors: Precision: Depending on mission requirements, the system must achieve desired accuracy. Power Consumption: Actuators and sensors consume power; efficient designs are vital. Mass and Volume: Spacecraft constraints demand lightweight and compact solutions. Reliability and Redundancy: Critical for long-duration missions. Environmental Factors: Radiation, thermal variations, and vacuum conditions influence component choice. Challenges include sensor drift, actuator saturation, external disturbances, and computational limitations, all addressed through robust control strategies and fault- tolerant designs. Emerging Technologies and Future Trends Advancements in attitude determination and control include: - Development of star trackers with higher resolution and miniaturization. - Use of machine learning algorithms for adaptive attitude estimation. - Implementation of reaction wheels with magnetic bearings for reduced wear. - Integration of optical communication systems for high- precision pointing. - Use of hybrid control approaches combining multiple actuators for efficiency and redundancy. 5 Conclusion The fundamentals of spacecraft attitude determination and control encompass a complex interplay of sensors, algorithms, actuators, and system design considerations aimed at maintaining the precise orientation of a spacecraft in the challenging environment of space. Accurate attitude knowledge enables scientific, communication, navigation, and exploration missions to perform optimally. Advances in technology continue to enhance the capabilities, reliability, and efficiency of attitude systems, supporting increasingly ambitious space endeavors in the future. Understanding these core principles is essential for aerospace engineers, mission planners, and researchers dedicated to the successful operation of spacecraft across diverse missions. QuestionAnswer What are the primary sensors used in spacecraft attitude determination? The primary sensors include star trackers, gyroscopes, sun sensors, magnetometers, and Earth horizon sensors, each providing different information to accurately determine the spacecraft's orientation. How does a star tracker contribute to attitude determination? Star trackers identify star patterns against a catalog, providing high-precision orientation measurements by comparing observed star positions with known celestial objects. What is the difference between open-loop and closed-loop attitude control systems? Open-loop systems rely on pre-planned commands without feedback, while closed-loop systems use sensor feedback to continuously correct and maintain the spacecraft's attitude. Why are reaction wheels commonly used in spacecraft attitude control? Reaction wheels provide precise, torque-based control without expelling mass, making them ideal for fine attitude adjustments and maintaining stability. What are the main challenges in spacecraft attitude control? Challenges include sensor noise and drift, actuator saturation, external disturbances like solar radiation and magnetic fields, and ensuring system stability and robustness. How does momentum management improve spacecraft attitude control? Momentum management involves desaturating reaction wheels and managing stored angular momentum to prevent saturation, ensuring continuous effective control. What role do control algorithms like PID and Kalman filters play in attitude control? PID controllers provide straightforward feedback control, while Kalman filters fuse sensor data to produce optimal state estimates, both essential for precise attitude control. What are the advantages of using control moment gyroscopes (CMGs) over reaction wheels? CMGs can produce larger torques more quickly and efficiently, making them suitable for rapid attitude maneuvers in large spacecraft or satellites. 6 How do external torques like magnetic torques influence attitude control strategies? External torques can cause unwanted attitude changes; control strategies often incorporate magnetic torquers or thrusters to counteract these disturbances and maintain desired orientation. Fundamentals of Spacecraft Attitude Determination and Control Understanding the fundamentals of spacecraft attitude determination and control is essential for ensuring that a spacecraft correctly orients itself in space to perform its mission objectives. Whether deploying satellites, conducting scientific experiments, or navigating interplanetary space, precise attitude control is vital for communication, payload operation, and overall mission success. This comprehensive guide explores the core principles, methods, and systems involved in spacecraft attitude determination and control, providing a detailed overview for engineers, students, and space enthusiasts alike. --- What is Spacecraft Attitude? Before delving into the determination and control mechanisms, it's important to clarify what is meant by "attitude." In aerospace terminology, spacecraft attitude refers to the orientation of the spacecraft relative to a reference frame, typically an inertial frame like the Earth-centered inertial (ECI) coordinate system or a body-fixed frame. Key Attitude Parameters - Euler angles: Describe orientation via three angles (roll, pitch, yaw). - Quaternions: A four-element vector providing a compact, singularity-free representation of orientation. - Direction Cosines: Elements of a rotation matrix connecting coordinate frames. Maintaining the correct attitude is crucial for: - Pointing antennas towards Earth for communication. - Orienting scientific instruments towards targets. - Controlling solar panel angles for optimal power generation. - Navigating accurately in space. --- The Importance of Attitude Determination and Control Attitude determination and control (AD&C) systems ensure that a spacecraft maintains or changes its orientation as required by its mission. The fundamentals of spacecraft attitude determination and control encompass the sensors, actuators, algorithms, and control laws that work together to achieve this objective. Why is AD&C Critical? - Mission Precision: Scientific observations often require precise pointing. - Communication: Antennas must be accurately directed towards ground stations. - Power Management: Solar panels need correct orientation for maximum efficiency. - Navigation: Attitude information assists in orbit determination and maneuvering. --- Components of Spacecraft Attitude Determination and Control The system can be broadly divided into two subsystems: attitude determination and attitude control. 