[PS]Robotic Scouting for Human Exploration*

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Abstract

From November 3-6, 2008, we conducted a full-scale test of a "robotic recon" system at NASA Ames. During this test, the K10 "Red" robot was used to establish a preliminary geologic map of an outdoor test area and to help plan a short 30-min follow-up EVA in shirtsleeves in that area. The goal of the test was to improve NASA's understanding of how robotic scouting can help plan EVAs, and also how robots might best be used to complement humans.

When humans return to the Moon around 2020, crews will initially be on the lunar surface less than 10% of the time. During the 90% of time between crew visits, however, robots will be available for surface operations under ground control. A central challenge, therefore, is to understand how robotic systems can be used to improve overall science return and mission productivity. One possible method is to use robots to perform scouting in advance of human activity.

Robotic rover scouting involves using a planetary rover to collect ground-level data. Scouting is well understood to be an essential phase of field work, particularly for geology, and can be: (1) traverse-based (examining stations along a route); (2) site-based (examining stations within a bounded area); or (3) survey-based (systematically collecting data along defined transects). Robot-

mounted instruments can be used to examine the surface and subsurface at resolutions (e.g., um to cm scale) and at viewpoints not achievable from orbit. The data can then be used to plan subsequent human or robot activity.

During our test, K10 Red carried three recon instruments: a scanning lidar (acquires 3D measurements of terrain at mm resolution), a color panorama capture system (consumer digital camera on a pan/tilt), and a high-resolution terrain imager (downward-facing consumer digital camera). We remotely operated K10 Red with a ground control team, which was located in the NASA Ames "FutureFlight Central" facility. The ground control team included a science team (strategic level planning), flight control team (tactical operations), and robot support team (diagnosis and repair).

In this paper, we summarize the objectives for the test, describe the test setup and protocol, and present results and lessons learned. In addition, we identify key issues and open questions that remain to be addressed, as well as suggest directions for future work.

Robotic Scouting for Human Exploration

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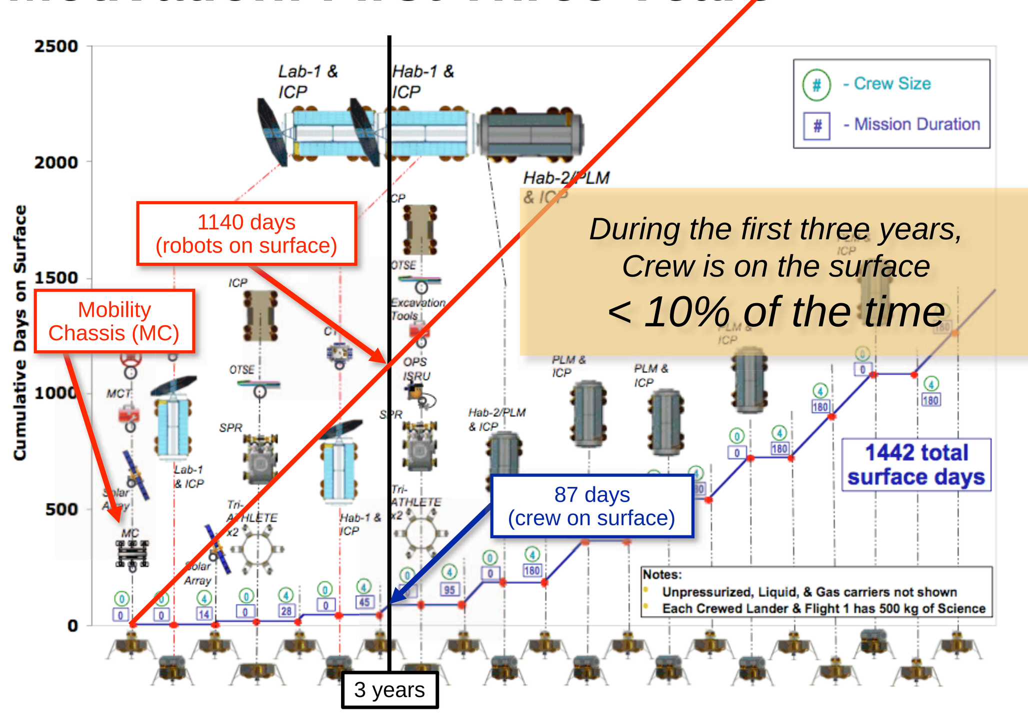
Overview

