Command and Telemetry Latency Effects on Operator Performance during International Space Station Robotic Operations

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INTRODUCTION

International Space Station (ISS) operations will require the on-board crew to perform numerous robotic-assisted assembly, maintenance, and inspection activities. Current estimates for some robotically performed maintenance timelines are disproportionate and potentially exceed crew availability and duty times. Ground-based control of the ISS robotic manipulators, specifically the Special Purpose Dexterous Manipulator (SPDM), is being examined as one potential solution to alleviate the excessive amounts of crew time required for extravehicular robotic maintenance and inspection tasks.

The SPDM (Figure 1) is a dexterous manipulator with two symmetrical seven-joint arms attached to a central body structure. Each arm is approximately 11.5 feet in length and has 3 degrees-of-freedom (DOF) at a shoulder joint, 1 DOF at an elbow, and 3-DOF at a wrist. In addition, the entire body of the SPDM can rotate. The Orbital Replacement Unit/Tool Changeout Mechanism at the end of each arm has grippers for grasping equipment and tools, a socket drive to manipulate bolts, and umbilicals for power, data, and video connectivity to payloads. Attached to the main body is a Tool Holder Assembly accommodating four robotic tools and a temporary platform for storage and transportation of ORUs and payloads. The rated capacity of the system is 600 kg.

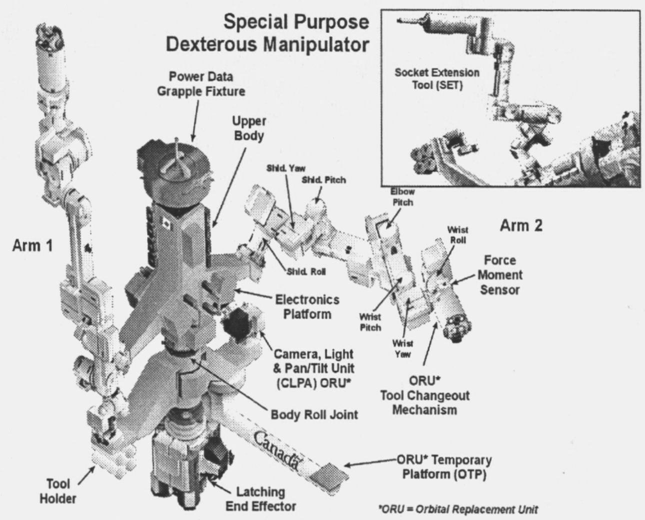

Figure 0. Special Purpose Dexterous Manipulator

Control and monitoring of SPDM components is from one of two redundant modular workstations. The workstation provides operator interfaces including three video monitors, two hand controllers for translational and rotational inputs, and a Display and Control panel. A portable computer is used to communicate with the SPDM software, allowing the operator to set operational parameters and send commands to the system. Data returned from the manipulator is displayed in graphical formats.

The SPDM will be deployed to the ISS within the next few years and will be used primarily for maintenance and payload servicing tasks, such as the removal, replacement, handling, temporary storage, transportation of the over 200 robotically compatible electronic devices on the Space Station's exterior (Currie, 2002). The SPDM can either be operated from the end of the Space Station Remote Manipulator System or as a stand-alone manipulator system, however only one arm can be operated at a time. SPDM timeline issues are due to excessive number of tasks required to complete external electronic equipment change-out, not necessarily due to the length of time required for any particular individual task. Current timeline estimates for some SPDM operations exceed available on-orbit crew time (approximately 6–17 hours for removal and replacement depending on the component).

Uplink and downlink times to and from the ISS have recently been studied. Not accounting for root sum square effects, the uplink data delay (time from a hand controller input at a ground control station to the time that the arm moves) is a maximum of 3.6 - 4.2 seconds. The total downlink time is approximately 3.105 seconds, with the majority of the latency effects incurred during data processing within Mission Control Center.

This study was conducted to characterize the effects of command and telemetry time delay on teleoperation of the SPDM by ground-based operators. The primary purpose of this project was to gather baseline human performance data on latency effects during highly accurate manual constrained motion control tasks using the standard workstation controls, displays, and procedures currently available. This data, as well as follow-on studies involving synchronous and asynchronous lags in video signal transmissions, will be used to determine whether augmentations to existing operator tools and procedures are required in order to safely and effectively control the SPDM from ground-based workstations.

METHOD

Participants

Five test subjects participated in this study. All of the participants were experienced astronauts who had completed ISS robotics training and had prior experience in operating ground-based simulations of the SPDM. Most of the subjects had also previously participated in ground verification studies of SPDM operations.

Apparatus

The operator test configuration was comparable to the expected configuration for orbital SPDM operations. Testing was conducted in the Dexterous Manipulator Trainer (DMT) at the Johnson Space Center. This facility emulates selected operations of the SPDM robotic system and provides a simulation of external ISS work site operations, concentrating on hardware contact operations experienced during ORU removal and replacement tasks. A replica of the ISS robotic workstation provides operators controls for the manipulators and their ancillary equipment, such as end effectors, tools, cameras and lights. External camera views, similar to those available at the ISS worksite, are presented to operators on workstation monitors. The removal and replacement phases of an ORU sequence involving a Remote Power Control Module (RPCM) was selected as a representative SPDM task. In order to limit this study to only command and telemetry latency conditions, representative external ISS camera views were provided to the operator at all times – no video degradation, failures, or loss of signal to the ground was simulated during this initial test.

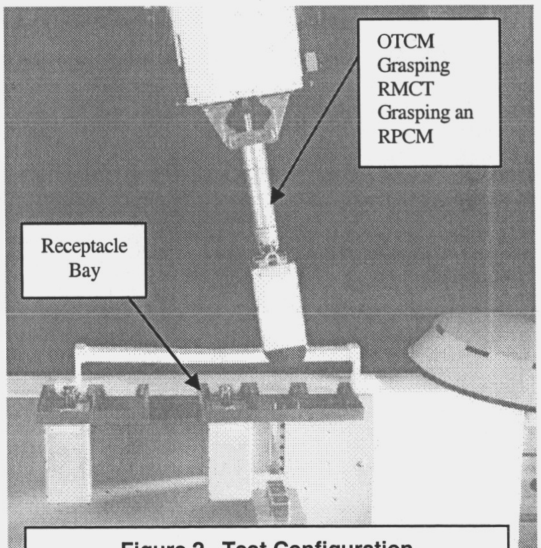

Figure 2. Test Configuration

Procedure

Prior to beginning test execution, each subject completed a training and familiarization session. Each operator then performed each of two tasks, Remote Power Control Module removal and insertion, under three latency conditions, over a period of several test sessions. Baseline data, considered to be comparable to operating the system from the current space-based control station (no time lag), was collected on each subject. Variable latency values (6 and 8 seconds) were used during testing to match the expected conditions if the SPDM was commanded from a ground-based workstation, given recently observed and reported transmission latencies to and