Tyrobot – First Robot to Explore Lunar Underground Caves Starting in 2015

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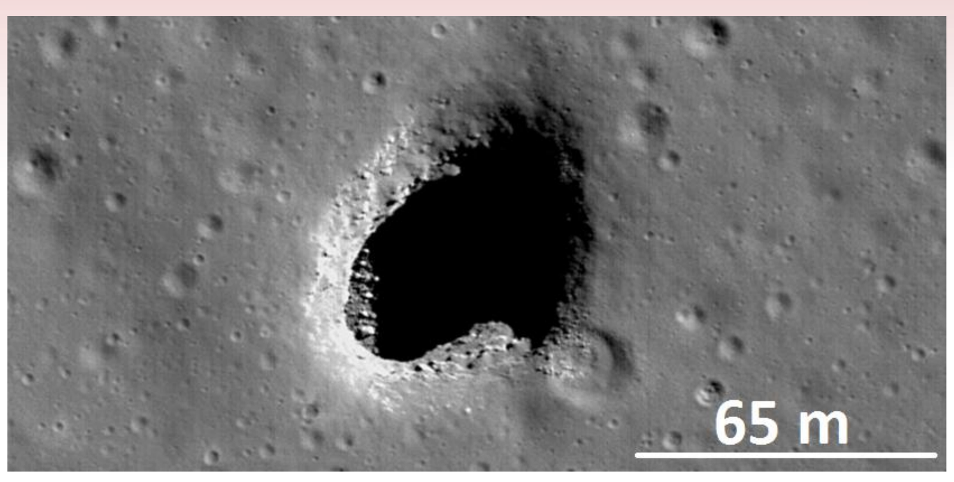
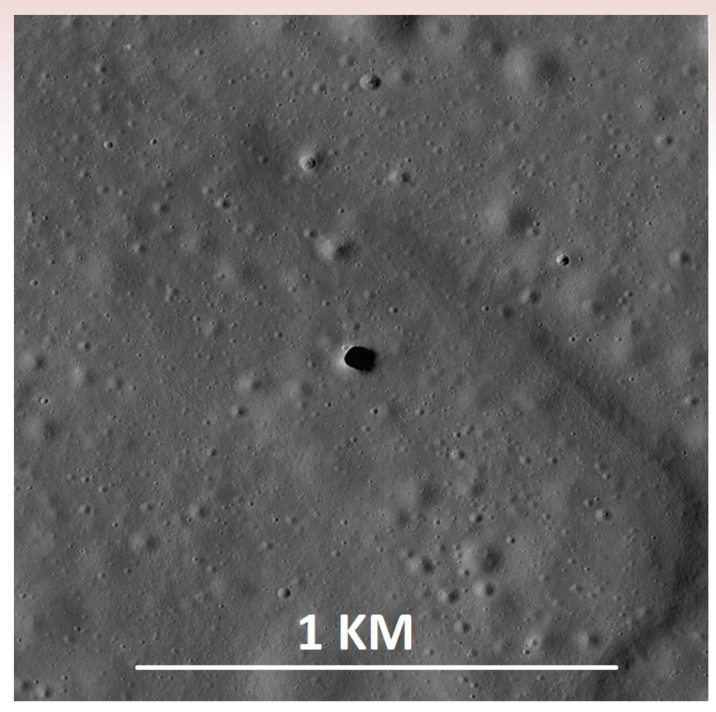
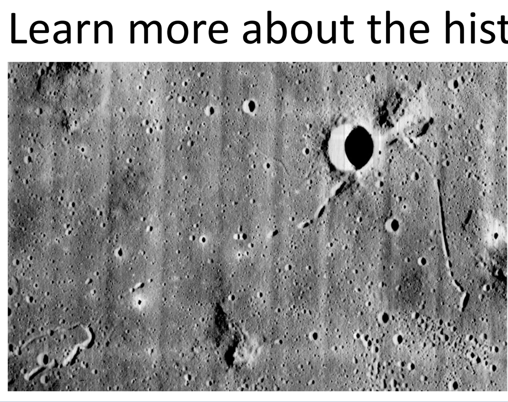
Mission Motivation

