Completed Element (2012 - 2014)

Human Robotic Systems (HRS): Extreme Terrain Mobility Element

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

ABSTRACT

The high level objective of the Extreme Terrain Mobility project element is to develop technologies that enable human and robotics systems in space to gain access to areas not currently accessible and to provide extra endurance or strength to crews on ISS and beyond.

ANTICIPATED BENEFITS

To NASA funded missions:

The Analysis of Alternatives performed for the Advance Exploration System (AES) Resource Prospector (RP) provided alternative designs, schedules and costs as a risk reduction effort for a 185 kg rover. RP is a lunar precursor mission scheduled in 2019, to search for volatiles at the lunar poles. The X1 prototype ankle exoskeleton and the X1 single-joint knee dynamometer will be delivered to the Space and Life Sciences Directorate at JSC for evaluation for eventual use on the International Space Station. Researchers at GRC's Traction and Excavation Capabilities (TREC) Lab are analyzing a duplicate of the Mars Science Laboratory (MSL) Curiosity rover's wheels, in an effort to understand how damage occurred to the wheels, with the goal of developing methods for further reducing the pace of damage and to anticipating how accumulation of damage to the wheels could affect performance. The liquid cooled technology has applications for future development of Robonaut and other space robots for EVA or deep space exploration.

To other government agencies:

The single wheel test-bed development will advance extreme terrain mobility technology to support the development of no-emission rovers at Summit Station in Greenland, supporting the National Science Foundation (NSF) polar program.

To the nation:

HRS is pursuing partnerships for transferring NASA by-wire rover

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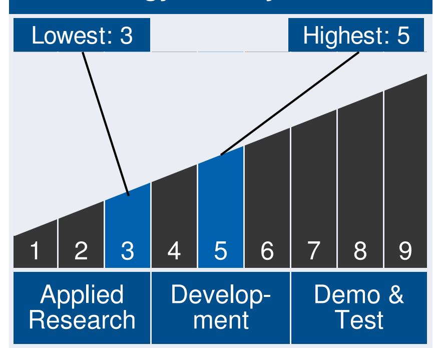
Technology Maturity



technology for a joint US Army/Department of Energy project to build automated vehicles for taking wounded soldiers to their appointments at Ft Bragg, North Carolina and as disaster relief vehicles.

DETAILED DESCRIPTION

During 2014, the Extreme Terrain Mobility project element is developing five technologies: Exoskeleton Development for ISS Evaluation Extreme Terrain Mobility Testbed Low Gravity Testbed using Tethered Stewart Platform Prototype Crater Access Robot Advanced Mobility Navigation Software Exoskeleton Development for ISS Evaluation During FY12, HRS and GCD developed the X1 exoskeleton with the ultimate intent of augmenting crew endurance/strength in future missions. Offshoots of the technology involved lightweight exercise devices for ISS and strength measurement by using the torque sensing in the X1's joints. The objective for exoskeleton development in FY14 is to build prototype exoskeleton ankles and deliver them to the JSC space and life sciences organization for evaluation as exercise devices and to design a single-joint knee dynamometer, based on X1 technologies, capable of measuring crew strength. Extreme Terrain Mobility Testbed The objective of FY14 work is to present mature systems that are ready to be carried forward by a Science Mission Directorate Principal Investigator (PI) willing to propose a system with greater mobility than exists on current Mars rovers. HRS has recently identified a potential national need with the National Science Foundation (NSF) that requires no-emission vehicles, such as NASA rovers, on the Arctic, Antarctic, Alaska and polar coastal areas. We have an opportunity to deploy NASA Space Technologies to these areas. Minimal success requires disseminating results to potential SMD PIs and potential partners within the NSF polar program. Early in fiscal year 2014, the HRS extreme terrain mobility group will prepare an Analysis of Alternatives study of a 170 kg rover for

