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CATEGORY 2: Software Systems: Guidance/Navigation and Control

Title: Autonomous Rendezvous and Capture System Design

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Marshall Space Flight Center has a long history of involvement in the design of Autonomous Rendezvous and Capture (AR&C) systems. The first extensive studies were begun in the late seventies, incrementally leading to the development of an assortment of Guidance, Navigation, and Control (GN&C) concepts and algorithms suitable for a variety of mission requirements and spacecraft capabilities, with a strong emphasis placed upon flexible system-level design. These efforts have led to the development of sophisticated algorithms for docking with tumbling targets, and simple but efficient algorithms for stabilised spacecraft; each has been tested and validated using dynamic system simulation, with hardware in the loop when practical. Recent investigations include the use of neural networks for video image interpretation, and fuzzy logic for control system implementation.

In the late seventies, there was a desire for an ability to dock with tumbling spacecraft using a small teleoperated vehicle which would be flown from the Shuttle aft flight deck. Its mission objectives included docking with and reboosting the Skylab space station, which had lost its attitude control system. Pilot-in-the-loop ground simulations indicated that this was a difficult task for a human operator becauase of the high angular rates present on the target vehicle. There was a clear need for an automatic system which could perform the necessary maneuvers with a greater degree of speed, precision, and flexibility. A survey (reference 1) was made to evaluate the state-of-the-art in sensor technology, and several design concepts were identified as promising. Video-based sensors were chosen for detailed study, because of the low cost and low development risk involved. The next step would be selection of a suitable docking target, along with appropriate image processing/interpretation and GN&C algorithms. A study was made of three candidate schemes (reference 2), resulting in the selection of a three-point target consisting of radio-activated strobe lights, viewed by a monochrome vidicon camera with synchronous scanning. A very robust control algorithm was used; it consisted of a standard phase-plane function driven by a goal-setting logic, which effectively determined the shape of the approach trajectory by establishing a dynamic "aim point" on the target docking axis. A Kalman filter was used to smooth sensor noise and facilitate continued flight during breif data interruptions. A comprehensive series of dynamic simulations established the ability of the system to capture tumbling targets and identified weaknesses for which fixes were devised (reference 3). A series of hardware-in-the-loop runs defined the attainable sensor performance, and served as the basis for further software upgrades (references 4 and 5).

To avoid over-dependence upon a particular technology, a low-level parallel study of radio-frequency (RF) -based sensors was conducted. They offer the advantage of being totally immune to lighting problems, although typically more expensive and less accurate. A then-new device known as a "nonlinear reflector" was evaluated for docking purposes (reference 6); although a passive device, it returns an RF wave on a integer multiple of its original frquency. Three of these reflectors attached 120 degrees apart around the front of the target spacecraft allow measurement of all six degrees of relative freedom.

In 1987 a cooperative effort with Richard T. Howard of MSFC's Information and Electronic Systems lab led to the first known full-scale hardware-in-the-loop demonstration of AR&D with a totally passive target. The use of a passive target provides a capability of docking with a totally dead spacecraft, which is important for servicing missions, such as the Solar Max repair of the early 80's. A video-based technology was chosen because of the low cost and extensive experience accumulated during the decade. A passive target was devised consisting of a standard RMS (remote manipulator system) target with pieces of reflective tape attached to the center post and the ends of the baseplate. This target was later patented (no. 5,020,876), being the first known target suitable for piloted and automatic operation alike. Two video trackers were tested; a CCD-based unit with multiple-wavelength laser illuminators was developed to provide complete clutter rejection. A proportional-derivative control algorithm with rate limiting proved suitable for this application, which involved docking with stable targets from 100 feet or less. The complete system (reference 7) has been subjected to extensive testing and is now considered ready for flight demonstration.

Current efforts in AR&C software at MSFC are directed at the exploitation of new technology such as neural networks and fuzzy logic to improve the performance, flexibility, and reliability of AR&C systems. A neural network has already been developed to derive relative attitude and position data from the target video coordinates (ref. 8). The brute force approximation previously in use was neither as accurate or computationally efficient. It is possible in fact to replace all of the existing image processing, GN&C, and thruster selection algorithms with neural networks, and acheive significant improvements in computational speed, mission flexibility and redundancy. The goal of these efforts is a hardware-in-the-loop demonstration or AR&C involving neural nets and fuzzy logic wherever beneficial, illustrating each of these features.

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