Orbit, Attitude, and Shape Estimation of Artifical Satellite around the Earth from Optical Observation

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論 文 名　：Orbit, Attitude, and Shape Estimation of Artificial Satellite around the Earth from Optical Observation
（地球周回の人工天体に対する光学観測による軌道，姿勢，形状の推定）

区　　分　：甲

論 文 内 容 の 要 旨

This thesis establishes precise orbit, attitude, and shape estimations by optical observations. To deal with orbital debris issues, orbital debris removal is believed to be essential for sustainable space development and utilization for human beings. However, it would be difficult for orbital debris removal satellites to approach and catch or grasp a tumbling object. Thus, it is expected to be helpful to first investigate on attitude motions and shape of the orbital debris.

First, the thesis explains a basic principal to estimate a given state by a batch least squares method. The algorithm of the batch least squares method is introduced in details. The method is applied to orbit, attitude, and shape estimations.

Secondly, this thesis deals with building a shape model considering self-shadowing effect. The proposed self-shadowing approach helps to separately compute external torque and brightness for each facet using a given shape. This enables to connect observed brightness with attitude motion or shape precisely.

Then, the thesis addresses orbit, attitude, and shape estimation, respectively. All the required matrices in the batch least squares method in each chapter are analytically formulated, which is beneficial in terms of the computation time and the accuracies in comparison with the numerically derived matrices. In addition, the analytical matrices do not need any tuning parameter. Thus, a user does not need empirical knowledge.

The proposed orbit estimator uses the analytical solutions for the state derivatives of the atmospheric drag, the solar radiation pressure, J_2 and J_{22} parts of the Earth’s oblateness, and the gravitational forces of the Sun and the Moon. These solutions let the computation 3.7 times faster than the numerical solutions. Furthermore, the proposed method gave the error of only 84 arcsec in the follow-up observations of Titan 3C Transtage after the proposed orbit estimation and two-months long-term orbit propagation, which is a better result than the commercial orbit determination software.

The attitude estimator based on the batch least squares method is proposed considering the self-shadowing effect. Since attitude estimation techniques in the field of asteroids would not be applicable due to the faster speed of spacecraft around the Earth. To deal with the issues, previous researches proposed estimators by an unscented Kalman filter. However, results depend on a tuning parameter. The proposed estimator in the thesis precisely models the relationship between the brightness and the attitude motion considering the self-shadowing effect. The proposed method is the first attitude estimation method ever. The numerical simulations are conducted and validated using the virtually generated light curves of H-2A rocket body.

The shape estimator based on the batch least squares method is developed including the self-shadowing effect, too. The method adopts spherical harmonics functions to express a shape by multiple facets. It can greatly reduce the size of the state than estimating all the components of the vertices. For example, the size of the required parameters is only 108 in the 5th degrees of the spherical harmonics, whereas the normal shape representation needs 64,279 vertices in total. In this thesis, the precise shape modeling by the spherical harmonics with the self-shadowing effect is proposed, which is the first approach for the spacecraft around the Earth ever. The numerical simulations are conducted, and even a low degree of the spherical harmonics successfully embodied the nozzle of the rocket body. This is a remarkable achievement although the simulations are performed under the ideal condition such as ignored attenuation of the reflected light.

Since the attitude and shape estimations have never been achieved for the Earth orbiting spacecraft considering the self-shadowing effect, the developments of these estimators would be valuable and contribute to better space environment and operations.