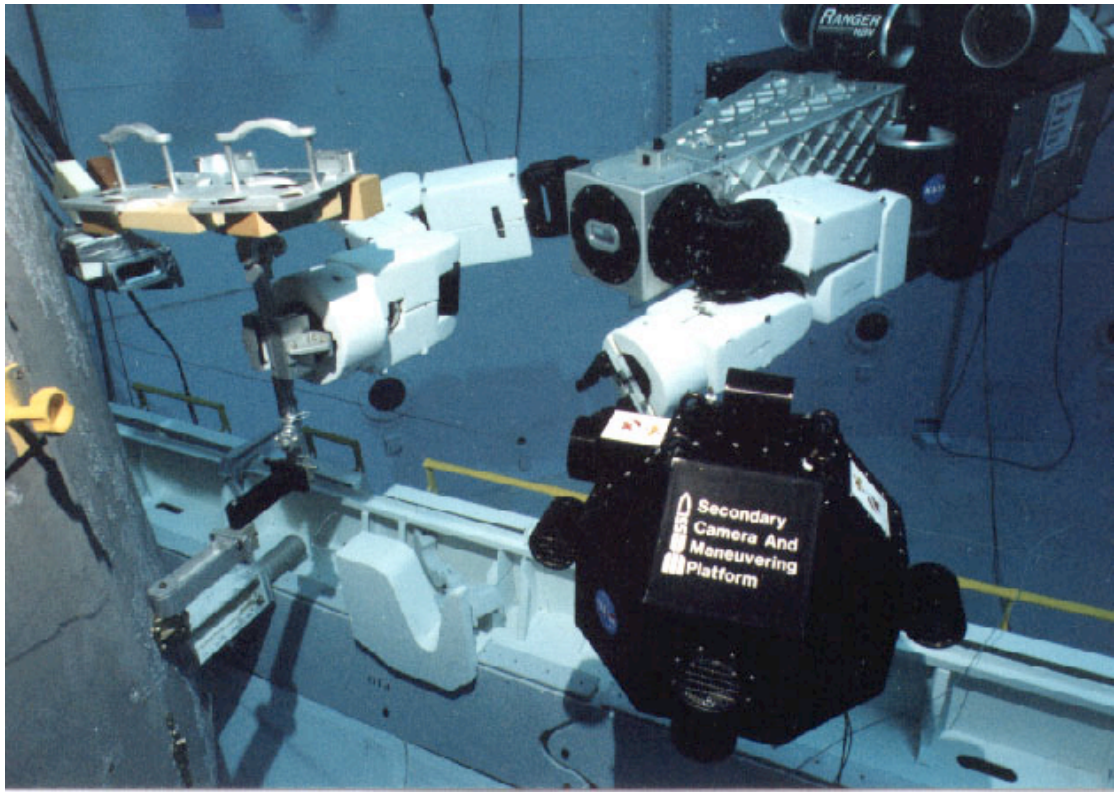
ICRA 2002 - WAI7: Telerobotics II



"Effects of Time Delay on Telerobotic Control of Neutral Buoyancy Vehicles"

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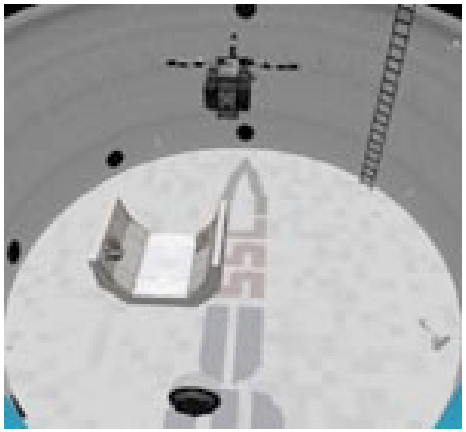
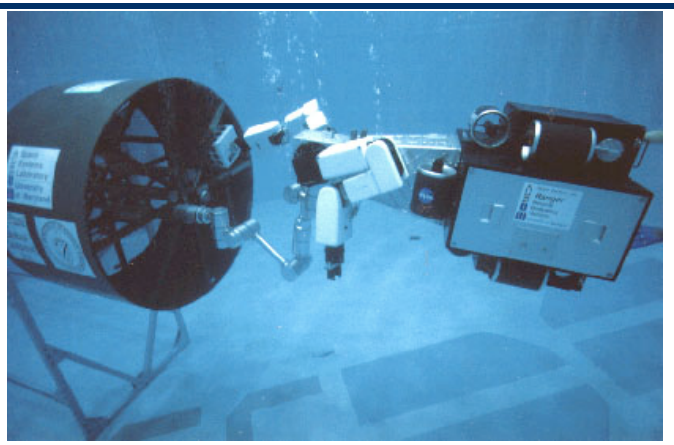
Outline