Management Team

Program Executive:
- Ryan Stephan

Program Manager:
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Project Manager:
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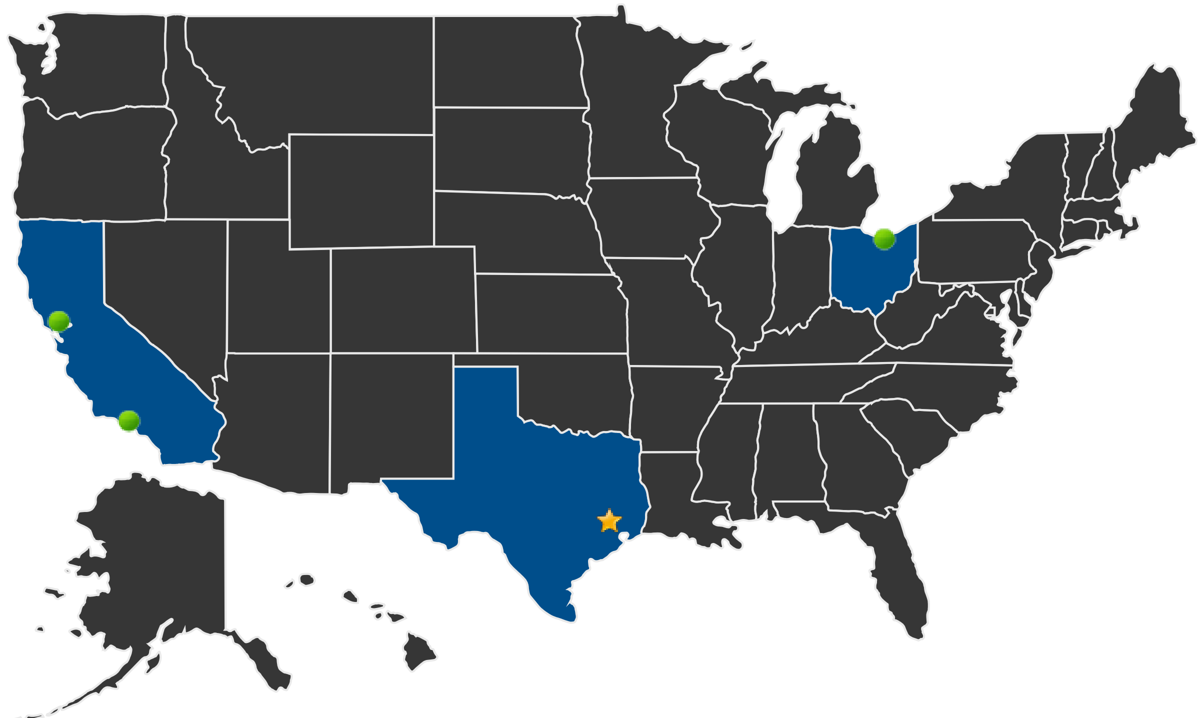
Technology Areas

- Robotics and Autonomous Systems (TA 4)
- Wheeled/Tracked/Hybrid Robots (TA 4.2.4.4)

the Advance Exploration System (AES) Resource Prospector (RP). Low Gravity Testbed using Tethered Stewart Platform This task creates a 6-DOF testbed for evaluating microgravity and low-gravity proximity and contact operations, e.g. in the vicinity of a Near Earth Asteroid (NEA). This is accomplished using an "inverted Stewart platform", where the vehicle under test is suspended by six computer-controlled cable winches so that it can be maneuvered in all 6 Degrees-of-Freedom. Prototype Crater Access Robot This task will develop and demonstrate a "mother-daughter" approach to exploring craters using tethered robots. The small robots will be tethered to the larger robot with winches on both ends so that the "mother" can recover the "daughter" even in the event of failure of the small robot. In normal operation, the daughter robot will pay out the tether to move further away, and spool it back in to return. In FY13, this task demonstrated deployment of the daughter robot with an internal winch on a tether. The daughter robot is designed to move on steep slopes, up to vertical, to carry and point close-up instruments, and to collect samples. In FY14, this task will design and build a tether that provides power from the mother robot to the daughter robot and provides for communications between them. Advanced Mobility Navigation Software The Advanced Navigation Software task is developing approaches for dealing with the significant challenges of autonomous planetary surface navigation, including descent on rough and steep terrain, exploring lava tubes, navigating long distances without communications, and localizing without infrastructure. In FY14, the team will build on its past Advanced Navigation work, leveraging and extending the development and testing performed previously. The proof-of-concept algorithms developed during FY13 will be improved, streamlined, and integrated into the rover software stack to run onboard and in real time. The resulting system will be tested in a live onboard test of the system in a realistic setting.

