

Preface

After entering the new century, a new strategic situation of “congestion, contest, and competition” has emerged in the international space field. The threat of space debris and shortage of orbit spectrum resources have become increasingly prominent, posing grave challenges to the long-term sustainable development of human space activities. According to the data released by the USA, currently there are 22,000 pieces of debris with a diameter of over 10 cm in the space, and millions or even billions of debris with smaller diameters. The large number of space debris increases the probability of space collision and may lead to a chain reaction, generating more debris and directly threatening the safety of on-orbit spacecraft. In addition, only a limited number of satellites can be accommodated in the geostationary Earth orbit (GEO) due to its uniqueness. The long-term cumulative effects have resulted in a shortage of the current GEO orbit spectrum resources, making it imperative to develop GEO defunct satellites removal technology in order to free up the occupied GEO resources. To address the issue of space debris removal, including defunct satellites, a key prerequisite is to find an effective way of on-orbit capture of space debris.

The capture of space targets is most commonly accomplished by using the space manipulator, which has been successfully applied in several on-orbit spacecraft rendezvous and docking missions since the technology is relatively mature. The manipulator-enabled space capture requires high precision in target tracking and measuring and bears a high risk of close-range collision, and it also requires a special capture interface; therefore, manipulators are mainly applicable to the capture of space cooperative targets. In general, the space debris are non-cooperative, not only unable to provide cooperative capture information, but also very difficult to be effectively controlled. In this sense, the manipulator-enabled space capture is more technically demanding and risky, making it necessary to develop new capture approaches, among which arises the novel concept of space net capture.

In a typical space net capture system, a chaser spacecraft ejects and deploys a net woven by flexible tether to cover and wrap the target spacecraft. The two spacecraft are thus connected together by the tether for on-orbit capture and removal.

Compared with the traditional manipulator-enabled capture, the space net capture system has the following distinctive features: Firstly, a capture distance of up to tens and hundreds of meters can effectively avoid the collision risk and increase the safety of on-orbit capture. Secondly, the fault-tolerant capture reduces the precision of target measurement and guidance control for the chaser spacecraft, and renders no need to customize a special capture interface. Thirdly, the capture from different directions of V-bar, R-bar, and the like can be realized by controlling the net ejection direction, thus reducing the fuel consumption of orbital maneuvers and increasing the application flexibility. As it were, the space net capture, a novel approach to remove the space debris, proves to be technically feasible and cost-effective, especially suitable for the capture of non-cooperative space targets.

The space net system has a unique structure of full flexibility and large deformation, whose dynamics issues and characteristics are beyond the scope of traditional aerospace dynamics studies. Specifically, it concerns rigid-flexible coupled dispersal and deployment dynamics, target contact and collision dynamics, complex de-orbit dynamics, and also involves the mechanical fundamentals on tether folding, winding, and fracture. All these problems directly affect and determine the design and application of the space net capture system, so they represent the theoretical problems that must be solved first in engineering application. Our research team began the theoretical and technical study of space net system from 2004, and has completed two doctoral dissertations and published dozens of papers in academic journals and on conferences at home and abroad. Based on our research work for over 10 years, this book systematically summarizes the recent theoretical and engineering fruits of space net, focuses on space net dynamics and space net system design, and provides a series of practical models, algorithms, simulation, and test results on space net dynamics, system and component design, ground tests, and so on.

This book consists of seven chapters. Chapter 1 introduces the application background, system concepts, and technical characteristics of space net capture, and describes its key technical problems and research progress. Chapter 2 gives the general cable dynamics modeling approaches and models, laying a theoretical foundation for the subsequent research and analysis of space net dynamics. Chapter 3 first introduces the structures, materials, and configuration design of the space net, derives the modeling approach, models and influences factors for space net dynamics, carries out the simulation and parameter sensitivity analysis of the space net dispersal and deployment dynamics, and gives the corresponding numerical simulation results and conclusions. Chapter 4 analyzes the dynamics process of contact and collision between the space net and the rigid target, and draws corresponding simulation results and conclusions based on the ANSYS/DYNA finite element analysis software. Chapter 5 establishes the dynamics models for the two phases of the rotating net deployment, respectively, based on the Lagrange equation and lumped mass method, puts forward the methods and strategies to control the rotating net deployment, and analyzes the motion stability. Chapter 6 studies the dynamics and coordinated control problems of a rigid-flexible coupling complex when the capture mission is completed and the complex needs to be transferred, and gives the corresponding simulation results and conclusions. Chapter 7 briefs the audience of relevant information on the

ground and airdrop tests. This book is overall planned, compiled, and proofread by Prof. Leping Yang. Chaps. 1, 3, and 7 are contributed by Prof. Qingbin Zhang; Chaps. 2, and 4 by Dr. Ming Zhen; and Chaps. 5 and 6 by Dr. Haitao Liu.

It should be honestly pointed out that this book is far from complete and comprehensive. Owing to the complicated rigid-flexible coupling dynamics and control problems in space net system studies, many problems still need to be further explored and investigated. Finally, due to our limited knowledge, there might be some mistakes and flaws in this book, so please do not hesitate to give your comments.

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