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Laboratory Demonstration of a Prototype Geosynchronous Servicing Spacecraft

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Introduction: The benefits of autonomous spacecraft rendezvous and capture for future military, civil, and commercial space missions are far-reaching and intriguing. These include satellite reposition, service life extension, debris removal, repair, replenishment, technology refresh, on-orbit assembly, and salvage. Because of the large number of high-value assets in the geosynchronous (GEO) belt, autonomous servicing of these spacecraft could provide the greatest utility. Furthermore, requiring modification of the target spacecraft bus to accompany aided docking sensors and mechanisms is impossible for existing GEO assets and impractical for most future assets that rely on existing standardized bus designs. Hence, development of a general-purpose space "tug" to service an unaided geosynchronous target is highly desirable. This tug will require the utilization and integration of many challenging technologies, such as long-range sensors for acquisition and tracking, machine vision for target imaging, algorithms for feature recognition and pose estimation, manipulators for end effector positioning, and intelligent robot arm control algorithms.

To evaluate and test these critical issues, the Defense Advanced Research Projects Agency (DARPA) is sponsoring the Spacecraft for the Universal Modification of Orbits (SUMO) project, a technology risk-reduction program executed by the Naval Center for Space Technology at the Naval Research Laboratory. The purpose of the program is to demonstrate the integration of machine vision, robotics, mechanisms, and autonomous control algorithms to accomplish approach and grapple of common hardpoint interfaces traceable to existing and future spacecraft hardware. To date, the SUMO program has consisted of three phases: an exploratory study phase in 2002, a concept design phase in 2003,[1] and a laboratory demonstration phase in 2004-2005. As described here, the laboratory demonstration phase provided realistic test and evaluation of the critical technologies associated with unaided target approach and capture.

SUMO Testbed Description: NRL's Proximity Operations Testbed was the primary test facility for the SUMO laboratory demonstrations. This facility represents a dual-platform spacecraft motion simulator that provides a realistic test environment for verification of sensor and control technologies. The facility consists of two independent 6 degree-of-freedom platforms, a local-area network architecture for real-time ground-to-platform and platform-to-ground communications, and software to emulate spacecraft mass properties, thruster and reaction wheel actuators, and on-orbit environmental disturbances. Figure 4 shows the testbed with the SUMO pursuer hardware and the target mock-up. The SUMO hardware consists of a 7 degree-of-freedom robot arm with an end effector and a force/torque sensor, visual stereo cameras on the platform and end effector for 3-D target mapping, active target illumination using a pulsed xenon flashlamp, and an electronics bank for arm control and hardware synchronization. The target platform emulates a realistic launch vehicle interface to a user-selected Boeing 702 GEO communications bus or a Lockheed Martin A2100 GEO communications bus.

Test Scenario and Results: A typical real-time test scenario consists of an approach of the SUMO platform toward the target along a desired flightpath, stationkeeping within arm's reach of the target, and capture of a target hardpoint using the arm and its end effector. During approach and stationkeeping, the relative pose (position and attitude) of the target is determined using range images and Tripod Operator[2] software. Figure 5 shows a set of target intensity images and the corresponding 3-D point cloud obtained during a typical approach. Capture of the target structural hardpoint is achieved by maneuvering the robot arm to within the end effector camera field-of-view, using real-time path planning logic to avoid potential obstacle collisions. Once inside the camera field-of-view, the target hardpoint is recognized and triangulated to determine its relative position. Hardpoint capture is then achieved by commanding the end effector tool to reach out and grapple the identified feature, using active compliance control from the force/torque sensor to provide soft spring-like contact. Figure 6 shows a typical arm maneuver and end effector grapple. For this particular target, the hardpoint feature is represented by the protruding launch vehicle bolt hole interface.

Summary: The critical technologies of machine vision, robotics, mechanisms, and autonomy associated with the capture of GEO spacecraft are being evaluated, integrated, and tested at NRL. Successful fusion of these technologies promises to enable future autonomous servicing missions, offering a potentially revolutionary advancement in spacecraft operations.

