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ZERO-SUM STOCHASTIC DIFFERENTIAL GAME BASED CONTROL FOR LANDING ON IRREGULAR SHAPED ASTEROID

Abstract

Motivated by the fruitful scientific discoveries of asteroid missions such as Hayabusa-II, OSIRIS-REx and Rosetta/Philae in the last decade, the aerospace community currently experiences the renewed interest in asteroid proximity and landing exploration. Among the optional exploring techniques (e.g. flyby, orbiting, hovering, etc.), landing a spacecraft on an asteroid has significant advantages over the others. The landing helps collect higher resolution data and also is necessary for the sample return and therefore, provides scientific contributions on understanding of the origin and evolution of the solar system. The additional promising reward may also be the characterization and quantification of asteroid as a source of extraterrestrial natural resources. Landing on an asteroid has long been treated as a challenging task. The particularity of the challenges for asteroid landing lies in the following aspects: 1) unlike planets in our Solar System with approximately spherical shape and gravitational field, those asteroids are usually small in size and irregular in shape and mass distribution, generating a weak and complicated gravitational field and thus complicating the dynamics of the lander; 2) perturbations like the solar radiation pressure (SRP); and 3) uncertainties in gravitational field and SRP. To deal with the severe impact of the irregular gravitational field around object asteroid, this paper proposes a novel asteroid landing control method through zero-sum stochastic differential game (ZSDG). Firstly, the ZSDG model of the asteroid landing problem is established considering the uncertainty of the irregular gravitational field, whose impact on the landing trajectory is analyzed through the uncertainty propagation technique. Then, the predetermined fixed landing site is converted into a visual stochastic moving landing site, whose motion is determined by the uncertainty propagation results. Consequently, the conventional asteroid landing control problem is transformed into a pursuit-evasion ZSDG problem, where the lander is governed by dynamics with a fully known gravitational field, and all the landing uncertain factors (including the irregular gravity) are designed into the motion of visual landing site. Combining the classic fuel-optimal performance index, this ZSDG model, along with the thrust magnitude constraint, is converted into a convex form by variable slack technique, and solved through convex optimization toolbox in every control loop. Thus, both of the optimality and onboard solving convergence is guaranteed. The numerical simulation results validate the effectiveness of the proposed control method of introducing the stochastic moving landing site on deal with the adverse effect of irregular gravitational field.