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
- Jet Propulsion Laboratory

DETAILS FOR TECHNOLOGY 1

Technology Title

Advanced Mobility Navigation Software

Technology Description

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

The Advanced Navigation Software task is developing approaches for dealing with the significant challenges of autonomous planetary surface navigation, including descent on rough and steep terrain, exploring lava tubes, navigating long distances without communications, and localizing without infrastructure.

This work will extend and enhance past HRS work in autonomous mobility, Dark Navigation, and hazard detection/display for high-speed crew mobility. In FY13, HRS developed multiple strategies for terrain relative navigation and absolute localization relative to a priori map data, such as orbital DEM’s, by registering rover observations to orbital observations automatically. These systems were tested using canned data from prior field tests. The software is integrated into HRS robot software and RAPID middleware.

In FY14, the team will build on its past Advanced Navigation work, leveraging and extending the development and testing performed previously. The proof-of-concept algorithms developed during FY13 will be improved, streamlined, and integrated into our rover software stack to run onboard and in real time. The resulting system will be tested in a live onboard test of the system in a realistic setting.

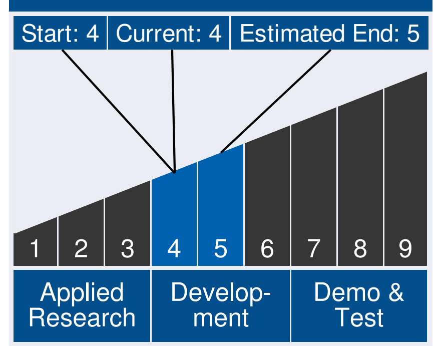
Capabilities Provided

Ability for robotic rovers to localize (determine location) and navigate without the need for localization infrastructure (such as GPS and beacons).

Technology Areas

Primary Technology Area:
Robotics and Autonomous Systems (TA 4)
└─ Mobility (TA 4.2)
  └─ Small-Body and Microgravity Mobility (TA 4.2.4)
    └─ Wheeled/Tracked/Hybrid Robots (TA 4.2.4.4)

Technology Maturity



Potential Applications

Advanced mobility has the potential to perform significant increases in the ability to determine location of a rover on a remote surface through combining visual odometry, horizon mapping, and digital elevation map matching. This work is already beginning to be used for science operations on Mars, giving the science team an update on the rover's location ahead of the official update.

Performance Metrics

Metric	Unit	Quantity
Absolute localization accuracy	m	10

DETAILS FOR TECHNOLOGY 2

Technology Title

Complete Low Gravity Testbed using Tethered Stewart Platform

Technology Description

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

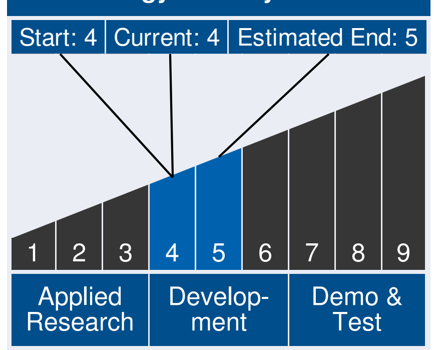
This task creates a 6-degree-of-freedom testbed for evaluating microgravity and low-gravity proximity and contact operations, e.g. in the vicinity of a Near Earth Asteroid (NEA), as well as steep slope climbing in 1/6th (e.g. lunar) or 3/8th (e.g. Mars) gravity simulations, without putting the hardware at risk. This is accomplished using an "inverted Stewart platform", where the vehicle under test is suspended by six computer-controlled cable winches so that it can be maneuvered in all 6 degrees of freedom. In addition, anchoring tools for use on asteroids and in steep slope climbing, will be prototyped and tested.

