Aerospace Europe Conference 2023
Joint 10th EUCASS – 9th CEAS Conference

Abstract #XXX *(to be filled by the organizers)*
Preferred Topics: FDGNCAV
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Type: Oral
Status of corresponding author: Regular
For student corresponding author: student member of one of the following:
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Title

Filtering techniques assessment towards pose estimation enhancement for image-based proximity navigation with uncooperative space objects

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Abstract

Autonomous relative navigation nearby uncooperative space objects represents a very hot spot in the space engineering framework. Such capability plays an essential role in missions focused on active debris removal, on-orbit servicing, sample canister capture and small celestial bodies proximity operations, which populate the near future missions' plans. Accurate yet robust relative state estimation skills are mandatory. This paper investigates different filtering techniques to refine the pose estimation whenever vision-based measurements are available on board. A loosely-coupled architecture is considered, made up of two separate building blocks: the pose estimation block processes the images acquired by a monocular camera to compute the target-chaser relative position and attitude, which are then fed to the next block; the navigation block itself is split into two functional components, namely the relative translational and the relative rotational filter. A classical Extended Kalman Filter (EKF) adopting a nonlinear dynamical model is compared against a H∞ filter which exploits the Yamanaka-Ankersen (YA) [1] state transition matrix, for the relative translation; that choice is driven by the fact that, the assumptions of the Kalman Filter (KF) may not be satisfied while dealing with optical measurements. In fact, the measurements' noise does not follow a Gaussian distribution, and the process noise may be time varying, depending on the illumination conditions. The exploitation of the YA model is not limited by elliptical orbits, and thus it does not restrict the validity of the proposed approach. Lastly, a linear filter allows limiting the overall estimation algorithm's computational burden. The rotation estimation is faced with a classical multiplicative extended Kalman filter (MEKF), which has been successfully employed in the vast majority of attitude determination applications [2], compared against filters which evolve on the Special Orthogonal group SO(3). Pesce et. al ([3]) work shows that the second-order minimum energy filter presented in [4] appears to outperform the MEKF; despite its high estimation accuracy, this filter is computationally intensive, due to the integration of the 6-by-6 gain matrix. Therefore this paper introduces a more computationally efficient alternative: the second-order equivariant observer is applied to the second-order kinematics of the relative attitude problem, as in [5]. This observer works on the symmetry group of the second order attitude state space, which has as similar structure to the Special Euclidean Group SE(3). The proposed observer relies neither on relative angular velocity measurements, nor on the knowledge of the target's inertial properties, being thus applicable to a wide range of scenarios. A comprehensive simulation study is presented to discuss performances of the filtering techniques, adopting the direct Image Processing output as input measurements. The filter initial uncertainty is initialized exploiting the pose initialization algorithm presented in [6]. The translational filters are tested against different relative trajectories, such as drifting orbits and along-track trajectories. The relative target-chaser distance is also considered to evaluate the performances of the selected techniques. Further, the consequences of an increasing target angular velocity on the estimation accuracy are presented.

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