When humans return to the Moon around 2020, crews will initially be on the lunar surface less than 10% of the time. During the 90% of time between crew visits, however, robots will be available for surface operations under ground control. A central challenge, therefore, is to understand how robotic systems can be used to improve overall science return and mission productivity. One possible method is to use robots to perform scouting in advance of human activity.

The "Human-Robot Site Survey" (HRSS) project is a multi-year activity investigating techniques for lunar site survey. Survey involves producing high quality, high resolution maps, including 3D surface models, mineralogy, terramechanics, and subsurface stratigraphy. These maps are required for scientific understanding, lunar surface operations planning, ISRU, and infrastructure emplacement.

Motivation: First Three Years



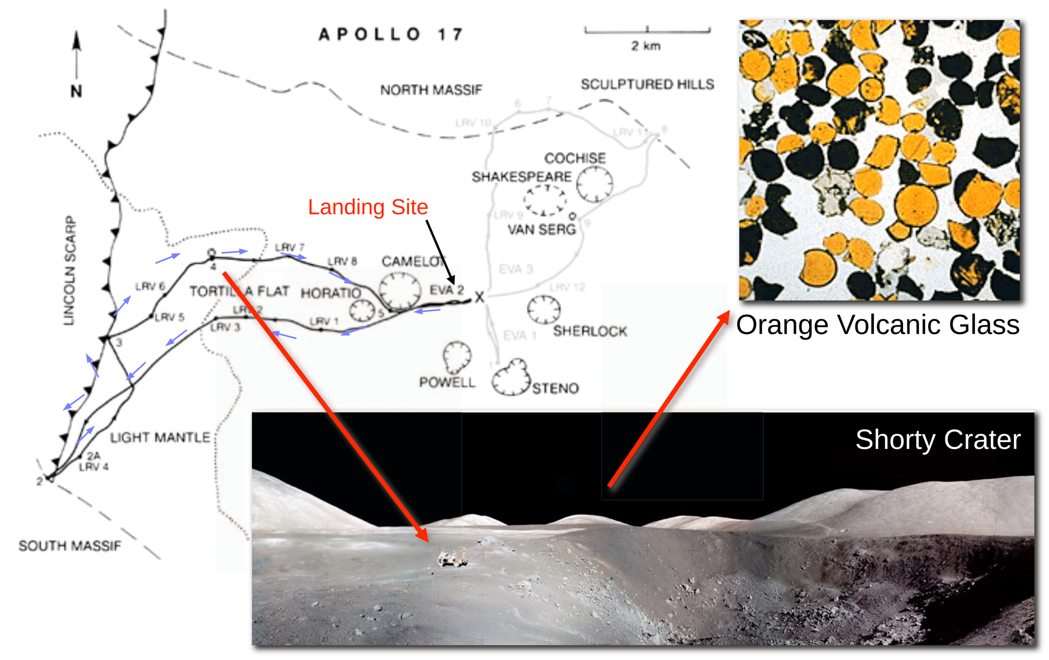
Robotic Reconnaissance

Robotic rover scouting involves using a planetary rover to collect ground-level data. Scouting is an essential part of field work, particularly for geology. Robot-mounted instruments can be used to examine the surface and subsurface at resolutions and from viewpoints not achievable from orbit. The data can then be used to plan subsequent human or robot activity.

During Apollo 17 EVA-2, the crew drove from the landing site to the South Massif, and worked back toward Shorty crater. At Shorty, Schmitt found orange glass, perhaps the mission's most important find. But little time remained for study.