Proximity and surface contact operations are simulated for an asteroid or other low-gravity situations by suspending terrestrial prototype hardware from six computer-controlled winch cables, giving 6-degree-of-freedom (6-DOF) control over a 3-meter work volume. "Real" sensor feedback in terms of imagery, ranging,

Technology Areas

Primary Technology Area:
Robotics and Autonomous Systems (TA 4)
└─ Mobility (TA 4.2)
  └─ Small-Body and Microgravity Mobility (TA 4.2.4)
    └─ Wheeled/Tracked/Hybrid Robots (TA 4.2.4.4)

Technology Maturity



and contact sensing using accurate force sensors, allows simulation of approach, landing, anchoring, release and departure statics and dynamics for near-Earth asteroid missions as well as 1/6th (e.g. lunar) or 3/8th (e.g. Mars) gravity simulations on extreme terrain, without putting the hardware at risk.

In prior efforts, a gantry frame has been installed into a high-bay at JPL, with six computer-controlled winches, a control system, and a 7x7 meter asteroid surface mockup procured from a Hollywood set. 6-DOF control has been demonstrated for test articles up to 1600 kg, and high-fidelity 6-DOF demonstrations of proximity operations, bounce reduction, and anchoring and release in very soft regolith.

During FY14, the task will focus on performing extreme-terrain, steep-slope climbing in simulated 1/6th and 3/8th –gravity, with anchoring and release.

Capabilities Provided

The low gravity testbed will provide “real” sensor feedback in terms of imagery, ranging, and contact sensing using accurate force sensors. This testbed will enable testing of robotic hardware prototypes in simulated approach, landing, anchoring, release and departure statics and dynamics scenarios, for near-Earth asteroid missions as well as 1/6th (e.g. lunar) or 3/8th (e.g. Mars) gravity simulations on extreme terrain (i.e. steep slopes), while greatly reducing the risks of damage to the hardware.

In addition, a set of low-gravity anchoring mechanisms will be designed, prototyped, and tested in reduced gravity.

Potential Applications

The low gravity testbed built as part of this task will serve as a testbed for current and future robotic missions to the moon or Mars, reducing risk and development costs.

The results of the anchoring mechanism design/test could inform asteroid planners with the Asteroid Redirect Mission on what might or might not work as anchors when the human exploration part of the mission is designed.

Performance Metrics

Metric	Unit	Quantity
Angle of climbing (low gravity testbed)	degrees	40

DETAILS FOR TECHNOLOGY 3

Technology Title

Exoskeleton Development for ISS Evaluation

Technology Description

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

In FY12, HRS and GCD developed the X1 exoskeleton with the ultimate intent of augmenting crew endurance/strength in future missions. Offshoots of the technology involved lightweight exercise devices for ISS and strength measurement by using the torque sensing in the X1’s joints. The objectives for exoskeleton development in FY14 are:

- Build prototype exoskeleton ankles and deliver them to the JSC space and life sciences organization for evaluation as exercise devices
- Design a single-joint knee dynamometer for measuring crew strength, based on X1 technologies

Capabilities Provided

The X1 exoskeleton is a multi-functional device in the emerging field of wearable robotics. Its space applications include:

- Increased endurance
- Increased strength
- Ability to provide resistance as a low-mass exercise device
- Ability to be used to measure crew strength by isolating individual joints with knee dynamometer

On earth, the same technology can be applied to aid in assistive mobility.

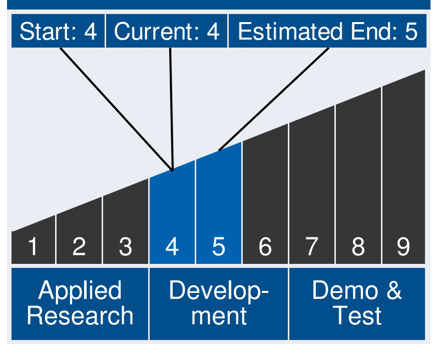
During FY14, components from the X1 exoskeleton will be iterated, specialized and evaluated for use in space.

