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

Human-robotic collaboration and interactions for space exploration
Human-Robot Teams

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
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)
Space Station Robots

Special Purpose Dexterous Manipulator (“Dextre”)
Space Station Robots

Robonaut 2

SPHERES

Astrobee (concept)
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
Human-robotic collaboration and interactions for space exploration

Real-time Operations (NASA Ames)
Mojave Volatiles Prospector
Mojave Desert, California
October 2014
Rover Operator Interface (VERVE)
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
“Fastnet” Mission Simulation with ISS

ISS Expedition 36

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.

Chris Cassidy
17 June 2013

Luca Parmitano
26 July 2013

Karen Nyberg
20 August 2013

Spring 2013
ISS Test Setup

- **“Live” Rover Sensor and Instrument Data (telemetry)**
  - Uplink
  - Downlink
  - 400 kbit/s (avg), 500 msec delay (max)
  - 400 kbit/s (avg), Out-of-Band

- **Interface Instrumentation & Evaluation Data**

- **Rover/Science Data (e.g. imagery)**
  - Post-test File Transfer
  - Rover Plan (command sequence)
  - 3 kbit/sec (avg), 500 msec delay (max)
  - 400 kbit/s (avg), Out-of-Band

- **K10 rover at NASA Ames**

Human-robotic collaboration and interactions for space exploration
Robot Interface (Supervisory Control)
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)
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 that efficiency.
Questions?

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