Attitude Determination Using Star Tracker Matlab Code

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 is an up-to-date compendium on spacecraft attitude and orbit control (AOC) that offers a systematic and complete treatment of the subject with the aim of imparting the theoretical and practical knowledge that is required by designers, engineers, and researchers. After an introduction on the kinematics of the flexible and agile space vehicles, the modern architecture and functions of an AOC system are described and the main AOC modes reviewed with possible design solutions and examples. The dynamics of the flexible body in space are then considered using an original Lagrangian approach suitable for the control applications of large space flexible structures. Subsequent chapters address optimal control theory, attitude control methods, and orbit control applications, including the optimal orbital transfer with finite and infinite thrust. The theory is integrated with a description of current propulsion systems, with the focus especially on the new electric propulsion systems and state of the art sensors and actuators.
Using inertial rate gyros and a single star tracker, attitude determination and estimation for a geostationary earth orbiting spacecraft was accomplished.
Stray light is defined as unwanted light in an optical system, a familiar concept for anyone who has taken a photograph with the sun in or near their camera's field of view. In a low-cost consumer camera, stray light may be only a minor annoyance, but in a space-based telescope, it can result in the loss of data worth millions of dollars. It is imperative that optical system designers understand its consequences on system performance and adapt the design process to control it. This book addresses stray light terminology, radiometry, and the physics of stray light mechanisms, such as surface roughness scatter and ghost reflections. The most-efficient ways of using stray light analysis software packages are included. The book also demonstrates how the basic principles are applied in the design, fabrication, and testing phases of optical system development.
This book de-emphasizes the formal mathematical description of spacecraft on-board attitude and orbit applications in favor of a more qualitative, concept-oriented presentation of these topics. The information presented in this book was originally given as a set of lectures in 1999 and 2000 instigated by a NASA Flight Software Branch Chief at Goddard Space Flight Center. The Branch Chief later suggested this book. It provides an approachable insight into the area and is not intended as an essential reference work. ACS Without an Attitude is intended for programmers and testers new to the field who are seeking a commonsense understanding of the subject matter they are coding and testing in the hope that they will reduce their risk of introducing or missing the key software bug that causes an abrupt termination in their spacecraft’s mission. In addition, the book will provide managers and others working with spacecraft with a basic understanding of this subject.
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.
Some modern spacecraft missions require precise knowledge of the attitude, obtained from the ground processing of on-board attitude sensors. A traditional 6-state attitude determination filter, containing three attitude errors and three gyro bias errors, has been recognized for its robust performance when it is used with high quality measurement data from a star tracker for many past and present missions. However, as higher accuracies are required for attitude knowledge in the missions, systematic errors such as sensor misalignment and scale factor errors, which could often be neglected in previous missions, have become serious, and sometimes, the dominant error sources. The star tracker data have gaps and degradation caused by, for example, the Sun and Moon blocking in the filed of view and data time tag errors. Thus, attitude determination based on the gyro data without using the star tracker data is inevitably required for most missions for the period when the star tracker is unable to provide accurate data. However, any gyro-based attitude errors would eventually grow exponentially because of the uncorrected systematic errors of gyros and the uncorrected gyro random noises. An improved understanding of the gyro random noise characteristics and the estimation of the gyro scale

factor errors and gyro misalignments are necessary for precise attitude determination for some present and future missions. The 6-state filters have been extended to 15-state filters to estimate the scale factor and misalignment errors of gyros especially during a high-slew maneuver and the performance of theses filters has been investigated. During a starless period, the inevitable drift of the EKF solutions, which are caused by the uncorrected gyro's systematic errors and the gyro random noises, can be replaced with the batch solutions, which are less affected by the data gap in the star tracker. Power Spectral Density and the Allan Variance Method are used for analyzing the gyro random noises in both ICESat and simulated gyro data, which provide better information about the process noise covariance in the attitude filter. Both simulated and real data are used for analyzing and evaluating the performances of EKF and batch algorithms.

This thesis uses a COTS camera as a star tracker to determine the position a spacecraft simulator and the error bounds associated with the system, as well as ridding the gyros on the simulator of their drift error.

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.

