is described in detail in the presentation showing that this sensor is outstanding for space use. It has, indeed, already gone through most of the space qualification criterion.

The Spine-Locking Screw is central to robotic (and astronaut hand tool) fastening. A fundamental change to the basic machine screw, it permits robots to fasten objects (and themselves in a walking mode) to other objects with high preload forces from small input torques and without any possibility of cross-threading. In addition, this fastener can be slightly modified to provide an outstanding electrical connection along with the mechanical. Like the "Capaciflector," this fastener already has been recognized as an outstanding system for use in space.

Taken together, the "Capaciflector" and the "Spine-Locking" Screw extend the state-of-the-art in automated berthing technology. It is now possible to have smart instrumented payloads with a sensing capability that can easily be fastened by robots with unprecedented control and safety throughout.

S14-32 N93-21421 146682 P. 2

A Binocular Stereo Approach to AR&C at the Johnson Space Center

by Timothy E. Fisher and Alan T. Smith
Johnson Space Center and Lockheed Engineering and Sciences Company

Automated Rendezvous and Capture requires the determination of the 6 DOF 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 that can provide several key advantages is a binocular stereo vision system.

Binocular stereo uses two video cameras on the rendezvous vehicle viewing the target vehicle. The target vehicle is equipped with a passive target that allows for easy and robust identification of the target. Range to the target is inferred from the different bearings in the left and right camera views of the target points. When the target has three or more identifiable points in a known geometry, the attitude of the target can be inferred from the bearings and ranges to the three points.

One of the main advantages of such a binocular stereo vision sensor is the simplicity of the hardware. The system uses standard video cameras and digital processing hardware. These items are likely to be present already on the rendezvous vehicle. The other major hardware components required include image digitizing electronics and possibly camera lens and pointing controls. Another advantage of this system is that it uses only passive sensors, limiting the amount of power required. Also, the system requires only a passive target so that rendezvous is possible with non-powered or dysfunctional satellites and systems.

Another advantage of the stereo vision approach is that the system designer has many design trade-offs that can be used to "scale" the system to a particular application (specific baseline, range accuracy, etc.). For example, the field of view of the cameras can be narrowed to increase the operational range of the sensor at the expense of limiting the minimum range at which the system can operate. Other variables that can be altered include camera resolution, baseline distance between the cameras, and vergence angle of the camera pair. Also, the system processor can be replaced with a more powerful one if faster update rates are necessary.

Binocular stereo has some limitations that need to be addressed when considering the sensor requirements. One of the key limitations of this system is the limited operational range of the sensor and the limited range accuracy at longer distances. Range is calculated using a triangle whose vertices are the two cameras and the target point. As the target point moves far away from the cameras, the triangle is elongated, and the errors in measuring the bearing angles dominates the measurement and accuracy suffers. Another reason for the limited operating range of the sensor is that the passive target must subtend several camera pixels before the target identification algorithms can work. These limitations can be counteracted by proper design of the system, but the tradeoffs necessary to achieve the desired results at long ranges may adversely affect performance at shorter ranges.

At JSC, we have developed an engineering development platform to investigate the issues involved in using stereo-based sensors for AR&C. We have successfully demonstrated a binocular stereo based automated rendezvous operation using a mobile robot and a simulated earth background. Preliminary results show range precisions on the order of 0.25% of range at close ranges. Detailed error calculations will be done in the near future.

A Comparison of Laser-Based Ranging Systems for AR&C

by Stephen J. Katzberg and Pleasant W. Goode IV
Langley Research Center

The three most common types of laser target ranging (time-of-flight, tone modulated, and FM-CW) are discussed first as far as principle of operation is concerned. The first, time-of-flight, is shown to depend more on the ability of support electronics than the fundamentals of the concept. Examples in the literature are cited to show the remarkably good performance of time-of-flight systems. A system developed in Finland has been shown to have an incremental ranging capability of a few millimeters. The system is not only robust; it does not include additions such as reference legs and the like, which are expected, for improvement in performance.

Though not immediately obvious, the second technique, tone modulated ranging is somewhat of an extension of the time-of-flight technique. Essentially the tone systems use the phase shift of the reflected laser (or LED, for that matter) power to determine the range. Since phase shift is just time shift times the "two PI per period" of the modulation, then this technique is directly analogous to the time-of-flight method already discussed. Limitations on the use of very high modulation frequencies for improved incremental accuracy in this technique arise from the ambiguity in total phase after one period. Tone modulated systems are fairly common, commercial versions have been developed. A simple analysis is presented to show the kind of performance that might be expected from the tone modulated systems.

Third, the FM-CW technique is presented. This is completely different from the tone or time-of-flight techniques, but is a direct translation of the same-named technique used in radar ranging systems. One major advantage for this application that lasers have over the RF version is precise aiming and lack of multipath interference. In this technique, the source must be a rapidly tunable laser source without mode hops of the main oscillating mode. The laser is chirped over its useful tuning range and transmitted to the target. After return from the target, the laser is heterodyne detected and processed. Since the round trip time to the target causes a delayed replica of the transmitted wave, heterodyne detection gives a beat frequency whose value is related to the tuning rate of the laser and the round-trip time. Knowledge of the tuning rate of the laser gives the range through utilization of frequency counters or detectors. It is noted that the FM-CW technique benefits from two factors: high signal-to-noise in heterodyne detection and much higher accuracy from the lack of phase ambiguity limitations. Performance analysis is given for comparison with the other techniques and some typical results are given to show how very accurate the FM-CW laser radar concept can be. As is typically the case, there are competing factors that limit the actual performance possible for FM-CW laser radars can achieve. One of the most important is the effect of lack of coherence length in the types of lasers capable of the wide tuning ranges needed. The effect manifests itself, not only in the loss of signal from coherence loss, but more importantly, the appearance of quantum phase noise associated coherence loss. Quantum phase noise represents a jitter in the phase part of the laser output, and although it is only phase and not amplitude, the effect is the same. Moreover, the phase noise is proportional to laser field amplitude squared, as