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Shuttle Bay Telerobotics Demonstration

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1. Abstract

A demonstration of NASA's robotics capabilities should be a balanced agenda of servicing and assembly tasks combined with selected key technological experiments. The servicing tasks include refueling and module replacement. Refueling involves the mating of special fluid connectors while module replacement requires an array of robotic technologies such as special tools, the arm as a logistics tool, and the precision mating of ORUs to guides. The assembly task involves the construction of a space station node and truss structure. It will highlight the proposed node mechanism. In the process, the servicer will demonstrate a coordinated, dual arm capability.

The technological experiments will focus on a few important issues: the precision manipulation of the arms by a teleoperator, the additional use of several mono camera views in conjunction with the stereo system, the use of a general-purpose end effector versus a caddy of tools, and the dynamics involved with using a robot with a stabilizer.

Proposed industry space manipulators range in lengths from two to fifty feet. If the robot is a free-flier, the length of the arms is a function of its docking location in relationship to its task. As a result, no one set of manipulators can do every job. One solution to the problem is a "reconfigurable arm." This concept requires a modular approach of assorted arm lengths and different size drives including special modular sections. An integrated package of a hand, wrist, and forearm with actuators is an example of a modular section.

Interchangeable end effectors and tools is another facet of this concept. Each configuration is customized to the application. The demonstration will test some aspects of the "reconfigurable arm" during the technological experiments.

The robotic servicer will be mounted on a pallet as an experiment in the shuttle bay. It will be integrated with a minimum of two task panels complete with knobs, connectors, switches, and doors. The pallet will be self-sufficient and able to test all the aforementioned capabilities. A portion of the tasks will involve the Remote Manipulator System (RMS) in picking up the robotic servicer. The demonstration will answer several important questions concerning a robot doing extravehicular activity (EVA) and non-EVA types of work.

2. Introduction

Space is a natural environment for a test bed of advanced technologies such as robotics. The most frequently described missions include repair, housekeeping, or emergency work. Eventually, servicing and assembly missions will be common occurrences. However, the technology is far from mature with several critical questions yet to be answered such as "what are the major components of such a robot and will it be able to accomplish its mission?"

A mature servicing robot cannot be developed without some key intermediate steps. One of these is the subject of this paper, a shuttle bay experiment that merits some attention. This demonstration will be based and operated in the shuttle bay. The robotic servicer is an extension of the Johnson Space Center (JSC) work being conducted on their anthropomorphic-sized robotic servicer, the Telepresence Work Station (TWS) [1].

This paper describes the system, including the robot and pallet structure. The versatile system will be able to test various servicing and assembly scenarios, and will test key technological experiments.

3. Concept

Mounted on a pallet (Figure 1), the telerobotic demonstration experiment will be conducted from the shuttle bay in an actual space environment. The pallet will contain all elements of the experiment with the exception of the operator's console, mounted in the aft flight deck. The pallet includes a dual-arm robot, task panels, equipment rack, support electronics, tether and take-up reel, and robot latch mechanism and launch restraint.

The robot (Figure 2) will be configured with dual arms, each with seven degrees of freedom (DOF). Their basic design will be based on the Protoflight Manipulator Arm (PFMA) with an advanced wrist (3-DOF, concurrent axes) and additional improvements at the component and subsystem level. This design will lower the risk associated with successfully fielding an advanced manipulator in a useful time frame [2]. Each arm will be reconfigurable to allow changes in length, drive strength, and end effector. This capability will provide increased flexibility and opportunity to determine optimum configurations for particular tasks. Additionally, an evaluation of a general-purpose end effector, as opposed to an assortment of specialized tools, can be conducted.

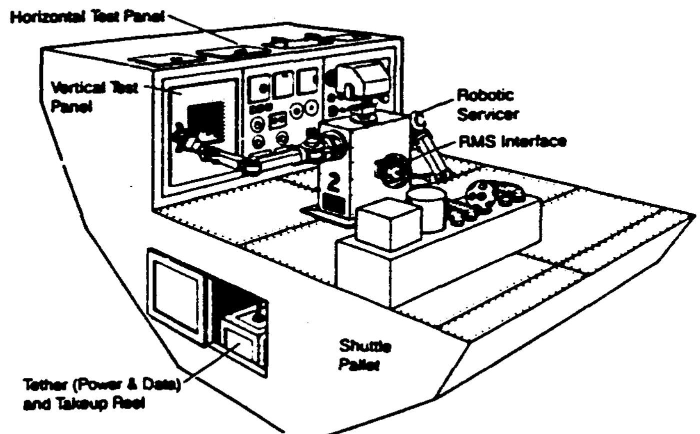

Figure 1. Telerobotic demonstrator on pallet

The robot vision system will include a stereo camera set housed on a 3-DOF mount, above and between the arm shoulder joints. In addition, a single camera will be mounted on each forearm to ensure a closeup view of the workspace if desired. How these mono cameras can be used in conjunction with the stereo system for enhanced task performance will be the focus of several experiments.