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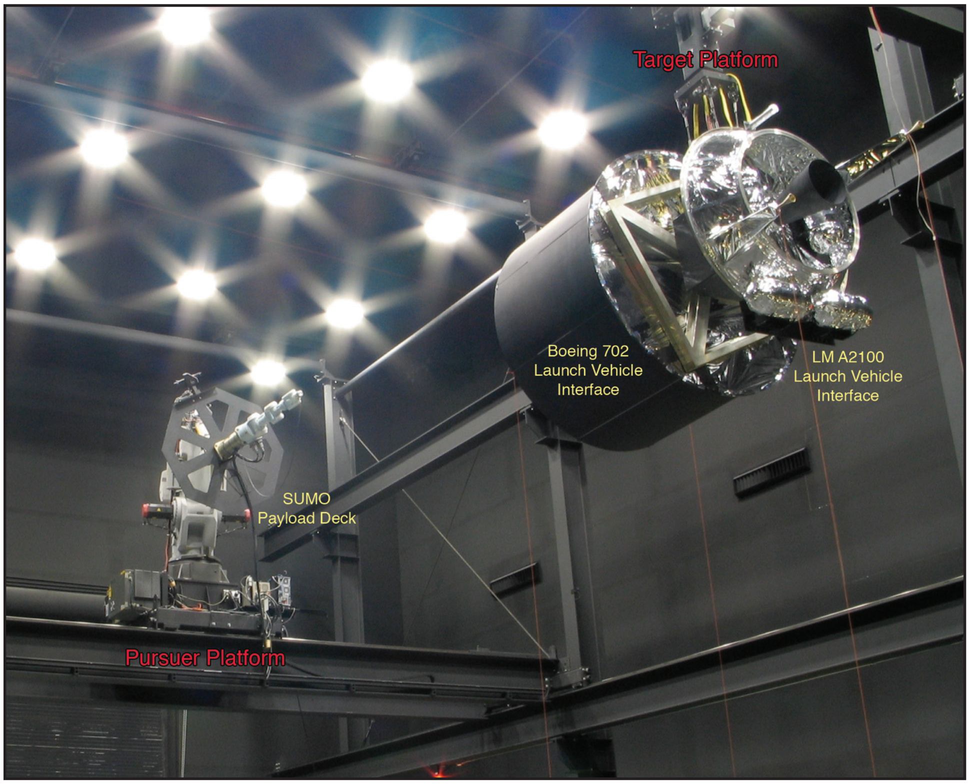
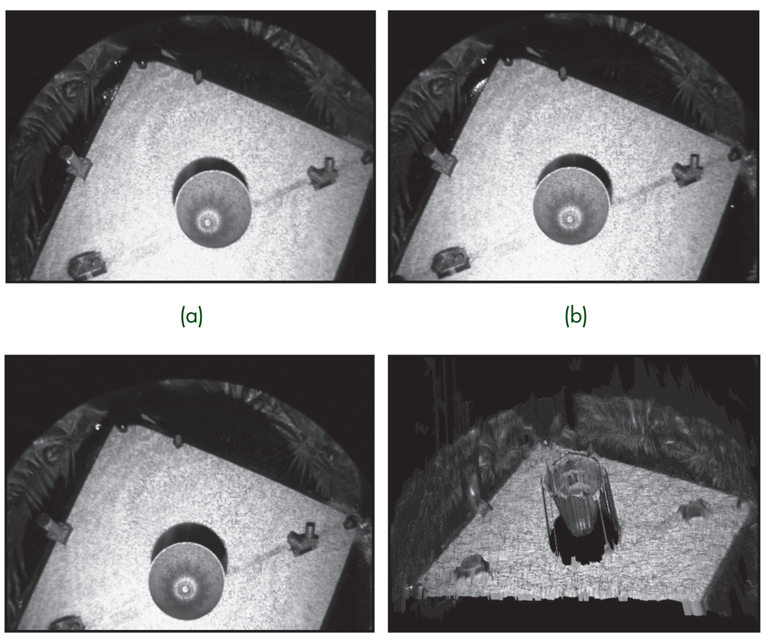


FIGURE 4
NRL's Proximity Operations Testbed with SUMO payload and common communication bus targets.



(a) (b)

(c) (d)

FIGURE 5
Typical target images. (a) Left camera intensity image; (b) Right camera intensity image: (c) Top camera intensity image; (d) 3-D point cloud image.

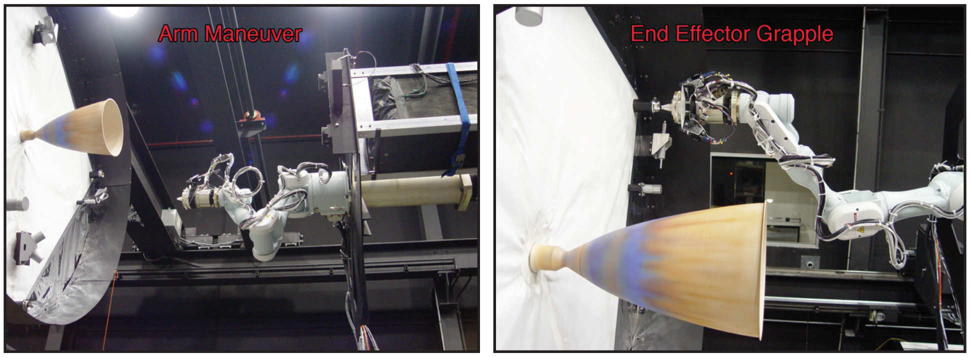


FIGURE 6
Arm maneuver and grapple of a target hardpoint.

References

[1] A.B. Bosse, et al., "SUMO: Spacecraft for the Universal Modification of Orbits," *Proc. SPIE* **5419**, 36-46 (2004).

[2] F. Pipitone, "Technique for Estimating the Pose of Surface Shapes Using Tripod Operators," U.S. Patent # 6,393,143, May 21, 2002.

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