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Robust Trajectory Design for the Hera Experimental Phase Using Intrusive Polynomial Algebra

Iosto Fodde[1]**, Jesús Gil-Fernández**[2]**, Jinglang Feng**[3]**, and Massimiliano Vasile**[4]
[1][3][4] *Department of Mechanical and Aerospace Engineering, University of Strathclyde, 75 Montrose Street,Glasgow G1 1XJ, United Kingdom. iosto.fodde@strath.ac.uk, jinglang.feng@strath.ac.uk, massimiliano.vasile@strath.ac.uk*
[2] *Systems Department, Guidance, Navigation and Control Section (TEC-SAG), European Space Agency,Keplerlaan 1, P.O. Box 299, 2200 AG Noordwijk, The Netherlands. jesus.gil.fernandez@esa.int*

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ABSTRACT

The Asteroid Impact and Deflection Assessment (AIDA) collaboration, consisting of NASA's DART mission and ESA's Hera mission, aims to test the capability of a kinetic impactor to deflect an asteroid. At the end of September 2022, DART successfully impacted the secondary of the binary asteroid system Didymos, called Dimorphos. Hera will launch in 2024 and aims to characterize the physical properties of Didymos and Dimorphos, and investigate the consequence of the impact made by DART in more detail. The close proximity operations of Hera consist of several different phases, each one having different scientific and technical requirements. The final nominal phase is the experimental phase, where the highest resolution images of the impact crater will be taken. As during this phase the closest fly-bys of Dimorphos will take place at around 100 meters from the body, it is important to ensure the safety of the spacecraft and minimise the risk of impact. Therefore, the trajectory design of these fly-bys needs to consider the possible execution errors of the ΔV manoeuvres and the uncertainties in the dynamical system, e.g. the mass of Dimorphos.

In this work, a novel method to design the experimental phase trajectories considering these various factors is developed. Due to the high non-linearity of the system and large uncertainties, accurate and efficient uncertainty propagation techniques need to be used to analyse the effect of the uncertainties. Here, the Generalised Intrusive Polynomial Algebra (GIPA) technique is used because of its efficiency and ability to remain accurate when the uncertainties become large. First, a nominal trajectory is designed based on the various operational and physical constraints of the mission, maximizing the possible resolution for the observation of the crater. As the ΔV execution errors and dynamical uncertainties are introduced, the resolution during close approach worsens and the chance that one or more of the constraints cannot be met can increase significantly. Additionally, the probability of impact with Dimorphos can become non-zero. Therefore, the GIPA method is used to propagate the uncertainties and the nominal trajectory is altered accordingly to have a high probability of abiding by all the constraints while minimizing the worst-case crater observation resolution. The resulting trajectory shows less sensitivity to the uncertainties, therefore reducing the risk while still achieving the goal of obtaining high resolution images of the impact crater.
This research shows the use of a novel technique based on GIPA to design a robust and safe trajectory. It is used here for the specific case of the close fly-bys during Hera's experimental phase, and thus shows its applicability to real-world scenarios.

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