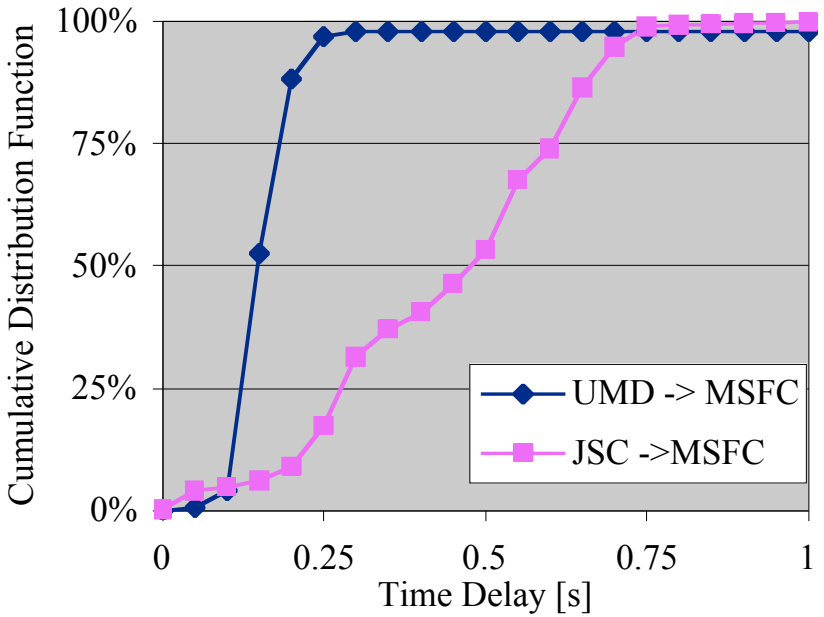
- Describe the robotic vehicles
  - Supplementary Camera and Maneuvering Platform (SCAMP)
  - Ranger Telerobot
- Summarize several time delay experiences
  - SCAMP operation during variable time delay
  - SCAMP free flight experiment with time delay
  - Ranger maintenance task under time delay
  - Simulation of Ranger performing a peg and hole task
- Direction of Future Work

Mobility and Manipulation

- The Space Systems Laboratory (SSL) has a 25-foot deep, 50-foot diameter tank to simulate microgravity environments.
- The Supplementary Camera and Maneuvering Platform (SCAMP) can be flown to any location to provide an additional camera view.
  - 6 degree of freedom (DOF) free floating camera platform using 6 thrusters for mobility, and an internal pendulum to control pitch and stabilize the camera.
- The Ranger Neutral Buoyancy Vehicle, a four-armed telerobot, was designed to perform on-orbit maintenance tasks.
  - Two 7 DOF dexterous arms
  - 6 DOF grappling arm to position Ranger about the tasksite
  - 6 DOF video manipulator provides a controllable stereo view
- Operators use a desktop computer (Macintosh or SGI), a 2 x 3 DOF hand controllers, and several video monitors to control the vehicles.

