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JPL SPACE STATION TELEROBOTIC ENGINEERING PROTOTYPE DEVELOPMENT

ADVANCED TELEROBOTICS SYSTEM TECHNOLOGY

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ADVANCED TELEROBOTICS SYSTEM TECHNOLOGY

Scope:

The Scope of the Advanced Telerobotics System Technology Task is to develop/prototype advanced telerobotics supervisory and shared control to enhance IVA teleoperation on Space Station. The technology provides enhanced telerobotics capabilities while operating within the expected constraints of computation limitations, time delay, and bus bandwidth. A local site operator interface has also been developed for specifying teleoperation and shared control modes as well as supervised autonomous macros for execution at the remote site. The primary objective of the task is to transfer the advanced technology to appropriate flight centers to enhance the baseline Station capabilities.

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ADVANCED TELEROBOTICS SYSTEM TECHNOLOGY

Scope:

- Remote Site Telerobotic System Development
  - Shared Control
  - Supervised Autonomous Control
  - Minimal Computational Requirements
- Local Site Operator Interactive Task Specification
  - UMI User Macro Interface
- Technology Transfer

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TECHNOLOGY TRANSFER

Two technology transfer deliveries to GSFC were successfully achieved. A document specifying the desired process for technology transfer was written with GSFC and its process was followed. The technologies transferred were Generalized Compliant Motion With Shared Control and the UMI User Macro Interface.

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TECHNOLOGY TRANSFER

Transferred to GSFC:

- Generalized Compliant Motion With Shared Control
- UMI User Macro Interface

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UMI USER MACRO INTERFACE

The UMI User Macro Interface was developed to provide local site interactive operator specification of the desired remote site robot execution. This included local site macro and task building, mode selection for shared control, supervised autonomous task sequencing, and task simulation on a 3 D simulator.

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UMI USER MACRO INTERFACE

Developed/Demonstrated Robust:

- Local Site Interactive Macro/Task Building
- Mode Selection for Shared Control
- Supervised Autonomous Task Sequencing
- Task Simulation

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SHARED AND SUPERVISORY CONTROL

Robust supervisory and shared control were developed and demonstrated in the laboratory. Shared control included the real-time merging of operator teleoperation inputs with autonomous force control. Three modes of shared control were provided: World, Tool, and Camera. There was also the option for partitioning the task degrees of freedom into operator and autonomous controlled degrees of freedom. Supervised autonomous control included the development of remote site task execution primitives including Generalized Compliant Motion.

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SHARED AND SUPERVISORY CONTROL

- Developed/Demonstrated Robust Shared Control
  - Real-Time Merging of Operator Inputs with Autonomous Control
  - World, Tool, Camera Modes
- Developed/Demonstrated Robust Supervised Autonomous Control
  - Remote Site Autonomous Control Primitives
  - Generalized Compliant Motion

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DUAL-ARM COOPERATIVE CONTROL
(Two Robots Manipulating One Common Object)

The supervisory and shared control capabilities developed for a single robot arm were expanded for dual-arm control. Two robots hold one common object. The operator moves one hand controller to specify the desired motion of the common object and the two robots move in concert with the object. Move-squeeze decomposition is used to decompose the forces sensed at the wrists of the two robots into squeeze forces which cause internal forces in the object and move forces that move the object or cause contact forces between the object and its environment. The Generalized Compliant Motion With Shared Control primitive was generalized to dual-arm control capability.

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DUAL-ARM COOPERATIVE CONTROL
(Two Robots Manipulating One Common Object)

- Demonstrated Shared Control
  - One Hand Controller, Cooperating Robots
- Demonstrated Supervisory Control
  - Dual-Arm Generalized Compliant Motion
- Demonstrated Move-Squeeze Decomposition of Dual Robot Forces

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LABORATORY EXPERIMENTS

Various laboratory experiments were performed to validate the technology. A videotape showing some of the experiments was made.

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LABORATORY EXPERIMENTS

- Single-Arm Control: Compliant Grasp, Bolt Seating and Turning, Electronics Card Insertion/Removal, Door Opening, Electrical Connector Insertion/Removal
- Single and Dual-Arm Control: Pin Insertion, Contour Following, ORU Manipulation
- Dual-Arm Control: Satellite Capture, Fluid Coupler Insertion/Removal

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OPERATOR PERFORMANCE STUDY

An operator performance study was designed and data collection is presently underway. The study is comparing three modes of teleoperation: force reflecting teleoperation, shared control, and feedforward position only. Nine operators are performing three tasks: electrical connector removal/insertion, ORU removal/insertion, and electronics card removal/insertion. Additionally, a multiple bolt seating/turning task is being done by a subset group of the operators. The results will indicate various results including time of task execution, force buildup, and various operator observations and preferences.

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OPERATOR PERFORMANCE STUDY

Performance Assessment Design (Data Collection and Analysis In-Process)

- Nine Operators
- Three Teleoperation Modes
  - Force Reflecting Teleoperation
  - Shared Control
  - Feedforward Position Only
- Four Tasks:
  - Electrical Connector Removal/Insertion
  - ORU Removal/Insertion
  - Electronics Card Removal/Insertion
  - Multiple Bolt Seating/Turning

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DESIGN OF NEW REMOTE SITE SYSTEM
MOTES: A MODULAR TELEROBOT TASK EXECUTION SYSTEM

To be more valuable to the flight community, the supervisory and shared control system is being rewritten in the Ada programming language (it was in C). The new system, Modular Telerobot Task Execution System (MOTES), maintains the capabilities of the previous system but requires less computation capability and is more modular in design.

