Pose estimation of Didymos' moon using CNN-based Image Processing algorithm for Hera mission

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INTRODUCTION

Hera is the European Space Agency (ESA)'s contribution to the international collaboration Asteroid Impact Deflection Assessment, aiming to deflect the trajectory of a binary asteroid system [1].

The target of this mission is the near-Earth asteroid (65803) Didymos and its moon Dimorphos.

The Close Observation Phase (COP) is a phase of the mission with the spacecraft at a distance varying from 4 to 22 Km from the target. Two CubeSats, Milani and Juventas, are planned to be released to perform detailed scientific observation and landing on Dimorphos, both operations requiring high level autonomy. Therefore a vision based Guidance, Navigation and Control system is designed, which comprises an on-board camera taking images of the asteroid, an Image Processing (IP) algorithm that extracts information from these images, and a navigation filter that processes the visual data [2].

CHALLENGES

1. No algorithm available on-board to estimate the relative attitude of Dimorphos with respect to the camera to perform safe close operations.

2. Post-impact chaotic tumbling of Dimorphos does not allow for feature tracking relative navigation.

SOLUTION

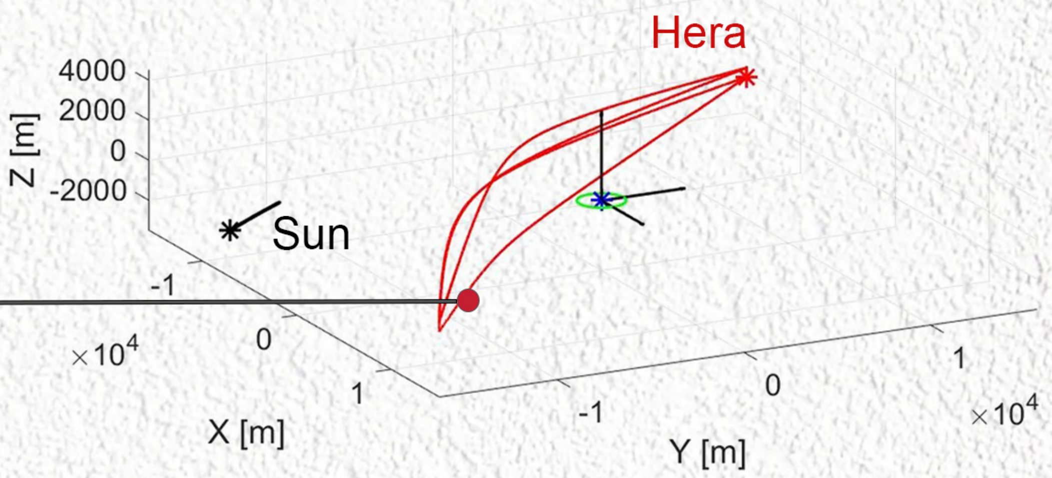
CONVOLUTIONAL NEURAL NETWORKS (CNN)-BASED IP ALGORITHM

1. It estimates the relative rotation matrix of Dimorphos expressed in Euler angles independently from the distance.
2. Does not require prior knowledge of Dimorphos rotation.

METHODOLOGY

1. COP TRAJECTORY

The trajectory consists of several hyperbolic arcs of total duration 14 days. Orbital manoeuvres are performed at the joint of two arcs [3].

