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DESIGN GUIDELINES FOR REMOTELY MAINTAINABLE EQUIPMENT

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1. INTRODUCTION

The quantity and complexity of on-orbit assets will increase significantly over the next decade. Maintaining and servicing these costly assets represent a difficult challenge. Three general methods are proposed to maintain equipment while it is still in orbit. First, an extravehicular activity (EVA) crew can perform the task in an unpressurized maintenance area outside any space vehicle. Second, intravehicular activity (IVA) crew can perform the maintenance in a shirt sleeve environment, perhaps at a special maintenance work station in a space vehicle. Third, a telerobotic manipulator can perform the maintenance in an unpressurized maintenance area at a distance from the crew (who may be EVA, IVA, or on the ground). However, crew EVA may not always be possible; the crew may have other demands on their time that take precedence. In addition, the orbit of the tasks themselves may be impossible for crew entry. Also crew IVA may not always be possible as an option for equipment maintenance. For example, the equipment may be too large to fit through the vehicle airlock. Therefore, in some circumstances, the third option, telerobotic manipulation, may be the only feasible option. Telerobotic manipulation has, therefore, an important role for on-orbit maintenance. It is not only used for the reasons outlined above, but used also in some cases, that may act as backup to the EVA crew in an orbit which they can reach.

If equipment is to be serviced by a telerobotic manipulator, then the orbital replacement units (ORU's), which make up this equipment, must have a compatible interface with the telerobot. If EVA crew maintain the same piece of equipment at times and changeout the same ORU's, then the ORU's must also have a compatible interface with crew EVA suit limitations and capabilities. Rockwell is very aware of the necessity for interface compatibility between ORU's and their mode of maintenance (telerobot and/or EVA crew). The Space Transportation Systems Division (STSD) has, therefore, a continuing project to develop guidelines for ORU's to ensure their interface compatibility (Figure 1). This paper describes the work performed so far onORU/telerobot interface compatibility.

STSD's work is progressing in three phases: telerobotic definition, ORU interface guidelines, and feasibility demonstration. Each phase is discussed below followed by a summary of the benefits resulting from this approach.

2. TELEROBOTIC DEFINITION

Rockwell STSD has already completed a project to define and describe a telerobotic manipulator arm, (the Extravehicular Teleoperator Assist Robot [ETAR]), capable of changing out common ORU's on present and future on-orbit equipment. The force reflecting arm (Figure 2), which features 7-degrees of freedom, was described in detail at the 1987 SOAR Conference. (Reference 1) This effort led to the remaining two phases of work.

3. ORU INTERFACE GUIDELINES

ORU interface guidelines were generated in a three-stage process: ORU identification, interface data base and requirements generation, and guidelines identification.

3.1 ORU Identification

The goal of this step was to identify specific ORU's on present and future planned satellites, manned space vehicles, and other on-orbit equipment. For example, 27 representative ORU's on satellites and scientific experiments were identified and analyzed. (Reference 2) In addition, over 1,000 Space Station ORU's were identified during Rockwell's Phase B Space Station Activity. These ORU's were classified into nine major types shown in Figure 3.

3.2 Interface Data Base and Requirements

The goal of this step was to compile a detailed data base of information on the ORU's identified in Step 3.1. Emphasis was placed on information that would impact the ORU's interface with a telerobotic manipulator and with EVA compatibility as a backup.

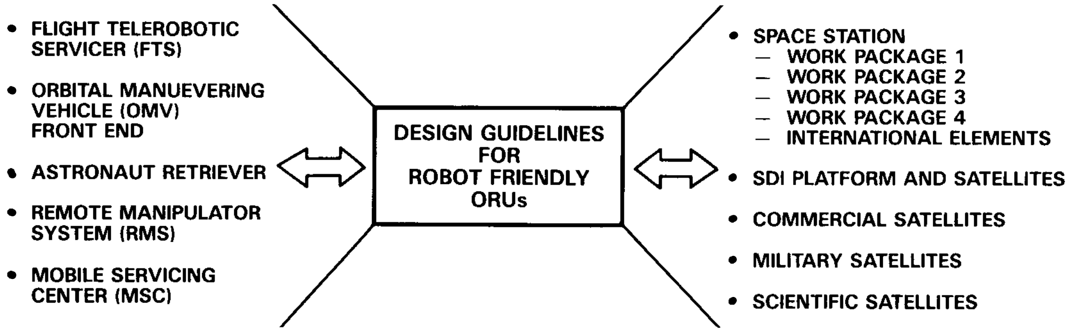

Figure 1. Design Guidelines Will Ensure Compatibility Between ORU's and the Robot

