Autonomous navigation around Didymos using CNN-based Image Processing*

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Abstract. The Asteroid Impact and Deflection Assessment (AIDA) is an international collaboration between the European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA) aimed to investigate the binary asteroid system (65803) Didymos and to demonstrate asteroid deflection technique with kinetic impact. NASA impacted the target on the 26th of September 2022 while ESA will launch Hera, an asteroid rendezvous mission that will observe the impact effects closely. The proximity operations of Hera's spacecraft around the target body rely on an autonomous optical navigation system that collects on-board visual information to estimate the relative position and attitude of the spacecraft with respect to the asteroid. The core component of this navigation method is the Image Processing (IP) algorithm that extracts optical observables from images captured by the spacecraft's on-board Asteroid Framing Camera (AFC). The Early Characterization Phase (ECP) is a proximity operation of Hera with the objective of conducting physical and dynamical characterizations of Didymos at a distance varying from 20 km to 30 km. In this phase, the IP algorithm is designed to estimate the position of the Center of Mass (COM) of the primary to enable Line of Sight (LOS) autonomous navigation. The COM measurements have to be coupled with range measurements of the primary to achieve the instantaneous relative position of the spacecraft with respect to the binary asteroid system. However, the distance to the asteroid is measured on-board by the Planet ALTimeter (PALT), a LIDAR experiment with an accuracy of 0.5 m with a working distance between 100 m to 14 km. Therefore, at ECP distances the PALT is not operative and the relative position of the spacecraft cannot be achieved.
Within this context, this paper develops a pipeline to estimate the state of the Hera spacecraft around binary asteroid system Didymos during the ECP using a Convolutional Neural Networks (CNN)- based IP algorithm. The proposed algorithm uses the images captured with the AFC camera to estimate the the following outputs: the position of the centroids of Didymos and its moon Dimorphos, the pseudorange with the primary and the Sun phase angle. To measure the pseudorange, the designed algorithm regresses a set of keypoints on the visible border of Didymos

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and evaluates its apparent radius. For the Sun phase angle, the pixel position of the subsolar point of the primary is leveraged.
Subsequently, the algorithm combines the measurements with an Unscented Kalman Filter to estimate the relative state of the spacecraft. The choice of the CNN over standard IP algorithms is based on three main reasons. Firstly, CNNs have the main advantage to be robust over adverse illumination conditions. Secondly, standard algorithms would require to analyze each pixel of the image and discard the ones belonging to the secondary in order to measure the apparent radius of the asteroid, which is time consuming and computationally expensive. Finally, CNNs are robust over the irregular shape of the asteroid, which is an important characteristic for the estimation of the pixel position of the keypoints. The training, validation and testing datasets are generated with the software Planet and Asteroid Natural scene Generation Utility (PANGU) at different epochs of the ECP trajectories. The High-Resolution Network (HRNet) is used as CNN architecture as it represents the state-of-the-art technology in keypoint detection.
The HRNet-based IP algorithm was already proved to provide an accurate estimation of the mentioned outputs and without dependency on the illumination conditions, the shape of the asteroid and the presence of Dimorphos. Therefore, the algorithm is expected to estimate the state of the spacecraft with high accuracy, hence to improve the performance of the autonomous optical navigation strategy.

Keywords: Image Processing · Convolutional Neural Networks · Hera