IAA-PDC-19-05-08
AUTONOMOUS GNC AND DATA FUSION FOR THE HERA MISSION

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Keywords: *Asteroids, vision-based GNC, autonomy, data-fusion*

Introduction

The HERA mission is based on extensive work done by the European Space Agency and European industry between 2011 and 2016 (AIM studies in the frame of the AIDA joint mission with NASA). The main mission objective is to demonstrate the kinetic impactor concept on a binary asteroid system. This technique is considered to be one of the most promising for planetary defense to deflect asteroids in the order of one hundred meters diameter. In order to be able to detect the slightest change into the system and to estimate the effect of the impact, close operations are baselined in the mission timeline. A highly autonomous system has been designed to allow such operations and it is part of the technologies demonstrators of the mission. As it is the first time that a binary asteroid system will be studied from short distance, it is also important to remark the value of the scientific return of the mission. The autonomous GNC system will allow to navigate safely close to the binary system, and the closer the trajectory will be, the more valuable will be the scientific data collected by the spacecraft.

The level of autonomy expected during the interplanetary cruise is limited to the execution of pre-planned, ground-defined, mission operations on-board. Indeed, during this phase, there is no need for fast and autonomous response. On the contrary, during proximity operations, an autonomous GNC system will allow a precise target pointing for the characterization phase. Furthermore, there will be a continuous safety monitoring of the close fly-bys that in case of a contingency scenario (e.g. unpredicted maneuver execution error) might lead the spacecraft into a collision course. A vision based navigation has been designed, developed and tested for the AIM mission and it will be further improved in the frame of HERA, including data fusion with the PALT (laser altimeter) during the closest approach to the binary system. A precise and robust on-board navigation estimation of the spacecraft state is the key to perform autonomous maneuvers and progressively reduce the pericenter of the fly-bys up to a few hundred meters altitude, also having the possibility to trigger Collision Avoidance Maneuvers in case of failures.

In the frame of HERA phase B1, the AIM autonomous vision based navigation has been consolidated including new data fusion functionalities and the test campaign, based on incremental validation from Model-In-the-Loop (MIL) to Hardware-In-the-Loop (HIL), will allow the technology to achieve a TRL 6 by the end of 2019.

Autonomous GNC Strategies

The following GNC modes have been identified and the GNC functions have been developed accordingly:

- SUM (Survival GNC mode)
- SAM (Safe GNC mode)
- RW (Operational Reaction wheels attitude based mode)
- PROP (GNC Propulsion mode)
- SAG (Semi-autonomous Attitude Guidance mode)

- ATCM (Autonomous Translational Control Maneuvers)
- CAM (Collision Avoidance Mode)

For the most part of the mission the spacecraft will be flown manually and only a part of the GNC modes will be active. Namely, the RW operational mode as nominal mode and the PROP mode during maneuvers. SAM and SUM are contingency modes in case of failures. SAG and ATCM are respectively semi-autonomous and autonomous GNC modes that will allow the fast reaction required in order to get closer to the asteroids. They have to be developed together with a CAM mode in case of contingencies (e.g. collision risk).

Semi-autonomous Guidance Mode

During the Interplanetary cruise and the first part of the asteroid characterization phase it is possible to command the spacecraft manually and the ground based navigation performance are enough to guarantee that the body stays in the camera FoV using pre-computed attitude profiles. When the distances are reduced to about 10 km, the hyperbolic arcs are designed to minimize the collision risk, but an autonomous correction of the primary pointing is required not to lose the main asteroid (Didymain).

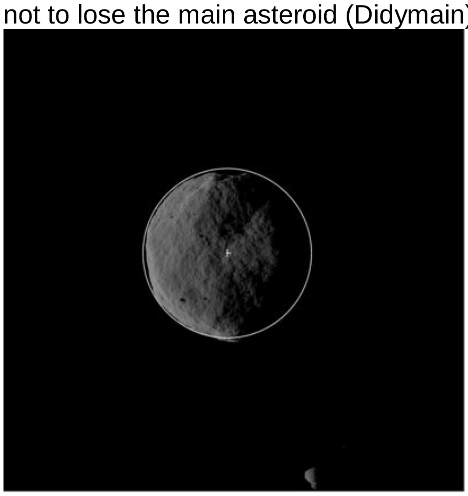

Figure 1: Image Processing – Centroiding

The HERA phase B1 test campaign demonstrated that this technology, based on centroiding image processing, allows to maintain the body in the FoV. Furthermore, being only a limited primary pointing correction, is controllable from the ground station operators (easy and safe on-flight testing).

