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Hypervelocity Spacecraft Guidance Control Analysis to Intercept Small Diameter Objects

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Near-Earth Objects (NEOs) are comets and/or asteroids that have orbits in proximity with Earth's own orbit. NEOs have collided with the Earth in the past, which can be seen at such places as Chicxulub crater, Barringer crater, and Manson crater, and will continue in the future with potentially significant and devastating results. Fortunately, such NEO collisions with Earth are infrequent [1, 2] especially considering the large number of small to mid size objects. Such events can, however, happen at any time. Therefore, technologies need to be developed and validated that would be able to prevent NEO collision with Earth.

One approach to mitigate future NEO impacts is the concept of a hypervelocity interceptor. This concept is to perturb the NEO using kinetic impactors as well as nuclear penetration devices to alter the NEO's trajectory via momentum exchange. The interceptor has to hit a target NEO at a relative velocity which imparts a sufficient change in the NEO's velocity. NASA's Deep Impact mission has demonstrated hypervelocity intercept with a 5 km diameter comet, Tempel 1, with an intercept speed of approximately 10.3 km/s [3].

This paper extends the team work on the development of hybrid guidance navigation and control (GNC) algorithms for precision hypervelocity intercept of small size NEO's as seen in [4]. Critical challenges of an intercept mission are high relative hypervelocity speeds and NEO's small size, which will

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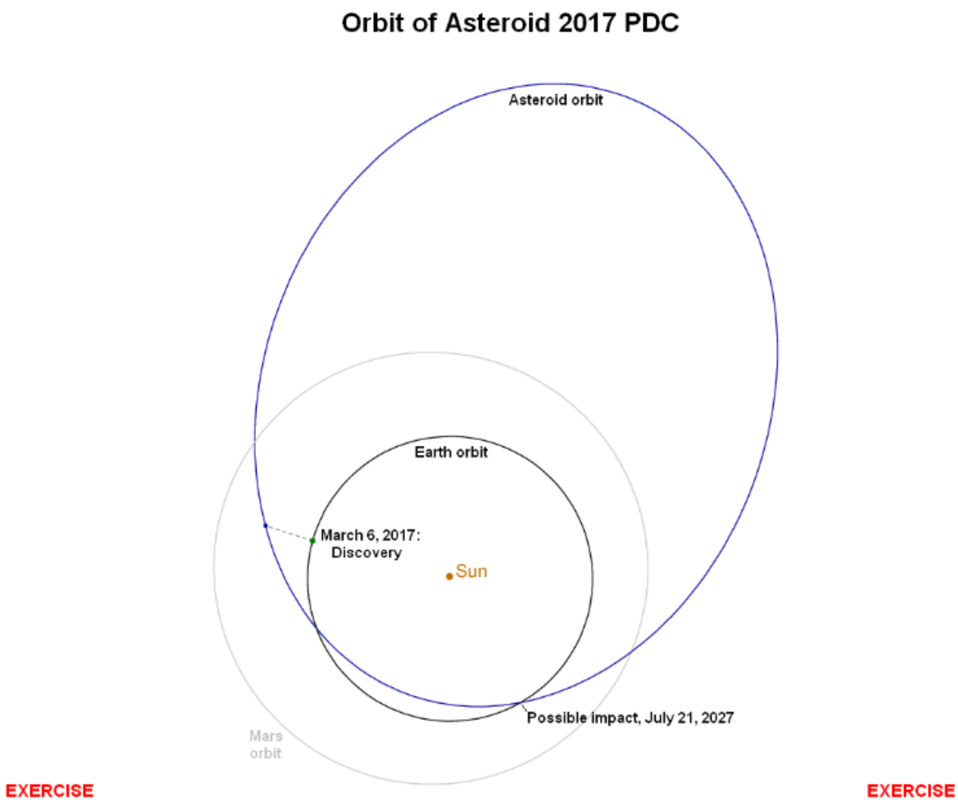