A tether and take-up reel will allow the robot to leave the pallet (Figure 3) and perform tasks in conjunction with the shuttle RMS without having to rely on a self-contained power source. This also allows the manipulator control electronics to be remotely located, further reducing weight and volume of the actual robot.

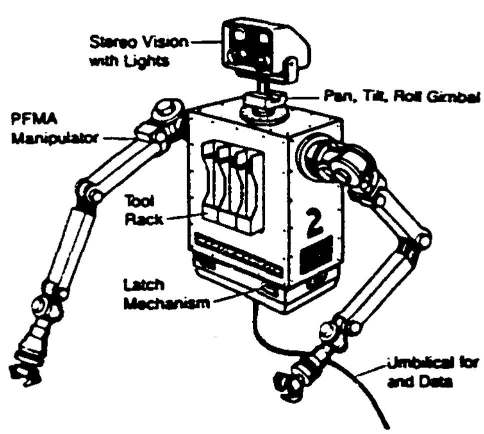

Figure 2. Robotic servicer

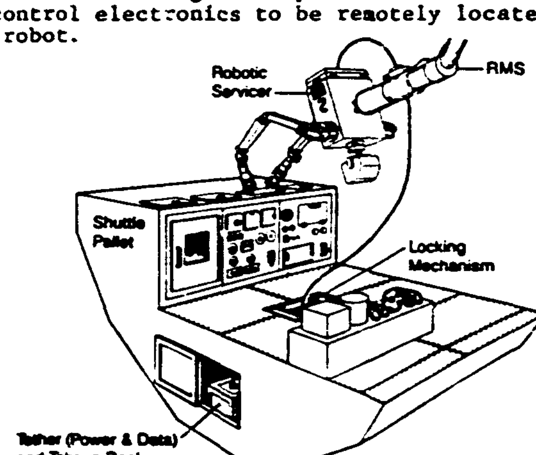

Figure 3. Robotic servicer on a tether

Integral to the pallet will be the task panels, representing a wide range of activities. At least two of these will be mounted askew to permit testing with the robot attached both to the pallet, or the RMS. These panels can be tailored to almost any task the manipulator would be required to perform. Their size would permit the simulation of portions of actual flight hardware, ensuring a realistic portrayal of a known servicing task, including obstacles to be encountered and avoided.

A nearby equipment rack will contain all elements of the desired assembly tasks. Having both within its reach envelope, the manipulator can use this rack of components in conjunction with the task panels, increasing the number and complexity of tasks that can be performed from a fixed location. The different tasks are systematically assessed for complexity before the demonstration by an index based on motion primitives [3].

4. Servicing

Servicing is a primary issue for any telerobotic system [4]. The failure of a fuse on the Solar Maximum Mission rendered the hardware useless until the unit was serviced. Some key servicing scenarios include module changeout (mating and demating connectors, fastener removal, precision alignment); inspection, checkout, and calibration; manually deploying an appendage; and cable take-up and untangling.

Module changeout is characteristic of any servicing mission. The Hubble Space Telescope has 12 primary orbital replaceable units (ORUs), such as batteries, electronic boxes, and fuse plugs [5]. When replacing an ORU, initial steps include the demating of several electrical connectors (signal and power). This requires a delicate and dexterous series of hand/wrist movements. The ORU can be removed once the fasteners are loosened. The subsequent reversal of this scenario replaces the module. Caution must be taken in precisely aligning the module during replacement. The module changeout can be demonstrated on the pallet system. Behind the door on the task panel would be a generic ORU. The robot would open the door and remove the ORU, then reattach the module to the equipment rack for storage. Conversely, the same ORU will be returned to the task panel. The experiment would be repeated with the robot fixed to its base and attached to the RMS.

