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Image Based Tracking Approaches to AR&C at the Johnson Space Center

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Automated Rendezvous and Capture (AR&C) requires the determination of the six degrees of freedom relating two free bodies. Sensor systems that can provide such information have varying sizes, weights, power requirements, complexities and accuracies. One type of sensor system which can provide several key advantages is an *image based* tracking system, or better known as a machine vision system. By *image based tracking* we mean that the sensor is some imaging device such as one or more video cameras, from which the tracking parameters necessary to support the rendezvous and capture operations (range, attitude, etc.) can be derived. Image based tracking offers many advantages such as relative hardware simplicity and reprogrammability. These advantages must be weighed against the disadvantages of these systems, such as limited operational range, poorer accuracy at greater distances and sensitivity to lighting conditions. However, with properly designed algorithms and targets these disadvantages can be minimized for many important applications. Rigorous testing in realistic environments can further increase the robustness and reliability of these systems. This presentation discribes the facilites used at JSC to support AR&C image based tracking development and the details of our binocular stereo approach to image based tracking.

At the Johnson Space Center (JSC), we have developed the Image Based Tracking Laboratory (IBTL) to explore these issues and to develop realistic, robust and functional automated rendezvous and capture image based tracking systems. A key element of our laboratory is the ability to accurately simulate the visual environment encountered in space. This environment is simulated by a large flat black room with six strategically located 1500 Watt lamps to simulate various sun angles, and a 5000 Watt spot light to create the harsh shadows and lighting conditions experienced in orbit. For completeness, we have also added starfield and earth backgrounds, a Martian landscape and various spacecraft models. The IBTL is equipped with various image processing equipment for developing image based tracking algorithms and mobile robots to simulate spacecraft. A Pipelined Image Processing Engine provides rapid prototyping of algorithms and is augmented with a Datacube based blob analysis system and various PC based frame grabbers and image processors. The laboratory provides JSC researchers the capability to rapidly explore image based tracking algorithms in a realistic environment.

The image based tracking approaches being pursued by JSC include an optical correlator for non-cooperative model based recognition, passive stereo, passive and active monocamera techniques for cooperative target recognition. This presentation will discuss the passive stereo techniques for determining the range and attitude measurements necessary to support AR&C. The optical correlator and some monocamera techniques are described in separate presentations at this technical review.

In these techniques we must operate within the limitations imposed upon us by the system. Since the operational range of image based tracking systems is limited, we must assume that some form of tracking ability exists that will bring the two spacecrafts to within 100 meters of each other. We also assume that the approach to the target does not require our sensors to look into the sun. We do not, however, require an empty space background for our target vehicle; we can accommodate Earth, moon and star field backgrounds. For simplicity, we have also assumed that coarse attitudes of both the target and rendezvous vehicles are known so that the docking target will be visible to the rendezvous vehicle. If this were not the case, we would have to maneuver the rendezvous vehicle around the target vehicle until the docking target came into view.

Under these assumptions, we are developing a stereo based range and attitude determination system. This system utilizes three parallel looking video cameras in a stereo configuration. The three cameras are spaced so that two cameras are as far apart as possible (on opposite sides of the vehicle) to yield the greatest range accuracy at long ranges. The third camera is placed between the other cameras to provide a shorter baseline for the terminal phase of the AR&C and also serves as a redundant camera should one of the outer cameras fail. During the initial rendezvous phase we use the outer cameras to provide range and bearing information to the target vehicle. As the vehicles get closer, the docking target will become resolvable and accurate attitude information will be available. The docking target is a pattern of markings in a known geometry. The three-dimensional coordinates of the markings are calculated after locating them in the left and right cameras of the stereo pair. Since the geometry of the marks is known, the ranges and bearing angles to the individual marks will allow us to determine the attitude of the docking target.

This work is still in the developmental phase. We have successfully provided range and attitude measurements in our laboratory for small distances (less than 10 meters) and simple backgrounds. The system has been interfaced to a mobile robot which can simulate a rendezvous with the docking target in the IBTL. The system accuracy has been measured using the very accurate six degree-of-freedom positioner available at JSC. Additional work will include the improvement of the target segmentation--the extraction of the alignment target from a complex image. This will include complicated backgrounds at infinite range, complicated spacecraft backgrounds and specular reflections off of the target spacecraft. Additional research will be conducted to develop alternate passive targets which ease the segmentation task and improve the robustness of the system.

Image based tracking offers many attractive features for an AR&C navigation and guidance system. These systems require minimal changes to the existing spacecraft hardware by making use of available cameras and adding a video processor to the rendezvous vehicle and a passive alignment target to the target vehicle. Still, with these advantages, image based tracking must prove that it can function reliably and robustly enough to achieve mission success. Future JSC research is intent on addressing these issues and demonstrating that image based tracking is, indeed, reliable and robust enough for real automated rendezvous and capture missions.