The first product will be a prototype ankle exoskeleton, which will

Technology Areas

Primary Technology Area:
Robotics and Autonomous Systems (TA 4)
└ Mobility (TA 4.2)
  └ Small-Body and Microgravity Mobility (TA 4.2.4)
    └ Wheeled/Tracked/Hybrid Robots (TA 4.2.4.4)

Technology Maturity



provide capability beyond the passive ankle in the X1 prototype. The new ankle exoskeleton device will be delivered to the Space and Life Sciences Directorate at JSC for evaluation as an exercise device.

The second new development will be the design of a single-joint knee dynamometer.

Potential Applications

The current state of the art of exercise equipment onboard the International Space Station is the ARED device, which weighs 320 kg. The X1 exoskeleton has the ability to significantly reduce the mass of crew exercise equipment for missions beyond low earth orbit to about 50 kg or less.

For the space program, the exoskeleton and exoskeleton devices can be worn in zero gravity to provide exercise resistance, which helps stave off bone and muscle loss. The new approach of using the X1 joints as a dynamometer, to measure and evaluate astronaut strength on-orbit, could give the life sciences doctors new tools and access to new data to study the effects of zero G on humans as well as evaluating the potential benefits of wearing resistive exoskeleton technology to help counteract the deleterious effects of prolonged exposure for zero G. The technology could also eventually lead to assistive exoskeletons to add strength and endurance for astronauts when in cumbersome space suits, on ISS or under the influence of gravity on the moon or Mars.

In addition, HRS's exoskeleton technology has already been demonstrated for use in providing mobility to humans with disabilities. Ultimately this technology could enable paraplegics to walk again, could assist disabled veterans, and could provide renewed mobility and strength for those with certain muscular disabilities.

Performance Metrics

Metric	Unit	Quantity
Exoskeleton exercise device mass	kg	50

DETAILS FOR TECHNOLOGY 4

Technology Title

Extreme Terrain Mobility Testbed

Technology Description

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

Over the past 8 years, NASA has been developing low cost, high-capability rovers. These rovers have varied in scale from crew sized rovers to science rovers. With this experience within the agency, the HRS team has the opportunity to give back some of these capabilities for new NASA missions and larger national needs.

This activity will design and build a single wheel module and field test the prototype in an outdoor test area at JSC. The single wheel testbed provides liquid cooling/heating to the actuators to allow them to function in locations where the temperature varies vastly from one side to the other, such as on the lunar surface.

The HRS team will continue to develop partnerships within and outside of NASA in the area of rover development. In the first quarter of FY14, the HRS mobility team will prepare an Analysis of Alternates for the AES Resource Prospector, a lunar precursor mission scheduled for 2019, which will prospect for volatiles at the lunar poles. AES asked the HRS team to look at alternative designs, schedules and costs as a risk reduction effort.

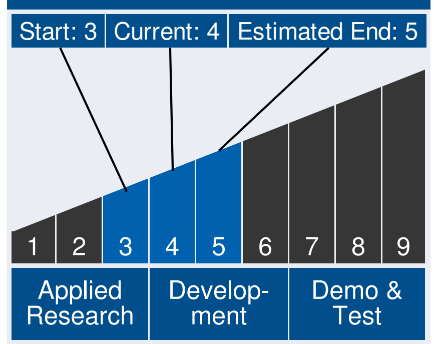
Capabilities Provided

This technology provides initial capabilities for access to extreme terrain on planetary surfaces and on Earth, allowing the robotic system to actively transfer heat where needed. The single-wheel testbed provides liquid cooling/heating to the actuators to allow them to function in locations where the temperature varies vastly from one side to the other, such as on

Technology Areas

Primary Technology Area:
Robotics and Autonomous Systems (TA 4)
└ Mobility (TA 4.2)
  └ Small-Body and Microgravity Mobility (TA 4.2.4)
    └ Wheeled/Tracked/Hybrid Robots (TA 4.2.4.4)

Technology Maturity



the lunar surface. This approach is analogous to how warm blooded animals manage heat within their bodies.