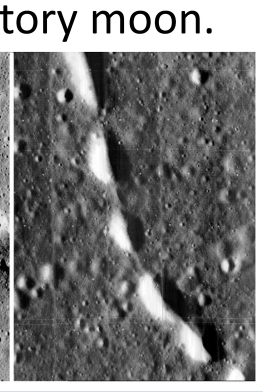




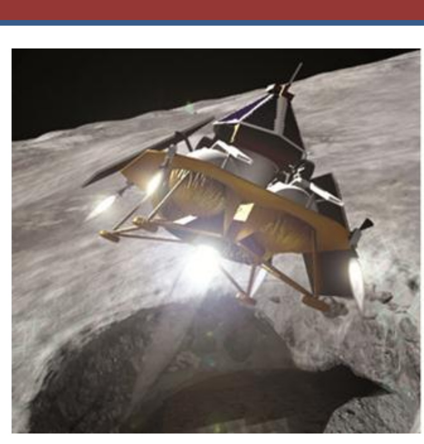
In 2009, Japan's *Kaguya* spacecraft first discovered "moon skylights", also known as *moon holes* [1]. NASA's Lunar Reconnaissance Orbiter (LRO) later provided more images from the volcanic Marius Hills region of the moon [2]. Scientists believe that these skylights can potentially be connected by a network of underground lava tubes [1][2]. These locations can provide the following for future colonization attempts on the moon:

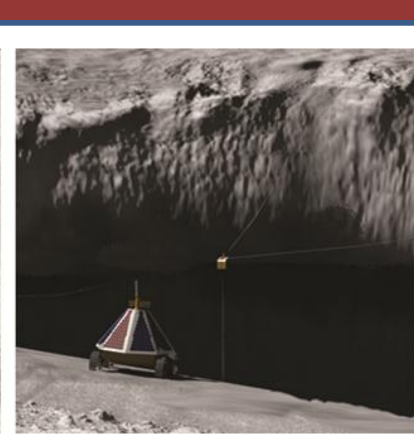
- Natural protection from deadly solar radiation.
- Shelter from meteorite bombardments.
- Stable underground temperature (30ºF to 40ºF) after 2 meters underneath.
- Possible use of natural resources.
- Learn more about the history moon.