1. Attitude Determination Systems These systems measure the current orientation of the spacecraft relative to a reference frame. 2. Attitude Control Systems These systems generate commands to actuators to modify the spacecraft's orientation as needed. --- Attitude Determination: Sensors and Methods Sensors Used in Attitude Determination - Gyroscopes (Gyros): Measure angular velocity; provide high-frequency attitude change data but suffer from drift. - Star Trackers: Capture images of star fields; provide highly accurate attitude Fundamentals Of Spacecraft Attitude Determination And Control 7 solutions over longer periods. - Sun Sensors: Detect the Sun's position relative to the spacecraft; useful for coarse attitude determination. - Magnetometers: Measure Earth's magnetic field; used with Earth's magnetic field models for attitude estimation. - Sun and Earth Sensors: Measure the Sun or Earth's limb position to infer orientation. Sensor Data Fusion Because each sensor has strengths and limitations, data fusion algorithms combine measurements to produce a reliable estimate of the spacecraft's attitude: - Kalman Filter: A recursive algorithm that optimally estimates the state by combining sensor data with models. - Extended Kalman Filter (EKF): Handles nonlinear systems, typical in attitude estimation. --- Attitude Representation Choosing the right mathematical representation is vital for accurate control and estimation. Common Representations - Euler Angles: Simple but suffer from singularities (gimbal lock). - Rotation Matrices: Orthogonal matrices representing rotations; robust but computationally heavy. - Quaternions: Compact, free of singularities, and computationally efficient; preferred in most modern systems. --- Attitude Control: Actuators and Control Laws Actuators for Attitude Control - Reaction Wheels: Spins to generate torque; provide fine control. - Reaction Control Thrusters: Small thrusters that exert torque via firing; used for larger maneuvers or momentum unloading. - Magnetorquers: Electromagnetic coils that interact with Earth's magnetic field; suitable for low Earth orbit (LEO) satellites. - Control Moment Gyroscopes (CMGs): Spin at variable speeds to produce torque without expelling mass; used in advanced spacecraft. Control Laws and Algorithms - Proportional-Derivative (PD) Control: Basic feedback control based on attitude error and angular velocity. - Optimal Control: Minimizes energy or time to reach desired attitude. - Sliding Mode Control: Robust against disturbances and model uncertainties. - Kalman Filter-based Control: Combines estimation and control for optimal performance. --- Spacecraft Attitude Control Process The process generally involves the following steps: 1. Attitude Estimation: Sensors provide raw data, which is processed via filtering algorithms to estimate current attitude. 2. Error Calculation: The difference between the current attitude and the desired attitude is computed. 3. Control Law Application: Based on the error, control laws generate torque commands. 4. Actuator Response: Actuators produce the necessary torques to adjust orientation. 5. Feedback Loop: The system repeats, continually refining the attitude. --- Challenges in Attitude Determination and Control Despite technological advances, several challenges persist: - Sensor Noise and Drift: Affect the accuracy of attitude estimation. - External Disturbances: Solar radiation pressure, magnetic torques, and atmospheric drag can perturb attitude. - Saturation of Actuators: Limited torque output may restrict control authority. - Singularities in Representation: Euler angles can lead to mathematical singularities. - Power Constraints: Power availability influences actuator usage and sensor operation. --- Practical Applications and Case Studies Earth Observation Satellites Require precise pointing for imaging sensors and communication antennas. They often use star trackers for high-precision attitude determination and reaction wheels for control. Deep Space Fundamentals Of Spacecraft Attitude Determination And Control 8 Probes Depend heavily on star trackers and gyroscopes for attitude determination, with thrusters used for larger reorientations. CubeSats and SmallSats Typically employ magnetorquers and sun sensors due to size, weight, and power constraints. --- Future Trends in Attitude Determination and Control Advances in technology continue to improve AD&C capabilities: - Miniaturized Sensors: Micro-electromechanical systems (MEMS) gyroscopes and magnetometers. - Machine Learning: Enhanced sensor fusion and disturbance estimation. - Autonomous Control: Increased onboard processing for real-time attitude management. - Hybrid Actuator Systems: Combining reaction wheels, CMGs, and thrusters for versatile control. --- Conclusion Mastering the fundamentals of spacecraft attitude determination and control is fundamental for the success of space missions. From selecting suitable sensors and actuators to implementing robust algorithms, each component plays a vital role in ensuring the spacecraft maintains the correct orientation for its operational tasks. As technology advances, the integration of sophisticated sensors, control algorithms, and autonomous systems will continue to enhance the precision, reliability, and efficiency of spacecraft attitude management, opening new frontiers for exploration and scientific discovery. --- References & Further Reading: - Wertz, J.R., & Larson, W.J. (Eds.). (1999). Space Mission Analysis and Design. Microcosm Press. - Wertz, J.R. (1978). Spacecraft Attitude Determination and Control. Springer. - Markley, F.L., & Crassidis, J.L. (2014). Fundamentals of Spacecraft Attitude Determination and Control. Springer. - NASA Technical Reports and Spacecraft Systems Engineering Resources spacecraft attitude control, attitude sensors, gyroscopes, star trackers, reaction wheels, control algorithms, quaternion representation, attitude dynamics, spacecraft navigation, control moment gyroscopes

