Completed Element (2012 - 2014)

Human Robotic Systems (HRS): Robotic ISRU Acquisition Element

Game Changing Development Program | Space Technology Mission Directorate (STMD)

ABSTRACT

The high level objective of the "Robotic ISRU Resource Acquisition" project element is to develop technologies that enable robotic prospecting and sampling of resources on remote bodies. The ultimate objective is to make HRS deliveries to the Advanced Exploration Systems (AES) Lunar Resource Prospector Mission (Mission Concept Review occurred Sept 17, 2013) and to provide prospecting and sampling technologies for the NASA Asteroid Initiative, and Mars ISRU (including Mars' moons). The technical approach within this project element in FY2014 is two-pronged. The first is to mature and field test HRS's Exploration Ground Data Systems (xGDS) set of tools to prepare them to be ready for use in the Resource Prospector Mission or Asteroid Initiative. The second path continues advancing knowledge and approaches for regolith sampling and excavation in reduced and microgravity environments. The purpose of the regolith acquisition is for ISRU prospecting and resource utilization.

ANTICIPATED BENEFITS

To NASA funded missions:

Exploration Ground Data Systems (xGDS) will support multiple Science Mission Directorate funded field tests including Mojave Volatiles Project and Pavilion Lake Research Project. Several xGDS capabilities will be ready for infusion into the Resource Prospector (RP), which will provide the rover with a traverse planner, real-time plotting, and raster mapping tools, and well as the ability to be controlled over a time delay and deal intermittent communications availability.

DETAILED DESCRIPTION

During 2014, the Robotic ISRU Resource Acquisition project element will develop two technologies: Exploration Ground Data Systems (xGDS) Sample Acquisition on Asteroids, Mars, Moons

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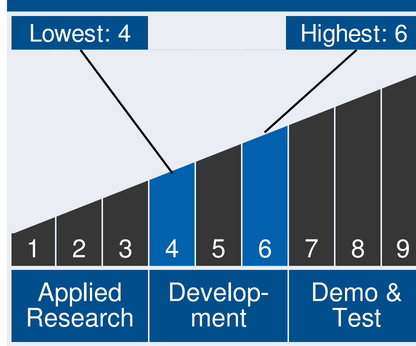
Technology Maturity



Management Team

Program Executive:
- Ryan Stephan

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of Mars, and Lunar Cold Traps A primary technology of this element is development of HRS's Exploration Ground Data Systems (xGDS) software, a set of planning, monitoring, archiving, and search tools for dealing with data sent to or received from robotic spacecraft or crew systems. xGDS is being matured through technology development under HRS (with STMD funds) and field-tested with funds from the Human Exploration and Operations Mission Directorate (HEOMD) and Science Mission Directorate (SMD). The outcome of this development will be that the desired parts of the xGDS system (likely the traverse planner, real time plotting, and raster mapping tools) will be ready to be infused into the lunar Resource Prospector Mission (RPM). The scope of FY14 xGDS work includes maturing time delayed image and video processing and archiving tools and adding support for mobile devices. During 2014, xGDS will support the AES-funded Regolith and Environment Science and Oxygen and Lunar Volatile Extraction (RESOLVE) payload thermal vacuum chamber testing the SMD-funded Mojave Volatiles Prospector (MVP) project. Another technology under this element will develop regolith sampling and excavation for reduced and low gravity environments. The objective for this work in FY14 is to acquire representative samples of target bodies in order to characterize the regolith for ISRU prospecting purposes which would also benefit science objectives and other relevant Strategic Knowledge Gaps (SKG's). The requirements of the Advanced Exploration Systems (AES) lunar Resource Prospector (RP) are focused on a lunar South pole mission near the impact site of the recent Lunar CRater Observation and Sensing Satellite (LCROSS) mission in order to obtain ground truth on the lunar surface. Orbital data from neutron spectrometers shows that most of the detected hydrogen on the moon is in these crater floor cold traps. The goal is to confirm the existence of volatiles such as water, hydrogen and helium in the regolith at the lunar poles. Other target bodies such as asteroids and Mars' moons will also need prospecting and

