used in space robots. Chapter 8 introduces a variety of sensors and associated estimation methodologies used by space vehicles. Although cursory in parts, this is essential knowledge and recommended reading for any aspiring space roboticist.

This book is useful particularly as a single source of information for the broad spectrum of technologies related to space robotics and would be a good overview of the most established concepts and methodologies for graduate students and researchers entering the field. It would be a suitable text for a dedicated taught module in space robotics, or as a guide for graduate study in robotics, dynamics and control related to space engineering. The text is very rich in equations, figures and tables, and the treatment is very theoretical, which leads to models occasionally becoming very complex. Undergraduate students and recent graduates may find it difficult to follow in some sections without additional guidance and examples being provided.

Overall, this book is a worthwhile read for capable space roboticists looking to build or extend their knowledge of the field.

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Spacecraft Modeling, Attitude Determination and Control: Quaternion-Based Approach

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CRC Press, Taylor & Francis Group, 6000 Broken Sound Parkway NW, Suite 300, Boca Raton, FL 33487-2742, USA. 2019. Distributed by Taylor & Francis Group, 2 Park Square, Milton Park, Abingdon OX14 4RN, UK. xi; 327 pp. £140. (20% discount available to RAeS members via www.crcpress.com using AKQ07 promotion code). ISBN 978-1-138-33150-1.

This book provides a good and comprehensive overview of spacecraft attitude dynamics, determination and control, including advances in the quaternion-based approach, with application to practical problems such as coupled attitude and orbit control and model predictive optimal control with realistic actuator constraints. Different options for spacecraft actuation are considered, including the use of momentum exchange devices such as control moment gyros for attitude control, thruster-based reaction control systems and magnetic torques for the desaturation of momentum exchange devices.

Chapters 2 and 3 provide the necessary background to orbital dynamics and attitude parameterisations, respectively. The orbital dynamics background is necessary to the later sections where the attitude is referenced with respect to a local orbit frame, particularly when applied to orbit raising manoeuvres, as in Chapter 12. The attitude parameterisations covered include the Euler angle-based rotational sequences with respect to fixed or rotating frames and the quaternion attitude parameterisation. The rotation matrix concept and quaternion properties are very clearly presented. The Euler rotational sequences could have been presented in a more comprehensive way to cover all 12 possible rotational sequences, but the focus was understandably on quaternions, which are the focus of the book.

In chapter 4, the equations of attitude dynamics and kinematics are derived from the differential equation relating angular momentum to external torques. It would have been helpful to start with the simpler case of torque-free motion where momentum is conserved, but the focus of the book is understandably on the effect of control and disturbance torques. The dynamical models represent the non-linear and linearised models, with respect to the inertial and nadir-pointing frames. The linearised models traditionally derived using Euler angles are presented using quaternion modelling, which is an interesting feature of the book. External disturbance torques are accurately modelled in chapter 5, including gravity gradient torques, aerodynamic torques, magnetic torques and the torques due to solar radiation pressure.

In chapter 6, sensor fusion methods allowing the determination of spacecraft attitude from a minimum of two vector observations are proposed, starting from the formulation of the Wahba problem with two vector observations that can be solved using the triad method before Davenport's Q-method is presented together with computationally efficient approaches to the problem such as the QUEST method. The author then proposes his own innovative research-based approaches to this problem using an analytic method in the case of two observations (section 6.4) using a minimum angle quaternion approach and multiple observations (section 6.5), based on a characteristic polynomial approach. The superiority of the analytic method is demonstrated by numerical tests.

In chapter 8, spacecraft attitude estimation uses the widely used Extended Kalman Filter (EKF) approach, which approaches the optimal estimates using a local linearisation. In this book, the EKF uses quaternions for the attitude kinematics and assumes a Gaussian process noise and a drift in the gyro angular rate measurements. A good engineering-based explanation is given about the way the Kalman gain is optimised. A reduced-order quaternion model is then introduced by the author and allows for the use of the standard linear Kalman filter, which simplifies estimator tuning. Given that the author covers the most advanced optimal control methods such as model predictive control, this discussion could have been extended to mention how some advances in non-linear optimal estimators such as particle filters may be required to address the estimation accuracy and robustness requirements of future space missions.