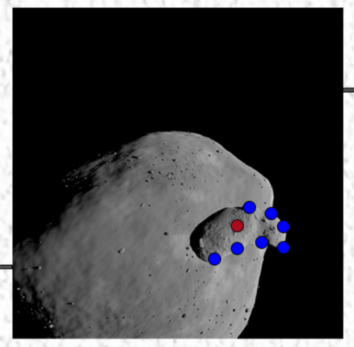


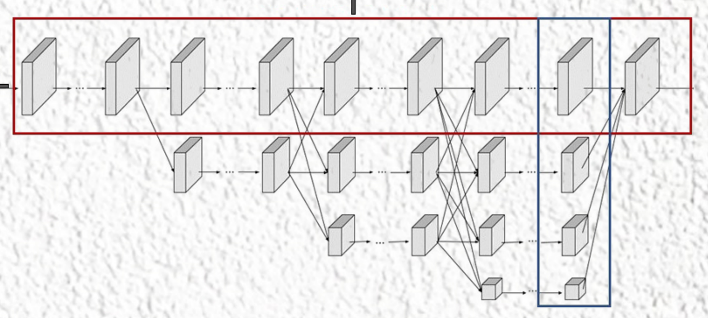
2. GENERATION OF IMAGES

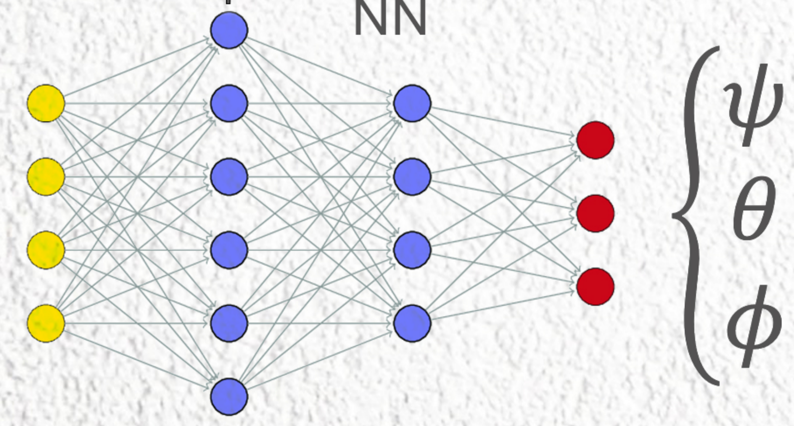
The software Planet and Asteroid Natural Scene Generation Utility is used to generate an image of the target as seen from the on-board camera at each epoch of the COP.

3. SEGMENTATION

We use the High Resolution Network (HRNet) to regress the Center of Mass and 30 keypoints on the lit limb of Dimorphos [4].







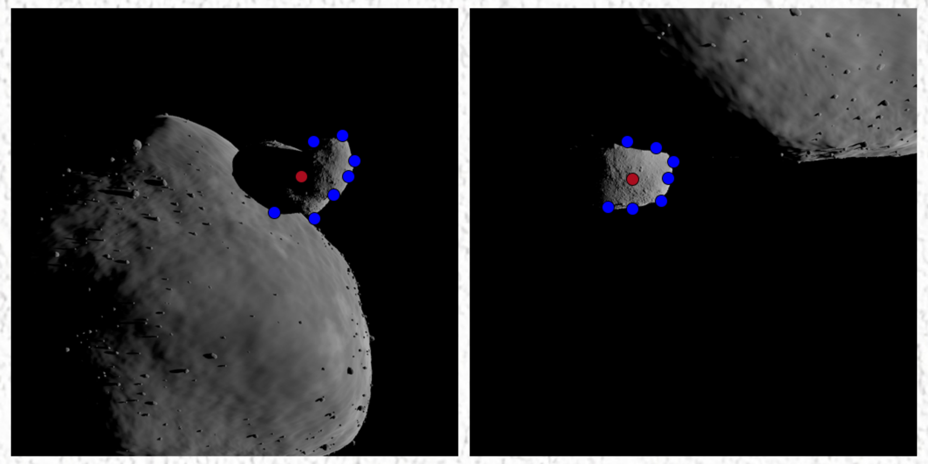
4. POSE ESTIMATION

We use these 31 keypoints to evaluate 30 apparent radii of Dimorphos which are input to a Neural Network (NN). The NN maps the input with the Euler angles that represent the attitude of Dimorphos with respect to the camera.

