TELEOPERATION OF LIFE-SCIENCE EXPERIMENTS WITH TELECOMMUNICATON TIME DELAY

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INTRODUCTION

To reduce the cost and time entailed in astronaut training and experiment execution, Life-Science Glovebox (LSG) experiments in the international space station should be teleoperated directly by scientists on the ground. However, the telecommunication time delay (up to 8 seconds) renders such move-and-wait teleoperation impractical. The objective of this project is to develop a teleoperation system that minimizes the adverse effects of telecommunication time delay and to use this system as a testbed for investigating human factors issues entailed in conducting life-science experiments from the ground.

CURRENT STATUS OF RESEARCH

Methods

The time-delay problem can be mitigated considerably by using the *supervisory control* method, which is essentially independent of the time delay: each task is divided into subtasks, and each subtask is commanded locally by the teleoperator and executed autonomously in a remote site after a single up-link time delay; sensory (primarily visual) feedback from the remote site allows the teleoperator to correct any errors or to proceed to the next subtask.

Results

Our research has been divided into two phases: development of a teleoperation system, and investigation of human factors entailed in controlling such a system. In the first phase we modified SRI's existing telesurgical system, which includes a pair of 6 degree-of-freedom (dof) arms: a local master arm and a remote slave arm. The operator manipulated the local arm to generate subtask commands (mostly joint trajectories) while watching a stereo image of a simulated remote site, and then transmitted these commands to the remote arm, which executed them autonomously after a single time delay. A pair of video cameras were used to visually servo the pose (position and orientation) of the end-effector of the remote arm towards its target and to send visual feedback to the operator for subtask verification. Subtask arm trajectories were executed using Jacobian-based incremental moves. This phase resulted in specifying a set of LSG requirements: (1) the arm should have at least 6 dof, have closed-form inverse kinematics (i.e., joint coordinates as functions of the end-effector pose), be precise, have free access to the entire LSG work space, but need not be identical to the local arm, (2) a stereo pair of video cameras should be inside the LSG and be movable (e.g., by mounting them on a separate manipulator) to have a clear stereo view of the end-effector interacting with objects in the LSG, (3) a small video camera should be on the arm's wrist to facilitate close-up view of object acquisition, (4) a force sensor should be attached to the arm's end-effector to facilitate move-till-touch, move-while-pressing, and other contact movements and to prevent collision damage. Few of these requirements (a 6-dof arm and stereo cameras) were met in our physical remote site.

In the second phase, investigation of human factors, we are focusing on the local site, where the operator controls the LSG experiments. We have replaced the physical implementation of the remote site with a virtual one in which all the LSG requirements can be met and different levels of random errors in subtask execution can be simulated. We have augmented our local site, which currently includes: (1) the local (master) arm for generating arm trajectories, (2) a stereo display of a virtual remote site, including arm motions generated by the local arm, (3) voice commands, replacing some of the keyboard commands, (4) use of a cursor to designate target objects or areas, (5) simulation of contact between two objects, and (6) graphics and text representing force feedback to the operator. A human operator will use these facilities to control each subtask in 5 steps: (1) programming—generating subtask commands, including arm trajectories, (2) review—verifying the programming step, (3) transmission—sending the commands to the remote site via a time delayed link, (4) execution—executing the commands upon arrival at the remote site, and (5) execution feedback—reviewing sensory (primarily video) feedback of subtask execution, including simulated errors.

Issues

Human factors issues to be addressed in the second phase of our research include: (1) effectiveness of subtask-programming tradeoffs, primarily manual vs. automated programming techniques but also keyboard vs. voice command, (2) alternatives for representation of sensory feedback of subtask execution from the remote site, and (3) operator programming-performance measures, including time and accuracy of moving the local arm, overall programming time, number and severity of programming errors, and success rate.

Conclusion

We have developed a remote robotic site with stereo visual servoing capabilities, using the Jacobian formulation to move the robotic arm incrementally towards its target, and determined a set of LSG requirements regarding its arm, video cameras, and force sensing. We have also developed a local site for the operator, including a programming arm, a stereo display of a virtual LSG, voice commands, cursor target designation, and force-feedback representation. We are designing experiments for addressing human factors issues, including programming automation, execution feedback, and operator performance.

FUTURE PLANS

We will investigate the efficiency of our supervisory control system by testing the performance of a number of subjects as they program life-science experiment subtasks and correct any execution errors based on sensory feedback from a virtual remote site.

INDEX TERMS
Life-science glovebox, life-science experiments, remote manipulation, time-delayed teleoperation, supervisory control, visual servoing, virtual robot, human factors, sensory feedback, subtask programming, robot-programming automation.