Bennunet - Applying Deep Learning for Optical Relative Navigation of an Asteroid

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This contribution presents Bennunet, a hybrid neural network-based method, devoted to on-board spacecraft relative position and attitude estimation in the vicinity of minor bodies like asteroids, comets or small moons, using monocular vision. In the context of navigating such minor bodies, traditional heuristic methods for spacecraft position and attitude determination encounter limitations in robustness and precision in the presence of adverse illumination conditions. Moreover, its performance is limited due to the computational cost resulting from the evaluation of a large number of possible pose hypotheses. In comparison, Bennunet solves the relative pose estimation problem by directly learning the nonlinear transformation from a 2-D grayscale image to the 6-D pose vector space.

Bennunet is conformed by a set of sequential convolutional neural networks (CNNs) organised in two levels. The high-level multiclass-classification CNN is in charge of determining the sector of the discretized 3D space. Then, based on the sector estimation, the image is ingested by a low-level regression CNN, trained specifically for that sector, which estimates the pose of the camera. In addition, a high-level regression CNN was added before the high-level classification with the purpose of estimating vertical and horizontal shift of the target centroid in the image. This de-shifting pre-processing substantially boosted the performance of the classification CNN. The secondary contribution of this research is the development of SPyRender, a tool for the generation of large sets of synthetic images, suitable for the training and testing of the designed CNNs. SPyRender implements GPU-accelerated physically-based rendering, enabling the efficient generation of photorealistic images. SPyRender has been used with 3-D models of asteroid Bennu for producing multiple image sets covering the whole range of camera position, attitude, and illumination conditions, allowing to study the impact of different geometries and image effects in the network performance.

Before Bennunet, a similar hybrid neural network-based method for relative navigation was applied to the case of comet 67P/Churyumov-Gerasimenko, visited by the International Rosetta Mission [1]. However, the data products derived from OSIRIS-REX of asteroid Bennu include multiple digital shape models with a spatial resolution ranging from 12 to 0.4 meters for global models, and up

Fig. 1. Sample sequence of simulated Bennu images.

to just 50 millimeters for local models [2]. These shape models can be used for evaluating the impact on performance of CNNs trained with a given spatial resolution model, or even using a combination of them. Including images generated with multiple resolution models in the training sets, would aid achieving spatial resolution invariance. Furthermore, the OSIRIS-REX Camera Suite (OCAMS) instrument consists of three cameras, PolyCam, MapCam, and SamCam, [2] each with a different field-of-view. Generating training sets based on each of the cameras allows for assessing the impact on accuracy of camera parameters, like field-of-view aperture angles or optical distortion. The synthetically generated sets will be presented, together with the results of training the designed CNNs with these sets and testing with real images from OSIRIS-REX.

References

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2. B. Semenov and M. Sitja, "OSIRIS-REx SPICE Kernel Archive Bundle," DOI 10.17189/1520435, 2021.