Surface Telerobotics

Human Exploration Telerobotics (HET) Project
Technology Demonstration Mission (TDM) Program
Space Technology Mission Directorate (STMD)

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Surface Telerobotics is an engineering test of a human-robot “opscon” for future deep-space human exploration missions

Candidate Missions

- **L2 Lunar Farside.** Orion crew module test flight (~2020) to Earth-Moon L2 point
- **Near-Earth Asteroid.** NEA dynamics and distance make it impossible to manually control robot from Earth
- **Mars Orbit.** Crew must operate surface robot from orbit when circumstances (contingency, etc.) preclude Earth control

What will the test achieve?

- Obtain baseline engineering data
- Validate & correlate prior ground simulations
- Reduce the risk that mission planning is based on inaccurate assumptions
Objectives
• Demo **crew-centric control** of surface telerobot from ISS (first operational system) based on L2 Lunar farside mission concept
• Test **human-robot “opscon”** for future deep-space exploration mission
• Obtain **baseline engineering data** of system operation

Approach
• Leverage best practices and findings from **prior ground simulations**
• Collect data from robot software, crew user interfaces, and ops protocols
• Validate & **correlate to prior ground sim** (analog missions 2007-2011)

Implementation
• **K10 planetary rover** in ARC Roverscape (outdoor test site)
• ISS astronaut + Mission Control
• L2 mission sims (3): **June-Aug 2013** (ISS Incr. 36: 10.5 hr total crew time)

Key Points
• **Complete human-robot mission sim**: site selection, ground survey, telescope deployment, inspection
• **Telescope proxy**: COTS 75 micron polyimide film roll (no antenna traces, no electronics, no receiver)
• **3.5 hr per crew session** (“just in time” training, system checkout, telerobot ops, & crew debrief)
• **Two control modes**: basic teleop and pre-planned command sequencing (with continuous monitoring)
• **Limited crew user interface**: no sequence planning, no science ops capability, no robot engineering data
Objectives

1. Demonstrate that crew can remotely operate surface robots from inside a flight vehicle to perform exploration work
   - Ability to supervise planetary robot from space craft (make correct decisions, take appropriate action)
   - Awareness of intent and outcome of rover autonomous actions for waypoint driving, image acquisition, payload deployment
   - Ability to detect and respond appropriately to robot problems affecting achievement of mission objectives

2. Mature technology required for crew control of surface telerobots (specifically robotic control interfaces for crew)
   - Information and capability for supervisory control of robot
   - Information and capability for mission tasks of site selection, antenna deployment, and antenna inspection
   - Usefulness and understandability of robot’s autonomous functions for waypoint driving, image acquisition, and payload deployment
   - Availability and timeliness of information (communication & data distribution)

3. Identify requirements and gaps for research and technology development programs
   - Identify HRP risks and gaps relevant to Surface Telerobotics
   - Document evidence of HRP risks or HRP risks avoided observed during sessions
L2 Lunar Farside (Waypoint) Mission Concept

Orion at Earth-Moon L2 Lagrange point
• 60,000 km beyond lunar farside
• Allows station keeping with minimal fuel
• Crew remotely operates robot on lunar farside
• Less expensive than human surface mission
• Does not require human-rated lander

Primary objective: lunar telescope
• Use telerobot to setup radio telescope
• Requires surface survey, antenna/receiver deployment, and inspection/documentation
• Lunar farside provides radio quiet zone for low-freq measurements cosmic dawn

Secondary objective: sample collection
• Use telerobot to perform field geology
• Requires scouting, sampling (possibly subsurface), and sample caching/return
• South Pole Aitken (SPA) basin sampling is the highest priority lunar science objective

Surface Telerobotics

(Lockheed Martin / LUNAR)
Polyimide Antenna Technology

Concept
• Metallic conductor deposited on surface of polyimide film (e.g., DuPont Kapton)
• Suitable for frequencies up to 100 MHz
• Polyimide remains flexible at lunar daytime temperatures, thus can be deployed by unrolling

Testing (to date)
• Vacuum chamber with thermal cycling & UV exposure similar to lunar surface conditions (Univ. of Colorado Boulder / NLSI LUNAR)
• Outdoor signal test (New Mexico)
Telerobotic Telescope Deployment Concept

(JPL / LUNAR)
Waypoint Mission Simulation (2013)

Phase 0
Pre-Mission Planning
Ground teams plan out telescope deployment and initial rover traverses.