Robotic recon can identify high priority targets before crew arrive. This information would change traverse plans, i.e., adding or dropping EVA stations, or changing the time allocated at a stations based on priorities and tasks.

Why Is Recon Useful?



Operational Readiness Test

From Nov 3-6, 2008, we conducted a full-scale test of a "robotic recon" system at NASA Ames. During the test, K10 "Red" was used to create a preliminary geologic map and to plan a 30-min follow-up EVA in shirtsleeves in the same area. The goal was to improve our understanding of how robotic scouting can help plan EVAs, and how robots might best be used to complement humans.

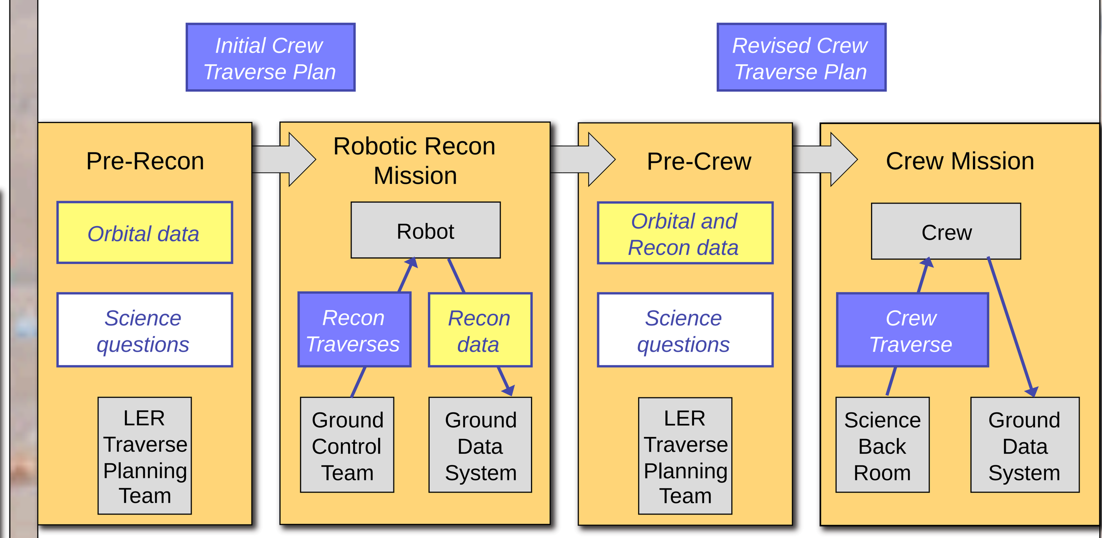
Approach

- Use K10 to establish geologic map
- Exercise new ground control team
- Post-recon: shirtsleeves EVA to assess impact of surface recon data

