PLENARY SESSION

TELEROBOTIC ACTIVITIES AT JOHNSON SPACE CENTER

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ABSTRACT

In today's expanding and exciting field of telerobotics, the Johnson Space Center continues to fulfil its responsibilities for technical leadership in the development and operations of the manned spacecraft for the United States. The JSC telerobotics efforts span three major thrusts: Sustaining and expanding the capability of the Shuttle manipulator, developing and integrating the multiple telerobotic systems of the Space Station, and fostering and applying research in all areas of telerobotics technology within the government, private, and academic sectors.

1. Introduction

Engineering development and mission operations of the manned spacecraft of the United States is the responsibility of Johnson Space Center. To continue the achievements of Mercury, Gemini, Apollo, Skylab, Apollo-Soyuz, and Space Shuttle, JSC currently maintains a labor force of 3400 civil servants and 5600 contractors, on 1600 acres in Houston, Texas, containing an acquired facility base of $ 810 million (book value) and operated at an annual budget of $ 750 million. The primary function of JSC is to put humans into space, meet the objectives of each mission, and to return the crews safely to earth. The general approach used at JSC is to derive "top down" the requirements and design of the spacecraft and crew procedures to meet high level program objectives while also fostering and applying technology developments in a "bottom up" manner to enhance system performance and safety.

Telerobotics activities at JSC have been ongoing for fifteen years and follow the top down / bottom up philosophy. At present, about two hundred employees are active in telerobotics projects throughout JSC which address all aspects of this multifaceted emerging discipline. Major programs supported include Space Shuttle, Space Station, Flight Telerobot Servicer, Office of Aeronautics and Space Technology, Small Business Innovative Research, several university programs, Office of Space Commercialization, and the JSC Director's discretionary fund.

2. Telerobotics Activites for the Space Shuttle

For Space Shuttle, JSC continues to refine the Payload Deployment and Retrieval System (PDRS) which consists of the Remote Manipulator System and its ancillary equipment: The Manipulator Positioning Mechanism, closed circuit television, lights, grapple fixtures on the payloads, the Shuttle general purpose computer, and the Shuttle Orbiter vehicle itself. The PDRS has performed successfully on all of its eighteen flights, both for its nominal functions and also as a resource for innovative solutions for problems arising in realtime.

The PDRS is the operational state of the art for space teleoperators. Its capabilities includes the grapple, transport, orientation, and release of payloads (from the payload bay) and conversely, the track, capture, grapple, transport, orientation, and berthing of satellites (into the payload bay). Additionally, it can provide transport, positioning, and orientation of EVA (Extra Vehicular Activity) crew via a mobile foot restraint attachment, local illumination via mounted lights, local directional television, positioning of enviromental sensing payloads into the orbital freestream, and power and data interface services to grappled payloads. Finally, the PDRS has been used as a resource for creative solutions to unexpected problems arising during flights such as force closure of a recalcitrant folding antenna, breaking ice from a vent nozzle, and use as a "flyswatter" to flip a toggle switch on an unresponsive satellite.

JSC provided the technical management and integration for the development of the PDRS and continues this function for the sustained use of the PDRS. For each mission application, JSC conducts non-realtime and realtime, crew in the loop simulations and analyses, mission planning and design, flight and ground procedures development, and mission control. JSC provides the requirements definition, integration, and flight worthiness verification of all functional upgrades and obsolescence-driven upgrades. JSC also sponsors, co-sponsors, and implements flight experimentation using the PDRS. For example, JSC is designing and implementing the on orbit Dexterous Manipulation Demonstration manifested for February, 1992, which will demonstrate force torque feedback, a magnetic end effector, and a boresighted closed circuit television end effector / payload alignment aid.

3. Telerobotics Activities for the Space Station

The Space Station has baselined multiple telerobotic flight systems from several different sources. These systems include 1) the Mobile Service Center which consists of the Canadian provided Mobile Remote Servicer and Special Purpose Dexterous Manipulator and the JSC provided Mobile Transporter, 2) the Goddard Spaceflight Center (GSFC) provided Flight Telerobot

Servicer, and 3) the JSC provided Assembly Work Platform. Furthermore, JSC is responsible for the delivery of the Multipurpose Application Console which is the crew workstation for control of all electrically activated flight systems (of which the telerobotics systems are a subset). JSC has also proposed the development of a free flying EVA crew support, voice commanded robot based on the successful ground demonstration of the EVA Retriever.

For Space Station, JSC is defining the functional and performance requirements for the Mobile Service Center in general and the JSC deliverable, the Mobile Transporter, in particular. These requirements are being based largely on the non-realtime and realtime simulations activities at JSC. These simulation facilities will be also used to verify the performance of flight components and systems as they are developed and integrated for flight. Major, innovative upgrades in these simulators and tools are being brought online now and will be used throughout the development, verification, and operation of the Space Station.