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DESIGN OF NEW REMOTE SITE SYSTEM MOTES: A MODULAR TELEROBOT TASK EXECUTION SYSTEM

Maintains Supervisory and Shared Control Capability While Minimizing Remote Site Computational Requirements

- Written in Ada Programming Language
- Communication With Local Site System
- Shared Control
- Supervised Autonomy
- Multi-Sensor Integration
- Fusion of Multi-Sensor Control
- Parameter Driven Task Execution

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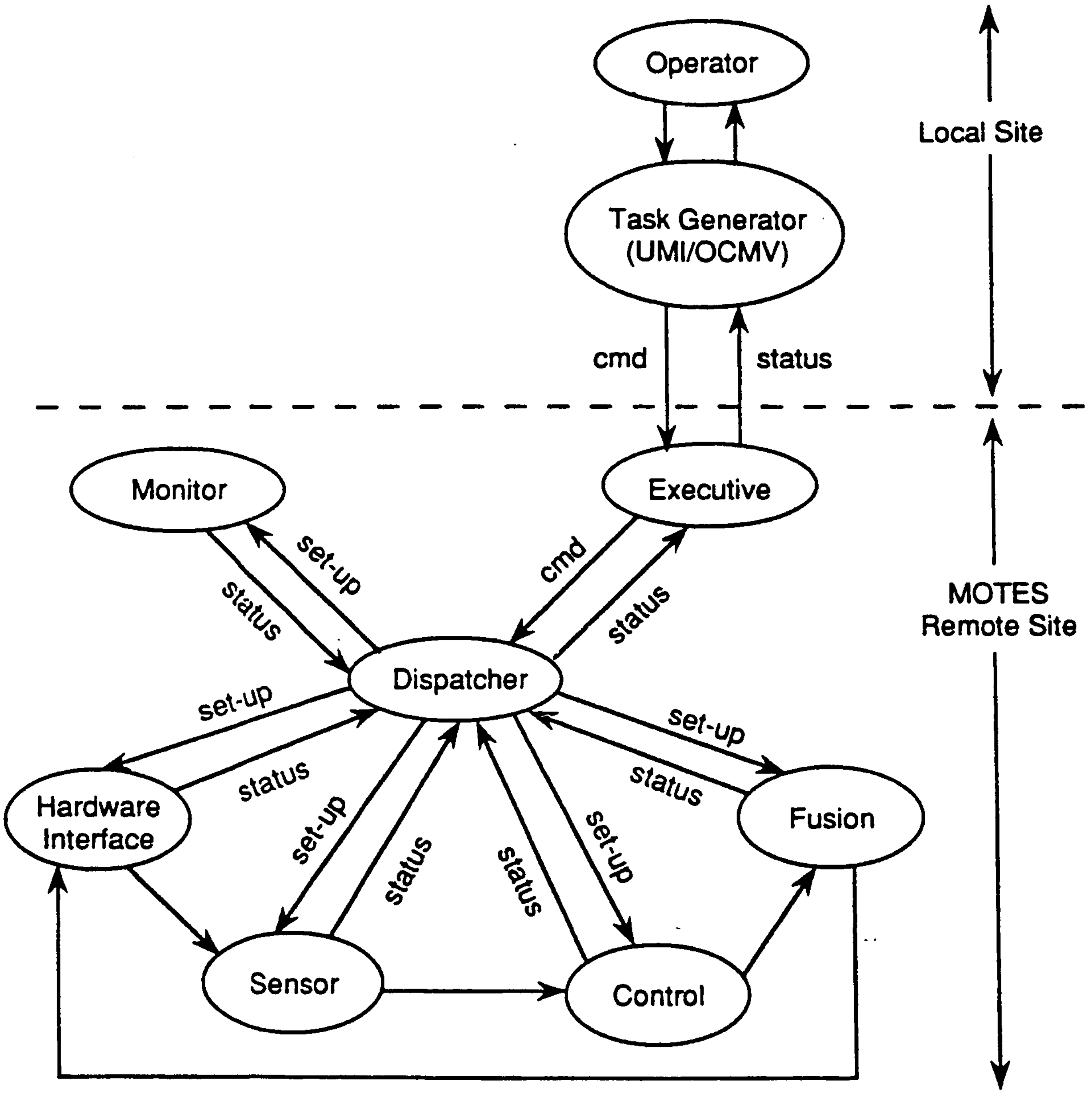
MOTES
MODULAR TELEROBOT TASK EXECUTION SYSTEM

The MOTES data flow diagram indicates the modularity of the system design. The Monitor, Hardware Interface, Sensor, and Control modules may each actually be multiple modules associated with different equivalent level functionalities, e.g., Sensor could include modules for force-torque sensing, proximity sensing, and trajectory generation.

MOTES
MODULAR TELEROBOT TASK EXECUTION SYSTEM



MOTES Data Flow Diagram

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FY91 ON-GOING WORK

REDUNDANT ARM CONTROL

Also, to better match the flight systems, the new MOTES system includes control of a 7 degree of freedom redundant manipulator. Besides the previous supervisory and shared control capability, the new system will provide redundant arm kinematics, efficient redundancy utilization, and simulation of the 7 DOF arm.

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FY91 ON-GOING WORK

REDUNDANT ARM CONTROL

Developing Supervisory and Shared Control for 7 Degree of Freedom Manipulator

- Redundant Arm Kinematics
- Efficient Redundancy Utilization
- Simulation of 7 DOF Arm