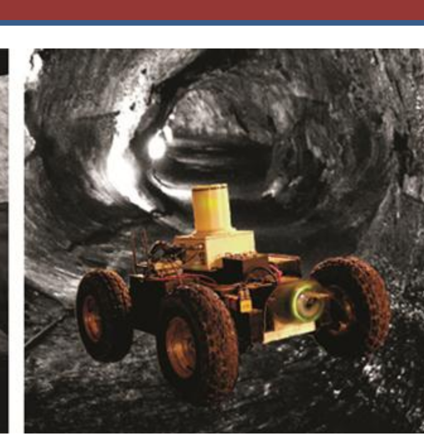




Mission Outline





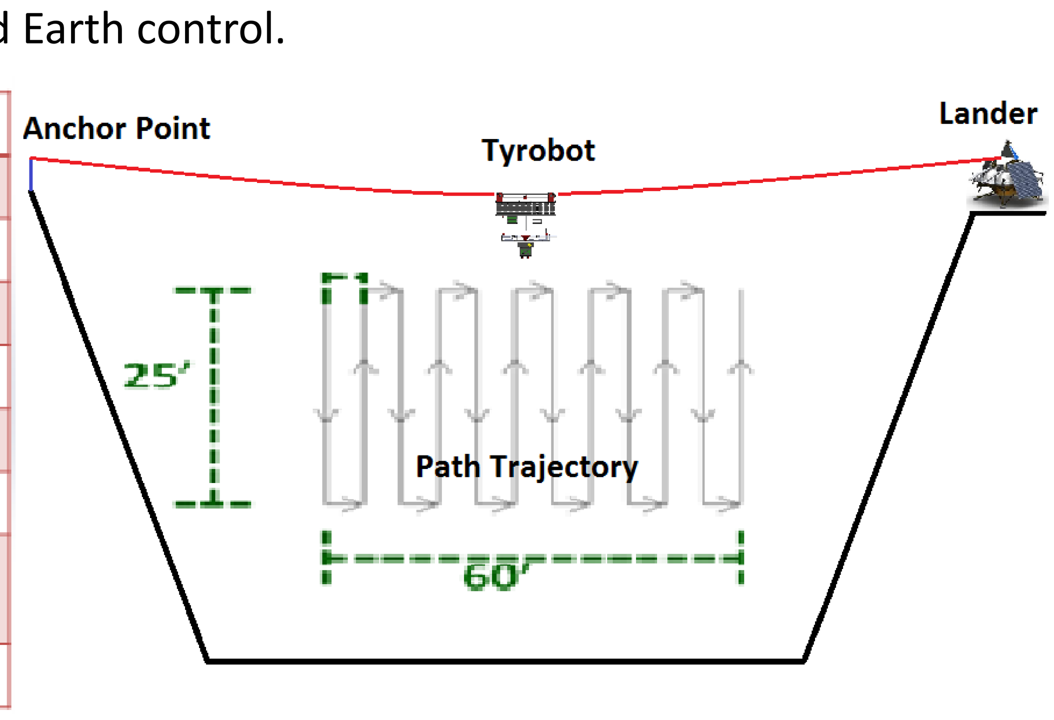


The mission to the moon envisions 4 major milestones spread over several years.

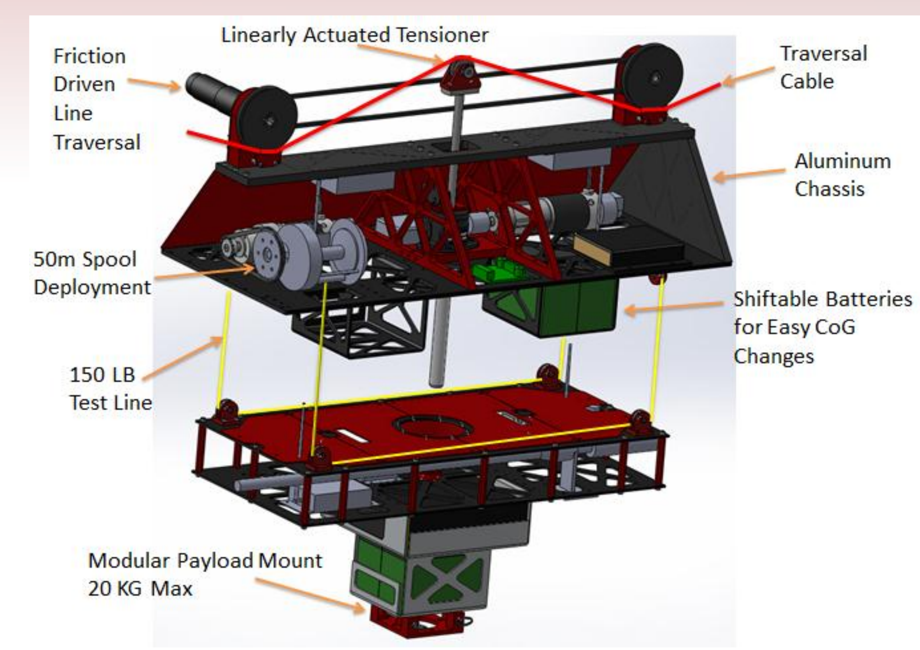
1. Perform various Astrobotic lander missions to determine landing accuracy. Land within 50 meters of the pit location.
2. Deploy rovers and/or ballista technologies for anchoring survey platform. Deploy the survey platform to acquire stratigraphic layers and 3-D modeling of the moon holes.
3. Release rovers to explore the soil of the moon holes and find caves.
4. Deploy rovers for deep cave exploration with penetrating radar technologies.

