JPL SPACE STATION TELEROBOTIC ENGINEERING PROTOTYPE DEVELOPMENT
FY 91 STATUS/ACHIEVEMENTS
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In this brief overview, it is important to provide the context in which the current engineering prototyping activity is being conducted. The primary operation activities through the addition of shared control and local-remote control; and, the enhancing of Space Station utilization during periods when the crew is not present in the man-tended phase, again, through the use of the local-remote control architecture. Both of these contextual areas were derived from earlier workload and tasking studies such as the Fisher-Price study. The two prototyping tasks that support these problem areas are 1) Telerobotics Ground Remote Operations (TGRO),and 2) Advanced Telerobotics System Technology (Shared Control).

1377

INTRODUCTION/BACKGROUND

- PROBLEM AREAS ADDRESSED THROUGH CURRENT ACTIVITY
  - STREAMLINING IVA TELEOPERATION ACTIVITIES ON SPACE STATION
  - ENHANCING SPACE STATION UTILIZATION DURING MAN-TENDED PHASE

- CURRENT PROJECT ELEMENTS
  - TELEROBOTIC GROUND REMOTE OPERATIONS (TGRO)
  - ADVANCED TELEROBOTICS SYSTEM TECHNOLOGY (SHARED CONTROL)

MAJOR FY 91 DEVELOPMENTS/ACHIEVEMENTS

- COMPLETED DUAL ARM COORDINATED CONTROL
- PERFORMED/DOCUMENTED TELEOPERATOR PERFORMANCE
  - POSITION/RATE CONTROL
  - FORCE REFLECTION
  - SHARED CONTROL
- DEVELOPED/IMPLEMENTED A SOUND TECH TRANSFER MECHANISM BETWEEN A RESEARCH FACILITY (JPL) AND A USER FACILITY (FTS/GSFC)
- MOVED PREVIOUS 6DOF ROBOT SHARED CONTROL SYSTEM TO A 7DOF ROBOTICS RESEARCH ARM CONTROL ENVIRONMENT
- MOVED S/W CONTROL ENVIRONMENT TO ADA FOR BETTER COMPATIBILITY WITH IMPLEMENTATION/USER COMMUNITY
- REDESIGNED CURRENT LOCAL-REMOTE ROBOT CONTROL ARCHITECTURE IN RECOGNITION OF
  - NEED TO KEEP CONTROL SYSTEM AS SIMPLE/STREAMLINED AS POSSIBLE
  - HIGHLY CONSTRAINED ON-BOARD COMPUTATIONAL RESOURCES (BOTH SSF AND SSRMS/SPDM/FTS)
  - DESIRE TO MOVE ENGINEERING PROTOTYPING S/W PRODUCTS INTO NEXT PHASE OF DEVELOPMENT IN ACTUAL USER/FLIGHT ENVIRONMENT (I.E., BETTER MODULARITY TO ACCOMMODATE GROWTH/TECH TRANSER)
- PARTIAL IMPLEMENTATION OF OPERATOR-GRAPHICS USER INTERFACE ON IRIS
  - OBJECT MODEL KB
  - X-WINDOWS GRAPHICAL USER INTERFACE
  - VIDEO DISPLAY ON IRIS

The major FY91 accomplishments to date are as follows:

-Dual arm coordinated control; this capability was developed to allow the manipulator arms to be controlled by one hand controller under equal status meaning that the arms individually monitor forces and torques about a center reference point and move so as to zero any external or internal buildup of forces.

-Performance/documentation of operator performance; three major modes of control (position/rate, force reflection, and shared control) were assessed using 10 trained teleoperators to establish which of the three modes appears best relative to total elapsed task time, force buildup, and operator errors.

-Technology transfer; a joint technology transfer specification was drawn up by JPL and GSFC to insure the transfer of new technology is done properly JPL successfully transferred the User Macro Interface (UMI) and Shared Control technologies to the GSFC telerobotics laboratory.

-7DOF Robot Control; to stay current with proposed flight like manipulator designs, the JPL Engineering Prototyping lab initiated the move of its current 6DOF shared con trol software to a Robotic Research Arm environment additionally, the software environment has now been shifted to ADA to also stay current with the SSF software environment. Local-Remote Control Architecture Implementation; the FY90 robot control architecture design has been moved towards a more streamlined version concentrating on the primary local components (operator interface, sensing interface, task building, and handcontrollers), and remote components (servo/primitive control component, sensor monitoring, and teleop/autonomous control fusion) this change has been driven by the desire to be sensitive to projected on board computing constraints of both the station and robots.