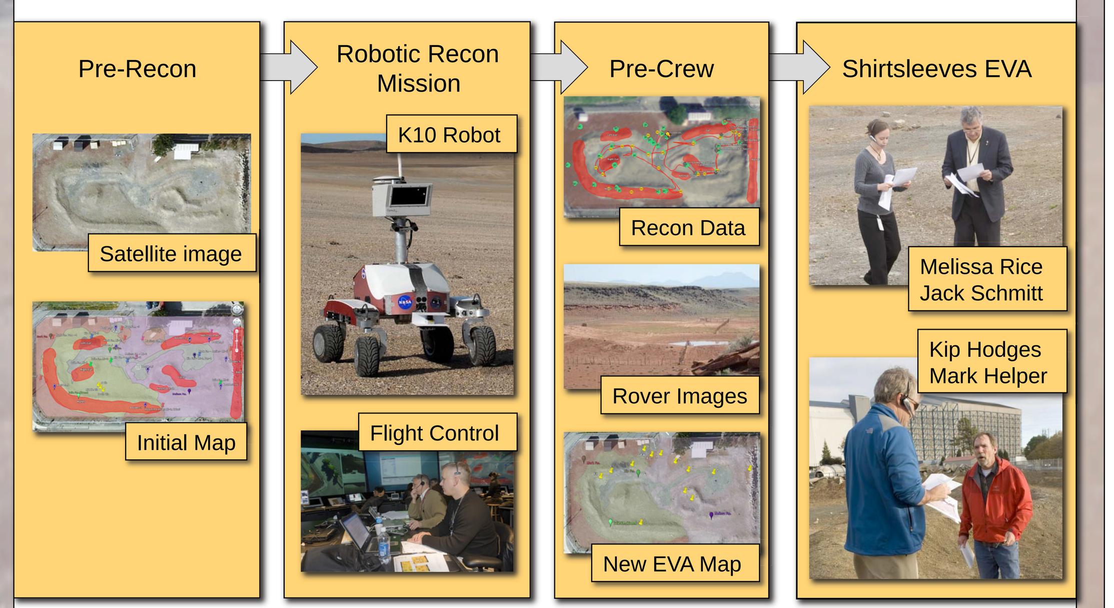
Lessons learned

- Recon significantly improves crew situational awareness & productivity
- Robotic recon complements & supplements orbital remote sensing
- Science ops is the bottleneck, not robot speed or remote ops

Approach: Four Phases



Approach: Four Phases



Approach

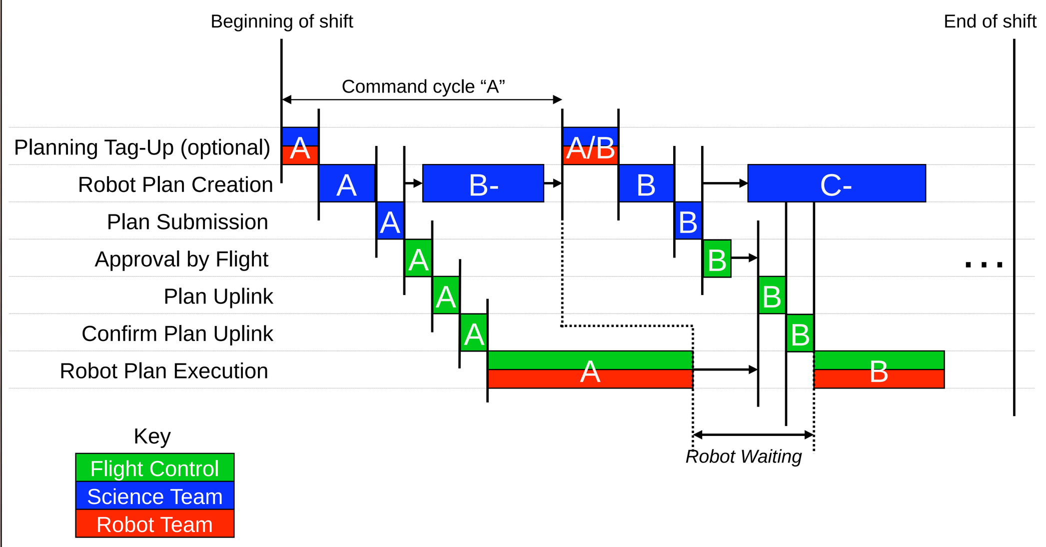
During our test, K10 Red carried three recon instruments: a scanning lidar (acquires 3D measurements of terrain at mm resolution), a color panorama capture system (consumer digital camera on a pan/tilt), and a high-resolution terrain imager (downward-facing consumer digital camera).

We remotely operated K10 Red with a ground control team, which was located in the NASA Ames "FutureFlight Central" facility. The ground control team included a science team (strategic level planning), flight control team (tactical operations), and robot support team (diagnosis and repair).

