Dynamics and Control of Autonomous Space Vehicles and Robotics

This book presents the established principles underpinning space robotics (conservation of momentum and energy, stability) in a thorough and modern fashion. Chapters build from general physical foundations through an extensive treatment of kinematics of multi-body systems, and then to conservation principles in dynamics. The latter part of the book focuses on real-life applications related to space systems.

Drawing upon years of practical experience and using numerous solved examples, illustrative applications, and MATLAB, Ranjan Vepa discusses:

- Basic space mechanics and the dynamics of space vehicles.
- Conservation and variational principles in dynamics and in control theory that can be applied to a range of space vehicles and robotic systems.
- A systematic presentation of the application of dynamics and control theory to real spacecraft systems.

Dr. Ranjan Vepa is currently a senior lecturer at Queen Mary University of London. He is the author of five books: *Biomimetic Robotics*; *Dynamics of Smart Structures*; *Dynamic Modeling, Simulation and Control of Energy Generation*; *Flight Dynamics Simulation and Control of Aircraft*; and *Nonlinear Control of Robots and UAVs*. His research interests include applications in space robotics, electric aircraft, and autonomous vehicles. He teaches advanced courses on robotics, aeroelasticity, advanced flight control and simulation, and spacecraft design, maneuvering, and orbital mechanics.

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To my parents, Narasimha Row and Annapurna, and to my family

Contents

Preface

This book is about the stability and control of satellites carrying robotic manipulators as well as the stability and control of the manipulators themselves. The book also addresses the issues related to the stability and control of planetary rovers that are used to explore the environment of a planet's surface. The book begins with an introduction to "Autonomous Space Vehicles and Robotics," followed by a chapter on "Space Vehicle Orbit Dynamics." Chapter 3 is entitled "Space Vehicle Attitude Dynamics and Control." The next chapter is about the dynamics of manipulators on board a spacecraft and is entitled "Manipulators on Space Platforms: Dynamics and Control." In particular, the focus of this chapter is on establishing the dynamic models of the robotic manipulators with a finite number of degrees of freedom operating on board a space vehicle. The dynamic stability and control of the coupled manipulator and satellite dynamics are also discussed in this chapter. "Kinematics, Dynamics, and Control of Mobile Robot Manipulators" is discussed in the next chapter, while Chapter 6 is devoted to the dynamics and control of planetary rovers. This chapter deals with mobile robots and is entitled "Planetary Rovers and Mobile Robotics."

The focus of the penultimate chapter is on "Navigation and Localization," and deals with specialized issues related to autonomous navigation and the issue of localization in mobile robotics, including triangulation, trilateration, dead reckoning, localization based on significant environmental characteristics, odometry, statistical and probabilistic approaches, Markov localization, and the use of Kalman filters for localization. Chapter 8 is about "Sensing and Estimation of Spacecraft Dynamics." In particular, the various types of sensors that are typical to the space environment and the problems associated with the estimation of the spacecraft's position and orientation will be discussed here.

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I would like to thank my wife, Sudha, for her love, understanding, and patience. Her encouragement was a principal factor that provided the motivation to complete the

project. I would like to thank my brother Dr. Kosla Vepa, who was always willing to discuss issues related to astronautics and space mechanics. Finally, I must add that my interest in the kinematics of mechanisms and in robotics was inherited from my late father many years ago. To him I owe my deepest debt of gratitude. This book is dedicated to his memory.

Acronyms

AC	Alternating current
AKM	Apogee kick motor
AUV	Autonomous underwater vehicle
BLF	Barrier Lyapunov function
CDM	Code division multiplexing
CG	Center of gravity
CM	Center of mass
CP	Center of (aerodynamic) pressure
DC	Direct current
DOP	Dilution of precision
ECEF	Earth centered earth fixed
ECI	Earth centered inertial
EDM	Enhanced disturbance map
EKF	Extended Kalman filter
ESA	European space agency
FDMA	Frequency division multiple access
GDOP	Geometric dilution of precision
GEO	Geostationary earth orbit
GPE	Gauss planetary equations
GPS	Global positioning system
GTO	Geosynchronous transfer orbit
HCW	Hill Clohessy Wiltshire
HDOP	Horizontal dilution of precision
IAGA	International association of geomagnetism and aeronomy
IGRF	International geomagnetic reference field
IR	Infra-red
ISS	*International space station*
JAXA	Japan aerospace exploration agency
JPL	Jet propulsion laboratory
LADAR	LASER detection and ranging
LASER	Light amplification by stimulated emission of radiation
LEO	Low earth orbit
LERM	Linear equations of relative motion
LIDAR	Light detection and ranging

LORAN	Long range navigation
LPE	Lagrange planetary equations
LQR	Linear-quadratic regulator
LVLH	Local vertical local horizontal
MER	Mars exploration rover
NASA	National aeronautics and space administration
NERM	Nonlinear equations of relative motion
PF	Particle filter
RAAN	Right ascension of the ascending node
RADAR	Radio detection and ranging
ROSCOSMOS	Russian federal space agency
ROV	Remotely operated vehicle
RTG	Radio-isotope thermoelectric generator
SI	Système internationale
SLAM	Simultaneous localization and navigation
SONAR	Sound navigation and ranging
SRP	Solar radiation pressure
SSO	Sun synchronous orbit
SSRMS	Space shuttle remote manipulator system
TDOP	Time dilution of precision
TLE	Two line elements
TVC	Thruster vectoring control
UKF	Unscented Kalman filter
VDOP	Vertical dilution of precision