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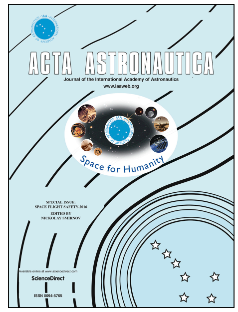

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A High-accuracy Constrained SINS/CNS Tight Integrated Navigation for High-Orbit Automated Transfer Vehicles

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Abstract:

High-accuracy and reliable autonomous navigation is increasingly crucial for automated transfer vehicles (ATV). This paper proposes a novel strapdown inertial navigation system / celestial navigation system (SINS/CNS) tight integration scheme aided by dynamic model constraints for high-orbit ATV to realize accurate and autonomous navigation. In this scheme, the complete weightlessness constraint in orbit is used to address the divergence of position and velocity caused by inaccurate accelerometer bias estimation problem encountered in the traditional SINS/CNS integration method, and the image point position-based tight integration model is derived to handle the adverse influence of time-varying attitude measurement noise due to changes of star geometry observed by a large-view-filed star sensor. Moreover, an information filter is devised to fuse the multi-rate measurements. The proposed algorithm is evaluated by a representative high-orbit ATV trajectory simulation, which indicates significant improvements in navigation accuracy compared with its traditional counterparts. The proposed algorithm can realize navigation accuracy enhancements without introducing additional sensors, strengthening its potentials in engineering application.

Keywords: Strapdown Inertial Navigation System (SINS); Tight Integration; Model Constraint; Automated Transfer Vehicle (ATV)

1. Introduction

The automated transfer vehicle (ATV) is a newly developed and largest unmanned cargo spacecraft, which is the first to complete automatic rendezvous, docking and refueling in Europe [1-3]. Apart from logistics services to the international space station (ISS), many potential flight scenarios have also been anticipated by European Space Agency (ESA), ranging from manned spaceflight to lunar or interplanetary exploration orbit. Combining with the space-based orbital express program [4, 5], the high-orbit ATV has an extensive prospect of applications, such as space debris capture, in-orbit spacecraft maintenance and interplanetary exploration, due to its orbital maneuverability from different altitudes. Accurate and reliable navigation is a key technique for the successful implementation of these missions. Limited by national territory area and geopolitics, however, ground stations cannot be distributed globally; it is risky to depend on ground sites for guidance and control in such case. This demands accurate and reliable autonomous navigation ability for high-orbit ATV.

The traditional INS/CNS integrated methods have been used for submarine launched ballistic missile (SLBM) to realize accurate and autonomous navigation and guidance [6-8]. Recently, the breakthroughs in electro-optics bring about excellent strapdown inertial navigation system (SINS). Aided by star sensor information to correct attitude error and gyro drift, the SINS/CNS integrated system is replacing its platform counterparts with comparable and cost-effective performance [6]. With SINS/CNS as the core module, more integrated schemes have been designed based on multi-source information fusion such as SINS/CNS/VNS [9], SINS/CNS/GNSS [6] and SINS/CNS/geomagnetic [10, 11]. It is worth mentioning that current ATVs devise an innovative navigation chain with redundancy