Management Team *(cont.)*

Program Manager:
- Stephen Gaddis

Project Manager:
- William Bluethmann

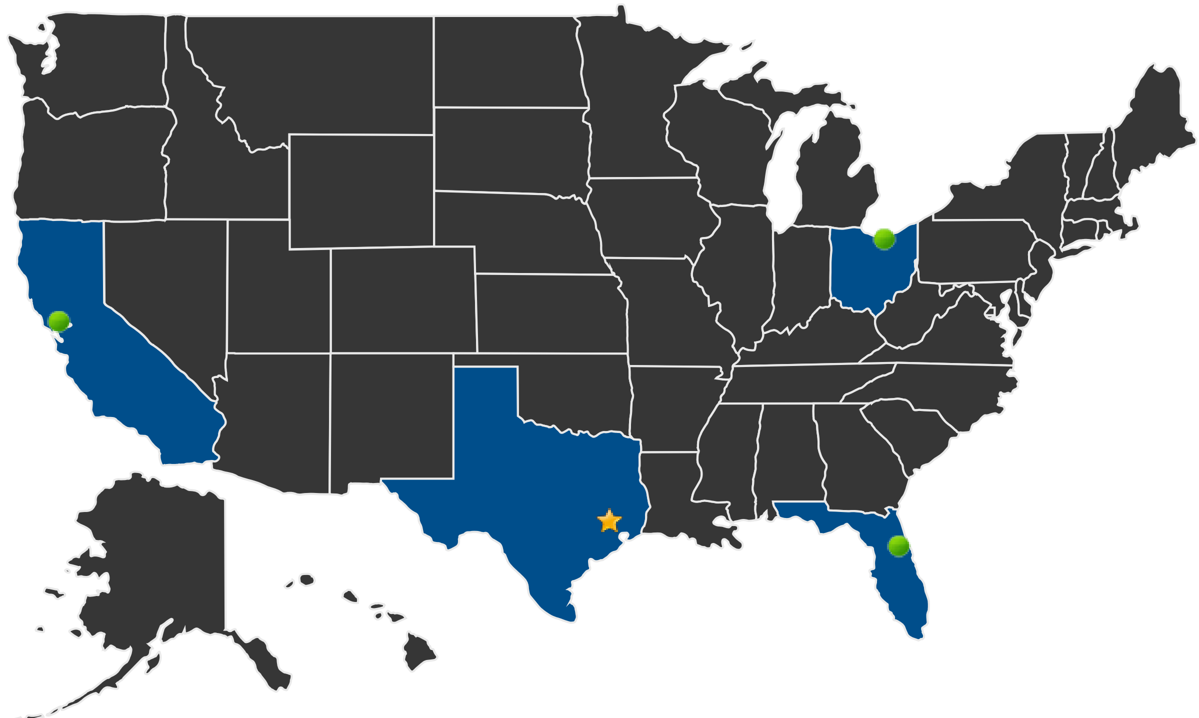
Principal Investigator:
- Robert Ambrose

Technology Areas

- Robotics and Autonomous Systems (TA 4)
- Robotic Excavation (TA 4.3.6.7)
- Human Exploration Destination Systems (TA 7)
- In-Situ Resource Utilization (TA 7.1)
- Penetrometers, Shear Gauges, Compaction, Density Instruments (TA 7.1.1.1)

characterization. One of the primary potential uses of the returned asteroid in the Asteroid Initiative is for ISRU demonstrations in lunar orbit. Sampling devices will be needed to prospect the asteroid for useful resources, such as water on a carbonaceous condrite. The Mars' moons and Mars itself are also of interest for ISRU purposes and can be sampled with robotic devices or by human crews to determine the ISRU value of their regolith. Regolith excavation and sample acquisition in low gravity environments (micro-G, 1/3 G, 1/6th G) is difficult due to the lack of reaction force from the weight of the excavation robot. On Earth, excavators are typically large and heavy to take advantage of this large reaction force to counter-act the digging forces. In space, new methods of digging and sampling must be found, due to their light weight in low gravity environments. Percussive excavation is one method for reducing digging forces, and in FY14, the HRS project will test interfaces for a large percussive excavation end effector: the Vibratory Implement for Percussive Excavation of Regolith (VIPER) which is designed to be mounted on the All-Terrain Hex-Limbed Extra-Terrestrial Explorer (ATHLETE) robot from JPL. The VIPER was designed and fabricated by HRS. A smaller percussive excavation implement called Badger, will be operated on the Centaur 2 mobility robot with a positioning mechanism. First, the Badger implement will be mounted for Geo-Technical Testing in a Controlled Simulant Bin. Afterward, the pair of devices from will be integrated onto Centaur 2 and tested at a NASA outdoor test facility. The Regolith Advanced Surface Systems Operations Robot (RASSOR) 2.0 will be completed and tested in a regolith test bed. The objective of this effort is to raise the technology readiness level (TRL) of sampling and excavation for reduced and low gravity environments to the point where it is viable for future precursor or Asteroid exploration missions. A second objective is to have technologies identified and proven to be feasible for lunar cold trap access and prospecting which could be a follow-on mission to the Resource Prospector. The same technologies may be useful for Mars prospecting at the poles. A third major objective is to demonstrate how to reduce digging forces and make low -weight excavators possible on low-gravity target bodies.