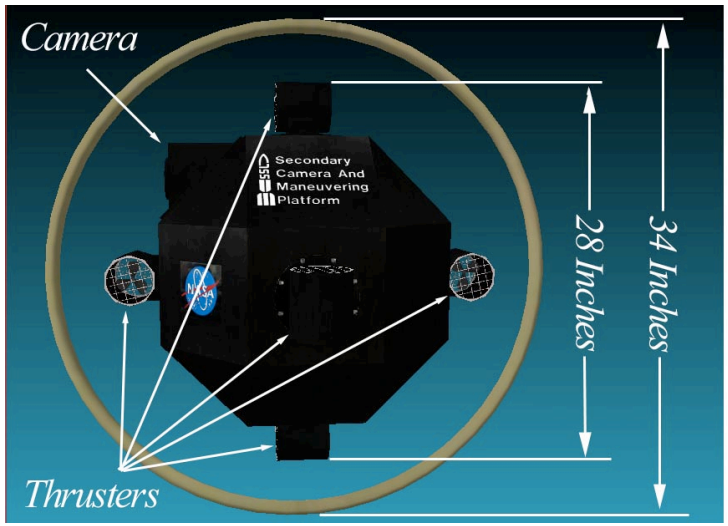
Variable Time Delay

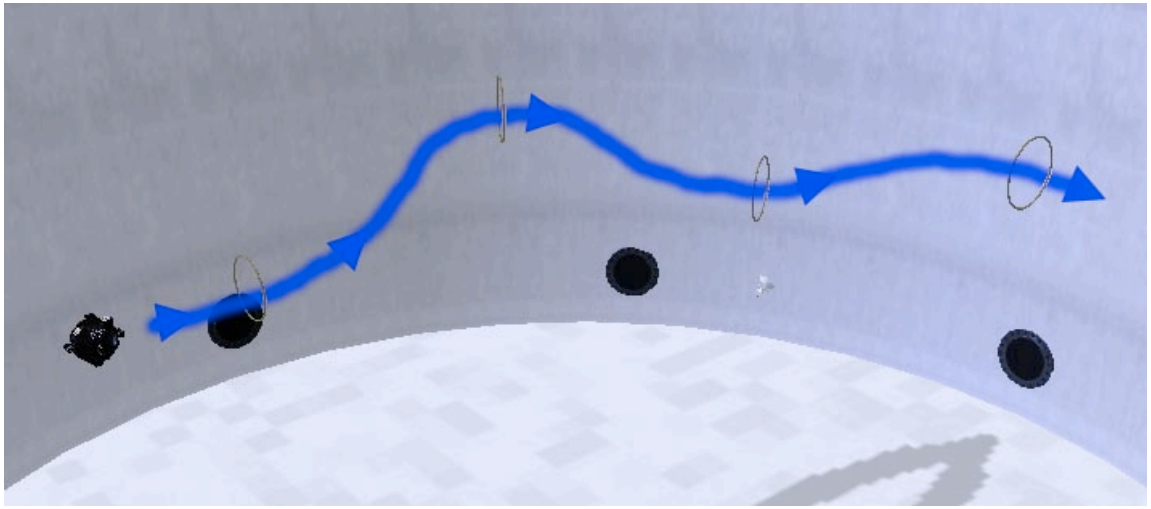


- On many occasions SCAMP has been controlled over long distances.
- SCAMP located at Marshall Space Flight Center (MSFC), Alabama, was successfully controlled from the following locations:
  - A high school in Florida
  - At the University of Maryland (UMD)
  - From the Johnson Space Center (JSC) in Texas

- In all cases, operators worked from satellite video and had around 250 ms delay.
- Controlling from UMD, 97% of the delay was less than 300 ms
  - Every few minutes a long delay from 1.5 - 6 seconds would occur.
  - These long dropouts would appear as if the vehicle stop functioning, frustrating the operators.
- Controlling from JSC, time delay was more variable, but had fewer dropouts.
- Operator comments were less concerned about the rare dropouts, but wanted to eliminate the variability of time delay, even at the expense of increasing average time delay.

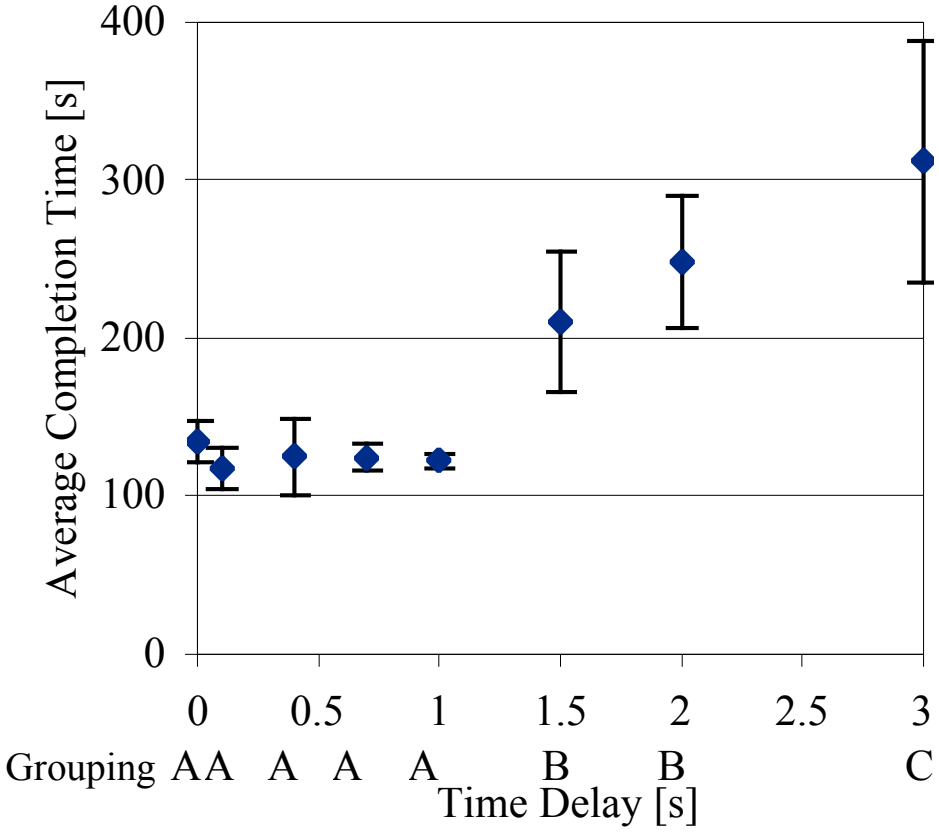
Free Flight Control with Time Delay





- **The Task**
  - **Successfully navigate SCAMP through a course of suspended hoops within the underwater tank.**
  - **Operators sent translational and yaw commands under different fixed time delays (0, 0.1, 0.4, 0.7, 1, 1.5, 2, 3 seconds).**
  - **Pitch and roll commands were blocked to simplify the operator workload.**
  - **The operator was provided with three camera views: two fixed camera views showing the course, and a third camera view from onboard SCAMP.**
  - **Two expert operators performed two trials for each time delay treatment.**