Autonomous Translational Control Maneuvers

In order to get closer to the asteroid, a specific autonomous GNC mode has been designed and implemented. This mode allows for translational autonomous maneuvers based on the on-board navigation knowledge solution. These maneuvers have the purpose of reducing the pericenter of the hyperbolic arcs flown by the spacecraft.

The precision to execute this very small maneuvers demands an accurate autonomous navigation, more than what a centroiding based navigation can give (considering also that the body will cover the entire FoV during such close operations).

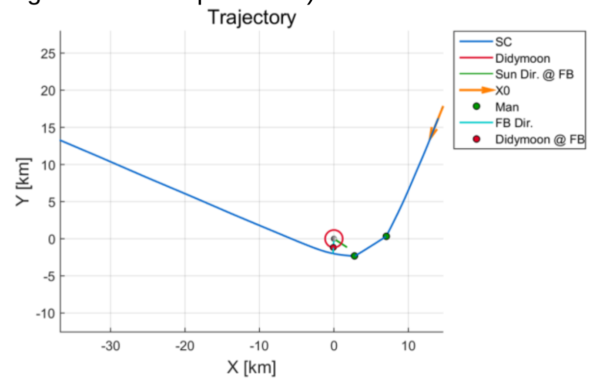

Figure 2: HERA close fly-by with autonomous maneuvers

For this reason a feature tracking image processing has been selected and it is implemented for this phase.

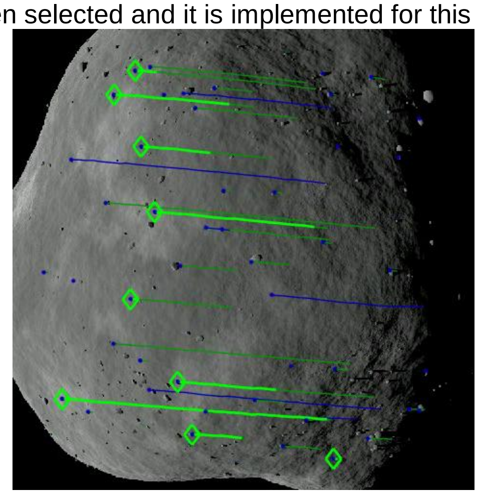

Figure 3: Feature tracking in close fly-by

Data-fusion with a laser altimeter has also being tested, showing the improved performance in the radial axis (less observable in vision based navigation).

Future work

Currently the GNC algorithms are going through the complete incremental validation chain in the laboratories at GMV. By the SRR, that will mark the end of HERA Phase B1 (Summer 2019), also Hardware-In-the-Loop tests will be performed, using the qualification model of the Asteroid Framing Camera (same camera of the DAWN NASA mission).

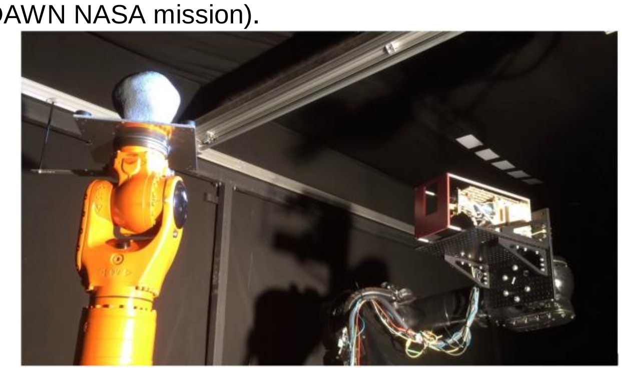

Figure 4: HIL tests in platform-art for AIM (HERA previous activity), currently repeated for HERA scenario