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A method for spatial effective coverage analysis in space-based optical observation

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ABSTRACT

Space-based optical observation is now developing rapidly and many researches have been done to analyze the various requirements for targets to be visible. However, there were few studies providing intuitive methods to solve the boundary of the effective coverage and the effective coverage rate integral, which are desperately needed to evaluate the actual coverage performance for the optical sensor systems. In this study, different shapes of field of views (FOVs) of an optical sensor and space geometrical visibility constraints are mapped to an observation celestial sphere mapping surface (OCSMS), which makes it feasible and convenient to calculate the effective coverage. This method shall be of significance for calculating the spatial covering capacity of optical sensor systems and furtherly optimizing the selection, installation and configuration of sensors during the design of space-based observation spacecraft.

1. Introduction

Space-based optical observation has now become a feasible and efficient way to observe space objectives because of its advantages in observation range [1]. A large amount of satellites with optical sensors has been launched, which proves the practicability and effectiveness of space-based optical observation.

Space-based optical observation is often used in Earth observation and scientific research. From 2005 to 2015, 194 Earth observation satellites, which are above 50 kg, have been launched all over the world. It is estimated that 419 more satellites will be in orbit within the next decade [2]. These satellites have been devoted into areas like defense, infrastructure and engineering, natural resource monitoring, maritime, location services, disaster management, energy and environment surveillance [2–4].

Optical sensors can also contribute to the surveillance, trace and orbit determination of space objectives. The Midcourse Space Experiment (MSX) satellite was launched by US Lincoln Laboratory in 1996 to realize space optical surveillance and detection [5]. Since then, a substantial number of experiments and researches has been done to promote space-based optical surveillance and trace [6–9]. Additionally, space-based optical observation can also be used in orbit determination of space objective [10,11].

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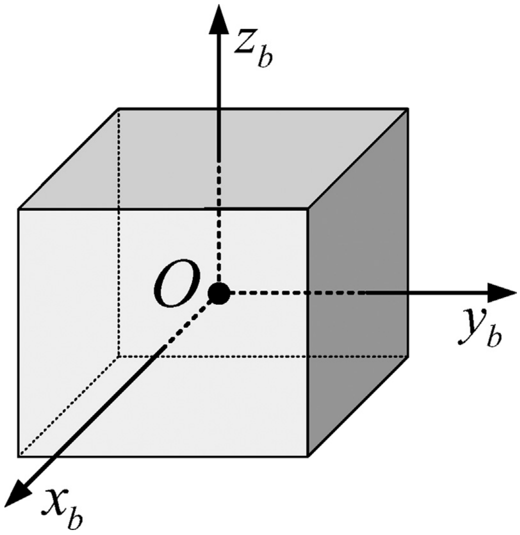

Fig. 1. Body fixed coordinate.

Recently, the increasing amount of space debris has cause great attention all over the world [12], and many works show that space-based optical observation has great advantage in monitoring these debris. Sun-synchronous Orbit (SSO), Geostationary Transfer Orbit (GTO) and Geostationary Earth Orbit (GEO) are suitable for space debris observation sensors [13]. Debris in Low Earth Orbit (LEO), GEO and GTO regions shall be under surveillance with passive optical observations [14].

Extensively, widely used optical sensors that enable satellites to realize attitude determination, such as star trackers, are also belongs to space-based optical observation sensors [15]. They are able to achieve the attitude information by detecting stars at different positions relative to the spacecraft [16].

Along with the deep application of space-based optical observation, the observation systems are given more functions like bi-satellites observation [3], constellation observation [17] and multi-sensor structure [1,7]. Meanwhile, the space-based optical observation itself is used to operate under complex constraints, which includes the Earth masking, the Earth shadow, the Earth light, the Earth heat radiation, the sunlight, the moonlight and so on [18–21]. Therefore, in order to calculate the effective coverage rate and evaluate the observation performance, an efficient method is expected to solve the boundary of the effective coverage and the effective coverage rate integral of observations systems with complex configurations under various constraints.

Some researches have been proposed to analyze the visibility from the perspective of the targets. Lan, Li, Ma and Xu [22] proposed a model of visibility prediction for targets by traversing all the requirements. Based on that, Liu, Liao, Wen and Zhang [18] analyzed the visibility of typical objectives observing from different altitudes of orbits with circular-FOV sensor. Taking the Earth objectives as the observation target, Geng [21] proposed a planar dynamic grids method to calculate the coverage on the Earth surface of a satellite constellation. These methods and models are impactful for determining whether a certain observing direction is available or not. However, they are not able to count the proportion of the available observing directions in all possible directions, because it is difficult to solve the effective coverage boundary and the coverage rate integral in a multi-constrained three-dimensional problem.

In this paper, a dimension reduced method based on observation celestial sphere mapping surface (OCSMS) is proposed, to describe the complicated spatial geometric relationships. This method makes it feasible to solve the mapping of the effective coverage range in an intuitive two-dimensional surface, and conversely integrate the coverage rate in equivalence.

2. The method based on the observation celestial sphere mapping surface

The main idea of the method based on the observation celestial sphere mapping surface (OCSMS) is to map the FOVs of different optical sensors and space geometrical visibility constraints to an OCSMS, and classify the efficient observation coverage in the whole observation celestial sphere.

2.1. Observation celestial sphere of spacecraft

The body fixed coordinate B of a spacecraft is defined artificially and often by three orthogonal principal axis of inertia, as Fig. 1 illustrates.

Considering the spacecraft as an observer, the observation celestial sphere is fixed in the body coordinate of the spacecraft. The relationship between the body fixed coordinate and the observation celestial sphere can be seen from Fig. 2.