U.S. WORK LOCATIONS AND KEY PARTNERS



U.S. States With Work

Lead Center:
Johnson Space Center

Supporting Centers:

- Ames Research Center
- Glenn Research Center
- Kennedy Space Center

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DETAILS FOR TECHNOLOGY 1

Technology Title

Exploration Ground Data Systems (xGDS)

Technology Description

This technology is categorized as complex electronics software for ground scientific research or analysis

Key challenges for future human and robotic missions will be situation awareness for extravehicular (EV) crew and dealing with large volumes of video or time-stamped imagery. Exploration Ground Data Systems (xGDS) is a set of planning, monitoring, archiving, and search tools for dealing with data sent to or received from robotic spacecraft or crew systems. xGDS uses web-based applications for portability and to support distributed remote users. xGDS leverages open source web platforms and open standards for maps and other file formats. During FY14, the core capabilities of xGDS will be matured and expanded. In particular, we focus on interacting with systems with constrained communications, including intermittent communications availability or lunar to near Earth asteroid (NEA) time delays of 3 to 50 seconds, applicable to near-term missions such as the lunar Resource Prospector (RP) or the Asteroid Redirect Mission (ARM).

Capabilities Provided

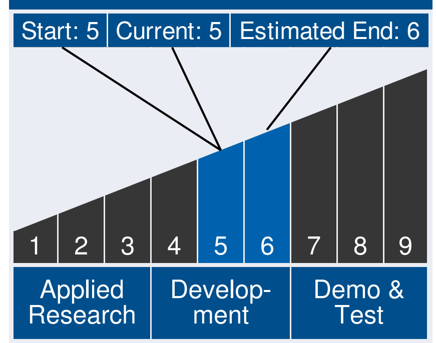
In FY14, we will develop time-delayed image and video processing and archiving tools, and add support for mobile devices. Video support components will include simultaneous real-time recording and viewing for multiple observers in distributed ops teams, fast access to recorded video for quick go-back reviews of recent events, and integrating playback into the xGDS system.

Mobile device support will enable operating with limited or intermittent communications, including access to maps, position

Technology Areas

Primary Technology Area:
Robotics and Autonomous Systems (TA 4)
└─ Manipulation (TA 4.3)
  └─ Sample Acquisition and Handling (TA 4.3.6)
    └─ Robotic Excavation (TA 4.3.6.7)

Technology Maturity



tracking, and structured data collection with a local data store, and synchronizing to the xGDS server when a network is available in a store-and-forward fashion. This will enable use without relying on continuous communications.

Deployment and field testing will be funded by the Science Mission Directorate (SMD) in support of the SMD Mojave Volatiles Prospector (MVP) field test, with the ultimate goal of maturing parts of the xGDS system (the traverse planner, real time plotting, and raster mapping tools) to a level where they will be ready to be infused into the lunar Resource Prospector (RP), which is being developed within NASA through a partnership between STMD/GCD and HEOMD/AES.

Potential Applications

The ultimate outcome of this development will be that the desired parts of the xGDS system, such as the traverse planner, real time plotting, and raster mapping tools, will be ready to be infused into the lunar Resource Prospector (RP).

Capability to perform simultaneous real-time recording and viewing for multiple observers in distributed ops teams

Fast access to recorded video for quick go-back reviews of recent events

Mobile device support will enable operating with limited or intermittent communications, including access to maps, position tracking, and structured data collection with a local data store, and synchronizing to the xGDS server when a network is available in a store-and-forward fashion, which will enable use without relying on continuous communications.