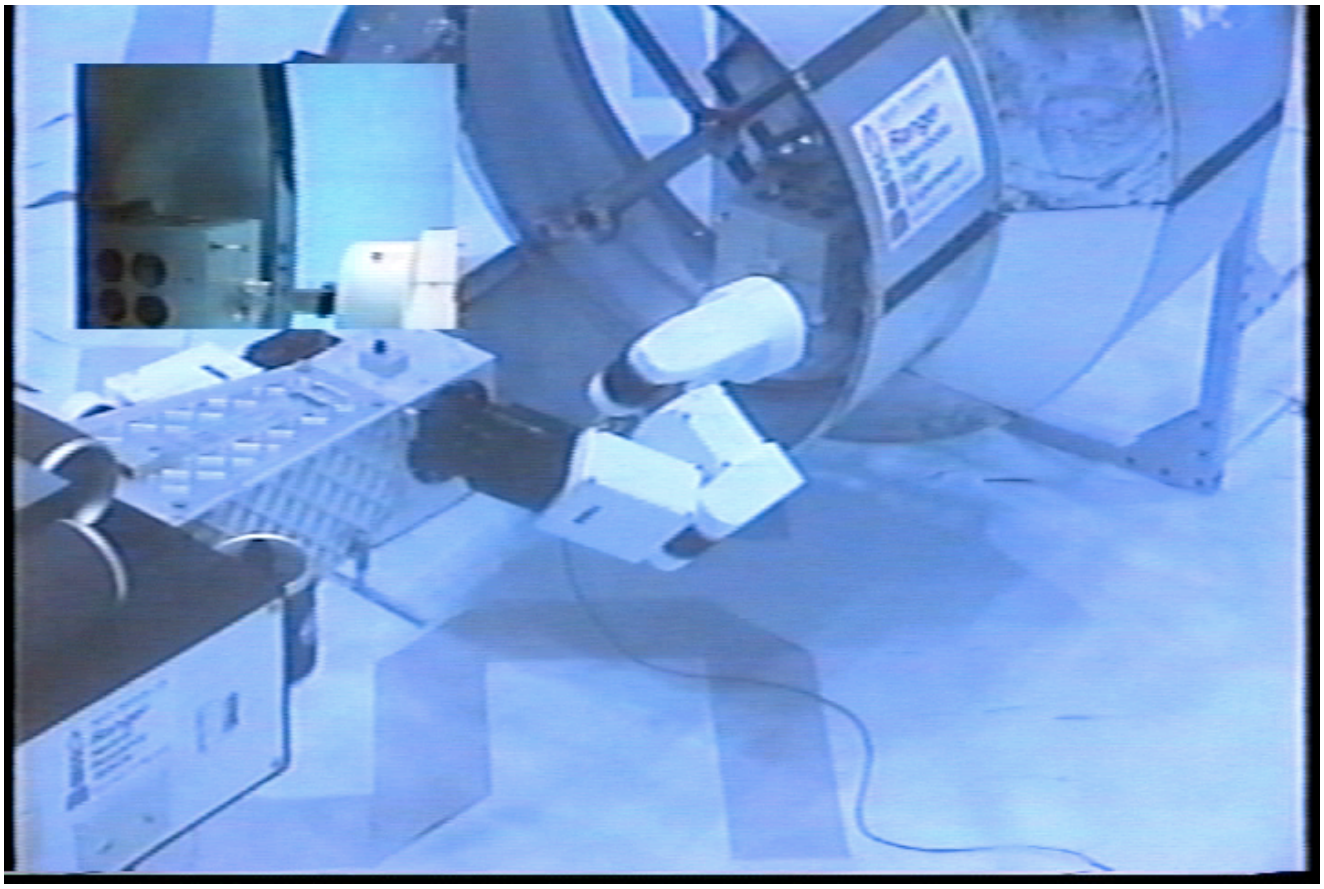
Time Delay Effect On Free Flying



- **Analysis of variance (ANOVA) used to show time delay had a significant effect on completion time.**
- **Each grouping was statistically significant to each other at the 0.05 level.**
- **No time delay effect found below 1 second**
  - **Difficulty controlling SCAMP in open loop**
  - **With no input, SCAMP would continue to drift**
- **Subjects reported increased task difficulty and used a move and wait strategy with delays over 1 second.**

