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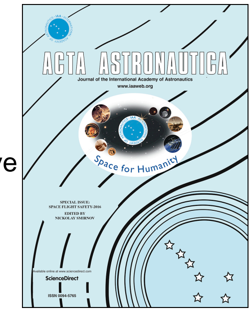

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FAULT-TOLERANT FEATURE-BASED ESTIMATION OF SPACE DEBRIS ROTATIONAL MOTION DURING ACTIVE REMOVAL MISSIONS

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Abstract

One of the key functionalities required by an Active Debris Removal mission is the assessment of the target kinematics and inertial properties. Passive sensors, such as stereo cameras, are often included in the onboard instrumentation of a chaser spacecraft for capturing sequential photographs and for tracking features of the target surface. A plenty of methods, based on Kalman filtering, are available for the estimation of the target's state from feature positions; however, to guarantee the filter convergence, they typically require continuity of measurements and the capability of tracking a fixed set of pre-defined features of the object. These requirements clash with the actual tracking conditions: failures in feature detection often occur and the assumption of having some a-priori knowledge about the shape of the target could be restrictive in certain cases. The aim of the presented work is to propose a fault-tolerant alternative method for estimating the angular velocity and the relative magnitudes of the principal moments of inertia of the target. Raw data regarding the positions of the tracked features are processed to evaluate corrupted values of a 3-dimentional parameter which entirely describes the finite screw motion of the debris and which primarily is invariant on the particular set of considered features of the object. Missing values of the parameter are completely restored exploiting the typical periodicity of the rotational motion of an uncontrolled satellite: compressed sensing techniques, typically adopted for recovering images or for prognostic applications, are herein used in a completely original fashion for retrieving a kinematic signal that appears sparse in the frequency domain. Due to its invariance about the features, no assumptions are needed about the target's shape and continuity of the tracking. The obtained signal is useful for the indirect evaluation of an attitude signal that feeds an unscented Kalman filter for the estimation of the global rotational state of the target. The results of the computer simulations showed a good robustness of the method and its potential applicability for general motion conditions of the target

Keywords: Non-cooperative Rendezvous, Occlusions, Kinematic Registration, Attitude Recovery

1. Introduction

Since the beginning of the space era, many dismissed spacecraft and part of launchers remained in orbit after the end of their operating life. Because of the intense space activity of the last decades, missions in Low-Earth Orbit are exposed to collisions with these objects. Moreover, hypervelocity impacts produce a huge number of dangerous fragmentation debris, as it happened in 2009 when Cosmos 2251 and Iridium 33 collided [1].

It is then important to design missions devoted to the removal of uncontrolled objects from orbits. A typical design of these missions includes a chaser spacecraft whose purpose is grasping and deorbiting the target debris [2]. For example, this can be done through robotic manipulators specifically designed for that purpose [3].

The completion of this maneuver involves the need of identifying with satisfactory precision the location of the center of mass [4], and the dynamic rotational state of the target, including angular velocity, and relative values of the principal inertia moments (ie. each principal inertia moment divided by the norm of a vector containing the three inertia moments). An example of a mission in which the kinematic state of the target and its inertial properties are assessed before planning the approach phase in a removal mission is shown in [5]. More generally, the estimation of angular rate and inertia moments helps in predicting torques and forces that will be transferred to the aforementioned manipulator for the grasping.

However, the dynamic state estimation is crucial not only for debris removal, but also in missions involving interactions between non-cooperative vehicles, for instance for the tracking of resident space objects, on-orbit servicing and responsive space missions [6].

A complete review of the main current techniques for pose estimation of non-cooperative spacecraft can be found, for instance, in [7].

Since these bodies have no energy reserves, they cannot provide any flight data measured by their onboard sensors. That involves the need of detecting their motion through external observation. For instance,