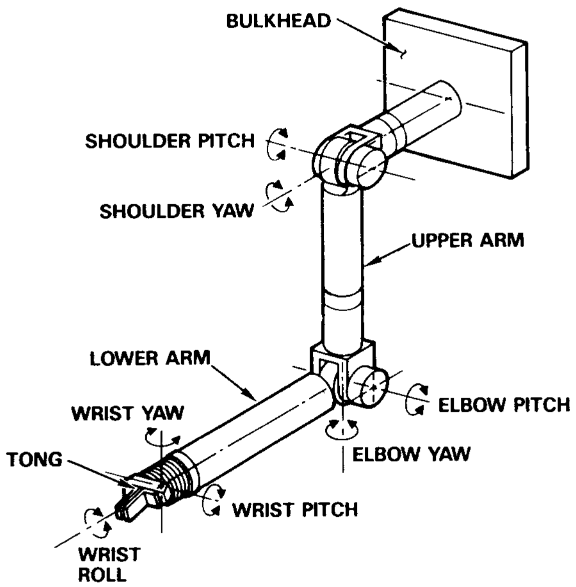

Figure 2. ETAR Arm Concept

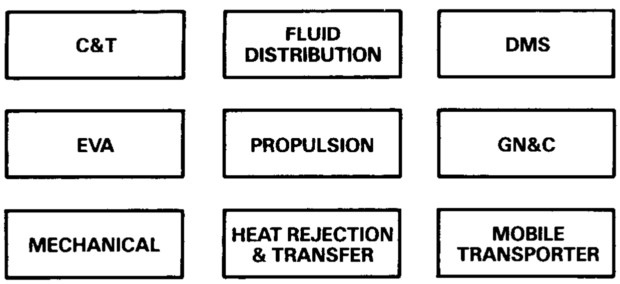

Figure 3. Identified ORU Types

We relied on a wide variety of sources for information including NASA engineers. Other data were obtained from two former astronauts who had performed EVA maintenance tasks, from vendors of commercially available space rated fasteners and connectors, and from other industries that use modular maintenance concepts e.g., commercial airlines. In addition, Rockwell ORU design engineers were asked to fill out an ORU Interface Requirements Questionnaire giving as specific information as they could on the ORU's mass, volume, shape, dynamics and kinematics of the changeout, cold plate contact, and so on. While the information was of necessity at a high-level and preliminary, it was very useful in allowing us to classify the large numbers of ORU's in terms of their requirements for interface with a teleoperated manipulator. An example of a possible classification scheme is shown in Table 1.

3.3 Guideline Identification

By using the data base generated in Step 3.2, we then identified specific guidelines for the various classification of ORU interfaces. The guidelines met the requirements for compatibility with a telerobotic manipulator with EVA compatibility as a backup. For example, a small number of fluid connectors, electric connectors, and mechanical fasteners were selected as having the potential to provide compatible interface with over 90 percent of the ORU's in our data base. Figure 4 shows an example of a candidate mechanical fastener, the over center clamp.

Table 1. Examples of Possible Interface Requirements

Mechanical fasteners
- High load bearing
- Low load bearing
- Special tools needed

Fluid Connectors
- Line Size
  - Type of fluid
- Pressure

Electronic Connector
- Power
  - Voltage
- Data Rate
- Pin Sizes

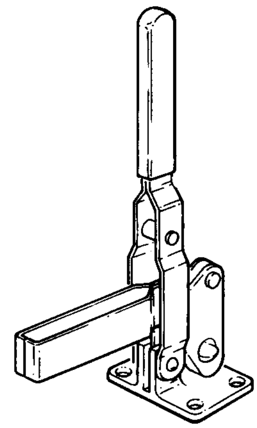

Figure 4. Over Center Clamp

4. FEASIBILITY DEMONSTRATION

To demonstrate the feasibility of the proposed guidelines, several ORU changeout demonstrations were conducted in the Rockwell Automation and Robotics Facility (Figure 5).

The facility contains an electromechanical teleoperated manipulator with two 7-degrees of freedom slave arms driven by a replica master. The facility also contains a four-degrees of freedom transporter to move the slave through its work place. Cameras are onboard the slave and also fixed at other locations in the work place.

Task boards contain mockups of a large variety of ORU's. A mockup of a standard data processor black box ORU was built in accordance with design and performance specifications of the Space Station data processing system. It was compatible with both EVA and telerobotics ORU design standards (Figure 6). The standard data processor (SDP) slides in position (along a rack) and is guided by a built-in key design. The electrical and fiber optic connectors are all blind mated and self aligned. These connectors are located in the back of the unit. The SDP can be secured in position by a simple forward motion of a handle bar that uses an EVA handhold design. This handle bar is designed as part of the rack and generates enough force to ensure proper contact with the cold plate located under the SDP.

