Robotic and EVA/Robotic Servicing: Past Experiences, Future Promise

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SSL Robotics/Servicing Timeline (80’s)

- **‘80**: SSL studies applications of automation, robotics, and machine intelligence for servicing Hubble and other Great Observatories for NASA MSFC
- **‘81**: Initial operational tests of Beam Assembly Teleoperator
- **‘82**: BAT used for extensive servicing tests on HST training mockup
- **‘83**: SSL develops ParaShield flight test vehicle for suborbital mission
- **‘84**: Robot-aided EVA structural assembly
- **‘85**: Experimental Assembly of Structures in EVA flies on STS 61-B
- **‘86**: **‘87**: **‘88**: **‘89**:
ARAMIS Telerobotics Study (1980)

- Survey of five NASA “Great Observatories” to assess impacts and benefits of telerobotic servicing - major results:
  - Ground-controlled telerobotics is a pivotal technology for future space operations
  - Robotic system should be designed to perform EVA-equivalent tasks using EVA interfaces
    - Maximum market penetration for robot
    - Maximum operational reliability
    - Designing to EVA standards well understood
  - Fully capable robotic system needs to be able to do rendezvous and proximity operations, grapple, dexterous manipulation
Fundamental Issues in Robotic Servicing

- Flexible Connections to Work Site?
- Capabilities and Limitations?
- Multi-arm Control and Operations?
- Interaction with Non-robot Compatible Interfaces?
- Hazard Detection and Avoidance?
- Development, Production, and Operating Costs?
- Effects and Mitigation of Time Delays?
- Utility of Interchangeable End Effectors?
- Ground-based Simulation Technologies?
- Human Workload Issues?
- Control Station Design?
- Manipulator Design?
- Ground Control?
Beam Assembly Teleoperator
<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>'90</td>
<td>SSL designs Ranger based on experience with HST servicing</td>
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<tr>
<td>'91</td>
<td>UMd NBRF opens</td>
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<td>'92</td>
<td>NASA selects Ranger TFX as low-cost robotic flight experiment</td>
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<td>'93</td>
<td>Ranger performs end-to-end HST servicing simulations</td>
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<td>'94</td>
<td>Ranger NBV operational</td>
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<td>'95</td>
<td>SSL directed to redesign Ranger for shuttle mission: Ranger TSX</td>
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<td>'96</td>
<td>Environmental testing at JSC</td>
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Ranger Telerobotic Flight Experiment
Ranger Neutral Buoyancy Vehicle I
Ranger Telerobotic Shuttle Experiment
SSL Robotics/Servicing Timeline (00’s)

- **’00**
  - Development of ECU operations timeline
  - Modular miniature servicer development for DARPA

- **’01**
  - Ranger TSX program cancelled

- **’02**
  - Ranger simulates SPDM for GSFC HRSDM testing

- **’03**
  - First tests of EVA/robot cooperation with Ranger

- **’04**
  - Ranger performs SUMO tasks at NRL

- **’05**
  - MX-2 suit operational; coop. EVA/robot servicing

- **’06**
  - Suit-integrated manipulators, advanced displays and controls

- **’07**
  - SAMURAI lightweight manipulator

- **’08**
  - Ranger simulates SPDM for GSFC HRSDM testing

- **’09**
  - Ranger performs SUMO tasks at NRL
Ranger Spacecraft Servicing System
Ranger System Specifications

- Approximately EVA-glove-sized end effectors with 30 lbf force and 30 lb-ft torque capability in any direction
- Two human-scale arms with intersecting workspaces mounted on narrow base for restricted work sites
- High-bandwidth active compliance-control loop
- 8DOF allows autonomous obstacle and singularity avoidance
- Interchangeable end effector mechanism with two mechanical tool drives to each end effector
- Rad hardened MIL-STD-1553B distributed control architecture recognizes and safes errors in ≤ 30 msec
- 800,000 lines of code for nominal and contingency ops
- Flight-certified through NASA Phase 2 PSRP
- Operable in 1G, underwater, and space environments
- Advanced control station mitigates time delays ≤ 6 sec
Ranger Arms for SUMO Grappling
Ranger Performing HST AI Changeout
EVA/Robotic Servicing of HST
Robotic Augmentation of EVA (from SM1)
On-Orbit Servicing Demand by Types