Potential Applications

This technology could potentially be used on the AES Resource Prospector or other future planetary rovers.

HRS has also identified a broader national need for a no-emissions rover at Summit Station in Greenland, supporting the National Science Foundation's (NSF) polar program. Scientists will need to conduct a 3-mile daily commute between the Summit Station "Big House" and the Isi station to monitor experiments. The instruments and measurements at Isi station are sufficiently sensitive that using internal combustion for the commute would compromise the science.

HRS is also pursuing partnerships for transferring NASA by-wire rover technology for a joint US Army/Department of Energy project to build automated vehicles for taking wounded soldiers to their appointments at Ft Bragg, North Carolina and as disaster relief vehicles.

DETAILS FOR TECHNOLOGY 5

Technology Title

Prototype Crater Access Robot

Technology Description

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

Crater exploration is important but risky and requires that high-value assets not be put at risk, with lower-value, possibly expendable, assets descending into a crater. On the steep or vertical walls, the strata are exposed, yielding scientific discover that is not currently possible with the Mars Science Laboratory (MSL). To be of value to the SMD principal investigator (PI) community, this concept must be matured to the point where a PI could propose a mission using this system and be confident of its success.

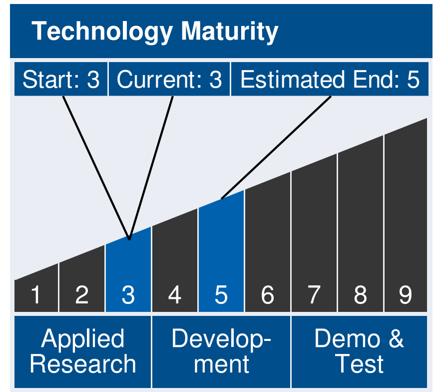
Capabilities Provided

This task will develop and demonstrate a "mother-daughter"

Technology Areas

Primary Technology Area:
Robotics and Autonomous Systems (TA 4)
└ Mobility (TA 4.2)
 └ Small-Body and Microgravity Mobility (TA 4.2.4)
  └ Wheeled/Tracked/Hybrid Robots (TA 4.2.4.4)

approach to exploring craters using tethered robots. The small robots will be tethered to the larger robot with winches on both ends so that the “mother” can recover the “daughter” even in the event of failure of the small robot. In normal operation, the daughter robot will pay out the tether to move further away, and spool it back in to return. In FY13, this task demonstrated deployment of the daughter robot with an internal winch on a tether. The daughter robot is designed to move on steep slopes, up to vertical, to carry and point close-up instruments, and to collect samples. In FY14, this task will design and build a tether that provides power from the mother robot to the daughter robot and provides for communications between them. Investigations will conclude on vertical cliff faces, with the capability of precisely positioning and pointing instrument(s) to features on cliff face as small as 1 mm.



Potential Applications

Some of the most intriguing science discoveries on Mars came from sites that are currently inaccessible for in-situ analysis and sample return. The recent discovery of recurring slope lineae (RSL), such as those observed in Newton crater, are on steep slopes (25° – 40°) that are hundreds of meters down from the crater rim. In-situ analysis and sample capture of out-flow deposits that have interacted directly with water on Mars would be directly responsive to science priorities described in both the Decadal Survey. The requirement for liquid water in habitable environments makes the retrieval of out-flow samples scientifically important for future return to Earth.

Potential applications of this technology include development of actual exploratory daughter robots for future lunar or Mars missions, capable of exploring cliff edges or the sides of steep craters and returning samples from places where no previous rovers have been able to explore.

Performance Metrics

Metric	Unit	Quantity
Range of crater access robot (i.e. length of power and data cable tether)	m	100