論 文 の 内 容 の 要 旨

論文題目　Relative Navigation and Guidance via Direction-Of-Arrival Estimation Method in Deep Space
(Direction-Of-Arriv al推定手法を用いた深宇宙における相対航法および誘導)

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Future deep space exploration is expected to be dominated by cooperative missions involving multiple spacecraft, which may include formation flights and rendezvous docking missions. Among these, missions using a large number of ultra-compact probes can enable exploration of target bodies that have been difficult to explore in the past. Autonomous relative navigation and guidance technology is a key technology for realizing missions using multiple ultra-compact probes. Navigation sensors such as cameras and LiDAR are effective when the relative distance between spacecraft is short. Several autonomous navigation and guidance methods using these sensors have been actively studied and demonstrated in orbit. However, there have been few studies conducted on navigation sensors that can be used at medium distances, ranging from tens to hundreds of kilometers.

Therefore, this thesis proposes an autonomous navigation guidance method that uses only angle information estimated by direction of arrival (DOA) estimation method using array antennas. An observer spacecraft receives radio signals emitted by a target spacecraft using an array antenna. The DOA estimation method is applied to the received signals to determine the direction of the

target. Navigation and guidance is then performed based on the angle information.

The purpose of this thesis is to establish the autonomous relative navigation and guidance method using the DOA estimation method for middle-range targets. This thesis also demonstrates a solution to a mission with a large number of ultra-compact probes.

This thesis first compares, organizes, and evaluates the array antennas and the DOA estimation algorithms proposed so far using numerical simulations.

Additionally, DOA estimation experiments are conducted using an array antenna and a signal processing system to demonstrate the feasibility of a spacecraft onboard navigation sensor.

Then, the requirements for applying the DOA estimation system to navigation and guidance are summarized. This thesis proposes three methods to meet the requirements, and verifies their effectiveness. The methods are: 1) a high-resolution array and low-cost estimation algorithm, 2) an optimum array design method, and 3) a combined system with a communication system. They are applicable not only for spacecraft navigation and guidance but also for general purposes.

Next, navigation and guidance are discussed. The DOA estimation only provides information about the direction of the radio source (the target spacecraft). Therefore, the features of navigation and guidance using only angle information are presented. Based on the features, an autonomous navigation and guidance algorithm that can be processed on-board is proposed and verified through numerical simulations.

The DOA estimation method and the angles-only navigation and guidance are combined to establish the navigation and guidance using DOA estimation method. First, through covariance analysis, the relations between array antennas, DOA estimation accuracy, and navigation and guidance accuracy are analytically clarified. It is demonstrated that DOA estimation is sufficient for navigation and guidance. Then, A series of steps in the design of the DOA estimation system and the operation of navigation and guidance are then presented.

Finally, a mission study is conducted. The numerical simulations demonstrate that the proposed navigation and guidance method using DOA estimation is feasible for a sample return mission with ultra-compact probes.