Attitude Determination Using Star Tracker Data with Kalman Filters

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This thesis researches different star pattern recognition and attitude determination algorithms for a three-axis rotational spacecraft. A simulated star field will be suspended above the experimental Three-Axis Spacecraft simulator to proved a reference for the star-pattern recognition algorithms. A star field inertial reference frame database of stars will be developed with the simulator at zero attitude. The angle, planar triangle and spherical triangle star patter recongition algorithms will then be used to identify which stars are within a camera's field of vision. The imaged stars will then be matched up to the corresponding stars within the test bed database. With the imaged stars identified and the corresponding inertial frame reference data, the test bed's attitude will be determined using the least-squares, TRIAD, and Quaternion Estimator (QUEST) attitude determination algorithms. On the three-axis simulator, an iterative algorithm is developed to demonstrate increasing star tracker accuracy with each update A matrix.

Reducing the cost of space program interests people more and more nowadays due to the concerns of budget limitation and commercialization of space technology. The Proceedings of the 3rd International Symposium on Reducing the Cost of Spacecraft Ground Systems and Operations bring together papers contributed by the authors representing the research organizations, academic institutions and commercial sectors of 10 countries around the world. The papers encompass the subject areas in mission planning and operation, TT&C systems, mission control centers, and mini and small satellite support, highlighting the issues concerned by the researchers and engineers involved in a wide range of space programs and space industries.

The objective of this research is to study different novel developed techniques for spacecraft attitude determination methods using star tracker sensors. This dissertation addresses various issues on developing improved star tracker software, presents new approaches for better performance of star trackers, and considers applications to realize high precision attitude estimates. Star-sensors are often included in a spacecraft attitude-system instrument suite, where high accuracy pointing capability is required. Novel methods for image processing, camera parameters ground calibration, autonomous star pattern recognition, and recursive star identification are researched and implemented to achieve high accuracy and a high frame rate star tracker that can be used for many space missions. This dissertation presents the methods and algorithms implemented for the one Field of View 'FOV' StarNavI sensor that was tested aboard the STS-107 mission in spring 2003 and the two fields of view StarNavII sensor for the EO-3 spacecraft scheduled for launch in 2007. The results of this research enable advances in spacecraft attitude determination based upon real time star sensing and pattern recognition. Building upon recent developments in image processing, pattern recognition algorithms, focal plane detectors, electro-optics, and microprocessors, the star tracker concept utilized in this research has the following key objectives for spacecraft of the future: lower cost, lower mass and smaller volume, increased robustness to environment-induced aging and instrument response variations, increased adaptability and autonomy via recursive self-calibration and health-monitoring on-orbit. Many of these attributes are consequences of improved algorithms that are derived in this dissertation.

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).

Precision attitude determination is essential to the success of many spacecraft missions, particularly those in remote sensing where slight deviations in instrument pointing can yield high measurement errors, such as for the Ice, Cloud, and land Elevation Satellite (ICESat). Characterizing and understanding the nature of star tracker distortion is beneficial to the development of improved models for estimation and correction in data post-processing towards achieving arcsecond pointing accuracy for applications such as geolocation. Using a localized attitude dependent distortion estimation algorithm, star tracker distortion throughout the seven-year ICESat mission lifespan is analyzed to determine how the estimated distortion changes with respect to certain parameters of interest. These parameters include time, apparent motion of stars across the star tracker field of view, region of the celestial sphere observed, frequency and duration of star tracker blinding events, star tracker temperature, and star color. Distortion is estimated for each operational period and for the full mission. An increase in the estimated distortion of approximately half an arcsecond to one arcsecond was observed over the duration of the mission. Regions of high and low distortion were observed to shift depending on the direction stars entered and exited the field of view. The region of the celestial sphere observed was determined to be insignificant relative to the effects of star motion across the field of view. Artificially high distortion observations that followed periods of blinding were confirmed to be the source of the high distortion estimated for certain operational periods of the mission. Star tracker temperature was determined to have no effect on the estimated distortion. Chromatic aberration could not be definitively confirmed. Recommendations are provided for implementation of this method on future missions. CCD aging effects should be considered if a static distortion model yields distortion residuals with a temporal dependence. The incorporation of telemetry from additional star trackers to support attitude determination while the star tracker of interest is blinded would eliminate high distortion observations caused by poor attitude estimates after periods of star tracker blinding. Adjustment of the distortion basis function to include star color dependent coefficients would allow for direct estimation of chromatic aberration. Proper consideration of the results presented in this thesis will yield a more robust distortion estimation and correction process for future missions which require precision pointing.