Another servicing task involves the deployment of antenna booms with failed actuators. In this event, a jackscrew must be turned for manual deployment. Affixed to the task panel is a simulated boom the robot must deploy by driving the actuation mechanism.

In many situations, parts and tools may be tethered on a line that must be reeled in. A tangled line can cause many complications. In this instance, the tether must be handled meticulously so as not to worsen the situation. In such a case, the manipulator must demonstrate a high degree of dexterity. A tangled tether can be put in one of the sliding drawers of the task panel. The robot must untangle the line, wind it up, and return it to the drawer.

The last servicing scenario is refueling. The critical step in refueling is mating the male fluid connector to its female counterpart, necessitating handling a cumbersome hose. For this demonstration, the female connector would be in the task panel. The male connector is reeled out of the equipment rack and mated to the task panel.

5. Assembly Tasks

Candidate assembly tasks to be performed by the shuttle bay telerobotic demonstrator include those necessary for Space Station deployment and assembly of future orbital platforms. Teleoperated robots could execute boring and repetitive assemblies that would easily fatigue a Space Station EVA crew member. Primary among these is assembly of the truss structure forming the keel of the Space Station. Elements of one design candidate proposed by Lockheed Corporation would be carried on the equipment rack and assembled/disassembled by the manipulator [6]. Figure 4 illustrates this truss construction mechanism and how the two basic elements are assembled. Dual-coordinated arm motions are required as the mechanism is designed to be operated with the gloved hands of an astronaut using no tools. This task would be conducted with the robot secured to the pallet, negating the requirement for an additional stabilizing arm.

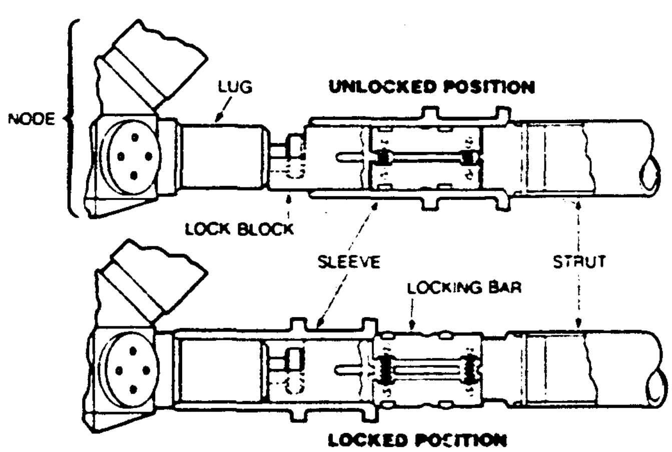

Figure 4. Truss construction mechanism

This experiment could also be repeated with the robot suspended from the RMS as a means of assessing the effectiveness of a single-arm stabilizer. In this position, one arm could act as the stabilizer, while the other performs the assembly of a truss element to a node rigidly attached to the equipment rack.

Additional assembly tasks include construction and installation of radiator panels, installation and connection of utility trays, and installation of payload support equipment.

Sample components from various tasks would be included in the equipment rack. Additionally, several configurations of the same task could be tested to determine the optimum design for a teleoperated environment.

6. Key Technological Experiments

In addition to assembly and servicing, there will be several key issues studied. One of these, the dynamics of a stabilizer, will be demonstrated by the assembly scenario on truss construction already mentioned.

By doing these real tasks, the teleoperator will have the opportunity to evaluate stereo viewing versus several mono views. As previously mentioned, the robot has a stereo vision "head" and supplemental mono cameras mounted on each arm. Optimizing the field of view for each of these is critical to ease task execution. Equally important is lighting. Both wide and spot beams will be evaluated. Understanding the limitations of the vision system is very important, and this experiment will surely point them out.

The robot will negotiate the standard complement of switches, knobs, and doors on the task panel. Also represented on the panel is a selection of fasteners and connectors, including the peg-in-the-hole experiment with the peg tethered. Figure 5 shows an example of a generic task panel. These tasks will test the manipulators' dexterity in space. We will also be able to investigate task sequencing as well as accomplishing a "time study." Each task is repeated with the robot both securely mounted to the pallet as well as being held by the RMS.