- Dexteroous Servicing
- Simple Servicing
- Reboost
- Inspection

Total Servicing Market ~$3-5B/year!
Proteus Actuator Technology

[Image of the Proteus actuator technology, showing its components and a schematic diagram.]
A Sample Proteus Toolbox

Modules
- Roll Actuator
- Pitch Actuator
- Pitch-Roll Actuator
- Long Arm Link
- Medium Link
- Short Link

End Effectors
- Force-Torque Sensor
- Pitch-Yaw Actuator
- High-Dexterity End Effector
- Handrail Gripper
- Stereo Pan-Tilt

Nodes
- Parallel Jaws
- Mini-Node
- Free-Flight Module
- Base Node
A Potential *Proteus* Configuration

Dexterous Arms and Interchangeable End Effectors for Servicing/Assembly

Free-Flight Module/Stand-Off Video Monitoring Source

Positioning Arm for Dexterous Manipulators

Legs for Local Mobility and Stabilization Using EVA Hand Rails
Current *Proteus*-Based Systems

- SAMURAI Deep-Submergence Manipulator
- MGA Exoskeletal System for Shoulder Rehabilitation
Advanced Robot-Integrated Suits

Robot-Augmented Suit Gloves

Suit-Mounted Manipulators

Advanced Controls and Displays

Morphing Space Suits
UMd Voice Command of GSFC RMS
End-to-end task assessment and mission simulations

Servicing operations from future spacecraft concepts
Advanced Technologies for Servicing

Lightweight Manipulator
Actuators and Sensors

Natural Admittance Control

Advanced Mitigation of Time Delays

Full Haptic Control Station

Advanced Interchangeable End Effector Mechanisms

Adaptive Nonlinear Control Algorithms for Manipulator Motion
The Ultimate Robotic Flight Experiment

• At some point, the Hubble science mission will end

• Lightweight robotic servicer could be added to deorbit mission

• On-orbit robotic HST servicing will leverage decades of experience in EVA servicing and demonstrate robotic capabilities
Overview of the UMd Space Systems Lab

- Dexterous Robotics
- Flight Programs
- Systems Design
- Human Systems
- World-Class Facilities
- Human/Robot Interaction

Approved for public release; distribution unlimited
SSL Background in Space Robotics

- Structural Assembly
- Formation Flying
- Crane-type Positioning Robot
- Walking Robots
- Multiple Cooperating Robots
- Orbital Maneuvering Vehicle Operations

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Current Robotics Projects

- Autonomous Deep Submergence Manipulators
- Free-Flying Inspection and Light Transport Robots
- Lightweight Modular Self-Reconfiguring Robots
- Advanced Dexterous Robotics
- Complex Satellite Servicing
Current Human Systems Projects

- In-Suit Metabolic Workload
- Maryland Advanced Research/Simulation (MARS) Suit MX-2
- Ballasted Partial Gravity Simulation
- Advanced Life Support Systems
- Biomechanics Instrumentation
- Advanced Space Suit Gloves
Human/Robot Interaction Projects

Morphing Space Suit Components

EVA/Robot Cooperative Space Operations

Exoskeleton Shoulder Rehabilitation Robot

Power-Assisted Space Suit Components

Suit-Integrated Manipulators

Space Systems Laboratory
Space Systems Design Activities

- Advanced Human/Robot Systems
- Transportation and Landing Systems
- Orbital Habitats
- Robotic HST Servicing
- Full-Scale Mockups for Human Testing
- Lunar and Mars Rovers
- Planetary Surface Habitats
Space Systems Lab Facilities

Flight Robotics Simulation Facility

Advanced Robotics Development Lab

Flight Electronics Fab & Test Lab

Space Suit Development Lab

Neutral Buoyancy Research Facility

Planetary Surface Mobility Simulator

Inspection and Secure Storage Lab