Interactive Exploration Robots

Human-robotic collaboration and interactions

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Human Planetary Exploration

Jack Schmitt & Lunar Roving Vehicle
Apollo 17 (December 1972)
What’s changed since Apollo?

- Kaguya
- Chandrayaan
- LRO
- Space Station
- Phoenix
- LCROSS
- Mars Rovers
- Robonaut 2
- Rosetta
Many forms of human-robot teaming

- "Robot as tool" is only one model
- Humans and robots do not need to be just co-located or closely coupled
  - Distributed teaming is also important

Concurrent, interdependent operations

- Human-robot interaction is still slow and mismatched (compared to human teams)
- Easy for robots to slow down the human
  - Loosely-coupled teaming (in time and space) should also be employed

Distributed teams

- Require coordination and info exchange
- Require understanding of (and planning for) each teammate’s capabilities
Interactive Exploration Robots

**Part 1**
Humans on Earth
Robot in space

**Part 2**
Humans on Earth
Robot on the Moon

**Part 3**
Humans in orbit
Robot on planet

**Part 4**
Real-time telerobotics

Human-robotic collaboration and interactions for space exploration
Humans on Earth / Robot in space
Space Station In-Flight Maintenance

Extra-Vehicular Activity (EVA)
- Not enough crew time to do everything (only 1-2 EVAs per year)
- Crew must always carry out “Big 12” contingency EVA’s if needed
  - Maintain electrical power system
  - Maintain thermal control system
- Prep & tear down: up to 3 hr per EVA

Intra-Vehicular Activity (IVA)
- Crew spends a lot of IVA time on maintenance (40+ hr/month)
- Routine surveys require 12+ hr/month
  - Air quality, lighting, sound level, video safety, etc.
- Crew must always carry out contingency IVA surveys
  - Find and repair leaks, etc.
Space Station Robots

Space Station Remote Manipulator System (Canadarm2)

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Space Station Robots

Special Purpose Dexterous Manipulator ("Dextre")

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Space Station Robots

Robonaut 2

SPHERES

Astrobee (concept)
SPHERES

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Smart SPHERES

Smart SPHERES Network Setup
Space Station Interior Survey (2012)

December 12, 2012
Crew: Kevin Ford, Expedition 33 Commander
Humans on Earth / Robot on another world
Mars Rovers

Mars Exploration Rover on Mars (artist concept)

Curiosity at “Big Sky”
Resource Prospector Mission

**Mission**
- Characterize the nature and distribution of **lunar polar volatiles**
- Demonstrate **in-situ resource utilization**: process lunar regolith

**Key Points**
- Class D / Category 3 Mission
- Launch: ~2021
- Duration: 6-14 Earth days
- Direct-to-Earth communications
- **Real-time subsurface prospecting**

**Rover**
- Mass: 300 kg (including payload)
- Size: 1.4m x 1.4m x 2m
- Max speed: **10 cm/s**
- Speed made good: **0.5 cm/s**
RP Mission Animation
Real-time Prospecting Field Test (2014)

Goals

• **Prospecting.** Mature prospecting ops concept for NIRVSS and NSS instruments in a lunar analog field test

• **Real-Time Operations.** Improve support software by testing in a setting where the abundance / distribution of water is not known a priori

• **Science on Earth.** Understand the emplacement and retention of water in the Mojave Desert by mapping water distribution / variability
Prospecting Rover and Instruments

Sample Evaluation
Near Infrared Volatiles Spectrometer System

Resource Localization
Neutron Spectrometer System
Real-time Operations (NASA Ames)
Mojave Volatiles Prospector
Mojave Desert, California
October 2014
Science Operations Interface (xGDS)
Exploration Ground Data System (xGDS)
Humans in space / Robot on the ground
“Fastnet” Lunar Libration Point Mission

**Orion MPCV at Earth-Moon L2 (EM-L2)**
- 60,000 km beyond lunar farside
- Allows station keeping with minimal fuel
- Crew remotely operates robot
- Does not require human-rated lander

**Human-robot conops**
- Crew remotely operates surface robot from inside flight vehicle
- Crew works in shirt-sleeve environment
- Multiple robot control modes

Credit: (Lockheed Martin / LUNAR)
“Fastnet” Mission Simulation with ISS

Pre-Mission Planning

Ground teams plan out telescope deployment and initial rover traverses.

