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TELEROBOTIC TRUSS ASSEMBLY

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SUMMARY

The Structures and Mechanics Division (SMD) at Johnson Space Center telerobotically assembled the ACCESS truss. The SMD wanted to assemble hardware that was designed for and been assembled by EVA astronauts. Many problems were identified. Most belong in one of three main categories.

1. Truss Hardware

2. Manipulator

3. Vision

The tight alignment constraints of the ACCESS hardware made telerobotic assembly difficult. A wider alignment envelope and a compliant end effector would have reduced this problem.

The manipulator used had no linear motion capability, but many of the assembly operations required straight line motion. The manipulator was attached to a motion table in order to provide the X, Y, and Z translations needed. A programmable robot with linear translation capability would have eliminated the need for the motion table and streamlined the assembly.

Poor depth perception was a major problem. Shaded paint schemes and alignment lines were helpful in reducing this problem. The four cameras used worked well for only some operations. We were unable to identify individual camera locations that worked well for all of the assembly steps. More cameras or movable cameras would have simplified some operations.

The audio feedback system was useful. Often the first indication that a strut made contact with a node was an audio signal rather than a video one. Also, if a strut inadvertently hit something in the workcell, the operator was alerted.

Many of the lessons learned will be used to design robot friendly hardware and to define tasks suitable for a space telerobot.

INTRODUCTION

During the summer of 1987, the Structures and Mechanics Division (SMD) at NASA's Johnson Space Center conducted telerobotic truss assembly tests. These tests had four objectives.

1. Identify problems with the telerobotic assembly of hardware designed for EVA astronauts.

2. Evaluate an audio feedback system.

3. Demonstrate simplified remote manipulator system (RMS) dynamics.*

4. Establish an experience base for the development of robot friendly hardware/tasks.

The Assembly Concept for Construction of Erectable Space Structures (ACCESS) hardware was selected for these tests. The ACCESS truss has been tested in space and the Weightless Environment Training Facility (WETF) and the struts and nodes were small enough for the Deep Ocean Engineering (DOE) manipulator to handle.

The problems encountered and their solutions as well as our evaluation of the audio feedback system are discussed.

CONCLUSION

Assembling the ACCESS hardware showed how difficult it is for a telerobot to handle hardware designed for astronauts. In order for robots to efficiently help build and maintain Space Station, the hardware must be designed to be robot friendly. Shaded paint schemes and alignment lines partially made up for the loss of depth perception caused by the video system. Less rigid alignment constraints and compliant end effectors will reduce misalignment problems. Audio feedback increased operator awareness and should be included in future telerobotic experiments. The experience gained from this experiment

*This phase of the test was not completed in time for this publication.

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will help in the design of robot friendly hardware and will help with the identification, testing and implementation of tasks suitable for a space telerobot.

DISCUSSION

For this test program there were seven major pieces of hardware. Figure 1 shows the layout of the hardware described below.

Hardware Description

1. 6-DOF Table

The six degree of freedom (6-DOF) table consists of a triangular shaped active table and six linear hydraulic actuators. The actuators provide the 6-DOF table with X, Y, and Z translation, Roll, Pitch, and Yaw. For this test, Roll, Pitch, and Yaw were not used.

2. DOE Arm

The Deep Ocean Engineering (DOE) arm is an electrohydraulic manipulator arm that was used to telerobotically assemble the ACCESS nodes and struts into a truss.

3. Linear Translation/Load Cell Table

The Linear Translation/Load Cell Table (LTLCT) was attached to the 6-DOF table through a set of load cells. The load cells will send load data to the computer for force and moment resolution during the dynamic simulation demonstration. The LTLCT supported the DOE arm and provided additional X-axis translation.

4. Mast

The mast was a mounting fixture to which the ACCESS nodes and struts were attached during the truss assembly.

5. Strong Back

The strong back is a fixed structure to which the mast and node/strut rack were mounted.

6. Node/Strut Rack

The node/strut rack stored the ACCESS nodes and struts before they were grasped by the DOE arm and assembled into a truss.

7. Video System

Television cameras were used by the teleoperator to monitor the truss assembly. They were mounted 1) to the left of the DOE arm, 2) on the ground below the mast, 3) behind the DOE arm on the 6-DOF table, and 4) on the DOE arm. Cameras 1, 2, and 3 had pan, tilt, and zoom capabilities. Camera 4 had a fixed view of the gripper.

Assembly Sequence

The top three nodes were manually mounted to the mast before beginning the demonstration just as they were for the WETF tests. The first step in the assembly process was to remove the fourth node from the node/strut rack and place it on the mast. This step was repeated until all six nodes were in place. Each of the 12 struts was connected using the following sequence. One strut collar was preset to the automatic position and the other collar was preset to the manual position. The strut was positioned between two nodes and linearly driven into place using the LTLCT. The automatic collar closed locking the strut onto one node. The DOE arm was then positioned near the manual collar where, using a friction pad, the collar was rotated to secure that end of the strut to the other node. The bottom three horizontal struts were connected, one at a time, to the nodes (refer to Figure 2). The top three horizontal struts were connected next, then the three vertical struts, and finally the three diagonal struts.