Unifying the most important methodology in this field, Multi-Resolution Methods for Modeling and Control of Dynamical Systems explores existing approximation methods as well as develops new ones for the approximate solution of large-scale dynamical system problems. It brings together a wide set of material from classical orthogonal function approximation, neural network input-output approximation, finite element methods for distributed parameter systems, and various approximation methods employed in adaptive control and learning theory. With sufficient rigor and generality, the book promotes a qualitative understanding of the development of key ideas. It facilitates a deep appreciation of the important nuances and restrictions implicit in the algorithms that affect the validity of the results produced. The text features benchmark problems throughout to offer insights and illustrate some of the computational implications. The authors provide a framework for understanding the advantages, drawbacks, and application areas of existing and new algorithms for input-output approximation. They also present novel adaptive learning algorithms that can be adjusted in real time to the various parameters of unknown mathematical models.

The star tracker experiment will demonstrate accurate, near real time, autonomous satellite attitude determination using a state-of-the-art charge-coupled-device star camera. The experiment will fly on a NASA spacecraft, designed to carry and support experimental payloads, and launched for a 40-hour mission from the space shuttle, and then retrieved for return to earth. The new camera and attitude software represent a significant step toward spacecraft autonomy. The experiment design and algorithm are discussed, along with a brief description of the data analysis plans. Features needed to improve the system to support a mapping application are also discussed.

ICESat attitude determination is based on sensor data from three star trackers and a hemispherical resonator gyro. Methods for estimating and correcting star tracker distortion using on-orbit data are studied here. Two methods for modeling distortion, one based on an estimate of the star tracker attitude and the other independent of attitude, are described. Two methods for structuring the least squares estimation of distortion are also described, one based on a patchwork of smoothly joined local estimates and the other using a single global estimate. A new method is introduced for the iteration of attitude and distortion estimation when using the attitude dependent distortion model. Analysis of ICESat's star trackers demonstrates the effects of significant distortion in one of the three star trackers, relative to the other two. These effects include a qualitatively different distribution of residual errors (the differences between observed and computed direction vectors), small scale localized structures in the distortion caused by hardware errors such as bad pixel columns, and discontinuities in attitude estimation corresponding to stars entering and leaving the star tracker field of view. Finally, application of these methods to a conventional camera as part of the ICESat ground calibration and validation program is described in the appendix.

This study adapts some established attitude determination techniques for use with star tracker measurements on satellites. Other work in this area has utilized gyro measurements with star tracker updates. Today's star trackers are giving measurements with accuracies of less than 6 arcseconds, and are therefore of high enough fidelity to be used alone. Computer simulation of a Linear Kalman Filter to process these measurements is presented. The Filter uses a linear, constant coefficient state matrix with the Optimal Control Law to provide negative feedback control. The control law uses information developed through the equations of motion of the spacecraft in a Molnyia orbit. Modifications to the Filter, including glitch rejection and various covariance manipulation techniques are discussed as possible sources for performance enhancement.

In the book are reported the main results presented at the Third International Workshop on Data Analysis in Astronomy, held at the EUore Majorana Center for Scientific Culture, Erice, Sicily, Italy, on June 20-27,1988. The Workshop was the natural evolution of the two previous ones. The main goal of the first edition (Erice 1984) was to start a scientific interaction between Astronomers and Computer Scientists. Aim of the second (Erice 1986) was to look at the progress in data analysis methods and dedicated hardware technology. Data analysis problems become harder whenever the data are poor in statistics or the signal is weak and embedded in structured background. Experiments collecting data of such a nature require new and non-standard methodologies. Possibilistic approaches could be merged with the statistical ones, in order to formalize all the knowledge used by the scientists to reach conclusions. Moreover, the last decade has been characterized by very fast developments of Intelligent Systems for data analysis (knowledge based systems, ...) that would be useful to support astronomers in complex decision making. For these reasons, the last edition of the workshop was intended to provide an overview on the state of the art in the data analysis methodologies and tools in the new frontieres of the astrophysics (y-astronomy, neutrino astronomy, gravitational waves, background radiation and extreme cosmic ray energy spectrum). The book is organized in two sections: - Data analysis methods and tools, - New frontieres in astronomy.