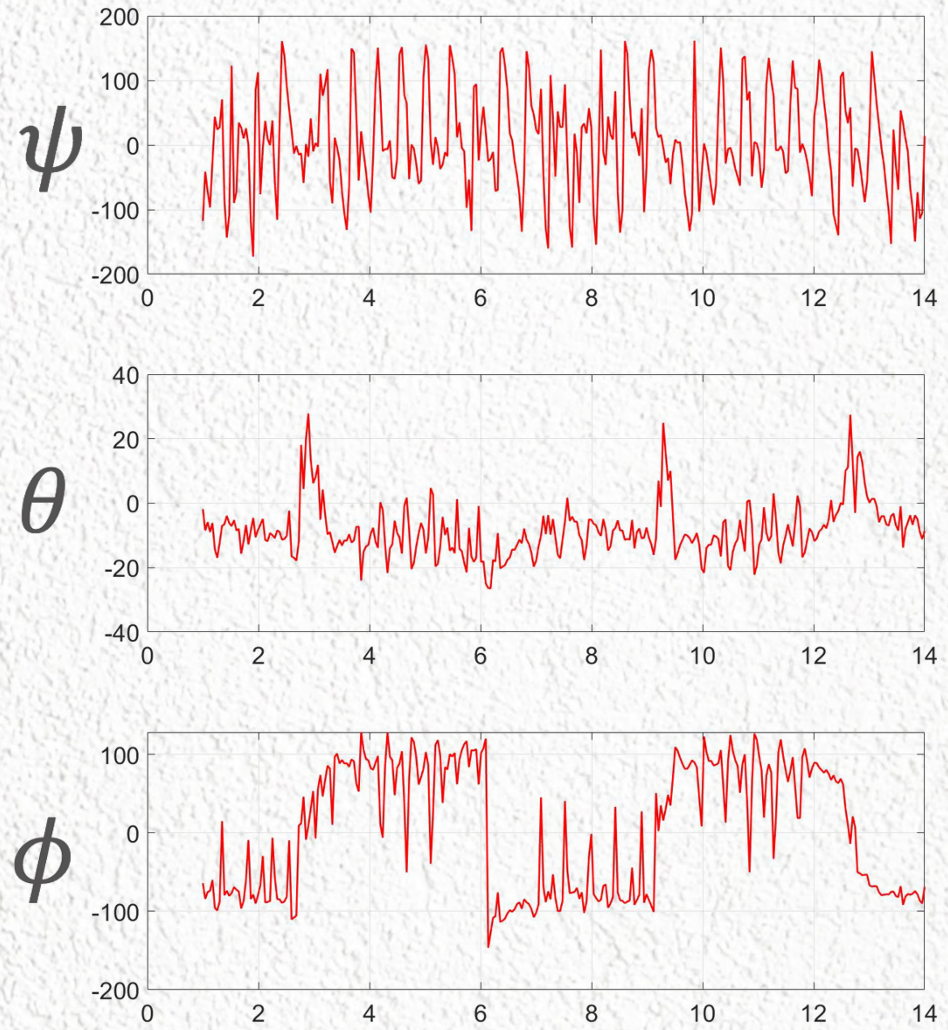
RESULTS & CONCLUSIONS

KEYPOINTS REGRESSION

The HRNet is able to estimate the position of the 31 keypoints with high accuracy independently from the presence of Didymos.



POSE ESTIMATION



The estimated Euler angles during the COP trajectory are accurate even though a noise that can reach up to 20 degrees of amplitude with respect to the real value is present. The results can be further improved by considering additional orbits for the training database of images, or by filtering the keypoints that do not provide any support in mapping the Euler angles.

SCAN AND POINT TO THE ASTEROID TO THE LEFT

References

[1] P. Michel, A. Cheng, and M. Küppers. *Asteroid Impact and Deflection Assessment (AIDA) mission: science investigation of a binary system and mitigation test.*

[2] A. Pellacani, M. Graziano, M. Fittock, J. Gil-Fernández, and I. Carnelli. *HERA vision based GNC and autonomy.*

[3] ESA Estec. *HERA: Proximity Operations Guidelines.*

[4] K. Sun, B. Xiao, L. Dong, and J.Wang. *Deep high-resolution representation learning for human pose estimation.*