Human-Robot Teaming:
From space robotics to self-driving cars

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Human-robot teams...
What is a team?

Teams are interdependent
- Members share a common goal
- Group needs > individual need
- Common ground & trust

Norms
- Background (experience, training, knowledge, etc.)
- Organizational structure
- Work protocol (taskwork)

Cornerstones of teamwork
1. Communication
2. Coordination
3. Collaboration
Research @ NASA Ames

Part 1: Communication
• Signaling for non-humanoid robots
• Convey robot state and intent using dynamic light and sound
• Ambient and active communication

Part 2: Coordination
• Achieve common (joint) objective
• Independent human and robot activities
• Robots work before, in parallel (loosely coupled) and after humans

Part 3: Collaboration
• Humans support autonomous robots
• Focus on cognitive tasks (planning, decision making, etc)
• Human-robot team may be distributed
Spatial negotiation

- When humans and robots must co-exist in the same space, there is often a need for spatial negotiation
- Cannot always rely on pre-defined rules (e.g., “right of way”) due to ambiguity and uncertainty
- Signaling (lights, movement, sound, etc) is an effective manner to communicate intent and elicit action.
Considerations

- **What** to convey (importance of the information)
- **When** to convey (timing of the information)
- **How** to convey (constrained/modulated by configuration, situation, etc.)
- **To whom** do we convey (user role, capability to receive/respond, etc.)

Astrobee

Free-flying space robot
- International Space Station internal environment
- All electric with fan-based propulsion
- Three smartphone computers
- Expansion port for new payloads
- Open-source software
- ~30x30x30 cm, ~8 kg

Uses
- Mobile sensor
- Remotely operated camera
- Zero-G robotic research

Autonomy
- Docking & recharge
- Perching on handrails
- Vision-based navigation
Astrobee light signal concept
Astrobee development
Astrobee on the Space Station

April 30, 2019
First power-on of “Bumble Bee”
Astrobee on the Space Station

April 30, 2019
Anne McClain verifies propulsion system
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Robots for human exploration

Robots before crew
- Prepare for subsequent human mission
- Scouting, prospecting, etc.
- Site preparation, equipment deployment, infrastructure setup, etc.

Robots supporting crew
- Parallel activities and real-time support
- Inspection, mobile camera, etc.
- Heavy transport & mobility

Robots after crew
- Perform work following human mission
- Follow-up and “caretaking” work
- Close-out tasks, maintenance, etc.

Human planetary exploration

Jack Schmitt & Lunar Roving Vehicle
Apollo 17 (1972)
Why robots should “follow-up” after humans...
Haughton Crater

- 20 km diameter impact structure
- ~39 million years ago (Late Eocene)
- Devon Island: 66,800 sq. km (largest uninhabited island on Earth)
Crew mission

Geologic Mapping
- Document geologic history, structural geometry & major units
- Example impact breccia & clasts
- Take photos & collect samples

Geophysical Survey
- Examine subsurface structure
- 3D distribution of buried ground ice in permafrost layer
- Ground-penetrating radar: manual deploy, 400/900 MHz
Geologic mapping results

- Stratified sediments
- Contact between carbonates
- View East into crater
- Gray carbonate breccia
Geophysical survey results

subsurface ice wedges
Robotic follow-up plan
Robotic follow-up results

Geologic Mapping

- **Verified the geologic map** in multiple locations (revisited and confirmed geologic units)
- **Amended the geologic map** in multiple locations (added detail to long-range crew observations)

Geophysical Survey

- **Detail study of “polygons”** (correlated surface & subsurface features identified by crew)
- **Measured average depth** of subsurface ice layer (refined observations from crew)

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Crew-controlled telerobotics: “Avatar” in real-life
Imperfect robot autonomy

Human-robot collaboration

• Humans provide high-level guidance (not low-level control) to assist when robot autonomy is inadequate, untrusted, etc.

• Address the many anomalies, corner cases, and edge cases that require unique solutions, but which are not currently practical to develop, test, and validate under real-world conditions

• Obstacle detection, path planning, sample collection decision making, etc.
Astronaut in space / Robot on Earth
Astronaut remotely helping a space robot

July 26, 2013

Crew: Luca Parmitano, Expedition 36 Flight Engineer
Self-driving cars at NASA Ames

Public/private partnerships

- **Google** (2014-15): collaborative testing of sensors and vehicles
- **Nissan** (2014-19): cooperative software development

**NASA interest**

- Expand knowledge of commercial autonomous systems
- Develop protocols and best practices for testing of autonomous systems under **complex real-world conditions**
- Facilitate transfer of NASA technology

**Technology maturation**

- Safe testing in urban environment
- **Leverage NASA expertise** in autonomy, robotics, safety critical systems, and rigorous testing
Imperfect vehicle autonomy

Edge cases, corner cases, and anomalies

• When a construction worker uses hand gestures to provide guidance, or direction, no autonomous car today can reliably make the right decision.

• When the sun is immediately behind a traffic light, most cameras will not be able to recognize the color of the signal through the glare.

• If we see children distracted by the ice cream truck across the street, we know to slow down, as they may dash toward it.

– Andrew Ng (Wired, 3/15/2016)
Support Center / Self-driving car on the road

“Mobility Managers” remotely supporting self-driving cars
CES 2017 demo

Human-robot teaming
Human remotely helping a self-driving car
Teaming with NASA: Small Businesses

SBIR / STTR program

• Adapt and mature terrestrial robotics technology for space use
• Identify and transition low-TRL technology from academia
• Build commercial products for economies of scale & sustainability
• Help NASA move beyond “one-off” components and systems
• Very important to understand NASA relevance before proposing !!
Teaming with NASA: Software Licensing

Human-robot teaming

Vision Workbench

RoverSW

Neo Geography Toolkit (Ames Stereo Pipeline)

NASA Tensegrity Robotics Toolkit

Exploration Ground Data Sys. (xGDS)

Visual Environment for Remote Virtual Exploration (VERVE)

RAPID (NASA robot middleware)

Astrobee Robot Software

Apache 2
Teaming with NASA: Partnerships

Academic
- The Robotics Institute
- Vanderbilt University
- Massachusetts Institute of Technology (MIT)
- Case Western Reserve University
- Berkeley University
- Rutgers University
- University of Idaho
- USC
- Brigham Young University
- Wisconsin University of Wisconsin-Madison
- Cornell University
- KAIST

Commercial
- Google
- Nissan
- Astrobotic
- SSL
- ENERGID Robotics and Machine Vision
- Otherlab
- Altius Space Machines

Government
- DARPA
- Marine Corps
- SPAWAR
- NPS
- NASA
- USGS

Human-robot teaming

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