This book is about spaceborne missions and instruments. In addition, surveys of airborne missions and of campaigns can be found on the accompanying CD-ROM in pdf-format. Compared with the 3rd edition the spaceborne part grew from about 300 to 1000 pages. The complete text - including the electronic-only chapters - contains more than 1900 pages. New chapters treat the history of Earth observation and university missions. The number of commercial Earth imaging missions has grown significantly. A chapter contains reference data and definitions. Extensive appendices provide a comprehensive glossary, acronyms and abbreviations and an index of sensors. An effort has been made to present the information in context, to point out relationships and interconnections. The book may serve as a reference and guide to all involved in the various national and international space programs: researchers and managers, service providers and data users, teachers and students.

"As interest in nanosatellites grows within the university community, the demand for inexpensive, space-grade hardware grows as well. Star trackers can be a luxury item for some spacecraft and therefore are often not considered due to their cost. Ideally, a star tracker could be built using inexpensive parts so long as the software is available. Unlike many other attitude determination instruments, star trackers are renowned for their high accuracy, yielding accurate and precise attitude estimates. However, development of this software can be overwhelming for the university settling, especially when multiple missions are on hand. If these instruments were readily available for more spacecraft, university-sponsored missions could expand to higher orbits and possibly deep space applications. Keeping in mind the cost and time constraints most university missions run into, the difficulty of developing an inexpensive star tracker stems from the integrated software. Hardware can be commercial off-the-shelf products, but the software is the more expensive of the two, and it is this software that is often lacking at the university level. With this, the proposed algorithm shows promise for the development, implementation, and testing of free star tracker software. The presented algorithm allows for a variety of interchangeable hardware, making it ideal for the academic community"--Abstract, page iii.

This book summarizes the research advances in star identification that the author’s team has made over the past 10 years, systematically introducing the principles of star identification, general methods, key techniques and practicable algorithms. It also offers examples of hardware implementation and performance evaluation for the star identification algorithms. Star identification is the key step for celestial navigation and greatly improves the performance of star sensors, and as such the book include the fundamentals of star sensors and celestial navigation, the processing of the star catalog and star images, star identification using modified triangle algorithms, star identification using star patterns and using neural networks, rapid star tracking using star matching between adjacent frames, as well as implementation hardware and using performance tests for star identification. It is not only valuable as a reference book for star sensor designers and researchers working in pattern recognition and other related research fields, but also as teaching resource for senior postgraduate and graduate students majoring in information processing, computer science, artificial intelligence, aeronautics and astronautics, automation and instrumentation. Dr. Guangjun Zhang is a professor at the School of Instrumentation Science and Opto-electronics Engineering, Beihang University, China and also the Vice President of Beihang University, China

This is the first book on the topic of all source positioning, navigation and timing (PNT) and how to solve the problem of PNT when the most widely-used measurement source available today, the GPS system, may be come unavailable, jammed or spoofed. Readers learn how to define the system architecture as well as the algorithms for GPS-denied and GPS-challenged PNT systems. In addition, the book provides comprehensive coverage of the individual technologies used, such as celestial navigation, vision-based navigation, terrain referenced navigation, gravity anomaly referenced navigation, signal of opportunity (SOO) based PNT, and collaborative PNT. Celestial Navigation is discussed, with stars and satellite used as reference, and star-tracker technology also included. Propagation based timing solutions are explored and the basic principles of oscillators and clocks presented. Initial alignment of strap-down navigation systems is explored, including initial alignment as a Kalman filter problem. Velocimeter/Dead reckoning based navigation and its impact on visual odometry is also explained. Covering both theoretical and practical issues, and packed with equations and models, this book is useful for both the engineering student as well as the advanced practitioner.

This research outlines a low-cost, low-power, arc-minute accurate star tracker that is designed for use on a CubeSat. The device is being developed at the University of Texas at Austin for use on two different 3-unit CubeSat missions. The hardware consists of commercial off-the-shelf parts designed for use in industrial machine vision systems and employs a 1024x768 grey-scale charge coupled device (CCD) sensor. The software includes the three standard steps in star tracking: centroiding, star identification, and attitude determination. Centroiding algorithms were developed in-house. The star identification code was adapted from the voting method developed by Kolomenkin, et al. Attitude determination was performed using Markley's singular value decomposition method. The star tracker was then tested with internal simulated star-fields. The resulting accuracy was less than an arcminute. It was concluded that this system is a viable option for CubeSats looking to improve their attitude determination. On-orbit demonstration of the system is planned when the star tracker flies on the planned CubeSat missions in 2013 or later. Further testing with external simulated star fields and night sky tests are also planned.