- **Tasks were performed in order of increasing time delay, therefore the higher time delay treatments had the benefit of learning.**

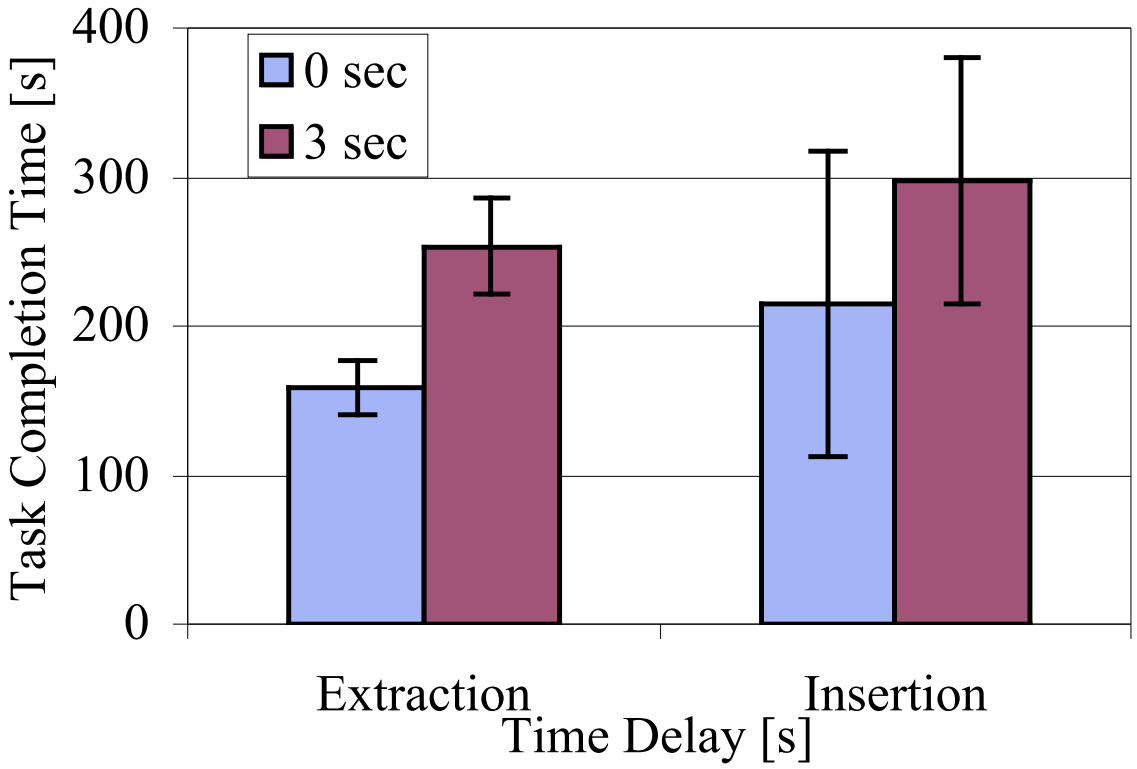
Manipulation Task - Replacement Box Changeout



- Ranger was used to changeout a neutral buoyancy version of a space orbital replacement unit (ORU) fluids box.
- An operator controlled the manipulator to:
  - grab a H-Handle fixture
  - actuate a tool drive to release the ORU
  - Extract the ORU from the receptacle.
  - Reinstall the ORU

- Four camera views were provided to the operator to perform the task:
  - Two fixed cameras providing an overview used for coarse arm motions
  - A close up view of the ORU receptacle used for fine maneuvering
  - SCAMP's free flying view, which would typically follow the manipulator's tool tip

