AUTONOMOUS NAVIGATION OF SPACECRAFT FORMATIONS FOR ASTEROID EXPLORATION

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ABSTRACT

This paper presents an autonomous multi-sensor navigation approach for a formation of spacecraft flying in the proximity of a near Earth asteroid. Each spacecraft embarks a different combination of high resolution cameras, Sun sensors, star sensors and LIDAR to estimate the state of each spacecraft in the formation and the formation as whole ([1]). The work investigates the combination of measurements coming from multiple heterogeneous sensors and nonlinear sequential filtering techniques to enable a formation to autonomously navigate in the proximity of asteroids. The approach is expected to extend the range of achievable mission objectives and accomplish goals such as the deflection ([2]) or the exploitation of a near Earth asteroid. Such missions require the definition of particular navigation strategies to increase the mission reliability and the possibility of coping with both unknown environment and system performance uncertainties.

This work is divided into two parts. Firstly, multi-sensor measurements of the relative position and velocity of the spacecraft with respect to the asteroid are combined with measurements of the relative position and velocity of the spacecraft within the formation to estimate the state of each spacecraft with respect to the asteroid. LIDAR provides range and range rate measurements between the spacecraft and the asteroid ([3]) while cameras, in conjunction with attitude sensors, are used to get a fix on the asteroid and triangulate the relative position of the spacecraft. A nonlinear filtering technique is used to data fuse these two measurements and reconstruct the state of each spacecraft. Fig. 1 and 2 show an example of position and velocity estimation using only onboard LIDAR and camera for a single uncontrolled satellite flying in the close proximity of the asteroid Apophis at an initial distance of about 1 km. The measurements are sampled every 30 minutes. The combined use of these instruments allows for accurately determining the spacecraft trajectory with a position error in the range of metres, and an error in velocity in the range of millimetres, as reported in Table 1. Each spacecraft employs and processes the measurements coming from its own onboard sensors combined with the information available from the other members of the formation and the measurements of the relative position and velocity among spacecraft. The analysis assesses the improvement of the localization performance of the navigation system by fusing the position information across multiple spacecraft with inter-satellite position information. A comparison between the different combinations of sensors and measurements will illustrate the difference in accuracy. Secondly, the combination of the autonomous orbit determination along with absolute measurements is considered. The absolute measurements includes range and range rate measurements from the

ground station and pseudo range measurements from on board Sun Doppler shift sensor ([4]). The combination of the two sets of measurements and state estimations from onboard and ground provides an interesting mean to accurately determine the orbit of the asteroid. This part presents an analysis of the use of different combinations of sensors and their impact on the orbit determination of the spacecraft formation.

The orbit determination process is based on an Unscented Kalman Filter. Spacecraft dynamics takes into consideration the effects of gravitational forces from the Sun and the asteroid. Solar pressure is also included in the dynamic model. In particular, the rotation of the inhomogeneous gravity field of the asteroid is modelled and included in the description of the motion of the formation. A few case studies are presented with four satellites to demonstrate the possibility and advantage to use multi-sensor navigation of small satellites to explore asteroids. Simulation results indicate that multi-sensor navigation can better solve the problem of the orbit determination of spacecraft formation in the proximity of near Earth asteroid. And it is worth combining the relative data with absolute orbit determination to improve the navigation performance.

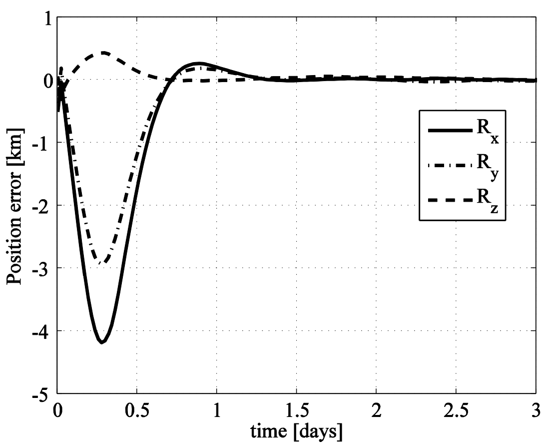

Fig. 1 Position error

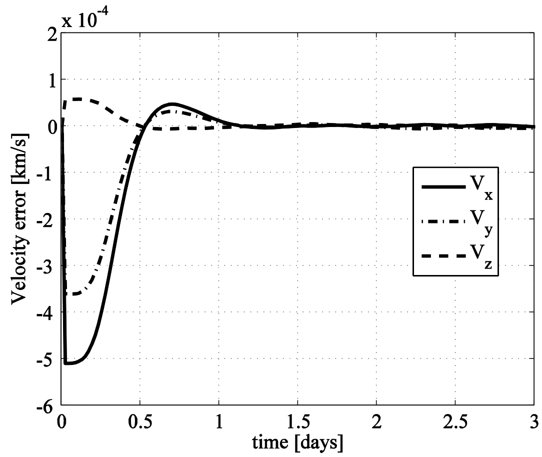

Fig. 2 Velocity error

Table 1 Error on position and velocity using camera and LIDAR observation

Rx [km]	Ry [km]	Rz [km]	V_x [km/s]	V_y [km/s]	V_z[km/s]
-4.1·10-3	-9.3·10-3	2.1·10-3	-2.1·10-6	3.7·10-6	1.76·10-6

REFERENCES

[1] Alonso, R., Du, J.-Y., Hughes, D., Junkins, J.L., and Crassidis, J.L., 2001. Relative Navigation for Formation Flying of Spacecraft. Proceedings of the Flight Mechanics Symposium, NASA-Goddard Space Flight Center, Greenbelt, MD, pp. 115-129.

[2] Vasile, M., Maddock, C., 2010. On the deflection of asteroids with mirrors. Celestial Mechanics and Dynamical Astronomy 107 (1–2), 265–284.

[3] Chung, L. R., 2006. Orbit determination methods for deep space drag-free controlled laser interferometry missions. Master thesis. University of Maryland.

[4] Yim, J.R., Crassidis, J.L., and Junkins, J.L., 2000. Autonomous Orbit Navigation of Interplanetary Spacecraft. AIAA Guidance, Navigation, and Control Conference, Denver, CO, AIAA Paper 3936.