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LOW-THRUST CONTROL FOR IGSO SATELLITE CONSTELLATION USING AN IMPROVED CONVEX OPTIMIZATION

Abstract

Satellite constellation orbiting in Inclined Geosynchronous Orbits (IGSO), such as Beidou-3 system (China, 2019) and GSSAP satellites (USA, 2014), provide a promising alternative to the increasingly crowded Geostationary Earth Orbit (GEO) belt as well as an extension to the space situational awareness system. On the other hand, selected highly elliptical orbits at geosynchronous altitude own the advantage of low delta-V budget due to their frozen parameters. Moreover, with the advance of electric propulsion systems, low-thrust control strategies present a key tool to further reduce mission costs. However, new challenges arise despite the obvious benefits of low-thrust operations in IGSO constellation. Real and multiple constraints, including shadow constraints, on-off profile of low thrust, result in a narrower solution space and lower optimization efficiency. This paper aims to present an improved convex optimization algorithm towards low-thrust control problems with multiple constraints. The convex optimization tool is introduced due to two main benefits: faster computational efficiencies and more reliable accesses to global optimal solution. According to the phase space study through a semi-analytical orbit propagation tool and assuming a virtual ideal satellite constellation, the equations of motion in terms of mean relative orbital elements are formulated in the first step. Afterwards, the system dynamic behaviors and boundary conditions are discussed such that the original problem can be transformed into a convex problem. The effects of multiple constraints on the optimization procedure are further analyzed through probability box. Inspired by the homotopy method, by carefully selecting initial constraint vector and gradient coefficients, a progressively strengthened constraint method is proposed to guarantee the convergence. Finally, the original problem is solved by a successive-solution process, where a sequence of convex problems as well as a second-order cone programming approach is formed. Two simulation scenarios are designed to validate the efficiency of the proposed method. The first scenario focuses on the comparisons between the improved and classic convex optimization algorithms as well as other indirect methods. The robust analysis of the proposed method is implemented in the second scenario, where orbit determination errors, thruster errors and modeling uncertainties are fully considered. Techniques proposed in this study will give practical alternatives to the IGSO satellite mission designers. The results of this work are of great significance to achieve sustainable exploitation of the inclined geosynchronous orbits.