https://doi.org/10.1595/205651321X16294492627823 *Johnson Matthey Technol. Rev.*, 2021, **65**, (4), 597–599

JOHNSON MATTHEY
TECHNOLOGY REVIEW
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"Space Robotics"

By Yaobing Wang, Springer Nature Pte Ltd, Singapore, 2021, 363 pp, ISBN 978-981-15-4901-4, £129.99, €155.99, US$179.99

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Introduction

"Space Robotics" by Yaobing Wang belongs to the series Space Science and Technologies co-published by Beijing Institute of Technology Press, China, and Springer Nature Pte Ltd, Singapore. The Editor-in-Chief of the series, Peijian Ye, is Academician of the Chinese Academy of Sciences in Beijing and has published a collection of 10 volumes. This volume's author, Yaobin Wang, is a research professor of Beijing Institute of Spacecraft System Engineering and Director of Beijing Key Laboratory of Intelligent Space Robotic Systems Technology and Applications. The book's 363 pages provide a condensed combination of theory and practice as engineering guidance.

Starting from the particularity of space environment and application, the book discusses the theory and method of space robot design. The purpose is to provide the basic concepts and theories and introduce the basic methods and steps of engineering implementation of space robots.

Systems and Design

In the following review, the 16 chapters will be described briefly. If you are not planning to design a space robot now, you might want to start reading at Chapter 15.

Chapter 1 provides a very short introduction and gives a brief description of space robot classifications (for example on-orbit operation, planetary exploration) and basic composition of space robots, like the mechanical system, power system and perceptual system. Chapter 2 details kinematics and dynamics, the basis of analysing the characteristics and control with kinematic equations and the modelling process for dynamics, analytics and path planning (**Figure 1**). Chapter 3 refers to motion planning which is the process of generating the desired motion trajectory in the

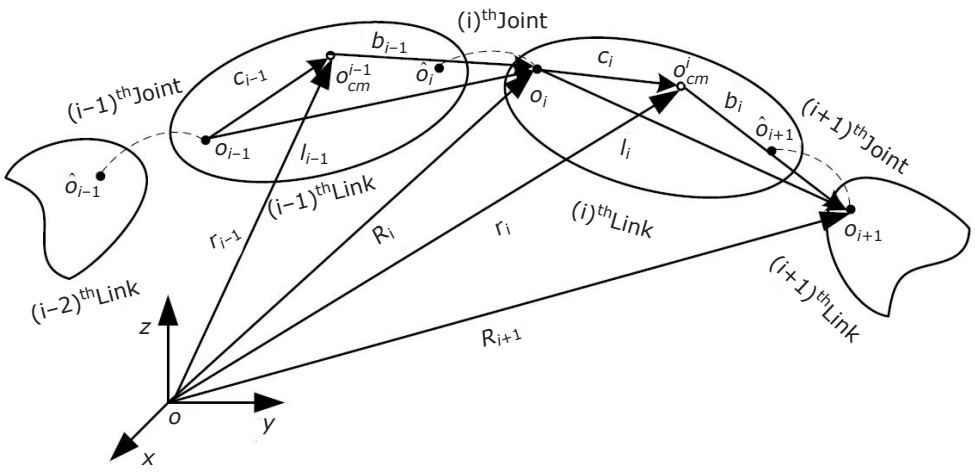


Fig. 1. Relationships of robot links. Copyright (2021). Reprinted with permission from Springer

robot joint space or Cartesian space according to the mission target. Path planning is to find an optimal motion path from the starting point to the target in the working environment with obstacles, which involves using an algorithm to find the optimal or near-optimal collision-free path and controlling the robot to track the planned path.

Chapter 4 follows with implementation of motion control after motion planning. This chapter takes the single joint control as example to illustrate the motion control method of space robots. The objective of motion control is to achieve the tracking of the desired joint states (angle, speed) with two main methods: three-loop servo motion control and dynamic model-based motion control. Chapter 5 describes robot force control, a method of modifying the contact force between the robot and the environment by controlling the joint output. The main purposes are to protect the robot or the objects in contact. Several methods have been proposed, most of which fall into two categories, namely hybrid force and position control and impedance control.

Chapter 6 lists general processes of space robot system design including task requirement analysis, design feasibility study, preliminary system design and detailed system design. The tasks comprise designs of configuration, information flow, thermal, ergonomic and safety. Chapter 7 details the mechanical system, the core of a space robot, which is used to enable the motion functions. Its performance directly affects the application effect. Mechanical system design generally includes material selection (for example alloys), structural parts design, mechanism components design, lubrication in space and verification scheme design. The environmental conditions are the main constraints to the main components structure, joint, end effector and mobile wheel. Chapter 8 describes the control system consisting of command scheduling layer, motion planning layer and execution control layer. Furthermore, it gives information on the design of the control system (centralised control and distributed control) including the control system architecture and software.

Chapter 9 focuses on the space robot perception system, for example visual perception system and force perception system, but mainly describing visual parts, being optical assembly, structural assembly and electronic assembly. The main functions of the space robot visual perception system are to realise target detection, recognition and measurement (for example binocular, laser).

Chapter 10 provides details on the teleoperation system which is an interactive tool between human and space robot. The design requires processes to be developed for the following elements: operator, the core of the system, communications, environment and the human-robot interaction interface, which includes information receipt, simulation of the state of the robot and environment and signal conversion. The teleoperation system generally has the main functions of status feedback and instruction generation.

