Effect of variable latency on teleoperation for space applications

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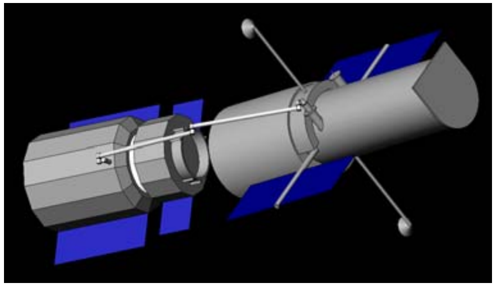
Introduction

Robotic servicing missions in space will likely include a mixture of autonomous and teleoperated robotic systems to accomplish tasks of varying complexity and urgency. Teleoperation from a ground control station requires communication via TDRSS (Tracking and Data Relay Satellite System) in geosynchronous orbit. Past experience with teleoperation through TDRSS indicates that the latency is approximately six seconds [1] but the exact value is not well characterized. A better understanding of this variable latency and its effect on teleoperator performance is essential for robotic servicing on orbit to be feasible.



A conceptual servicing robotic vehicle captures the Hubble Space Telescope

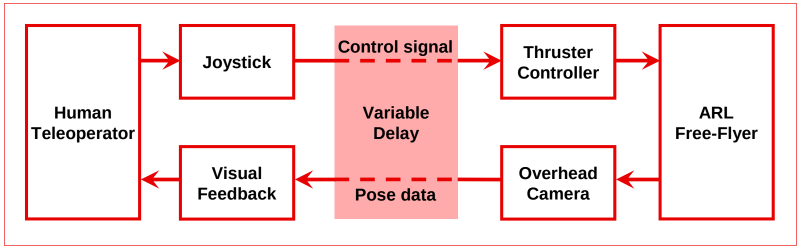
Experimental Setup

Previous studies on constant latency measured the time to complete a simple task such as tapping the end of a pole [2]. The task performed for this study was a 0.75 meter straight-line traverse. In each traverse, a fixed mean and standard deviation are selected to generate a new random latency value every 0.5 seconds. This latency delays both the forward control signal as well as the feedback pose data.

Initial experiments were performed on a Free-Flyer robot in the Aerospace Robotics Laboratory. The robot floats on an air cushion to allow near-frictionless motion in the horizontal plane. Compressed air is used in cold-gas thrusters to provide thrust in four directions. An overhead camera provides position, heading, and rate data. A joystick provides control input to the thrusters.

Three metrics are used to assess different aspects of teleoperator performance:

1) Radius of convergence (precision);
2) Effort to reach the target (aggressiveness); and
3) Effort to maintain station (efficiency).



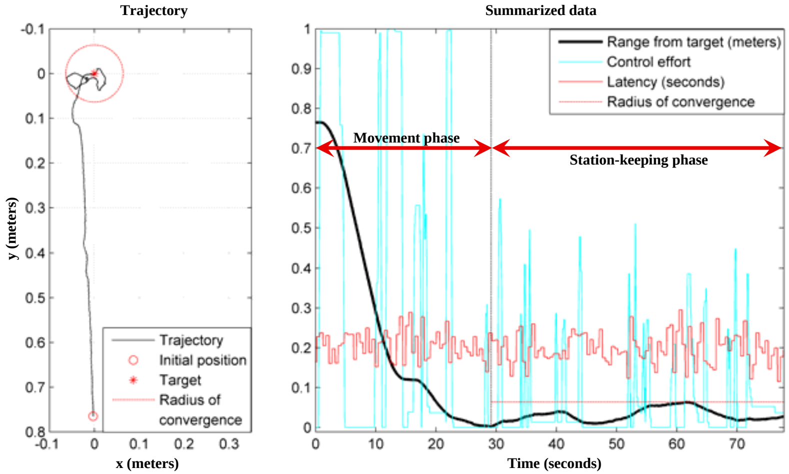
Block diagram of experimental hardware architecture.

Preliminary Results

From the initial experiments, it is possible to extract some information on control strategies that were used during two distinct phases of the traverse. When approaching the target (the movement phase), the strategy was generally to apply forward thrust until the velocity reached a maximum comfort threshold, coast, and start applying reverse thrust shortly after half the traverse was completed.

Upon reaching the target (the station-keeping phase), there were two noticeable control strategies. With low latency, single thruster pulses were applied to effect changes in velocity. In high-latency runs, paired pulses in opposing directions were used to effect a change in position without much change in velocity. In general, rapid thruster pulses were used rather than sustained lower magnitude inputs.

ARL Free-Flyer robot used in teleoperation experiments.



Plots from a typical traverse (Mean latency: 0.2 seconds; standard deviation: 0.04 seconds). Note the pulsed control during the station-keeping phase.

Future Work

Development of a simulated robot in software to replace the ARL Free-Flyer will greatly increase the rate and consistency of data acquisition. A large body of data is required in order to conjecture a relationship between variability of latency and teleoperator performance.

If a dependency is found, control schemes can be developed to optimize performance of robotic systems in a variable-latency environment. Firstly, human-in-the-loop systems can be improved by adjusting the balance between magnitude and variability of latency. Secondly, autonomous control algorithms can be developed to take advantage of strategies that human operators use to mitigate the effect of latency. This can lead to improvements not only in teleoperated systems but also in distributed autonomous robotic systems such as planetary rover fleets.

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References

[1] Imaida, T.; Yokokohji, Y.; Doi, T.; Oda, M.; Yoshikwa, T., “Ground-space bilateral teleoperation experiment using ETS-VII robot arm with direct kinesthetic coupling,” *Robotics and Automation, 2001. Proceedings 2001 IEEE International Conference on*, vol.1, pp.1031-1038.

[2] Bejczy, A.K.; Kim, W.S.; Venema, S.C., "The phantom robot: predictive displays for teleoperation with time delay," *Robotics and Automation, 1990. Proceedings., 1990 IEEE International Conference on*, pp.546-551 vol.1, 13-18 May 1990.