Spacecraft Attitude Determination and ControlFundamentals of Spacecraft Attitude Determination and ControlSpacecraft Attitude Determination and ControlDevelopment of Novel Satellite Attitude Determination and Control Algorithms Based on Telemetry Data from an Earth SatelliteFault Tolerant Attitude Estimation for Small SatellitesGPS-based Attitude Determination and ApplicationsSpacecraft Modeling, Attitude Determination, and ControlAttitude Determination and Control Hardware Development for Small SatellitesAn Attitude Determination and Control System for Small SatellitesA flexible attitude control system for three-axis stabilized nanosatellitesADCS - Spacecraft Attitude Determination and ControlDevelopment and Analysis of a Small Satellite Attitude Determination and Control System TestbedAttitude Determination and Control System for the Dawgstar NanosatelliteSpacecraft Attitude Control ProgramMultisensor Attitude EstimationGuidance and Control 1995Attitude Determination and Control for KUTESat PathfinderGuidance and ControlGuidance and Control 1980Spaceflight Dynamics 1998 James R. Wertz F. Landis Markley James Richard Wertz Narendra Gollu Chingiz Hajiyev Peiqing Xia Yaguang Yang Marc Fournier Margaret Hoi Ting Tam Gordon, Karsten Michael Paluszek Corey Whitcomb Crowell Deddy Gunawi Murlidhar Rajagopalan Hassen Fourati Robert D. Culp Umakanth Goud Mogili Louis A. Morine Thomas Stengle

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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

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 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

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 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

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

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

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

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