The above accomplishments and task descriptions have been driven by domumented quirements derived via workload and tasking studies done over the last three years.These studies suggest that the ability to offload some tasks (that exceed the operator's bandwidth or are highly repetitive) to the remote autonomous system, or, perform some tasks from the ground, provides substantial potential to enhance station utilization and reliability. Further, the technology is developing at a rate which will allow it to have an impact on post FEL baseline operations. The requirement for this technology has been reasonably endorsed by station management, and the Level II Robotics Working Group.

CAPABILITY IS ESSENTIAL TO SSF PROGRAM

- HAS THE POTENTIAL TO INCREASE SSF UTILIZATION/RELIABILITY DURING MAN-TENDED PHASE.

- TECHNOLOGY CURRENTLY DEVELOPING AT RATE WHICH WILL ALLOW IT TO HAVE IMPACT ON BASELINE OPERATIONS.

- SUPERVISED AUTONOMY (A COMPONENT OF THE SHARED CONTROL CAPABILITY) AND GROUND CONTROL ARE TWO OF THE SEVEN ROBOTIC TECHNOLOGIES CURRENTLY ON LIST OF CODE M TECHNOLOGY PRIORITIES; LIST OF TECHNOLOGIES TRANSMITTED TO A. ALDRIDCH IN W. LENOIR LETTER OF APRIL 26, 1991.

- REQUIREMENT FOR SHARED CONTROL TECHNOLOGY ENDORSED BY SSF LEVEL II ROBOTICS WORKING GROUP (MAY 1991).

- SSF LEVEL II ROBOTICS WORKING GROUP FORMED SPLINTER WORKING GROUP ON GROUND CONTROL (MAY 1991).

- TECHNOLOGIES INCLUDED IN LIST OF RECOMMENDATIONS IN FISHER-PRICE STUDY

Within the two engineering prototyping tasks described in the preceding viewgraphs, there exist several areas of focus:
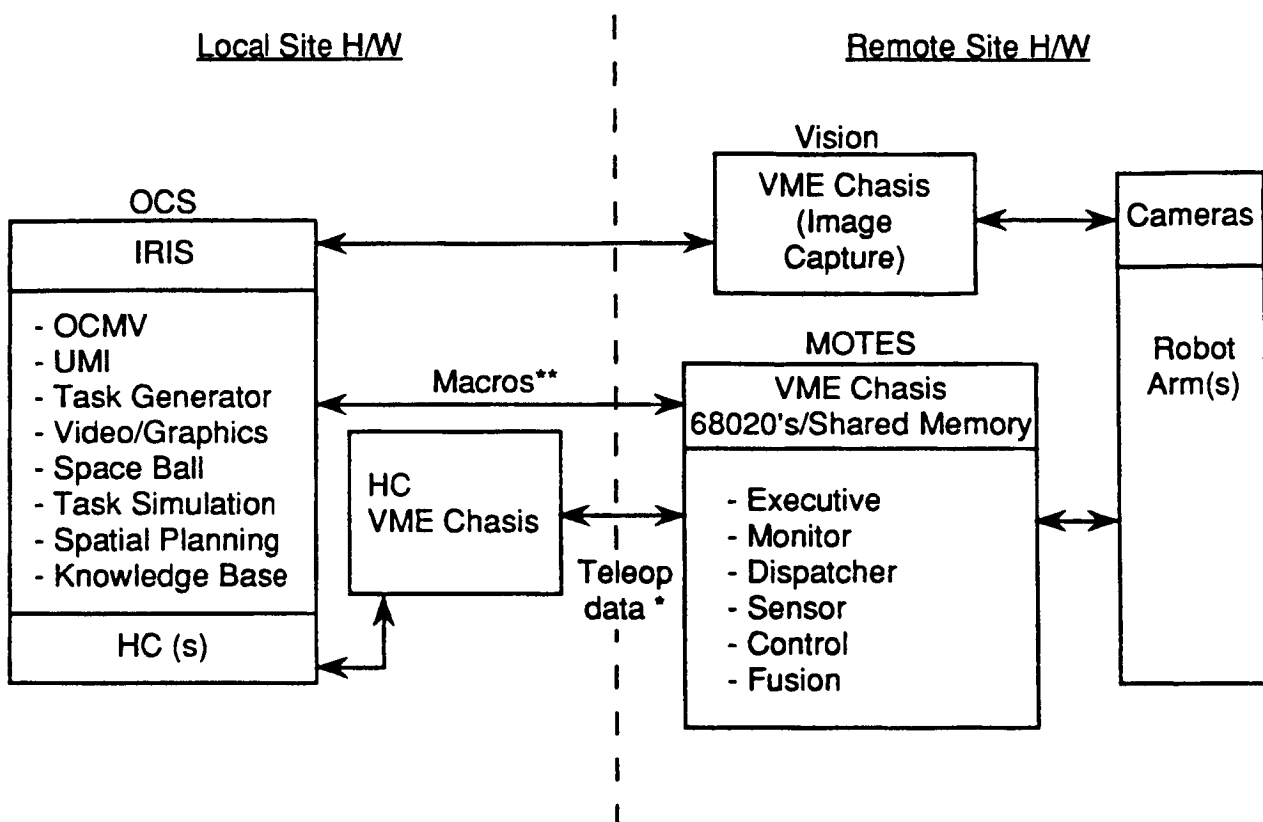
- Development of a robust local-remote control architecture which enables robot control in the presence of time delays such as bus latencies or ground remote operations via TDRSS.

