Improving Robotic Operator Performance Using Augmented Reality

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Robotic operations performed in Earth orbit face unique challenges. In the case of the special-purpose dexterous manipulator (SPDM), a two-armed robotic device, operations can last multiple orbital days (figure 1). Because of the dynamic sunlit days and very dark nights on orbit, direct and indirect visibility can be difficult; we therefore developed and tested the use of augmented reality (AR) technology with a ground-based trainer (figure 2) to reduce the negative effects of these conditions.

The most difficult operator task is the alignment of an orbital replacement unit (ORU) attached to the end effector of the SPDM with the point of insertion into the ORU destination location. Alignments are accomplished based on the intrinsic physical features of the tool, payload, and surroundings as viewed through video cameras. On orbit it can take 8 to 10 hours, encompassing multiple days and nights, to complete a planned ORU replacement or maintenance operation. Multiple alignment tasks are interspersed within the same time period.

The purpose of these experiments was to determine whether overlays improve performance in maneuvering an ORU. The experiment was a classic "mixed"-factors design that had one factor (order of presentation of treatments) between subjects and one factor (treatment type – overlay or no overlay) repeated within subjects. Each subject performed a total of eight trials divided into two sets of four trials each. One set was performed without overlays, and the other set was performed with AR graphical overlays. Half of the subjects experienced a set of four trials with overlays followed by a set of four trials without overlays. The balance of the subjects experienced the same sets in reverse order. The need to use certified operators of comparable skill limited the number of subjects to 12. The remaining operators were used for pilot testing to optimize the design of the augmentation, the number of trials, and the design of the dynamic lighting conditions.

All trials involved maneuvering the ORU from a predetermined starting position toward the same receptacle. The same set of four different starting positions was used in the same order for the trial groups under the two treatments. Starting positions for the trials were selected to produce the same minimum time for completion (as determined by the mechanical characteristics of the dexterous manipulator trainer). Objective-dependent measures for this study are related to the ORU position/orientation at the pre-insertion position above the destination receptacle. These four measures included: (1) roll alignment error (deg) about the X axis; (2) composite pitch/yaw alignment error (deg); (3) translation alignment error in the YZ plane (in.); and (4) elapsed time to trial completion (seconds). In addition to the objective data collected, subjective evaluations of experimental treatments and methods were gathered by means of a written questionnaire provided to each subject following completion of the trials. We

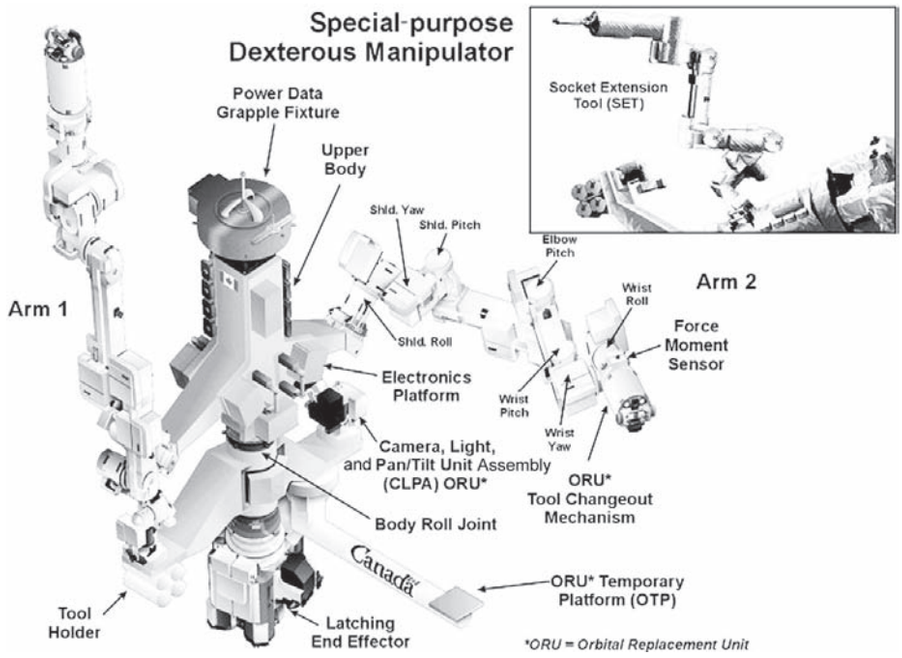

Fig. 1. *Special-purpose dexterous manipulator.*

encouraged these subjects to record any comments regarding the experiment on the questionnaire.

Data analysis included analysis of variance (ANOVA) and post-hoc testing of means with all of the significant dependent variables. Means comparisons were performed using contrasts to circumvent assumptions of homogeneity of variances among sample populations when necessary.

We designed the overlay symbol system to provide the following advantages: (1) alignment of ORU and receptacle within insertion tolerances using a single camera view, even under adverse lighting conditions; (2) "rubber-band" features that prompt appropriate control command motions, even when the destination receptacle is outside the field of view of the camera; and (3) separation of needed translation and rotation control inputs.

Performance on the alignment tasks described above was examined using ANOVA and post-hoc means tests. In comparing errors produced during the trials, large differences in variances were noted between the no-overlay-then-overlay and the overlay-then-no-overlay orders of trial presentations. This was the case in all but the YZ alignment error trials. For this reason, contrast test techniques that are not sensitive to nonhomogenous variances were used for the means comparisons.

Immediately after the subjects finished the trials, they completed a survey of questions about the test. The outcome of the survey clearly indicates that the overlays were helpful. All 12 subjects completely agreed that the overlay information was helpful or useful in performing the ORU alignment operation, and that it did not hinder completion of the ORU alignment.

The results of this experiment indicate that overlays improve performance in maneuvering an ORU in preparation for inserting it into a receptacle. Despite the small number of subjects who were available to participate in the test, three of the four performance metrics show statistically significant improvements in pre-positioning accuracy using overlays. Trial completion time results are slightly less clear-cut, but variability in performance was reduced for all metrics during trials using overlays.

This study illustrates some potential for the application of AR overlays in robotic control systems. With appropriate simulation software, the overlays might provide an advantage in training for robotic applications. A simulation that has the appropriate fidelity and AR overlays to prompt correct actions might provide valuable "refresher" training among infrequent actual robotic tasks during extended Exploration missions.

Fig. 2. *Dexterous manipulator trainer.*

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