Chapter 11 explains the system verification methods. Comprehensive and rigorous ground verification prior to launch are important and are done *via* simulation and physical testing. Due to the complexity of the robot systems, the verification of all parameters is generally done *via* the design of a prototype using physical test verification, semi-physical simulation verification and mathematical simulation verification.

Chapter 12 is the first chapter mentioning a design example of a large space manipulator mainly used in the field of manned space exploration, such as the construction and operational support of a space station (for example Canadarm for the International Space Station (ISS)). It covers the engineering background, system design, mechanical system design, control system design, perception system design and design verification. Chapter 13 follows with a design example of a planetary exploration mobile robot, currently only in operation on Mars and lunar surfaces (**Figure 2**). The wheeled movement scheme requires extra design and verification of landing platform, suspension schemes, driving and steering schemes and obstacle avoidance systems. Chapter 14 provides another design example of a planetary surface sampling manipulator which is a space robot that performs sampling tasks on the planet surface, usually mounted on a planetary lander or a planetary rover to perform multi-point sampling and other operations. In this chapter the design and verification are introduced, detailing on performance, task, interface, system and constraints as well as joint design, arm design and sampler design.

Chapter 15 starts with the evolution of space robots in the 1980s before moving towards the current research and usage of space robots in space stations and planetary exploration. A list with brief information on on-orbit operation robots and planetary exploration is provided. Chapter 16 is the final chapter and focuses on future prospects of space robots which will be developed with regard to their tasks of manned spaceflight, deep space

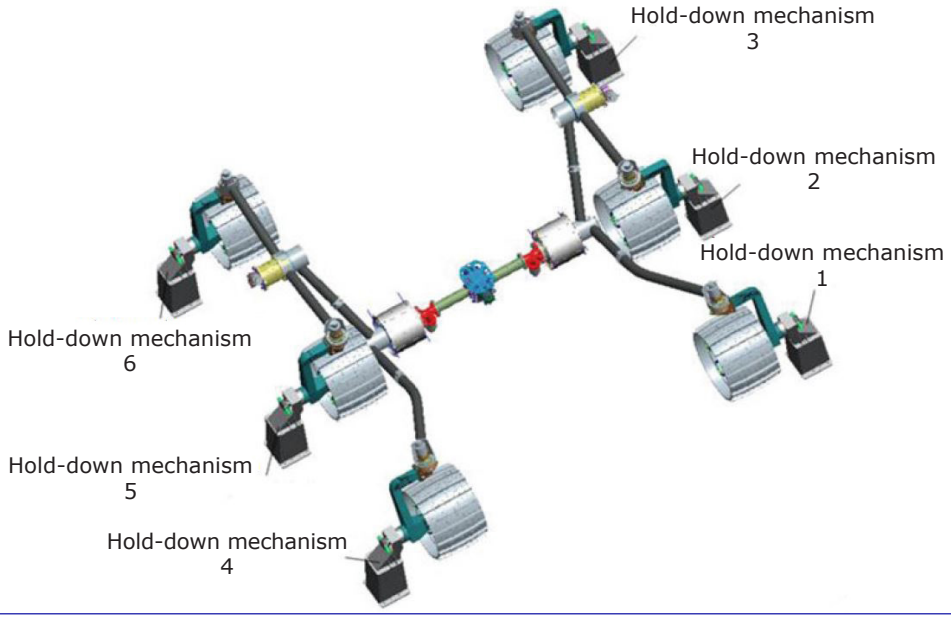
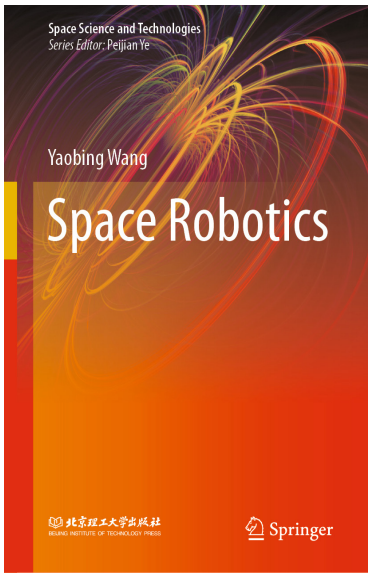


Fig. 2. Composition of the mechanical system of the planetary exploration mobile robot. Copyright (2021). Reprinted with permission from Springer

exploration and on-orbit services. Driven by the mission demands, space robots will integrate the latest achievements in the development of science and technology and will be constantly improved in form, function and performance to meet the needs of space missions. Some new concepts include soft robots, flying robots, space cloud robots, space multi-robot systems and artificially intelligent space robots.

Conclusions

The book is recommended for university students, researchers and engineers in the related fields. Most of the book focuses on theory, definitions and mathematical expressions, making the book a helpful tool for design of a space robot from the theoretical side. I would have expected details on currently operating space robots. In almost 400 pages only two tables provide a very basic overview of on-orbit operation and planetary exploration robots. Chapters 15 and 16 were most interesting as they go beyond the theoretical background, describing the current state and future prospects of space robots.



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The Reviewer

Wolfgang Kaltner is Head of Strategic Hydrogen in Fuels and Energy, Catalytic Technologies at Johnson Matthey, Germany. He is a chemical engineer and holds a PhD in Technical Chemistry. His interest in hydrogen and novel technologies has shaped his professional career.