The initial assembly time was four hours for one bay. Before the second assembly several changes were made to the workcell shown in Figure 1. Camera 1 was moved 10 feet in the -X direction and four feet in -Y. This location provided a better view from which to see strut to node alignment. Camera 2 was repositioned four feet in the -X direction and one foot in -Y. Moving four feet in the -X direction made strut to node alignment easier to determine for the horizontal and diagonal struts. Moving one foot in the -Y direction made vertical strut insertions easier to see. The node/strut rack was rotated 90^{o}. This change decreased the wrist roll actions by nearly one half. A combination of these modifications and an increase in operator proficiency reduced the assembly time to two hours.

One of the major time consumers during the assembly was the 6-DOF table. Vibrations from the 6-DOF table's hydraulic pumps caused the DOE arm to vibrate at approximately 5 Hz. This vibration made the assembly process very difficult. Also, the 6-DOF table moves very slowly and approximately one half of the two hour assembly time was needed to move the DOE arm from the node/strut rack to a position near the mast where the insertion action could begin.

Low pass filters were put into the 6-DOF tables control system to eliminate the vibrations. The smooth operation made strut insertions easier and speeded up the movement of the table. This did not decrease the assembly time because the automatic collars would sometimes not close. Apparently the vibrations helped overcome some of the binding between the struts and the nodes which helped close the collars.

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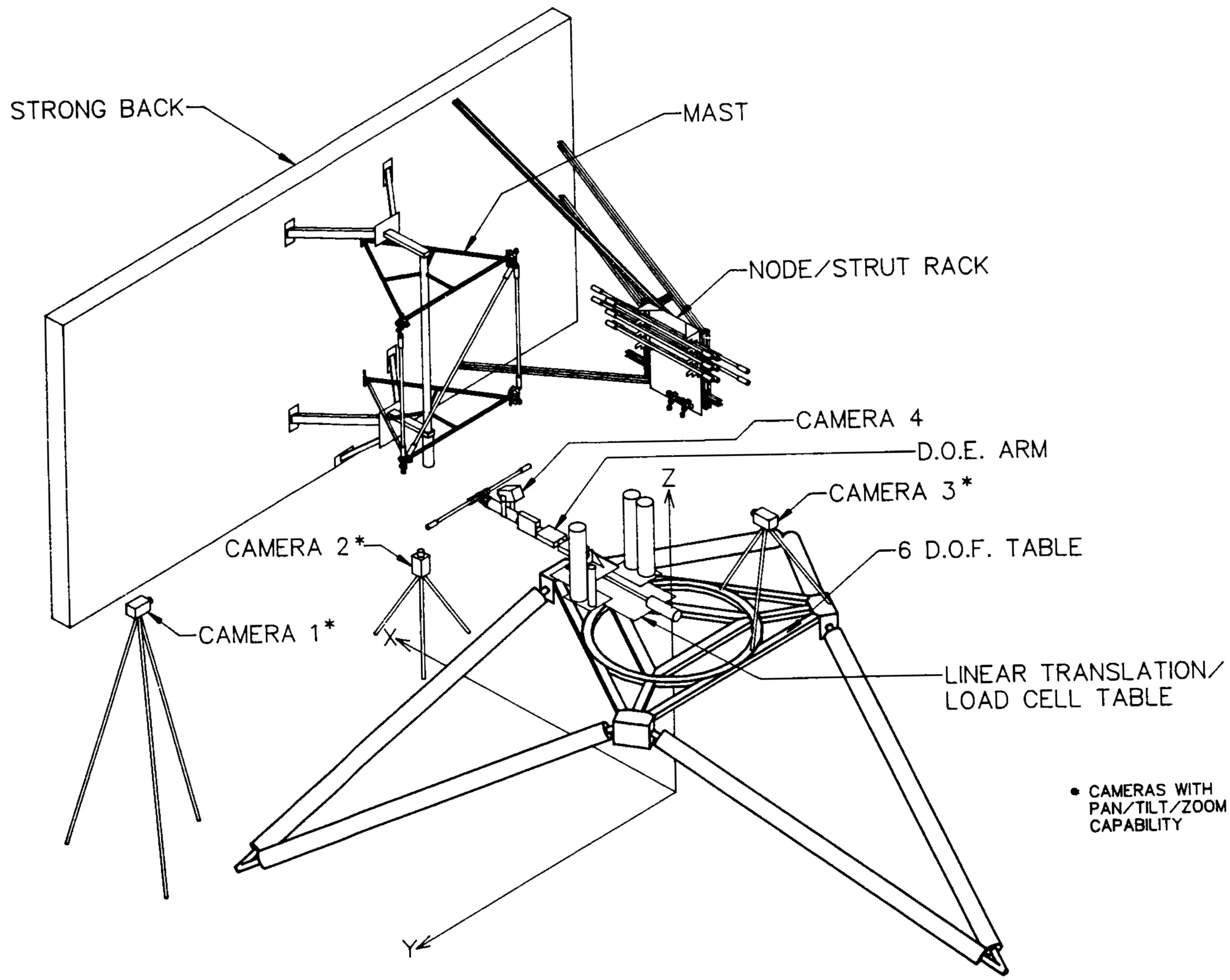

