博士論文（要約）

Active Shape Control of Spinning Solar Sails for Orbital Maneuvers Using Boundary and Distributed Actuators

(スピン型ソーラーセイルの軌道変換に向けた
境界・分散アクチュエータによるアクティブ形状制御)

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As an ultimate form of spacecraft propulsion, the concept of solar sailing has been studied for more than 100 years. Since a solar sail can be accelerated without consuming propellant, it enables various missions that cannot be achieved using reaction engines. Starting from the world's first successful flight of a solar sail in 2010 by the Interplanetary Kite-craft Accelerated by Radiation Of the Sun (IKAROS), the technologies of solar sails have developed rapidly in the recent decade.

The on-orbit operation of IKAROS revealed a potential problem of solar sails that had not been recognized until then. Even a small deformation of a solar sail membrane causes strong, uncertain, and unpredictable disturbances on attitude motion because it changes the influence of solar radiation pressure (SRP) locally. The disturbance makes it difficult to follow steering laws designed for orbital maneuvers. Many missions have demonstrated fundamental technologies of solar sails so far, but none of them has succeeded in controlling the infinite-dimensional dynamics of membrane deformation. Although we now stand at the dawn of spaceflight by solar sails, this problem is critical to realizing solar sails for practical use.

This thesis proposes an active shape control method of solar sail membranes for the sake of orbital maneuvers. Actuators attached to the boundary or surface of a sail membrane give a periodic input to excite transverse vibrations. Thereby, the sail membrane forms a vibration mode corresponding to the input frequency, resulting in a three-dimensional configuration. Furthermore, the excited waveform can be static in the inertial frame by synchronizing the vibration with the spin of the spacecraft. This static waveform can produce constant change in SRP. Thus, the variation of SRP can be controlled rather than be perturbed, which enables a new concept of deformation-based solar sail steering.

In this thesis, the vibration mechanics of a spinning sail is uncovered first in preparation for the design of shape controllers. An analytical and general framework to describe membrane deformation is established. Next, control systems for active excitation are developed using the analytical model. Classifying the control methods into boundary control and distributed control, the control law of each system is designed. The performance of the control systems is evaluated by multibody simulations that consider nonlinear dynamics of membrane deformation. In addition to the numerical simulations, the proposed method is demonstrated by ground experiment. A hardware of the shape controller is designed and produced, and a polyimide film is vibrated in a vacuum chamber using the control device. Finally, simultaneous attitude-orbit control of a solar sail is investigated by applying the shape control method.