Light Curve Analysis and Attitude Estimation of Space Objects Focusing on Glint

Yuri Matsushita(1), Ryohei Arakawa(1), Yasuhiro Yoshimura(1), and Toshiya Hanada(1)

(1) Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan

ABSTRACT

Active Debris Removal (ADR) is one of the effective measures to maintain and/or reduce the number of orbital debris in LEO [1]. Grasping dynamic states of orbital debris such as their attitude motion and shape in advance is important to carry out ADR missions and to monitor the health of operational satellites. Light curve inversion is a dynamic state estimation technique using light curves, brightness of space objects as a function of time obtained by ground-based observations. This study aims to show a state estimation method using light curves with high precision. A previous study discusses the dynamic state estimation of a space object in GEO from its light curve using Unscented Kalman Filter (UKF) and Multiple-model Adaptive Estimation (MMAE) [2]. However, the problem is that this estimation method requires the initial attitude and the initial angular velocity of a space object that are very near to the true values with considering limiting magnitude of a telescope to be used for observations. In the case of no limiting magnitude in the light curves, the allowance errors are ± 30 deg for the initial attitude and ± 0.4 rad/hour for the initial angular velocity. To make matters worse, the estimation accuracy decreases significantly when considering the limiting magnitude. To avoid this difficulty, the previous study determines the initial values by using images obtained with radar or adaptive optics. Imaging by radar is very expensive due to its large instruments. Adaptive optics, which is a more reasonable method than radar, have a risk of getting insufficient images for the state estimation because of ambiguity by atmospheric disturbance. This paper proposes a high-accurate estimation method only with light curves by focusing on the characteristic, especially the rapid change of magnitude, called “glint”. It is known that the vicinity of glint has high observability and the large amount of information [3]. This paper shows conditions and characteristics of glint detection as the first step, which help excluding meaningless values from initial value candidates or updating values at glint detection when estimating with a filter. The glint detection geometrically constrains a surface of a space object and the position of the sun and an observer. The space object’s attitude at glint detection can be determined within a certain range by using the constrain and a peak value of glint.

To show conditions and characteristics of glint detection, two models are constructed: Static Light Curve Model and Quasi-static Light Curve Model. Static Light Curve Model is a simulation model to find the relationships among glint and attitude, apparent areas, and specular reflectance. It calculates magnitude of a target from sun vector, observation vector and attitude described by Euler angles to show a light curve. Ashikhmin-Shirley model is adopted as a reflectance model. Parameters for glint detection is only γ, the angle between the bisector angle of observer vector and sun vector and the normal vector of each surface. Apparent areas and specular reflectance affect the peak magnitude and size of glint. Quasi-static Light Curve Model is also a simulation model to find the relationship between glint and moment of inertia. This model combines actual attitude motion and light curves by getting Euler angles from the Euler Equation and put them into Static Light Curve Model. In the case of the same moment of inertia in three axes, it is a periodic rotation around one axis. On the other hand, in the case of the different moment of inertia in three axes, the rotational axis is changing. Glint is detected in both cases, but the surface of glint is different in two cases. It can be concluded that it is difficult to determine the surface of glint only by light curves. However, the qualitative understanding of space objects motion focusing on glint can make it possible to determine the surface of glint.

[1] NASA Orbital Debris Program Office, *Orbital Debris Quanterly News*, vol. 22, no. 1, p. 10, 2018.

[2]Toshiya Enomoto, ”Estimation of Space Object Behaviour Using Optical Measurements,” Master Thesis, Kyushu University, 2016.

[3] Joanna C. Hinks, Richard Linares, John L. Crassidis, “Attitude Observability from Light Curve Measurement,” AIAA Guidance, Navigation, and Control Conference, Boston, August 19-22, 2013.