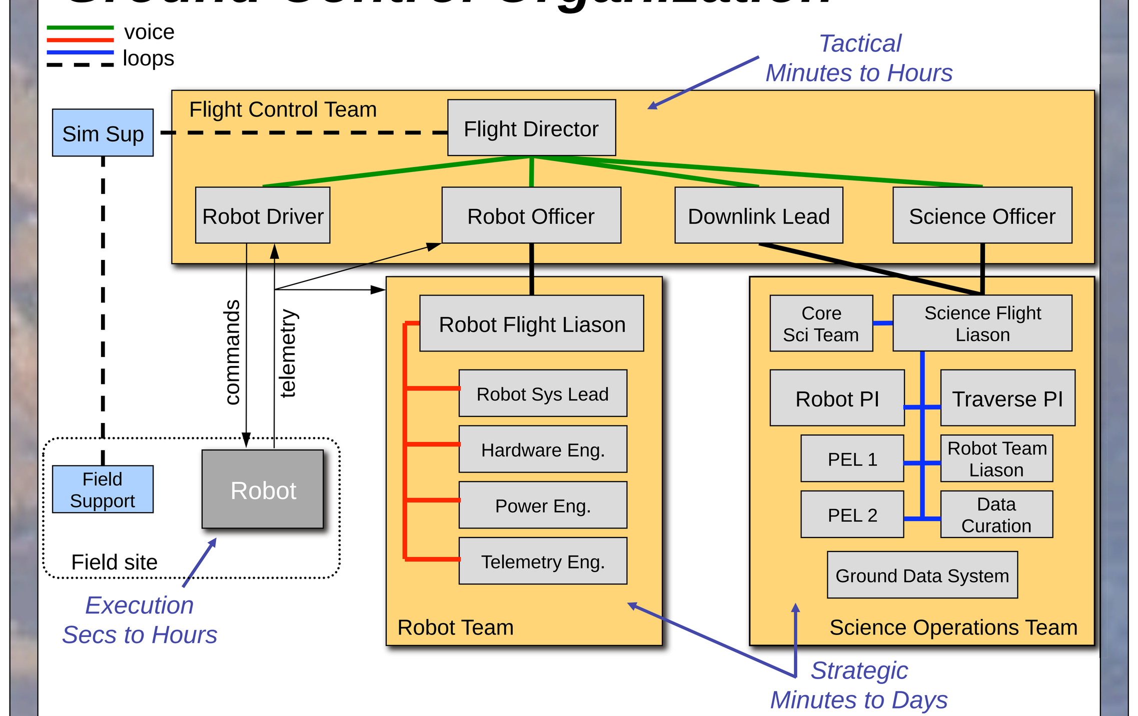
Information gathered during the robotic recon operations was used to plan a follow-up EVA in shirt-sleeves. The impact of recon on crew efficiency was subjectively rated. Future controlled experiments will quantify this impact.

Robotic Recon Operations

Approach: Tactical Ops Timeline



Ground Control Organization



Post-Recon Shirtsleeves EVA

EVA traverse plan

- Developed using orbital image + robotic recon data
- 19 Stations, 21 Nominal and 8 "get-ahead" tasks
  - ✓ Assess relative ages of formations
  - ✓ Sample major units
  - ✓ Inspect particular boulders