The spacecraft attitude control problem is first formulated using a Linear Quadratic Regulator (LQR) approach, for which the

https://doi.org/10.1017/aer.2020.110 Published online by Cambridge University Press

analytic solution is analysed and linked to a robust closed-loop pole assignment problem. On page 111, the analysis is correct but it is unclear why the author refers to the Karush–Kuhn–Tucker (KKT) conditions, as the problem only has equality and no inequality constraints, so the conditions used correspond in reality to the simpler Lagrange conditions. Interesting examples show how control requirements on settling time and overshoot can be met by using the robust pole assignment method based on linear control theory, even in the presence of small nonlinearities (10^o on all three axes) and model uncertainty on the cross diagonal elements of the moment of inertia matrix.

After a brief introduction of actuator models in chapter 10, chapter 11 addresses the conditions on spacecraft controllability using only magnetic torques before deriving the periodic Riccati equation because of the periodic nature of the magnetic field vector variations. The effectiveness of the magnetic control algorithms as a means of slow attitude control is demonstrated by numerical simulation analysis. Magnetic torquers are then applied to momentum desaturation using a quaternion-based LQR approach, which is then extended to discrete time-periodic LQR. An interesting analysis of computation time using the proposed LQR implementations, both analytically and numerically, is then presented in section 11.5.3. The quaternion-based attitude control approach used throughout the book is then compared with the Euler-based approach for an orbit raising manoeuvre using thrusters.

Model Predictive Control (MPC) is then introduced as one of the promising methods for attitude control following advances in the computational capabilities of spacecraft. MPC is applied in chapter 13 to the spacecraft attitude control problem subject to actuator constraints. The MPC algorithm uses a box constrained convex Quadratic Programming (QP) approach, which is solved using an efficient interior point method that solves the KKT conditions and ensures convergence to the optimal solutions. The approach is applied to the thruster-based control problem of chapter 12. The additional practical considerations when attitude control is performed using Control Moment Gyros (CMGs) to ensure agile manoeuvring are covered in chapter 14, where an MPC approach is also proposed to optimise performance under robustness constraints. Finally, the proposed quaternion-based MPC approach is applied in chapter 15 to the coupled attitude and orbit control problem for a soft spacecraft docking application. This research area has received increased attention in recent years. Useful appendices are provided, particularly for the fundamentals of optimal control and robust pole assignment.

In conclusion, the book is a good and useful resource for researchers and research-minded engineers wishing to develop a more detailed understanding of some of the latest advances in robust pole placement and model predictive control to spacecraft attitude control. The quaternion-based approach is applied to practical attitude estimation and attitude control problems ranging from nadir pointing using reaction wheels or CMGs to momentum dumping using magnetic torquers and coupled attitude and orbit control for spacecraft docking. Rigorous proofs of stability and optimality are provided by the author for the quaternion-based robust pole placement, LQR, MPC and other control methods used throughout the book. The proposed methods are methodically analysed and numerically simulated, evaluated and compared against published research in the field.

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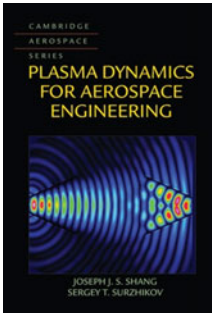

Plasma Dynamics for Aerospace Engineering

J. J. S. Shang and S. T. Surzhikov

Cambridge University Press, University Printing House, Shaftesbury Road, Cambridge CB2 8BS, UK. 2018. xiv; 387 pp. Illustrated. £89.99. ISBN 978-1-108-41897-3.

This book aims to summarise the development of plasma physics over the past 50 years and to link this development to aerodynamics. The authors are two very experienced researchers who have made substantial contributions to the application of computational plasma physics to aerodynamics, among other things.

One important emphasis that is made in the book is the interdisciplinary nature of this subject, with computations often requiring a complex mixture of scales from the quantum to continuum level. The target audience is aerospace engineers and researchers who wish to explore how plasmas can affect aerodynamics. The approach taken in the book is to present many of the fundamental aspects