In order to evaluate this concept, a series of tests were conducted in the Rockwell Automation and Robotics Facility. In all cases there

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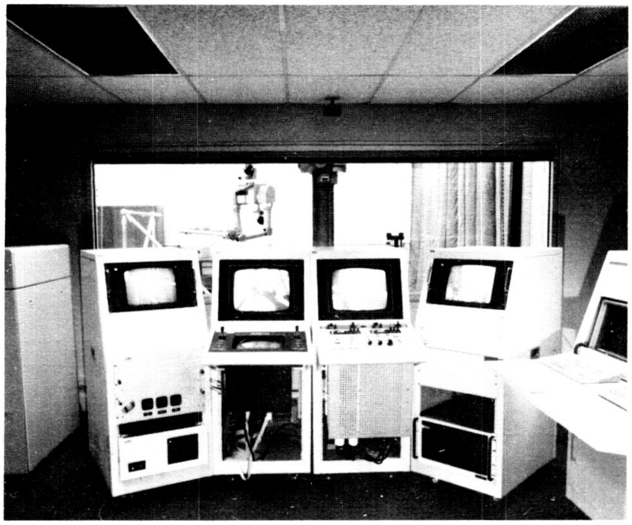

Figure 5. Rockwell Automation and Robotics Facility

was no direct visual contact between the operator and the work site. The operator had access to six television camera views—two of which were located on the slave arms and four of which provided views of the work space at four different angles. The force and torque feedback sensors did not decrease the operation time nor enhance the operation performance. Therefore, in most test cases, the force and torque sensors were turned off. Simple parallel jaws with friction pads were used as end effectors and appeared to be fully compatible with the SDP handle bars. Overall, these tests confirmed the simplicity of the SDP replacement operations. They also indicated that the developed guidelines provided compatibility between the robot and ORU's.

5. BENEFITS

Numerous benefits may be realized by our approach in suggesting standardization of connectors between many ORU's. Costs for design, development, test, and evaluation (DDT&E) of connectors and racks, as well as crew training, are reduced because the number of different types is reduced. Fewer spares must be warehoused. In addition, fewer varieties of tools and end effectors are required. Also, capability to reconfigure is increased. Furthermore, future automation becomes more efficient because standardized end effectors are used. Consequently, less robotic software must be written.

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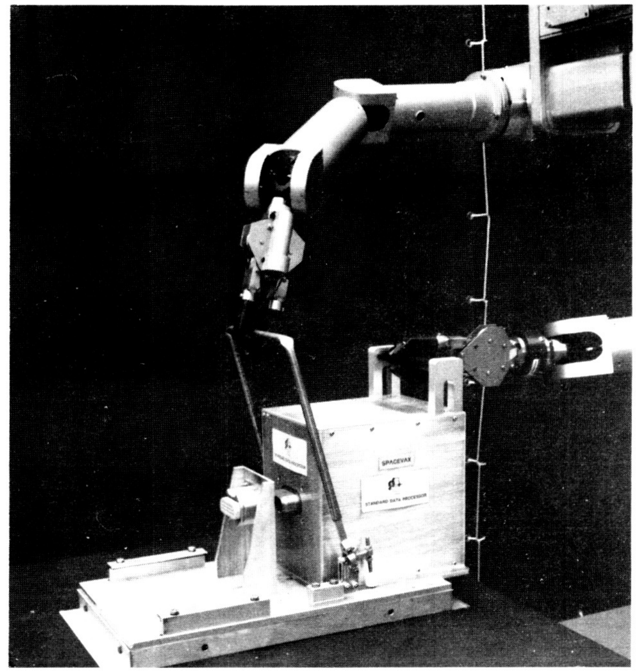

Figure 6. RM-10A Manipulator Arms Have Demonstrated SDP Changeout

Finally, these benefits would also assist the whole Space Station integration effort in that fasteners could be common across all four work packages.

6. REFERENCES

1. Clarke, Margaret M., Divona, Charles J., and Thompson, William M., Manipulator Arm Design for the Extravehicular Teleoperator Assist Robot (ETAR): Applications on the Space Station, Proceedings, 1987, First Annual Workshop on Space Operations Automation and Robotics (SOAR), Houston, Texas, August 1987, Pages 471-475.

2. Clarke, M.M., Thompson, W.M., Divona, C.J., "Requirements and Conceptual Design of the Manipulator System for the Extravehicular Teleoperator Assist Robot (ETAR)", SSS 86-0139, Rockwell International, Space Station Systems Division, Downey, California, November 1986.