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Measuring the Hubble Space Telescope's position and orientation in orbit

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A new algorithm provides real-time measurements for automated docking without special targets or any sensor more complex than a video camera.

The Hubble Space Telescope has provided astronomical data of unsurpassed value. It has also required astronauts to repair it in orbit four times. Currently, Hubble needs further repairs. Two of its instruments no longer work, its gyroscopes and batteries are likely to fail soon, and its orbit is decaying. Because of the Columbia disaster, NASA has concerns about sending astronauts to Hubble, since they'd be unable to take shelter in the International Space Station if the shuttle couldn't re-enter the atmosphere. Ideally, NASA would be able to service Hubble using robots instead of astronauts.

For a robotic servicing craft to dock safely with Hubble, it needs a way to measure how far away Hubble is and how Hubble is oriented relative to it. Many of the sensors that make these kinds of measurements actually measure the distance and orientation of a special target mounted on a spacecraft. For instance, the Russian KURS system uses a radio beacon,[1] while NASA's Advanced Video Guidance System uses an arrangement of optical retro-reflectors.[2] Hubble has no such special targets. Our approach uses a standard video camera and an algorithm that was originally developed for military automatic target recognition. The approach doesn't require special targets, though it can take advantage of them if they exist.

The ULTOR® P3E algorithm uses image correlation to make its measurements. Roughly speaking, image correlation takes a filter and asks the question, "Is the object that this filter represents somewhere in the image? If it is, where in the image is it?" It involves applying a Fourier transform to an image, comparing that to a reference library of filters, and inverse Fourier transforming the result. Each filter corresponds to an object or to an object's feature.

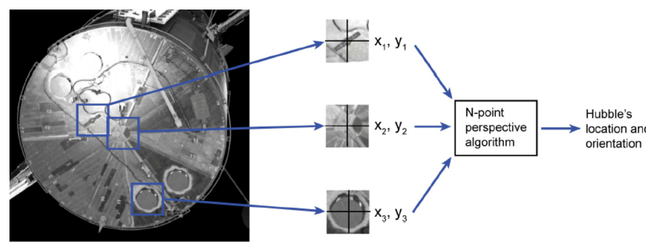

Figure 1. *An example of the feature approach showing three features.*

The algorithm uses image correlation to find specific features on Hubble, such as its vents.[3] It has a library of filters that match those features, and knowledge of where the features are located on Hubble relative to each other. By performing image correlation using each of those features' filters, we can locate them in the image. The way the features are oriented relative to each other provides information about Hubble's location and orientation, which we calculate by solving the n-point perspective problem.[4] Figure 1 illustrates this approach.

As part of the next Hubble re-servicing mission, NASA will test an automated system for docking with Hubble that will include ULTOR® P3E. Three visible-light cameras will record imagery of Hubble during both approach and departure beginning at a distance of 200m. The imagery will be fed to a field-programmable gate array (FPGA) based reconfigurable computing platform that hosts our algorithm. It in turn will provide measurements and a confidence factor at 3Hz.

We have tested our algorithm against a high-fidelity Hubble mockup in NASA Marshall Space Flight Center's Flight Robotics Lab. The Hubble mockup was placed on a specialized crane and maneuvered in front of the cameras to simulate approach and departure trajectories beginning at a distance of 30m. Measurements using our system were then compared to the truth data from the crane. Table 1 shows our root-mean-square measurement errors from three trajectories that were run during the tests.

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Table 1. *Measurement errors from the three trajectories tested with a mockup*

	Approach Trajectory	Departure Trajectory	Alternate Departure Trajectory
X Error	0.6cm RMS	1.3cm RMS	0.67cm RMS
Y Error	5.0cm RMS	1.7cm RMS	0.56cm RMS
Z Error	2.0cm RMS	4.5cm RMS	0.92cm RMS
Roll Error	0.3 deg RMS	0.02 deg RMS	0.54 deg RMS
Pitch Error	0.04 deg RMS	0.03 deg RMS	0.48 deg RMS
Yaw Error	0.04 deg RMS	0.03 deg RMS	0.28 deg RMS

ULTOR® P3E could be used to allow robotic repairs to the Hubble Space Telescope in real time without needing special targets or unusual sensors. Our initial tests against a high-fidelity Hubble mockup were very successful, and we continue to refine the technology in advance of its flight on the next mission to Hubble.

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References

1. E. M. Hinman and D. M. Bushman, *Soviet automated rendezvous and docking system overview*, **NASA Automated Rendezvous and Capture Review**, pp. 34–35, 1991.
2. R. T. Howard, M. L. Book, and T. C. Bryan, *Video-based sensor for tracking three-dimensional targets*, **Proc. SPIE 4167**, pp. 242–251, 2001. doi:10.1117/12.413832
3. M. Balch and D. Tandy, *A pose and position measurement system for the Hubble Space Telescope servicing mission*, **Proc. SPIE 6555**, p. 65550F, 2007. doi:10.1117/12.720302
4. M. A. Fischler and R. C. Bolles, *Random sample consensus: A paradigm for model fitting with applications to image analysis and automated cartography*, **Comm. ACM 24** (6), pp. 381–395, 1981.