Interactive Exploration Robots

Human-robotic collaboration and interactions

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What’s changed since Apollo?

- Kaguya
- Chandrayaan
- LRO
- Space Station
- Phoenix
- Robonaut 2
- LCROSS
- Mars Rovers
- 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

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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)
Space Station Robots

Special Purpose Dexterous Manipulator ("Dextre")

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Space Station Robots

- Robonaut 2
- Astrobee (concept)
- SPHERES
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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**
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
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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
ISS Test Setup

- **“Live” Rover Sensor and Instrument Data (telemetry)**
- **400 kbit/s (avg), 500 msec delay (max)**
- **Upplink**
  - Data transfer to laptop storage
- **Downlink**
  - 400 kbit/s (avg), Out-of-Band
- **Uplink**
- **Post-test File Transfer**
- **Rover/Science Data (e.g. imagery)**
- **Interface Instrumentation & Evaluation Data**
- **Rover Plan (command sequence)**
- **3 kbit/sec (avg), 500 msec delay (max)**

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)
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 that efficiency.
Questions?

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