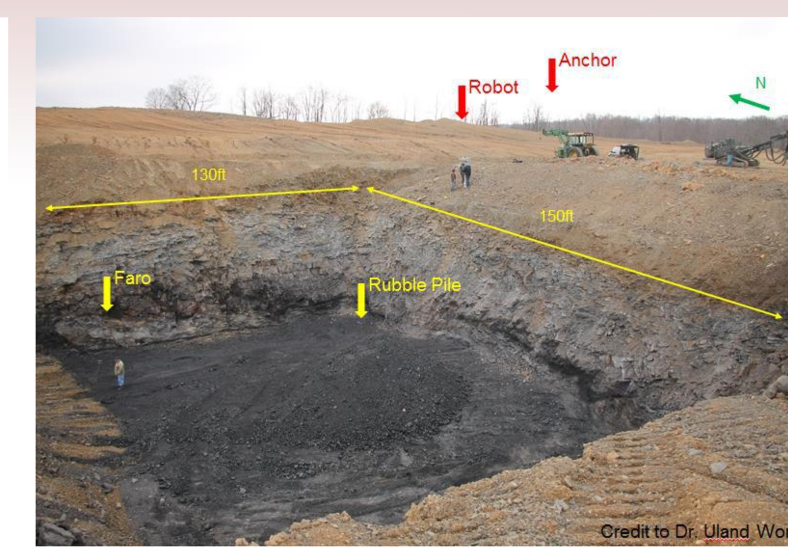
Currently, mission development focuses on the deployment of a survey platform that will accurately map the walls of the moon holes as it performs different path trajectories. As directed from Earth, the survey platform must be able to provide scans and video feedback to a ground operator on Earth. It must operate autonomously and respond to operator changes of the instruction plan. As a system, the mission hardware must endure the harsh conditions of space and adapt to varying communication levels between the computer, devices, and Earth control.

Requirements	
Max Traversing speed	20 cm/sec
Max Raise/lower speed	20 cm/sec
Operational time	2.5 hours
Max slope	20 degrees
Max carriage mass	25kg
Max payload	15kg
Max payload power draw	50W
Max deployment depth	50 m



Tyrobot Surveying Platform

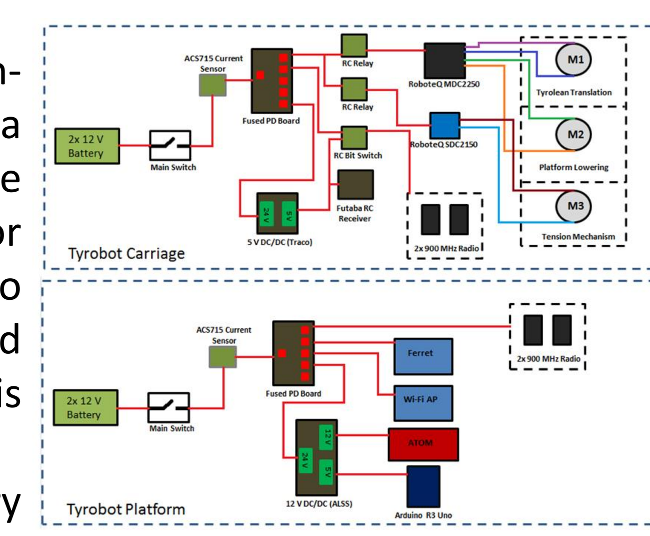




Coal mine location for survey tests

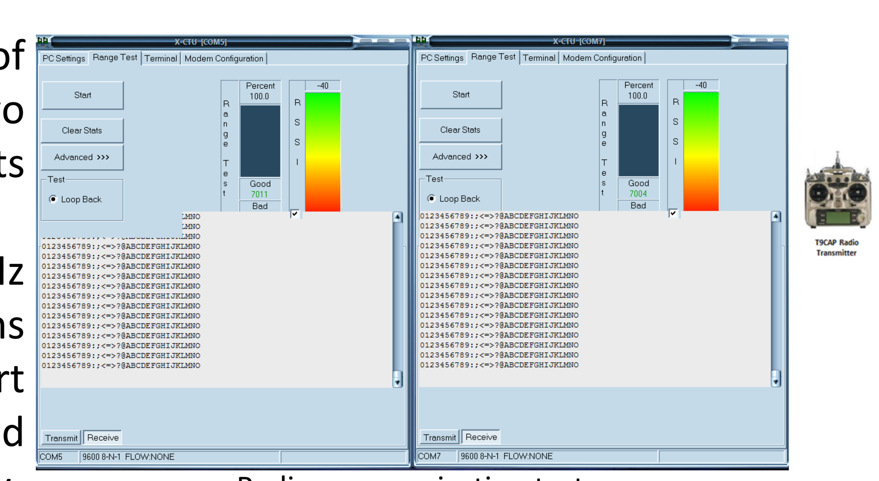
The *Tyrobot* survey platform was created to perform Earth-based tests of the controls, communications, and data acquisition. The robot consists of 2 main parts: the carriage (x-axis motion) and the platform (z-axis motion). Sensor synchronization is provided via clock distribution system to match sensor scans, line tension, and position as measured by a ground survey system. Bench tests have validated this concept for the wireless communication mechanism.

