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Autonomous satellite navigation using starlight refraction angle measurements

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Abstract

An on-board autonomous navigation capability is required to reduce the operation costs and enhance the navigation performance of future satellites. Autonomous navigation by stellar refraction is a type of autonomous celestial navigation method that uses high-accuracy star sensors instead of Earth sensors to provide information regarding Earth's horizon. In previous studies, the refraction apparent height has typically been used for such navigation. However, the apparent height cannot be measured directly by a star sensor and can only be calculated by the refraction angle and an atmospheric refraction model. Therefore, additional errors are introduced by the uncertainty and nonlinearity of atmospheric refraction models, which result in reduced navigation accuracy and reliability. A new navigation method based on the direct measurement of the refraction angle is proposed to solve this problem. Techniques for the determination of the refraction angle are introduced, and a measurement model for the refraction angle is established. The method is tested and validated by simulations. When the starlight refraction height ranges from 20 to 50 km, a positioning accuracy of better than 100 m can be achieved for a low-Earth-orbit (LEO) satellite using the refraction angle, while the positioning accuracy of the traditional method using the apparent height is worse than 500 m under the same conditions. Furthermore, an analysis of the factors that affect navigation accuracy, including the measurement accuracy of the refraction angle, the number of visible refracted stars per orbit and the installation azimuth of star sensor, is presented. This method is highly recommended for small satellites in particular, as no additional hardware besides two star sensors is required.
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Keywords: Autonomous navigation; Stellar refraction; Starlight refraction angle; Earth satellite; Accuracy analysis

1. Introduction

Autonomous satellite navigation is the ability to determine satellite position and velocity in real time without the assistance of external support (Collins and Conger, 1994). On-board autonomous navigation can provide a significant reduction in ground operating costs and great improvement in satellite survivability (Fesq et al., 1996). Various autonomous navigation methods have been studied, including methods using celestial objects, a magnetometer (Brown et al., 2012; Juang et al., 2012), the Global Positioning System (Montenbruck and Ramos-Bosch, 2008; Aghav and Gangal, 2012), and Doppler Orbitography and Radio positioning Integrated by Satellite (DORIS) (Jayles et al., 2010; Willis et al., 2010). Different methods have different accuracy levels. In real-time, the current level of precision that can be achieved by GPS and DORIS is on the order of decimeters, provided appropriate on-board software. However, in a sense, they are only semi-autonomous methods. Moreover, not all satellites can be equipped with GPS receivers, such as many future mini-, micro- and nano-satellites. Thus, celestial navigation might be a good choice because instruments such as star sensors, Earth sensors, etc. are typically installed on most satellites.

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