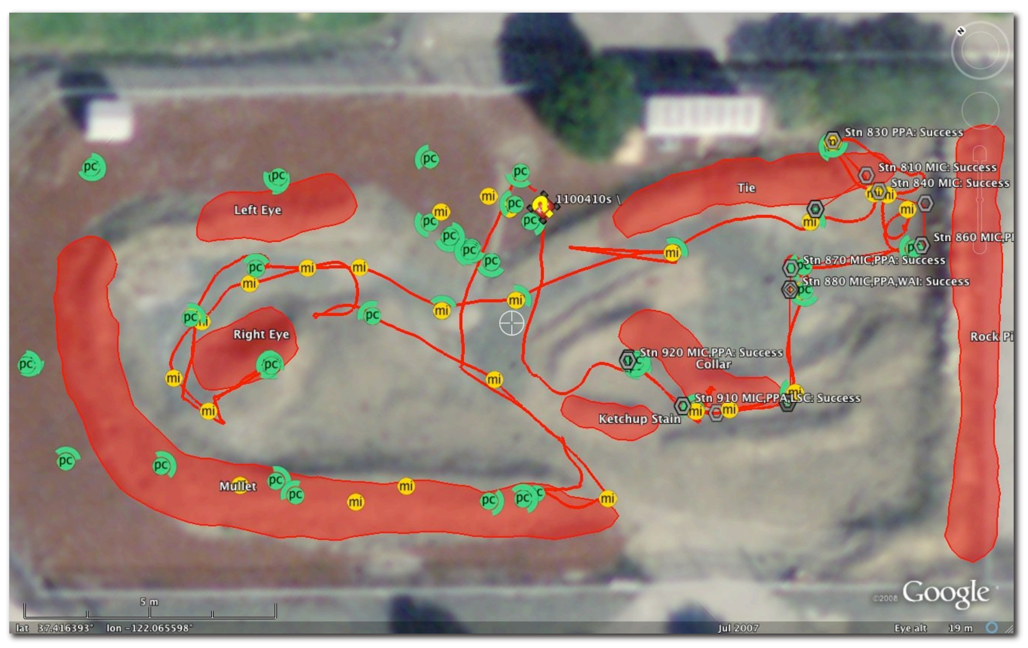
Three Two-person crews

- Melissa Rice (Cornell) & Jack Schmitt (NASA)
- Kip Hodges (ASU) & Mark Helper (UT Austin)
- Jerry Schaber (USGS ret.) & Julie Chrittendon (ARC)

Testing

- Subjective evaluation of science productivity (post-EVA questionnaire + focused debrief)
- Each crew implemented same traverse plan
- Science Team provided support via "CapCom" (voice comms)

Recon Data Map



Lessons Learned

Recon improves situational awareness: site, relations, targets,objectives

- Increases familiarity with site (terrain, extents, scale, etc.)
- Improves identification and resolving of geologic contacts
- Provides close-up knowledge of science targets
- Better preparedness: helps crew know what to expect / look for
- Greatly increases chance of success

Recon improves crew productivity

- Improves situational awareness & knowledge of site
- Helps eliminate unnecessary (unproductive) tasks
- Increases chances of success
- Reduces unproductive time

Ground truths and fills in gaps in remote sensing information

- Higher spatial, spectral, and temporal resolution
- Can find things you cannot see from orbit
- Coupled to the ground, contact, and sub-surface

Lessons Learned

Robotic assistant does not mean "use only when crew is around"

- Robots should be used before, during, and after crews
- Robots can perform activities independently (under ground control)
- Crew time is most important resource
- Do not focus on "Which tasks for humans? For robots?"
- Focus instead on: *"How can humans and robots work together in a coordinated manner to increase productivity?"*

Primary bottleneck is science operations

- Robot speed is not the limitation
- K10 moves & gathers data faster than the science team can operate (0.5 m/s average speed is more than fast enough)
- Need improved tools for data analysis, visualization, & planning

Keep the sensor suite simple

- Current instruments (pancam, lidar, MI) work very well
- For recon, passive observation is more important than manipulation

ORT Team

Flight Control Team

- **Directors**: Rob Landis, Steve Riley
- **Controllers**: Matt Deans, Eric Park, Debbie Schreckenghost, Tifanie Smart, Hans Utz

Science Team

- **Geologists**: Pascal Lee, Mark Helper, Kip Hodges, Jerry Schaber, Jack Schmitt
- **Instrument leads**: Julie Chittenden, Marwan Hussein, Melissa Rice, Jeff Tripp
- **Support**: Dave Lees, Trey Smith

Robot Team

- **System Lead:** Maria Bualat
- **Engineers:** Xavier Bouyssousnouse, Vinh To, Susan Lee

Test Team

- Simulation Supervisor: Terry Fong
- Project Manager: Linda Kobayashi
- Assessment: Estrellina Pacis, Mike Lundy, Simon Rutishauser
- Observer: Ken Ford