A major feature of this *Tyrobot* prototype focuses on recovery when performing Earth tests by using RC hardware as an override.

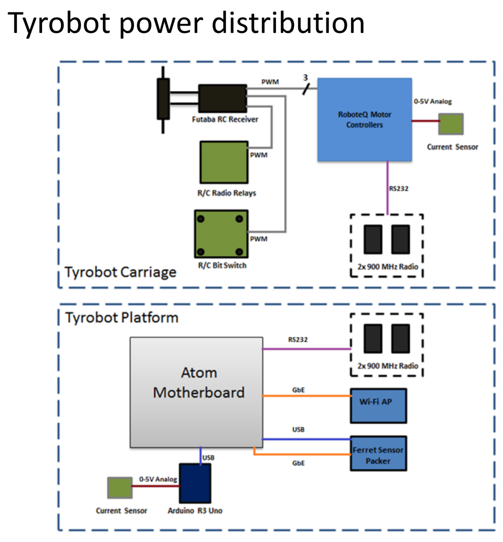


Tyrobot power distribution

To prevent the use of a tether, the two main compartments communicate wireless via 900 MHz paired-radio modems to issue and report motor commands and velocities periodically.

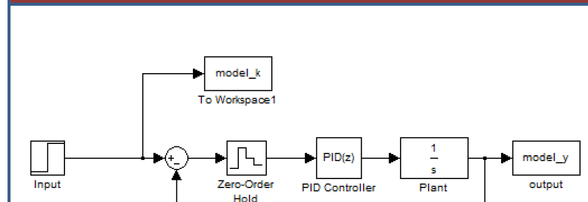


Radio communication tests



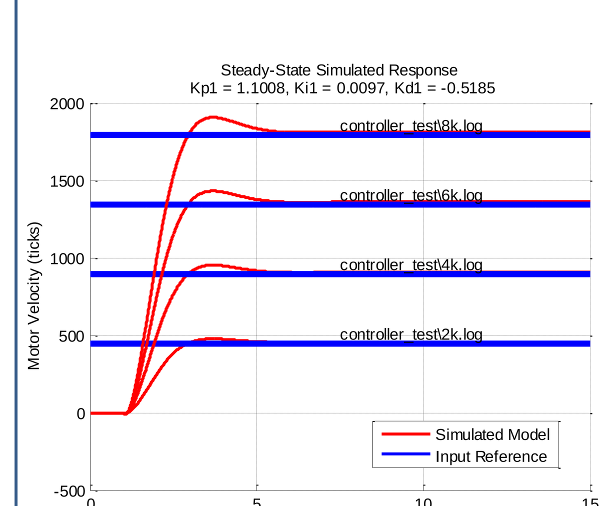
Tyrobot communications

Tyrolean Control Algorithm

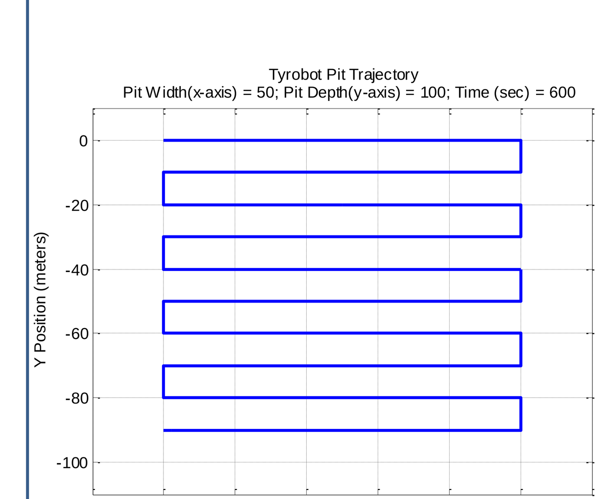


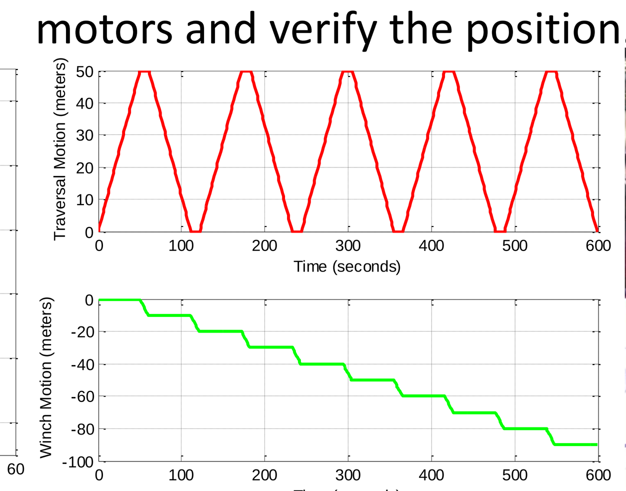
Control algorithms for the traversal (x-axis) and winch (z-axis) motors were developed to improve the data acquisition. A PID algorithm was chosen due to the ease of use, tuning capabilities, and common understanding across engineering fields supported by several studies and work for Earth-based applications [3][4].

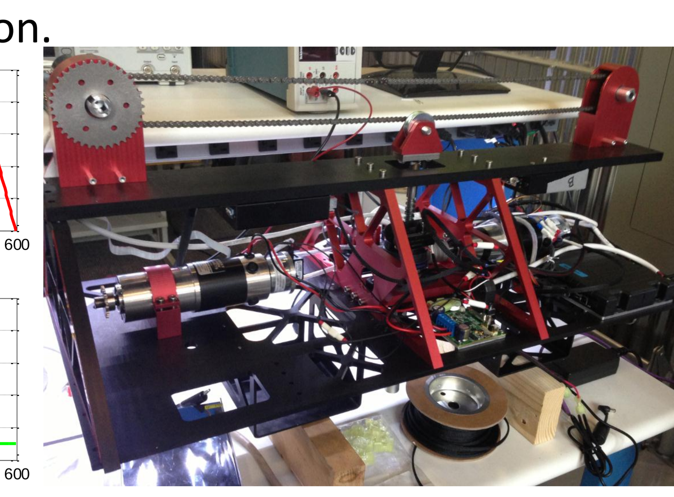
A simulated plant model (with 10% uniform noise) was used as the basis for creating the controller. The discretized controller successfully shows reaching steady-state within 5 seconds for a matched set of speeds. Future work will improve simulation to reflect physical limitations of motors and improve energy efficiency.



A modular and parameterized path planner algorithm was created to provide a velocity command file containing time, traversal velocities, and winch velocities. This file is then read by the main UI program of *Tyrobot* to issue speeds to the motors and verify the position.







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[Back of Poster Material]

Main Citations:

[1] B. Handwerk. (2009, 10, 26). *First Moon "Skylight" Found – Could House Lunar Base?* [Online]. Available: http://news.nationalgeographic.com/news/2009/10/091026-moon-skylight-lunar-base.html

[2] D. Coulter. (2010, 7, 12). *Down the Lunar Rabbit-Hole.* [Online]. Available: http://science.nasa.gov/science-news/science-at-nasa/2010/12jul_rabbithole/

[3] W. Su. "A Model Reference-Based Adaptive PID Controller for Robot Motion Control of Not Explicitly Known Systems." Vol. 12. No 3. September 2007. Int'l Journal of Intelligent Control and Systems

[4] U. Nagarajan, G. Kantor, and R. Hollis. "Integrated Planning and Control for Graceful Navigation of Shape-Accelerated Underactuated Balancing Mobile Robots." May 2012. IEEE ICRA. CMU Press.

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