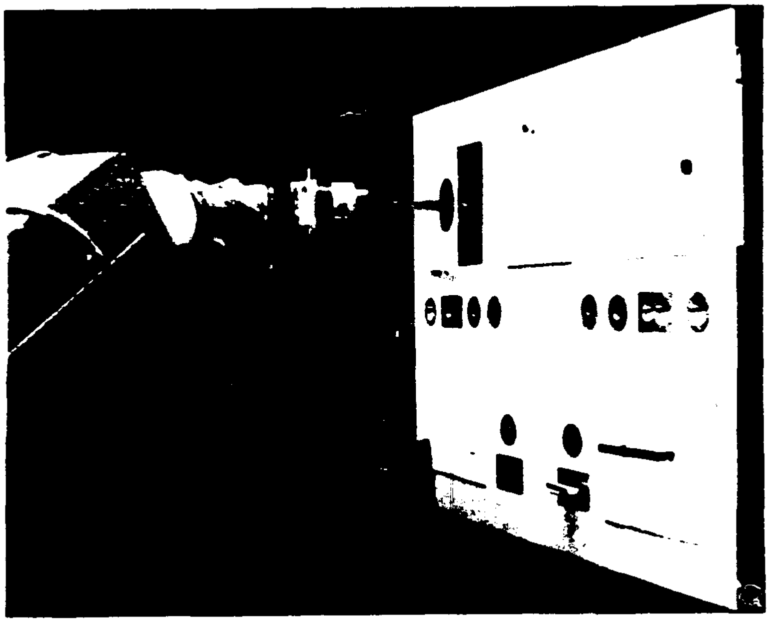

Figure 5. Example of a task panel

A major topic is the issue of modularity. Length is a major consideration in manipulator design. If the arm was anthropomorphic, it would be approximately four feet long, in contrast to the shuttle RMS, which is fifty feet long. With this large disparity, it can be proven that no single manipulator can do every task. The answer comes from the application. The length of the arm is dictated by its location with respect to the task location. For example, if the servicer is attached to a docking port ten feet from the task, then the arm should be at least ten feet long to be able to reach it.

The logical solution is to have more than one size arm. What we are proposing is a "family" of manipulator components, that when assembled, would lend itself to a variety of jobs (Figure 6).

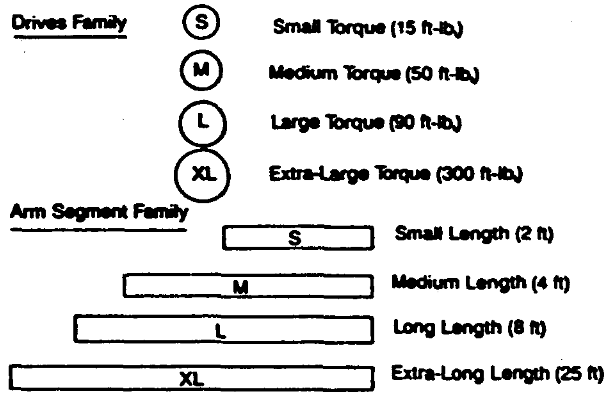

Figure 6. Family of drives and arm segments

By assembling these "families" of components, it is feasible to construct several different arms (Figure 7) to satisfy an assortment of missions. The result is some standardization of the manipulator with no major standardization of the tasks to be performed. As a consequence, the manipulators could be easily upgraded to incorporate new emerging technologies.

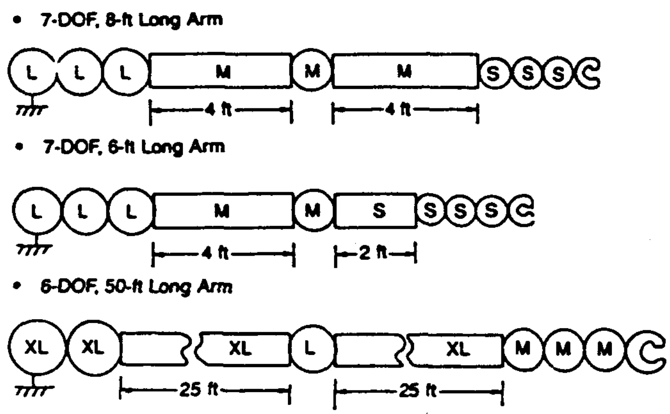

Figure 7. Several different manipulators

This concept is flexible, a compromise between distributed and totally integrated actuation; a hybrid we would like to call "reconfigurable" (Figure 8).