For the Flight Telerobot Servicer, JSC provided onsite at GSFC participation in the Skunkworks design concept effort, the in-house Phase B activity, and currently the Phase C/D source evaluation board. JSC is also currently providing to GSFC engineering support in the form of Space Station assembly tasks definition, EVA crew interface requirements, analyses on crew workstation concepts for both Orbiter and Space Station, robotic task definitions, communications systems analysis, and integration support for both Space Shuttle and Space Station.

The on-orbit assembly of the Space Station is a major challenge to define and implement and is heavily dependent upon the Space Shuttle. JSC's experience base in Shuttle is being applied to this problem in the definition of upgrades to the PDRS, displays and controls, communications, and other Orbiter systems that are required for proper support of the Space Station assembly flights.

4. Telerobotics Technology Activities at JSC

As an active member of the NASA's Telerobotics Intercenter Working Group that is sponsored by the Office of Aeronautics and Space Technology (OAST), JSC is pursuing the tranfser and application of telerobotics research from other NASA centers as well as conducting technology development itself. These efforts are fostered through OAST, Small Business Innovative Research, several university programs, Office of Space Commercialization, Space Shuttle flight experiments, Space Station advanced technology, and the JSC Director's Discretionary Fund.

Telerobotic research at JSC spans all five component disciplines as defined by the Intercenter Working Group:

Sensing and perception, planning and reasoning, control execution and mechanisms, crew interface, and system architecture and integration. In sensing and perception, JSC is pursuing intelligent ranging and tracking sensors, tactile sensing, and image processing; in planning and reasoning JSC s developing trajectory planners that include provisions for moving object avoidance and reactive planners for the accomodation of systen faults; in control execution and mechanisms, JSC has control efforts in hierarchical and parallel control laws, kinematic redundancy, smart hands, closed loop force torque control, and robot friendly components'; in crew interface JSC is pursuing flat panel color displays, advanced hand controllers, control and monitoring of multiple manipulators with total degrees of freedom of fifty or more, presentation of hidden workspace to operators; and in system architecture and integration JSC is pursuing evaulations of component and system fault tolerance through like and unlike redundancy patterned after the Shuttle avionics fault tolerant design.

A major three year design and integration telerobotic technology effort that is currently mid way complete is the JSC EVA Retriever. This inhouse project is a ground demonstration of a voice commanded, supervisory controlled robot that flies a space qualified Manned Manuevering Unit on a precision air bearing floor and has repeatably demonstrated the real time discernment of objects, path planning, rendezvous, grappling of a chosen object, and the return to home base. In its final configuration, EVA Retriever will be able to operate among moving objects while avoiding collision.

5. Telerobotics Facilities at JSC

JSC has a full spectrum of technical discipline laboratories that test, evaluate, and develop generic space technologies such as sensors, computing elements, human factors standards, controls, and actuators which have application to telerobotics. JSC also has the Advanced System Development Laboratory that prototypes proof of concept integrated telerobotic systems.

Flight crew interaction with concepts and design occurs at all levels but is especially emphasized in the full scale simulators. The real time, Systems Engineering Simulator (SES) is a high fidelity dynamics, multiple mission phase design tool that can simulate on orbit Shuttle, Space Station, Manned Manuevering Unit, and Orbital Manuevering Vehicle concurrent environments for crew and system dynamic interaction. The SES is bringing online a leading edge computer graphics system update to its out the window scene generation system that will provide high fidelity lighting and luminance modelling capabilities that will be critical to the viewing and cueing by the flight crew of the telerobotic construction and operations.

In contrast, the Manipulator Development Facility provides a full scale physical Shuttle payload bay and hydraulically operated PDRS that provides contact forces of grappling and berthing payloads. The Shuttle Mission Simulator is used for PDRS procedures and protocol design and checkout between the Shuttle crew and the mission controllers and experiment investigators. The Weightless Environment Training Facility provides a neutral bouyancy for interaction among EVA suited crew, the PDRS, and payloads. Finally, the Shuttle Avionics Integration Laboratory provides a ground instantiation of the Shuttle flight system that continues to perform the verification of all changes to the Shuttle software and avionics hardware. The functionality of these Shuttle dedicated facilities will be reproduced in Space Station equivalent facilities.

6. Concluding Remarks

JSC is experienced and active in the development and operations of putting humans into space, having them achieve mission objectives, and returning them safely to Earth. JSC also has an extensive base in the development and operation of the world's only space teleoperator, the Shuttle Payload Deployment and Retrieval System. JSC also is very active in the pursuit of telerobotic technology development and the transfer and application of telerobotic technologies developed by other NASA centers, academia, and the private sector. NASA's commitment to the Space Station offers major challenges and opportunities in the development, integration, on-orbit assembly and operation of multiple telerobotics systems. Our next step is to achieve humans and robots, together working productively in space.

Let's do it !

(For a copy of the charts and color photographs used for this paper in the JSC Plenary Session, contact the author at (713) 483-1523)