Surveying

Crew gathers information needed to finalize the telescope deployment plan.

Telescope Deployment

Crew monitors the rover as it deploys each arm of the telescope array.

Telescope Inspection

Crew inspects and documents the deployed telescope for possible damage.

ISS Expedition 36

Chris Cassidy

17 June 2013

Luca Parmitano

26 July 2013

Karen Nyberg

20 August 2013

Spring 2013

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ISS Test Setup

Human-robotic collaboration and interactions for space exploration

“Live” Rover Sensor and Instrument Data (telemetry)

Rover/Science Data (e.g. imagery)

Post-test File Transfer

400 kbit/s (avg), 500 msec delay (max)

Uplink

400 kbit/s (avg), Out-of-Band

Downlink

400 kbit/s

Post-test File Transfer to laptop storage

Interface Instrumentation & Evaluation Data

Rover Plan (command sequence)

K10 rover at NASA Ames

3 kbit/sec (avg), 500 msec delay (max)
Robot Interface (Supervisory Control)

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

Task Sequence

Run Task Sequence Controls

NASA

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Crew-controlled Telerobotics (2013)
Crew-controlled Telerobotics (2013)
Assessment Approach

Metrics

- **Mission Success**: % task sequences: completed normally, ended abnormally or not attempted; % task sequences scheduled vs. unscheduled
- **Robot Utilization**: % time robot spent on different types of tasks; comparison of actual to expected time on; did rover drive expected distance
- **Task Success**: % task sequences per session and per task sequence: completed normally, ended abnormally or not attempted; % that ended abnormally vs. unscheduled task sequences
- **Contingencies**: Mean Time To Intervene, Mean Time Between Interventions
- **Robot Performance**: expected vs. actual execution time on tasks

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 (Bedford Scale), situation awareness (SAGAT)

M. Bualat, D. Schreckenghost, et al. (2014) “Results from testing crew-controlled surface telerobotics on the International Space Station”. Proc. of 12th I-SAIRAS (Montreal, Canada)
Real-time Exploration Telerobotics
Real-time Exploration Telerobotics

Telepresence Remotely Operated Vehicle (TROV)

- Benthic ecology survey of McMurdo Sound (Nov-Dec 1993)
- Remote operations from NASA Ames via satellite (832 kbps downlink)
- Virtual environment + telepresence video (head tracked stereo display)

Telepresence ROV (1993)
Real-time Exploration Telerobotics

Marsokhod at Kilauea

• Geologic mapping of Southwest Desert at Kilauea (Feb 1995)
• Remote operations from NASA Ames via satellite (T1 link)
• Virtual environment + telepresence video (stereo display)

Marsokhod at Kilauea (1995)
Lessons from TROV & Marsokhod

Latency

- Latency is only one factor for remote exploration: type of science, instruments & data, cost, risk, staffing, robot capabilities, etc.
- Remote (robotic) exploration is not dominated by control latency. Data collection (with instruments), analysis (many steps), and decision making (strategic and tactical planning) are all far more significant.

Spatial displays

- 3D visualizations is essential for most field studies
- Head-mounted and stereo video displays are pseudo 3D, not true 3D, which leads to many issues (accommodation errors, etc)
- High levels of presence can be achieved even with limited data.

Real-time telerobotics

- Telepresence (immersive real-time presence) is not a panacea
- Manual control is imprecise and highly coupled to human performance (skills, experience, training)
- Minimizing risk is often (far more) important than efficiency.
Questions?

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