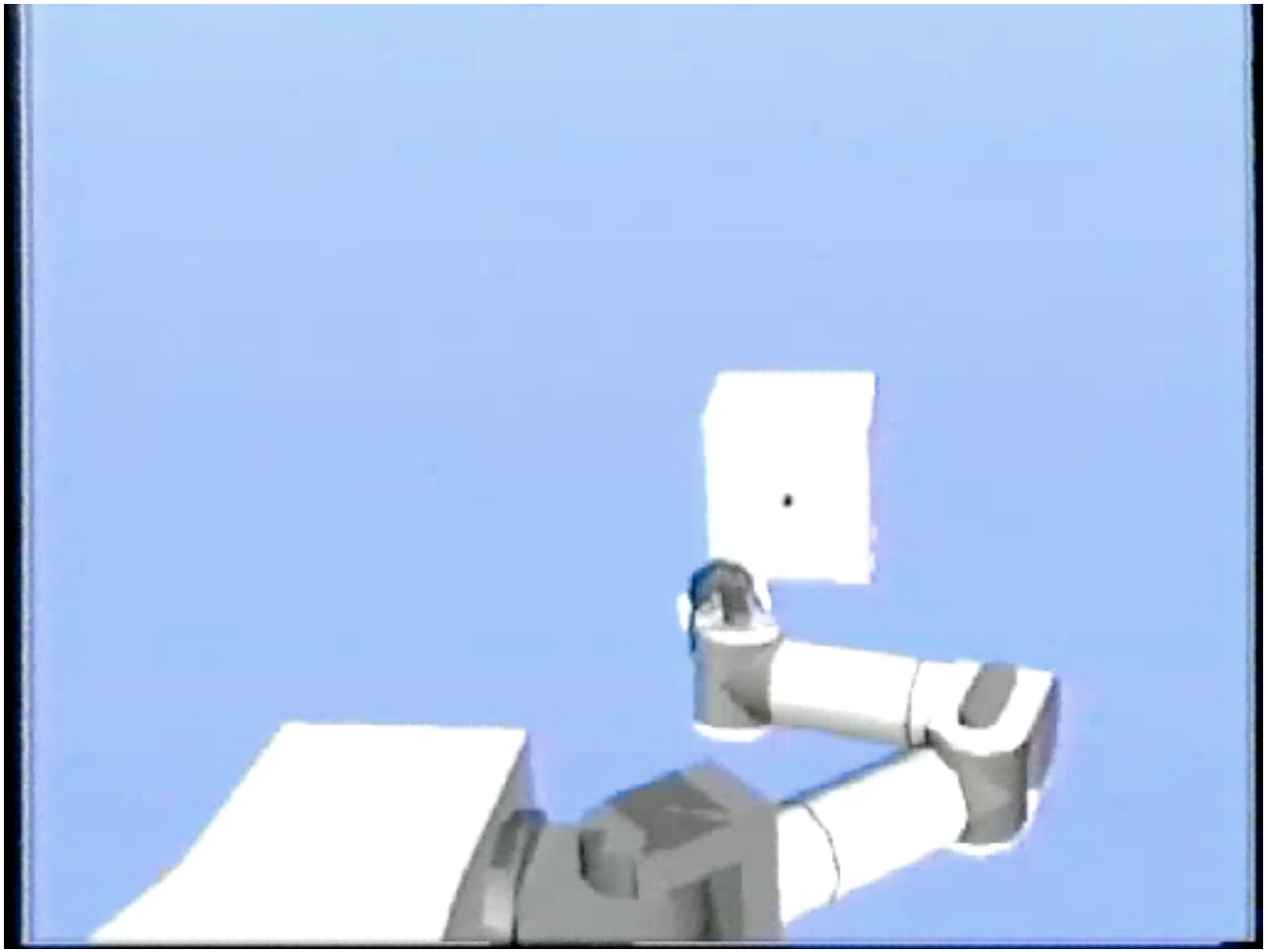
Manipulation Task with Time Delay Results



- **Two experienced operators completed about 3 insertion and extraction tasks for each time delay (0 and 3 seconds).**

- **A generalized linear model ANOVA showed a statistical significant effect, at the 0.01 level, on completion time due to time delay.**
- **The insertion task took significantly longer, at the 0.05 level, due to the increase difficulty inserting the ORU into the receptacle.**
- **Interaction effect between subjects and task.**