DETAILS FOR TECHNOLOGY 2

Technology Title

Sample Acquisition on Asteroids, Mars, Moons of Mars, and Lunar Cold Traps

Technology Description

This technology is categorized as a hardware system for ground scientific research or analysis

Recent Mars Curiosity rover data indicates >5% of water trapped in the regolith and available globally on Mars. Water can provide hydrogen and oxygen for propellant at the destination, avoiding

Technology Areas

Primary Technology Area:
Robotics and Autonomous Systems (TA 4)
└─ Manipulation (TA 4.3)
  └─ Sample Acquisition and Handling (TA 4.3.6)
    └─ Robotic Excavation (TA 4.3.6.7)

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the launch and transportation of propellant from Earth. The current lunar Resource Prospector will be followed by other ISRU missions to the moon, asteroids and Mars. NASA Mars Design Reference Architecture 5.0 requires ISRU as an enabling technology. Water-based ISRU via regolith excavation would eliminate the need to transport hydrogen in large volume tanks to Mars for Sabatier CO2 atmospheric processing.   This type of propellant ISRU could radically change the space mission architectures of the future, requiring significantly less propellant from Earth. It is the key to sustainable space exploration and life support, by cutting our logistical ties to the Earth. However, all the resources are contained in the regolith and the sunlight energy. Without excavation, it might not be possible to acquire the resources in the regolith. In order to enable these transformative space exploration mission architectures, low reaction force excavation is a key enabling technology. Excavation is the first step towards utilization of discovered resources. Without lightweight excavation robots, the resources cannot be acquired, processed and consumed.

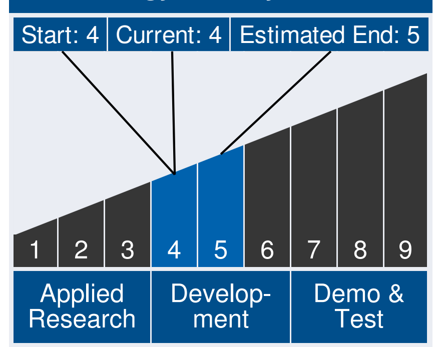
Resource materials in space are primarily contained in the regolith of target bodies such as Asteroids, Comets, Mars, Mars' moons, and lunar cold traps. After prospecting for the right type of regolith, a sample must be obtained for "ground truth" characterization. Science and In-Situ Resource Utilization (ISRU) customers need proven technologies and devices for regolith and volatiles sample acquisition in very challenging environmental conditions such as micro-gravity (1/1000th G), low temperatures (~40 K) and dusty environments (< 100 microns particles). These samples will help us to better understand the solar system and to use the resources for human and robotic exploration purposes. Existing HRS robots, excavation implements and regolith simulant test bins will be leveraged to provide a NASA agency capability for regolith sample acquisition in very challenging space target body environments.

Technology Areas *(cont.)*

Secondary Technology Area:
Human Exploration Destination Systems (TA 7)
└ In-Situ Resource Utilization (TA 7.1)

Additional Technology Areas:
Human Exploration Destination Systems (TA 7)
└ In-Situ Resource Utilization (TA 7.1)
  └ Destination Reconnaissance, Prospecting, and Mapping (TA 7.1.1)
    └ Penetrometers, Shear Gauges, Compaction, Density Instruments (TA 7.1.1.1)

Technology Maturity



First, an existing percussive bucket end effector (Badger) will be tested in calibrated regolith simulants to characterize the reduced digging force performance advantages. Static digging buckets will be used as a “control test” baseline for quantitative comparison and future modeling validation. Percussive buckets will be integrated and demonstrated on HRS mobility platforms: Centaur 2 and ATHLETE showing medium and large-scale regolith and volatiles sampling capabilities for planetary surfaces.

The RASSOR 2.0 counter-rotating bucket drum technology will be tested to determine the feasibility of repetitively acquiring, retaining and delivering regolith in reduced (1/6th G and 3/8 G) gravity and micro-gravity.

Capabilities Provided

The results of this technology development will be prototype excavation and sampling for reduced and low gravity environments.

Potential Applications

Infusion of these technologies will be via ISRU prospecting, sampling and mining missions.

- Sampling and excavation for reduced and low gravity environments future In-situ Resource Utilization missions and Asteroid exploration.
- Accessing lunar cold trap for prospecting which could be a follow-on mission to the Resource Prospector and Mars prospecting at the poles.
- Excavators for reduced digging forces and low-weight excavation on low-gravity target bodies.
- Construction and civil engineering on planetary surfaces (such as preparing landing pads)

Performance Metrics

Metric	Unit	Quantity
Force reduction of VIPER large scale percussive excavation compared to non-percussive excavation	%	75
Force reduction of Badger medium scale excavation compared to non-percussive excavation	%	75
Total sample mass goal for micro gravity asteroid regolith (1 micron to 1mm particle size)	grams	100