OUR HOME WITH THE ROBOTS

From planetary rovers to self-driving cars

Terry Fong
Chief Roboticist
NASA Ames Research Center
terry.fong@nasa.gov
Human Planetary Exploration

Jack Schmitt & Lunar Roving Vehicle
Apollo 17 (1972)
What’s Changed Since Apollo?

Kaguya
Chandrayaan
LRO
Space Station
Phoenix
Robonaut 2
LCROSS
ATHLETE, K10, Chariot
Mars Rovers

Our home with the robots
Human-Robot Teaming for Space

**Improve performance**

- Study how **humans can remotely support autonomous robots**
- 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
- Humans provide high-level guidance (not low-level control) to assist when autonomy is inadequate, untrusted, etc.
Lunar Mission Concept

Orion at Earth-Moon L2 Lagrange

- Astronaut remotely operates lunar rover from orbiting spacecraft – **AVATAR in real-life!**
- Spacecraft orbiting 60,000 km beyond lunar farside
- High-bandwidth, low-latency data communication between spacecraft and surface robot

Credit: (Lockheed Martin / LUNAR)
**Lunar Mission Simulation**

**“Surface Telerobotics” Project**
- Simulation of the “Orion at Earth-Moon L2 Lagrange” concept
- Astronauts in the International Space Station (ISS)
- K10 planetary rover at NASA Ames
- Data comm via satellite relay with short delay (750 msec round-trip)
- Asynchronous bandwidth (3 Kbps downlink, 800 Kbps uplink)

**ISS Expedition 36 testing**
- June 17, 2013 – C. Cassidy, survey
- July 26, 2013 – L. Parmitano, deploy
- Aug 20, 2013 – K. Nyberg, inspect

**Human-robot mission sim:** site survey, telescope deployment, and inspection

**Telescope proxy:** Kapton polyimide film roll (no antenna traces, electronics, or receiver)

**3.5 hr per crew session** (“just in time” training, system checkout, ops, & debrief)

**Robot ops:** manual control (discrete commands) and supervisory control (task sequence)
Astronaut in Space / Robot on Earth
Chris Cassidy remotely operates K10 from the ISS to perform site survey (2013-06-17)
K10 performing surface survey
Luca Parmitano works with K10 to deploy simulated polymide antenna (2013-07-26)
K10 deploying simulated polymide antenna
Deployed simulated polymide antenna (three “arms”)
Karen Nyberg works with K10 to document deployed simulated antenna (2013-08-20)
K10 documenting simulated polymide antenna
Astronaut Remotely Helping Space Robot
Astronaut Remotely Helping Space Robot

July 26, 2013

Crew: Luca Parmitano, Expedition 36 Flight Engineer

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Human Remotely Helping Self-driving Car(s)

Mobility managers at a support center
Vehicle assist: Situation assessment
Vehicle assist: High-level guidance
NASA and Self-Driving Cars

Common Technologies

Autonomy
Advanced Planning & Scheduling Algorithms, etc.

Human-Autonomy Teaming
Robotic Supervision including Human/Robotic Interactions, etc.

Networked Operations
Remote Vehicle Management, etc.

Prognostics / Diagnostics
Including State Management, etc.

Sensors and Perception
Data Processing / Fusion Methodologies, etc.

Verification and Validation
Methodologies & Application Experiences, etc.

NASA Missions
Planned human-machine interaction
Natural and time delayed environments
Aerial, space, and planetary navigation
On-board and ground control autonomy
Cyber-security for “one-off” systems

Self-Driving Cars
Diverse human-machine interaction
Structured environment
GPS & map-based navigation
Distributed and cloud-based autonomy
Cyber-security for consumer product
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
Working 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!!

sbir.nasa.gov
Working with NASA: Software Licensing

- Vision Workbench
  - Apache 2
- RoverSW
  - NOSA 1.3
- Neo Geography Toolkit
  - (Ames Stereo Pipeline)
  - Apache 2
- NASA Tensegrity Robotics Toolkit
  - Apache 2
- Exploration Ground Data Sys. (xGDS)
  - Apache 2
- Visual Environment for Remote Virtual Exploration (VERVE)
  - Apache 2
- RAPID (NASA robot middleware)
  - Apache 2
- Astrobee Robot Software
  - Apache 2
Working 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 (BYU)
- Wisconsin University
- Cornell University
- Universiteit Gent
- KAIST
- SETI Institute

**Commercial**
- Google
- Nissan
- Astrobotic
- SSL
- ENERGID
- Otherlab
- ALTUS Space Machines
- PI
- TRAC Labs
- ProtoInnovations

**Government**
- DARPA
- Marine Corps
- SPAWAR
- NPS
- Naval Research Laboratory
- USGS

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Questions?

Intelligent Robotics Group
Intelligent Systems Division
NASA Ames Research Center

irg.arc.nasa.gov