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Autonomous Rendezvous and Capture System Design

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The presentation addressed the different tradeoffs necessary to get an automated rendezvous and capture system design that meets the requirements. The topics covered are piloted versus autonomous capture design considerations, navigation sensor selection tradeoffs, control algorithm design requirements and concepts, performance evaluation through simulation, system mission readiness verification and validation, and advanced AR&C control system technologies.

In looking at piloted versus autonomous design considerations, the autonomous system has many advantages. The advantages include mission flexibility, potential fault tolerance/redundancy, greater inherent reliability/predictability, reduced mission support/operations cost, reduced fuel consumption, and enhanced mission performance capabilities. The advantages of the piloted system are reduced hardware/software development costs and a reduced development schedule risk. Given the overwhelming advantages of the automated system, it was the one chosen as the baseline for the Cargo Transfer Vehicle Program.

In the area of navigation sensors, several candidate technologies look promising. Scanning laser radars have good accuracy, but higher cost and development risk than other choices. Video scene interpretation methods take advantage of an inexpensive mature technology but have limited acquisition range. Radio frequency techniques offer long acquisition ranges and high accuracy, but pose a high development risk.

In developing a control algorithm, the approach requirements drive what type of algorithm is required. Tumbling or spinning targets require continuous tracking of the docking axis, resulting in a spiral approach trajectory and complex algorithms. Stable target docking can be achieved using simple proportional derivative controllers. The required approach initiation range and position also effect the control algorithm. Approaches along the v-bar from short (< 150 ft) initial distances are simplest. V-bar approaches from greater distances require significant vertical orbital mechanics effects compensation. R-bar approaches require significant orbital mechanics effects compensation at all ranges.

Performance evaluations through simulation are an important element of AR&C. MSFC used AR&C Pathfinder funds to achieve the first known full-scale demonstration of passive target AR&C using MSFC's air-bearing vehicle. The system uses a CCD video sensor to acquire an image of a patented three-point reflective docking target, illuminated by an array of laser diodes. Since the AR&C system was not required to take control until 150 feet, a simple proportional-derivative control loop proved adequate for generating thruster commands. Hundreds of runs have been made and system performance exceeds that of human pilots who have flown the air-bearing vehicle in the past. It is now considered ready for flight qualification and testing.

Requirements for system verification and validation include environmental and dynamic elements. The system should be tested for tolerance of temperature, vibration, vacuum, etc. The dynamics testing should be full scale and continuous from the beginning of rendezvous until final docking is achieved. A flight experiment, either in space or by means of a properly equipped aircraft, is recommended before use of AR&C on high value missions. Collision avoidance capabilities also should be demonstrated along with the planned trajectory.

Two emerging software technologies, neural networks and fuzzy logic, offer significant potential in the area of AR&C. Neural networks are a recently rediscovered computational concept that relies heavily upon parallel architecture and negative feedback to "learn" to solve control, transformation, and pattern recognition problems by correcting its own errors. MSFC has developed a network for computation of relative attitude and position of two spacecraft using video images. Fuzzy logic provides a convenient means of modeling nonlinear functions that are difficult to represent explicitly. This class of algorithms has proven useful for many control tasks normally performed by humans.