FIGURE 1. ATAD LAYOUT

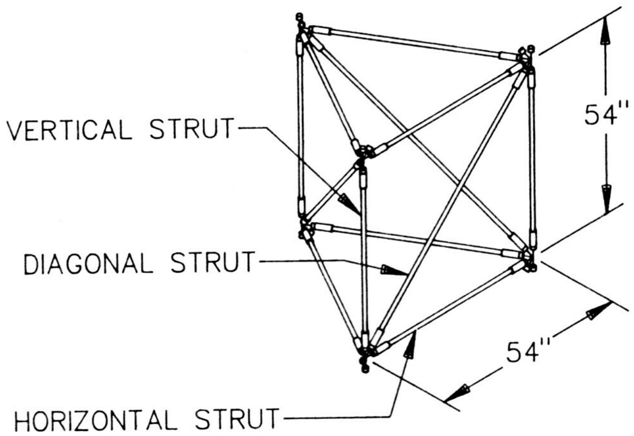

FIGURE 2. ACCESS TRUSS

Problems and Solutions

The problems we had belong in one of three main groups.

1. Truss Hardware

The ACCESS hardware has tight alignment constraints. Figure 3 shows a strut partially inserted into a node. If these two components are not perfectly aligned the strut cannot be locked into place. Larger alignment envelopes, guides, and a compliant end effector would have reduced misalignment problems.

2. Manipulator

The DOE manipulator has:

a. No linear motion.

b. No automation.

c. No joint position indicator.

Most of the operations during this test were completed using the linear motion provided by the 6-DOF table or the LTLCT. The movement of the 6-DOF table was very slow. A robot with linear motion would have eliminated

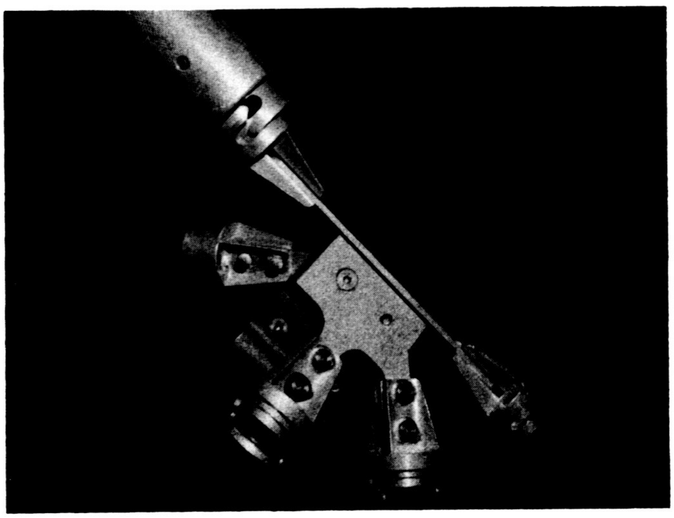

FIGURE 3. Strut Partially Inserted Into Node

the need for the 6-DOF table, and decreased the assembly time. A semiautomated operation would have been more efficient than a fully manual one. Preprogrammed manipulator positions would have been helpful, but because of variations in the ACCESS hardware and mounting fixture positions the actual strut/node connection was necessarily teleoperated. Many alignment problems were partially caused by an inability to put the DOE arm's joints into exact, known positions. Joint position indicators would have lessened the alignment problems.

3. Vision

Normal video equipment greatly reduces depth perception. Stereo vision may help with this problem. Shaded paint and alignment lines on the truss hardware partially compensated for the lack of depth perception.

Some of the camera positions used were very good for some operations and very poor for others. Adjustable (X, Y, Z) camera positions, or more cameras would have decreased the assembly time. Camera #4 did not have pan, tilt or zoom capabilities. These features would have been useful.

The ACCESS hardware and most of the fixtures in the workcell were bare aluminum. The reflected light caused glare which washed out some detail. Painting some of the fixtures flat black greatly reduced this problem. Anti-glare paint should be used for everything in the workcell.

Audio Feedback

The DOE arm has an accelerometer in its forearm that sends signals through a control unit to a headset worn by the operator. During this test the linear drive motor, collars closing, and node/strut contact were heard. The sounds heard through the headset were very similar to the actual sounds. The first two types of sounds made the operator feel closer to the workcell. The node/strut contact noise was very useful. It partially made up for the lack of depth perception. Often the contact was detected through audio feedback before it was detected visually.

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