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p 3

AN AUTOMATED SYSTEM FOR SPACECRAFT PROXIMITY OPERATIONS

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With the advent of multiple-vehicle operations in support of the space station, on-orbit refurbishment, and several other missions, there is a need to intelligently plan proximity operations trajectories that will conserve limited available fuel while avoiding collisions. Upon reaching the objective, the capture process entails several unique considerations, such as coordinating motion with a tumbling target, the capture itself, and adapting to control of the new configuration resulting from the capture operation. This paper outlines a systematic process of technical development over several years at the Draper laboratory, culminating in a capability to perform manual augmented or fully autonomous rendezvous, capture, and control of the resulting configuration.

This proximity operations system incorporates five main elements: a sequencing function, an automated proximity operations planner and execution system, a plume impingement and collision avoidance algorithm, the grapple system, and an adaptive autopilot. The grapple system will not be addressed here.

The A* node search method has been chosen for the proximity operations trajectory planner for several reasons. By its nature, the A* algorithm can develop the most fuel efficient trajectory while avoiding obstacles or other constraints. The A* algorithm is more global than gradient search methods in its optimization, and it is much less likely to converge on a local minimum. Because of these factors, the A* algorithm is a good approach to the proximity operations trajectory planning problem.

For reaction control vehicles, a finite number of effectors and variations in mass properties imply that control authority is a function of direction. The Shuttle, for example, has more control authority in roll than in pitch or yaw, and has more control authority in z than in -x . Relative authority levels also can change significantly with a change in mass properties, jet failures, or deselection of jets to avoid plume impingement. The actual geometry of the relative control authority can be hard to visualize, and only in rare circumstances is the maximum control authority aligned with the body axes.

The conventional assumption of uniform control authority may result in very costly trajectories compared to optimal trajectories. The planner must incorporate substantial information from the autopilot to take best advantage of the vehicle effectors in performing proximity operations. An adaptive autopilot, based on a system successfully flight tested on

Shuttle, is used with the planner. This autopilot is capable of operating complex and changing reaction control jet configurations to obtain fuel optimal control. It is through this autopilot that the system gains the ability to handle jet failures, changing mass properties and deselection of jets to avoid plume impingement.

A spacecraft must avoid contacting other vehicles or obstacles as it performs its maneuvers. With simple, compact vehicles (such as the Apollo spacecraft), it was not difficult to find docking trajectories that would avoid vehicle collisions. However, with more complicated vehicle shapes or multiple vehicles, attaining mission objectives while avoiding collisions becomes a more challenging problem. A collision avoidance algorithm is incorporated into the system to avoid undesired contact between the vehicle and target. As a byproduct of this process, plume impingement on the target can be anticipated and jets deselected to avoid such impingement.

After grappling the target, the attitude control system must stabilize the new configuration. if the target is significant in size and mass properties relative to the active vehicle, this may entail significant accommodation. The control authorities will change significantly, and several jets may be inhibited to avoid plume impingement. the previously mentioned adaptive autopilot is capable of meeting both needs if the properties of the new configuration are known. A mass property identification scheme has also been incorporated into the system for the case where the target is uncertain, or the target is grappled in an orientation other than anticipated. This algorithm "learns" the new configuration mass properties by comparing anticipated and actual vehicle response to jet firings. this information is then used by the autopilot to maintain efficient control of the new configuration.

The effectiveness of the proximity operations system was demonstrated on the Draper Space Systems Simulator. The Space Systems Simulator is a high-fidelity simulation of on-orbit motion of two vehicles. The space systems simulator independently integrates the equations of motion in six degrees of freedom using a fourth order Runge-Kutta algorithm. The outputs of the Space Systems Simulator include plots of each component of the vehicle state and fuel use. The simulator also has the capability of graphically depicting the maneuver as it is executed from any point of view or viewing distance.

There are several potential uses for the system. First, it could be used prior to flight to assist in flight planning by providing suggested trajectories that may not otherwise be obvious. The system could also be used on the ground during mission contingencies. If, for example, a jet unexpectedly fails, the system could be used to help obtain an alternate trajectory more quickly than might be possible using other methods.

When sufficient confidence is gained in the system, it could be used as a "pilot's associate," implemented onboard. When a situation arises for which a clear plan of action is not apparent, the pilot's associate could develop alternative plans, subject to current objectives and constraints for the pilot to evaluate. The pilot could then either follow the plan, or allow the system to execute it automatically.