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  Robonaut 2  LCROSS
Mars Rovers  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
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)
Human-robotic collaboration and interactions for space exploration
Smart SPHERES

Smart SPHERES Network Setup

Diagram showing network setup with various components including JEM, Node 2, Android Smartphone, DTN Gateway SSC, OPS LAN, JSC Building 30, OCA LAN, OCA Ground Router, SPHERES WS, White Sands, and TDRSS.
Humans on Earth / Robot on another world
Mars Rovers

Mars Exploration Rover on Mars (artist concept)

Curiosity at “Big Sky”
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
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

Human-robotic collaboration and interactions for space exploration
ISS Test Setup

"Live" Rover Sensor and Instrument Data (telemetry)

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

Uplink to laptop storage

Rover/Science Data (e.g. imagery)

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

Post-test File Transfer

Downlink

Interface Instrumentation & Evaluation Data

3 kbit/sec (avg), 500 msec delay (max)

Rover Plan (command sequence)

K10 rover at NASA Ames

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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 (accomodation 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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