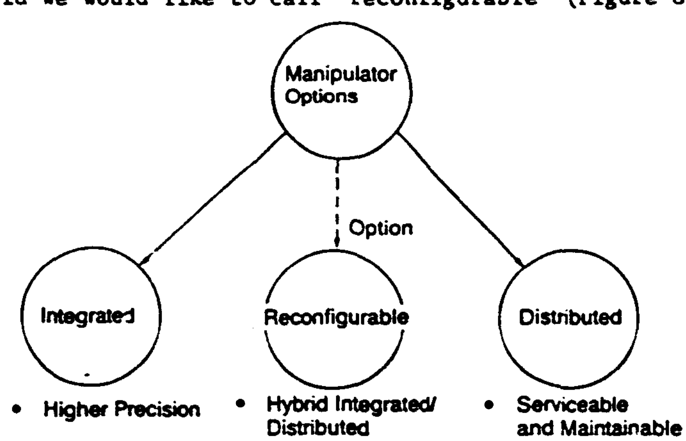

Figure 8. Hybrid manipulator option

The concept optimizes the manipulator by using both integrated and distributed modules. One example would be to use a Protoflight Manipulator Arm (PFMA) at Marshall Space Flight Center with selected upgrades. The existing arm, from the elbow back to the shoulder, has distributed actuators. The lower arm would be an integrated module consisting of the forearm/wrist/end effector. With the actuators built into the forearm, the wrist could be compact and dynamics improved. Figure 9 is an illustration of two possible configurations.

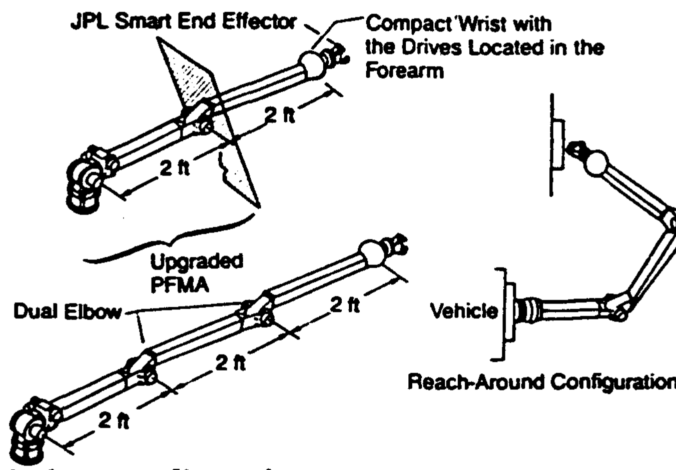

Figure 9. Two typical arm configurations

The success of the reconfigurable arm is dependent on an intelligent controller, and a mechanical attachment scheme that is easily connected or disconnected. The controller must be able to handle any arm configuration; from long to short and from simple to multijointed, and adapt to changing inertias, frictions, and other drive parameters.

Our concept will include one reconfigurable arm. The initial demonstration will include reconfiguring a 4-foot arm (two 2-foot segments) into an 8-foot arm (two 4-foot segments). The ability of the adaptive control system to compensate for this increase in length will be tested on the task panel. The attachment scheme should be light but rigid. It will be scaled for the different size interfaces. Next levels of component sizes are compatible (Figure 10).

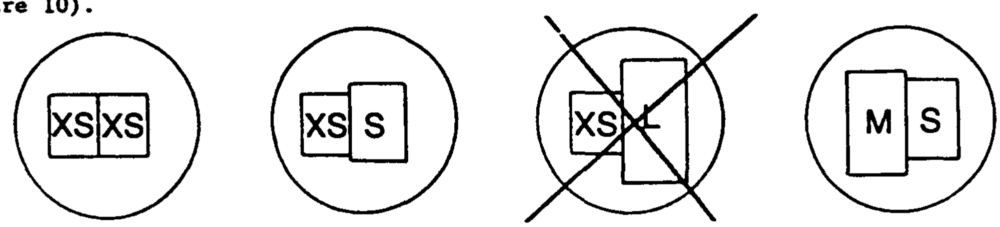

Figure 10. Compatibility of adjoining level component sizes

The modular theme also affects the end effector issue. The majority of servicing and assembly tasks require the use of some tool in conjunction with the human hand. The hand is the most flexible gripper or tool existing. The same is true for the robotic hand. At times, the hand will perform as a tool; for example, unscrewing a loose bolt without a wrench. However, it would not be efficient for our robot to have a tool holding another tool. Figure 11, from the TWS study, shows a mechanism that interfaces to a variety of tools such as a gripper or a ratchet. This mechanism has power and signal channels. There would be a locking interface to the different tools much like a bayonet mount, with a built-in power takeoff. This power takeoff is a single drive that actuates any tool that is compatible with its interface. As a result, the weight for a motor in each tool is eliminated.