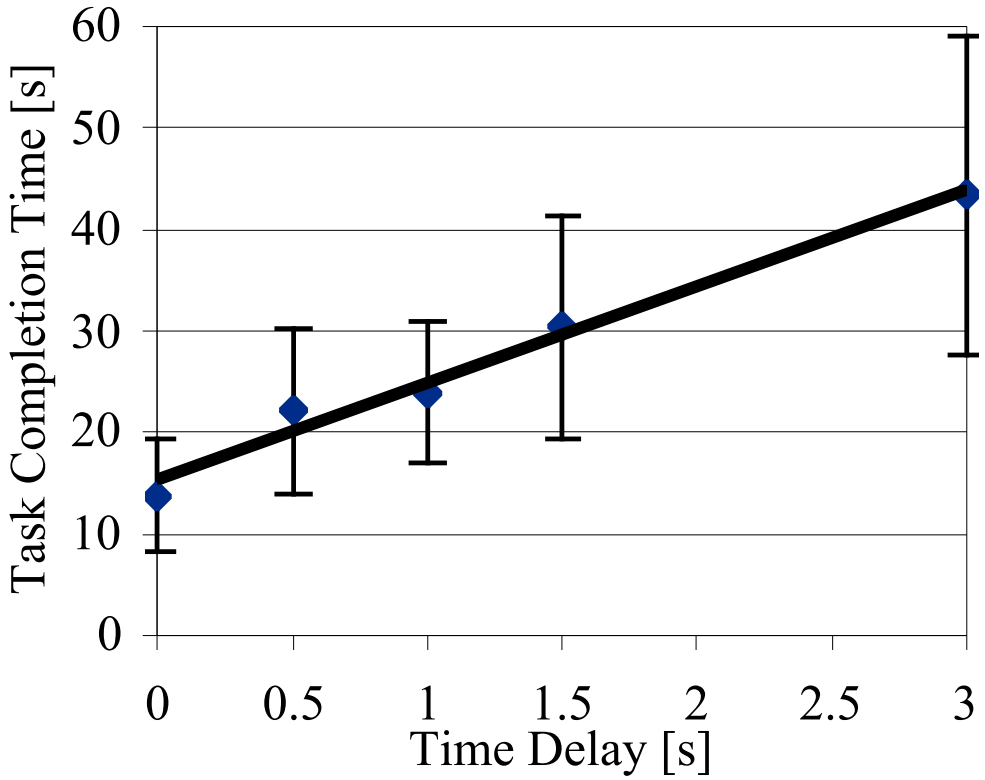
Peg and Hole Simulation



- Five subjects controlled Ranger's manipulator, within a graphical simulation, to insert its bare bolt tool into a hole.
- Subjects used the same hand controllers and control station software that is used to command the actual robot.
- About 10 hours of training was provided to each subject before testing.

- Each subject performed 32 trials for each of the 7 time delay treatments (0, 0.5, 1, 1.5, 2, 2.5, 3 seconds).
- The subjects could switch between three fixed views: an overall view and two orthogonal close up views of the hole for fine positioning.

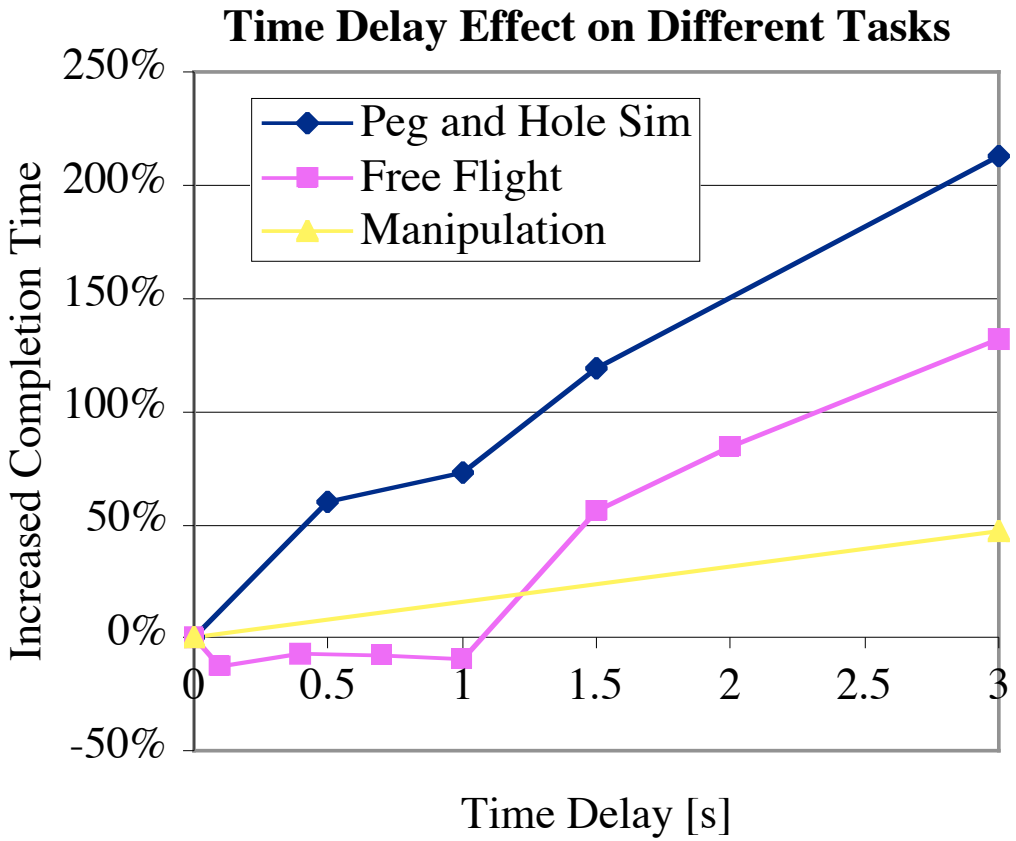
Simulation Results



- **Each treatment of time delay was significantly different, at the 0.01 level.**
- **This supported Held (1966) and Warrick (1969), indicating even small time delays could influence performance.**
- **Also a linear trend between time delay and completion time can be established.**

- **Time delay had a larger effect in simulation results than ORU test.**
  - **ORU test had non positioning subtasks (activating tool drive) that were less susceptible to time delay.**
  - **Simulation using Peg and hole task was easier (with simplified friction model).**
  - **Simulation results had very little learning effect, due to many hours of training.**