Phase 1
Surveying / Scouting
Crew gathers information needed to finalize the telescope deployment plan.

Phase 2
Telescope Deployment
Crew monitors the rover as it deploys a single arm of a telescope node.

Phase 3
Telescope Inspection
Crew inspects the deployed telescope node looking for tears and folds.

Crew Session 1
Spring

Crew Session 2
June 17

Crew Session 3
July 10

August 8
K10 Specifications
- 4-wheel drive, 4-wheel steer
- Split rocker chassis
- Size: 1.3 x 0.9 x 1.0 m (HxWxL)
- Speed: 0.9 m/s (on 10 deg slope)
- Power: 1900 W (Li-ion batteries)
- Weight: 100 kg (with 25 kg payload)
Deployed Telescope Simulation
Robot Interface (Task Sequence Mode)

- Alert Bar
- Tip Bar
- Rover Status
- Tab Panel
- Bird’s Eye 3D View
- Top Down 3D View
- Primary Button Panel
- Hazard Camera View
- Status Bar
- Terrain hazards
- Rover camera display

Task Sequence Controls

- Run Task Sequence Controls

Surface Telerobotics
Robot Interface (Teleop Mode)

- **Motion controls**
  - Forward
  - Backward
  - Rotate Left
  - Rotate Right
  - Panorama

- **Camera controls**
  - Start
  - Snapshot

- **Terrain hazards**

- **Rover path**

- **Rover camera display**

[Image of a computer interface for remote robotic control, including options for motion and camera controls, a map of terrain hazards, and a display of the rover's path and camera feed.]
Data Communications

Robot User Interface on SSC

“Live” Rover Sensor and Instrument Data (telemetry)

Rover/Science Data (e.g. imagery)

Note: Normal uplink ~1Mbps, spike after LOS is ~2Mbps for 2 sec

Uplink

384 kbits/sec (min), Out-of-Band

Downlink

Post-test File Transfer

Rover Task Sequence (text file)

Interface Instrumentation & Evaluation Data

384 kbits/sec (min), 5 sec delay (max)

8 kbits/sec (min), 5 sec delay (max)

K10 rover at NASA Ames
Tasks & Activities (ISS Crew)

Each crew session is 3.5 hours

Review, Training, Conference (1 hour)
- Watch Intro Video, Read Big Picture Words (15 min)
- Run through Just-in-time Training module (30 min)
- Crew conference with PD team (15 min)

Surface Telerobotics Ops (2 hours)
- Downlink task plans to robot and monitor execution
  - Interrupt execution for problems (e.g. cannot reach waypoint)
- Handle contingencies as needed (run “teleop” plans)
  - Teleop to avoid obstacles
  - Perform additional data collection as needed to reacquire data
- As observation data arrives, verify that data is valid
- Interact with ground support as needed

Debrief with mission control (0.5 hours)
## Technology Advancement

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Start</th>
<th>End</th>
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</thead>
<tbody>
<tr>
<td>Supervisory control user interface (ST Workbench)</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>In-line metrics, summarization, and notification systems</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Science data analysis interface (xGDS)</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Autonomy for short-delay interactive supervisory control (RoverSW)</td>
<td>5</td>
<td>7</td>
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<tr>
<td>Command/telemetry messaging (RAPID)</td>
<td>5</td>
<td>7</td>
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<tr>
<td>Time-delay mitigation</td>
<td>4</td>
<td>7</td>
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</tbody>
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**TRL 4** = Component and/or breadboard validation in lab

**TRL 5** = Component and/or brassboard validation in relevant environment (simulation of target operational environment)

**TRL 6** = System/subsystem model or prototype demonstration in a relevant environment (under critical conditions). Engineering feasibility fully demonstrated.