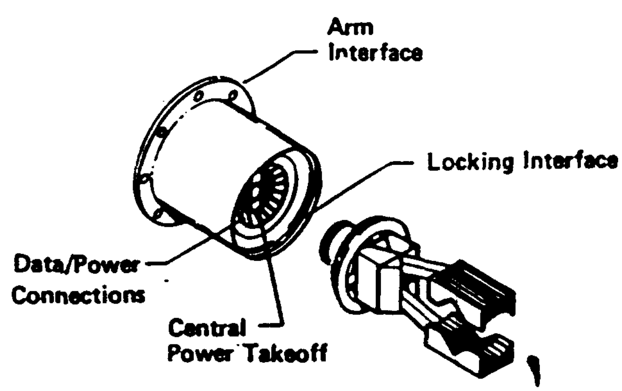

Figure 11. Power takeoff mechanism

Presented is a modular approach to the utilization of a variety of tools. The numerous tools will vary from a parallel gripper to a camera as shown in Figure 12. This flexibility allows this modular end effector to perform in more roles than a single tool, such as a screwdriver, could.

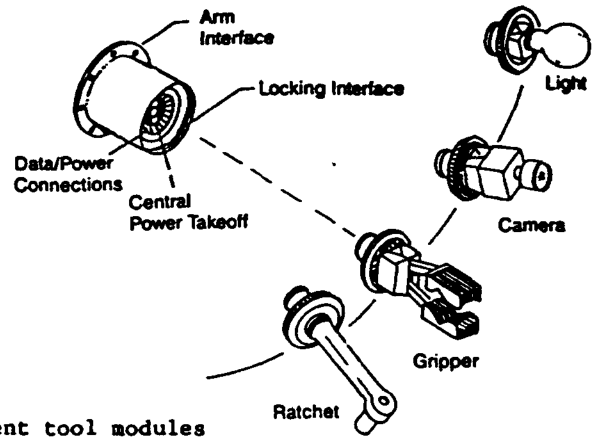

Figure 12. Different tool modules

At this time, it is not conceivable that an articulated hand can be packaged in the same manner as the previously mentioned tools. For this shuttle bay demonstration, there will be two lower arm assemblies. One assembly consists of the lower arm, compact wrist, and a dexterous hand. The other assembly is identical with the exception of the dextrous hand and the addition of a power takeoff mechanism. Both lower arm assemblies will be mounted on the equipment rack. The various tools to be exchanged will be attached to a holder on the same equipment rack.

7. Conclusion

Experiments, such as the shuttle bay telerobotics demonstrator, are necessary for the realization of a mature servicing robot. There are too many unknowns associated with assembly and servicing tasks, and as many as possible must be resolved to successfully transition from a manual environment to teleoperation and automation.

This experiment will provide an ideal environment where several key issues can be explored, including the following:

- Advanced control schemes designed to enhance telerobotic operation. Their higher level control modes can improve manipulator dexterity, and ability to adapt automatically to changing task environments. It is felt these control schemes may help ease the time-delay problems associated with in-orbit activities controlled from ground stations. Simulated random time delays would permit this evaluation and comparison to more conventional schemes such as bilateral force reflection.
- Vision and lighting systems, and how they affect the operators performance. How the mono camera information can be presented and used in conjunction with the stereo system to aid the operator while working in a cluttered or cramped environment. Visual acuity is extremely important when faced with complicated tasks and relatively little or no experience.
- Even with an adequate vision system, the ability to maneuver the manipulator arms around obstacles and perform dextrous tasks in cramped quarters must still be proven. The pallet demonstrator does not have to rely on the RMS to provide this type of challenge, as it is capable of performing many complex tasks with the manipulator fixed in its base.

Individually, many of these issues have been demonstrated or are being developed in a simulated environment. It now must be shown that they all can play together and perform in the place that counts: space.

The different elements of the experiment must be carefully chosen so adequate experience will be gained where most needed. Appropriate hooks and scars will be built in for future growth and to ensure a system with a long, useful life.

The shuttle bay experiment is not mission critical. It is well constrained on the pallet and presents minimum risk to other shuttle payloads and crew members. Its most significant impact will be on the knowledge and experience gained, by industry, in all disciplines of robotics.

8. References

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