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Closed Loop Terminal Guidance Navigation for a Kinetic Impactor Spacecraft

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ABSTRACT

One of the most viable concepts for altering the course of an asteroid found to be on an impact trajectory with the Earth is to deflect it by hitting the asteroid at a very high velocity with a spacecraft. The resulting transfer of momemtum, although small, is sufficient to perturb the asteroid's trajectory enough such that it misses the Earth. The technology to perform a high speed impact has already been demonstrated to a large extent by the Deep Impact (DI) mission, which successfully collided with the comet Tempel 1 on July 4, 2005. Nevertheless, it would still be prudent to test this technique on a mission that more closely matches the parameters of a potential asteroid threat, and there is a reasonable likelihood that such a mission could be undertaken in the next decade.

One of the primary challenges that will be faced by a deflection spacecraft is the precise navigation needed to hit the surface of the asteroid at very high velocities. Standard ground-based navigation techniques are sufficient to guide the spacecraft to the approximate location of the impact spot, but due to various factors including the rapid pace of events in the terminal phase and the late detection of a small, dim body, these techniques do not have the accuracy necessary for impact. DI faced the same problem on its mission; the solution that made the impact possible was to employ an onboard closed loop autonomous navigation system called AutoNav (Ref. 1).

At its core, AutoNav performs the navigation function, which includes determining the spacecraft's orbit relative to the target body, then subsequently designing and executing maneuvers to achieve the targeting conditions, wholly self contained onboard the spacecraft. The data types used by AutoNav include images of the target body taken by the onboard camera, plus information about velocity changes imparted on the spacecraft by thrusting events. The data are combined in a filter to

determine the orbit, and this information is used to predict the future course of the spacecraft. At predetermined times, maneuvers are implemented to guide the spacecraft to the target if the predicted trajectory is found to be off-course.

For missions where only one chance exists to achieve its goal (a category which asteroid deflection falls into), the terminal guidance navigation system must be highly robust. Thus, numerous Monte Carlo simulations must be performed which test the system under all types of conditions, both nominal and with unforesen faults. This was done on DI where filter settings and sequence of events performed by AutoNav to achieve the impact were determined through many simulations to maximize the probability of impact for this particular spacecraft and scenario. Some of the critical parameters were the size of the comet (roughly 6 km in diameter), approach velocity (10.5 km/s), and the approach phase angle (62 deg). The parameters for an asteroid deflection could be considerably different. The range of possible sizes could be as low as 100 m in diameter or less, the approach velocity could range from below 10 km/s to as high as 20 km/s, and the approach phase could range from near 0 deg to near 180 deg (i.e., fully lit or no solar illumination). Thus, before a deflection mission is undertaken, it is important to understand how the terminal guidance will perform under a range of conditions.

In this paper, we expand the experience base of using AutoNav for terminal guidance in an asteroid deflection mission and parameterize the probability of achieving a successful impact on a sample set of deflection missions. A sample set of mission profiles is available to bound the scope of scenarios for a deflection mission (Ref. 2). Using this, Monte Carlo simulations of AutoNav terminal guidance were performed on selected scenarios, varying all relevant parameters, to obtain statistics on probabilities of impact. The simulations are run using high fidelity models which describe the spacecraft trajectory, spacecraft attitude errors, and ephemeris errors of the target body.

The results of the simulations indicate the probabilities of impact for several different representative scenarios. These results can eventually be used to narrow down the choices for selecting a deflection demonstration mission. Or, in the case of an actual threat, the results can be used to properly design the spacecraft parameters to increase the probability of impact for the mission.

References

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