- Development of robust single and dual arm shared control that provides the operator with multiple options in parsing/performing tasks under teleoperation or supervised autonomy.

- Development of extremely robust supervised autonomous control architectures and control macros; this development also includes the construction of error recovery schemes.

- Development of a rich User Interface; the current implementation of this interface the User Macro Interface (UMI) which was developed to provide the operator with a flexible means of building task sequences and simulating that sequence before actually executing the control sequence at the remote robot site.

- Development of Operator Coached Machine Vision; as part of the above user interface, it is important to allow the operator to accommodate changes or errors in the task environment this capability is a step in that direction.

- Operator performance assessment; this component of the current work is considered essential to understanding limitations of the existing technology.

- Technology Transfer; the JPL activity considers the transfer of technology to development testbeds at user flight centers entremely important if indeed the technology is to ever be employed.

CURRENT AREAS OF A/D FOCUS

- CONTROL ARCHITECTURE DESIGN ENABLING REMOTE ROBOT CONTROL WITH TIME DELAY.

- SHARED CONTROL (FLEXIBLE/FLUID CONCURRENT ROBOT CONTROL BY BOTH OPERATOR AND AUTONOMOUS SYSTEMS).

  - ABILITY TO PERFORM TELEOP FUNCTIONS IN CONJUNCTION WITH AUTONOMOUS FUNCTIONS.

  - ABILITY TO DOWNLOAD REAL TIME CLOSED LOOP CONTROL PARAMETERS COMPLETELY TO REMOTE AUTONOMOUS CONTROL SYSTEM.

- SUPERVISED AUTONOMY.

- USER MACRO INTERFACE (ABILITY TO DEVELOP LARGE ARRAY OF TASKS USING KERNEL OF ROBOT PRIMITIVES WITH A SPECIFIC INPUT PARAMETER SET [CALLED MACROS]).

- OPERATOR COACHED MACHINE VISION (INTERACTIVE OBJECT MODELING/WORLD MODEL UPDATE AND CORRECTION).

- OPERATOR PERFORMANCE ASSESSMENT.

- TECHNOLOGY TRANSFER TO DEVELOPMENT TESTBEDS.

The previous viewgraphs discussed the importance of the local-remote architecture in relation to allowing robust robot control in the presence of either bus latency induced time delays, or the desire to perform ground-remote robot control during the man-tended phase. As an introduction to the current work being done to stream-line the old version of the local-remote control architecture, the enclosed figure shows the high level hardware implementation and data flow. The operator coached machine vision (OCMV) and UMI will represent the primary operator interfaces residing on a Silicon Graphics Workstation (IRIS) at the local site. At a more detailed level, the UMI task macro generator will also be a software module on the IRIS. The video/ graphics modules will support the OCMV system on the IRIS, and in conjunction with UMI, will also have supporting knowledge bases of object model/robot control parameters. The spaceball allows the operator to manipulate the various graphics elements. It is planned to eventually incorporate the spatial planning capability into the task simulator. Also, the complete IRIS workstation will eventually replace a large portion of the current operator control station. In the near term, the IRIS will be ported to the prototyping laboratory to be in proximity to the handcontrollers and alternate camera views of the work cell. At the remote site the control architecture will contain two VME chasis- one chasis to capture video images for transmission to the videoport on the IRIS; and, the second chasis to perform all robot control/monitoring functions. The Modular Telerobotic Execution System (MOTES) runs in the second VME chasis and contains several functional software control modules which not only enable robot control, but are also designed to allow for growth. Both the local site design and remote site design are described in greater detail in the following viewgraphs.

Streamlined Local-Remote Telerobot Control Architecture

Local Site H/W | **Remote Site H/W**

OCS

IRIS

- OCMV
- UMI
- Task Generator
- Video/Graphics
- Space Ball
- Task Simulation
- Spatial Planning
- Knowledge Base

HC (s)

Macros**

HC VME Chasis

Teleop data *

Vision

VME Chasis (Image Capture)

Cameras

MOTES

VME Chasis 68020's/Shared Memory

- Executive
- Monitor
- Dispatcher
- Sensor
- Control
- Fusion

Robot Arm(s)

Note: * This implementation is for real-time teleoperation.

** This implementation will allow macro parameters to be sent to the remote site VME chasis; but, in the future, HC data will also be sent across this communication link.