Figure 1: **2017 PDC asteroid's, Earth's, and Mar's orbit. Illustration courtesy of Planetary Defense Conference's scenario web page:** `http://neo.jpl.nasa.gov/pdc17/`

not fill the filed-of-view until a few seconds before the final intercept. The focus of the paper is to in-

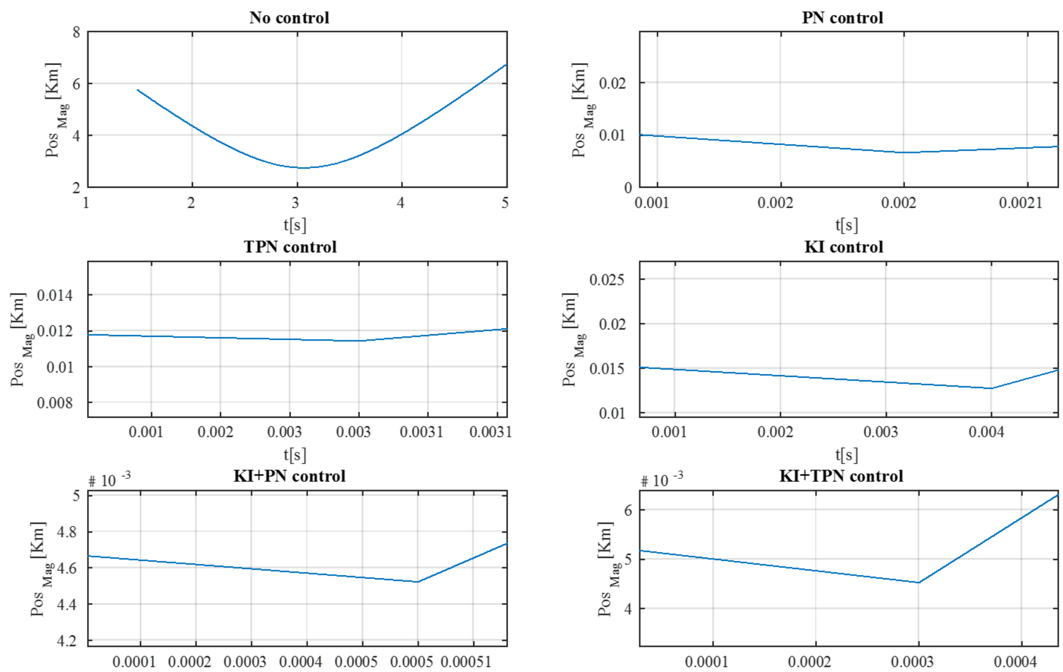

Figure 2: **Preliminary results for asteroid miss distance using difference Guidance schemes**

vestigate error sources of the guidance controller design and their mitigation techniques. The error sources includes spacecraft and asteroid initial state uncertainties in position as well as velocity, 3-axis spacecraft attitude, and random centroid image pixel noise with bias.

The guidance controller that will be investigated with error sources are classical proportional navigation (PN) based guidance that use a first order difference to compute the derivatives, Three Plane Proportional Navigation (TPPN), and the Kinematic Impulse (KI) [5, 6]. In addition to continuous models, PN and TPN will integrate the use of a Schmitt trigger, where as the KI scheme will use preplanned pulses. 2017 PDC asteroid will be used to compare the three methods with inclusion of Schmitt trigger and planned pulses. An illustration containing the reference orbit can be seen in Figure 1. Moreover, a hybrid approach that combines KI and PN or TPPN guidance schemes will be investigated to find the most effective, error tolerant, and power saving approach.

A 3-dimension mission scenario software simulator, called Hypervelocity Intercept Guidance Simulator (HIGS) is developed for testing the terminal guidance concepts and to analyze the effects of the error sources. The current result demonstrates that a miss distance of less than 12 meters is found using the PN and TPPN guidance laws, without the Schmitt trigger, for a small asteroid in the presence of the error in the spacecraft state. These can be seen in Figure 2. Additionally, this paper will present results using Schmitt triggers and pulsed guidance as well as the further investigation of the hybrid control approach in the presence of modeling and/or measurement errors. The simulation's preliminary results indicate that our approach would enable future successful intercept missions.

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