**TRL 7** = System prototype demonstration in an operational (space) environment. Well integrated with operational hardware/software.
Test Protocol

Data Collection

Obtain engineering data through automatic and manual data collection

- **Data Communication:** direction (up/down), message type, total volume, etc.
- **Robot Telemetry:** position, orientation, power, health, instrument state, etc.
- **User Interfaces:** mode changes, data input, access to reference data, etc.
- **Robot Operations:** start, end, duration of planning, monitoring, and analysis
- **Crew Questionnaires:** workload, situation awareness, critical incidents

Metrics

Use performance metrics* to analyze data and assess human-robot ops

- **Human:** Bedford workload rating scale & SAGAT (situation awareness)
- **Robot:** MTBI, MTCI for productivity and reliability
- **System:** Productive Time, Team Workload, and task specific measures for effectiveness and efficiency of the Human-Robot system

* Performance metrics used for prior analog field tests: 2009 robotic recon, 2010 lunar surface systems, 2010 robotic follow-up, 2009-2011 Pavillion Lakes research project, etc.
## Schedule

<table>
<thead>
<tr>
<th>Date</th>
<th>Event Description</th>
</tr>
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<tbody>
<tr>
<td>11/29/11</td>
<td>ISS Payloads Office authorization received</td>
</tr>
<tr>
<td>1/30/12</td>
<td>ISS Research Planning Working Group approval received</td>
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<tr>
<td>9/5/12</td>
<td>PCM (PLUTOs, Flight Director, MSFC, Ames)</td>
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<tr>
<td>11/13/12</td>
<td>SSC Lab testing</td>
</tr>
<tr>
<td>11/26/12</td>
<td>JSL Lab Testing for first Comm Test</td>
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<tr>
<td>11/29/12</td>
<td>SSTF-based end-to-end test</td>
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<tr>
<td>1/28/13</td>
<td>First ISS-to-ground Comm Test</td>
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<tr>
<td>3/13 – 5/13</td>
<td>Engineering and Ops Readiness Tests at Ames</td>
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<tr>
<td>4/3/13</td>
<td>Crew Usability Test – SSTF to Rover at Ames</td>
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<tr>
<td>5/8/13</td>
<td>JSL Lab Testing for Crew Ops</td>
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<tr>
<td>6/10/13</td>
<td>Second ISS-to-ground Comm Test (due to ODAR, etc.)</td>
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<tr>
<td>6/17/13</td>
<td>Crew Ops session #1 – Site survey</td>
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<tr>
<td>7/22/13</td>
<td>Crew Ops session #2 – Antenna deploy</td>
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<tr>
<td>8/5/13 (tbc)</td>
<td>Crew Ops session #3 - Inspection</td>
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K10 rover at dawn in the ARC “Roverscape”
K10 performing surface survey with cameras & lidar
K10 deploying simulated polymide antenna
Chris Cassidy studies the “Surface Telerobotics Workbench” (2013-06-17)
Chris Cassidy uses the “Surface Telerobotics Workbench” to remotely operate K10 from the ISS (2013-06-17)
ISS Mission Control (MCC-H) during Surface Telerobotics test (2013-06-17)
View of robot interface (top left) and K10 at ARC (top right)
“PLUTO” Multi-Purpose Support Room at JSC: provides data comm & crew laptop support
Multi-Mission Operations Center at ARC: manages Surface Telerobotics test sessions
K10 support team at ARC: provides rover engineering & test logistics
Remote Operations Center at UC-Boulder: mission simulation science team