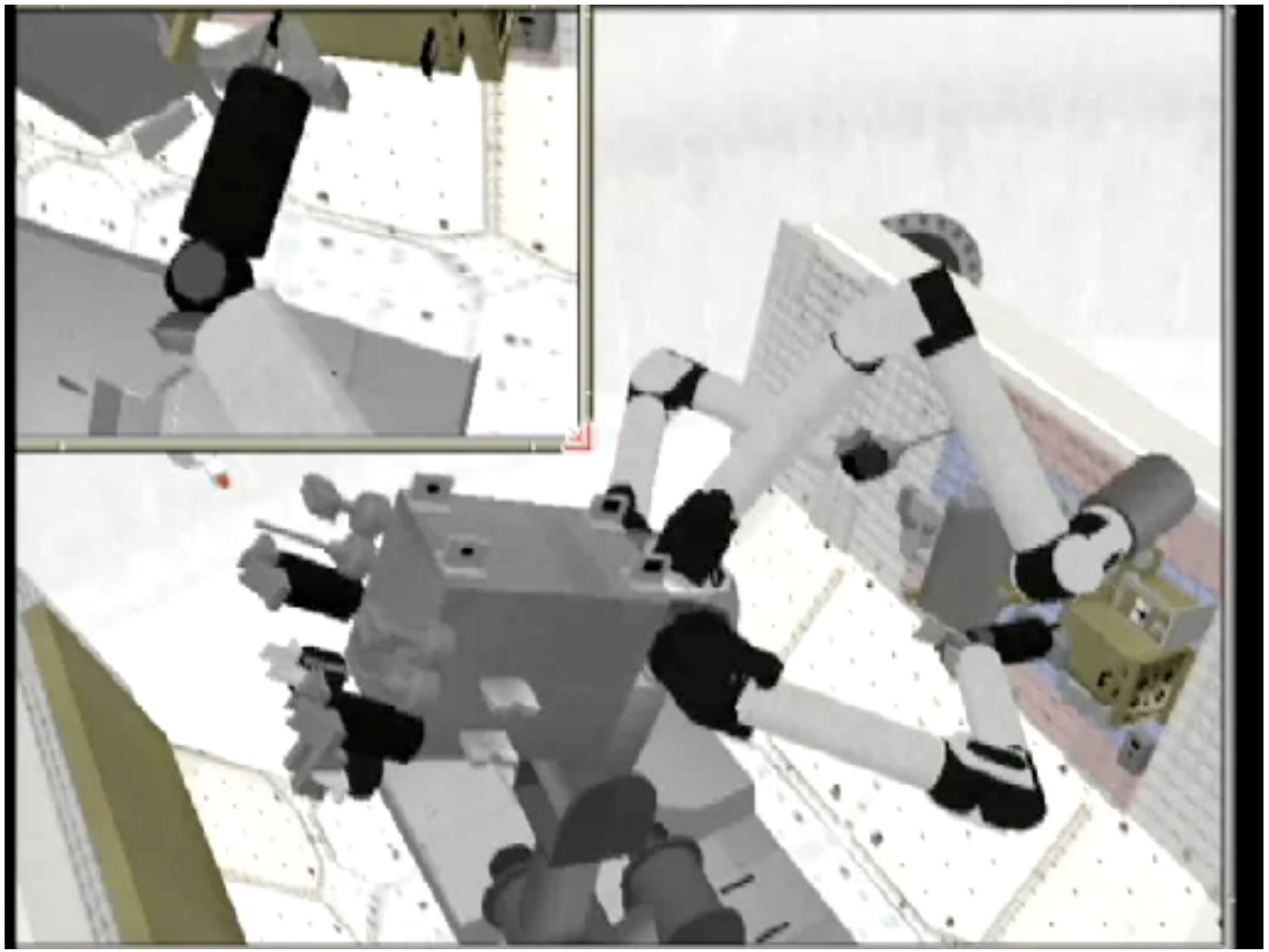
Conclusions and Future Work



- **A 3 second delay caused the completion time to increase by varying amounts**
  - **132% increase in a free-flight maneuver task**
  - **47% increase in a manipulator maintenance task**
  - **213% increase in a simulated manipulator positioning task**

- **Future work**
  - **Using SCAMP simulation to develop autonomous algorithms and predictive displays for teleoperation.**
  - **Improve Ranger's graphical simulation to test more realistic tasks**
  - **Use Ranger itself to investigate time delay effects on complex tasks**

Simulation Future Work



- **Improve the graphical simulation with better interaction dynamics**
- **Test time delay with multiple arm operations**

Ranger II Operations

- Use next generation Ranger telerobot in more complicated tasks.
- Include time delay with multiple arm operations.