Sun-Synchronous Robotic Exploration


Frequently Asked Questions

What is sun-synchronous navigation?

Sun-synchronous navigation is a technique that involves tracking the sun while exploring terrain. It is accomplished by traveling opposite to planetary rotation and in synchrony with the sun to always remain in sunlight. Robotic explorers on the planets and moons can employ sun-synchronous navigation to maintain continual exposure to sunlight to acquire the power necessary to sustain operation for extended periods of time. By setting their speed appropriate to their latitude and navigating to avoid shadows cast by local terrain, these solar-powered robots will be able to operate continuously. Furthermore for some missions, by following the dawn (specifically by lagging the night-to-day terminator by the appropriate amount) these rovers may be able to regulate their climate by remaining in the transient temperature region between nighttime cold and daytime hot.

Why is sun-synchronous robotic exploration important?

Sun-synchronous Navigation is important because it provides the means by which robots may be able to extend the distance and duration of their surface exploration. The technique would enable solar-powered robots to conduct long-duration missions covering vast areas. To date the amazing achievements of planetary rovers have been accomplished in a few weeks or months in an area limited to the landing site. Robots that can explore the environment while reasoning about how much power they need and how to capture the solar energy for it, can potentially operate for many months or even years.

Planetary rovers need to be broadly cognizant of their environment—the time, their position and orientation, the position of the sun, and their available and required energy levels to simultaneously optimize a path through the terrain and the amount of solar radiation they receive. Advancing the ability of robots to reason about themselves and their environment is important for many applications including the capability for sun-synchronous navigation.
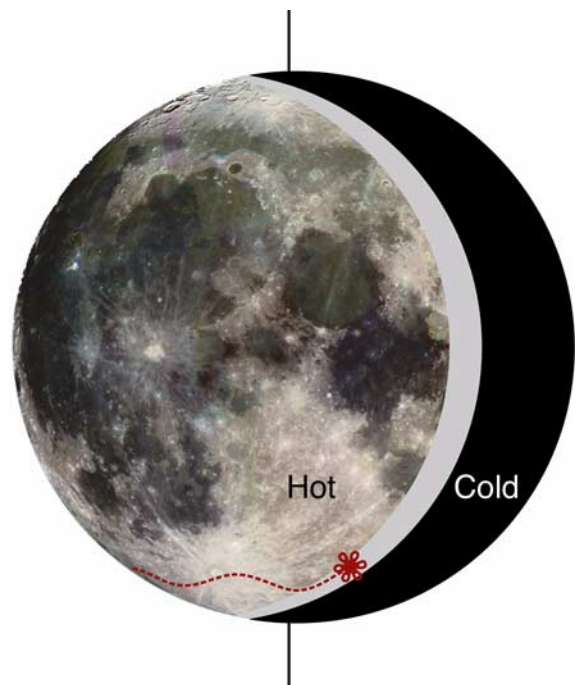
Why is the robot called Hyperion?

The name Hyperion comes from Greek mythology. Hyperion was a Titan, a predecessor to the Gods, who in myth fathered the Sun, Moon and dawn. The word Hyperion roughly translates to: *he who follows the Sun,* which is remarkably descriptive of what Hyperion the robot is intended to do.

What does Hyperion look like?

Hyperion is 2 meters long and 2 meters wide and almost 3 meters tall with a near-vertically mounted solar panel of 3.5 square meters. It carries this panel mounted upright to catch the low-angle sunlight of the polar regions. To support the panel its chassis is comparably sized. It is fabricated of aluminum tubing and has four wheels on two axles. On the front axle an A-frame stands 1.5 meters high to support the stereo cameras and laser scanner at a proper height to see the surrounding terrain. All of Hyperion's computers, electronics and batteries are enclosed in a single sleek body mounted between the axles. The robot weighs 156 kilograms.

3.5m²

Passive
Steering
Axis

2m   2m
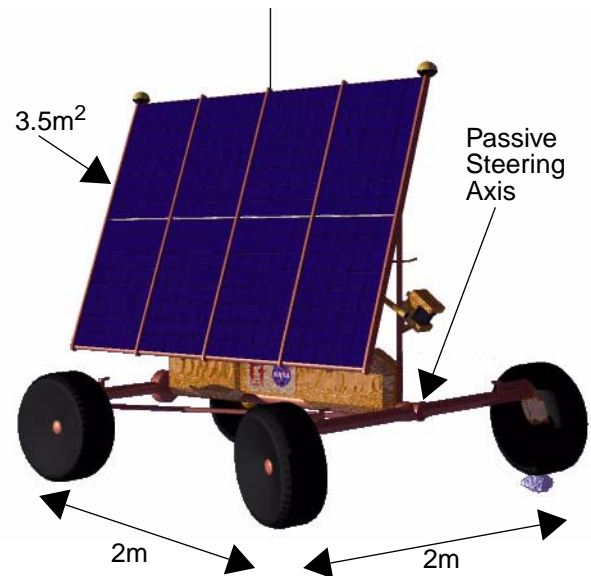
How does Hyperion drive and steer?

Hyperion is driven by four motors, one for each wheel. It has a passive (unactuated) joint at the front axle that can roll and yaw relative to the back end—similar to a wagon. It steers by driving the wheels at different speeds but instead of skidding like a bulldozer, the passive joint turns and the robot smoothly follows arcs. The advantage is that the number of actuators is minimized (there are only four motors) but energy is not wasted skidding the wheels to when turning.

What sensors does Hyperion use?

Hyperion uses a pair of digital cameras to image the terrain in front of it and a laser line scanner to detect close in obstacles. It carries a third camera with that can produce panoramic images so that remote observers can view its complete surroundings. Hyperion's laser scanner sweeps a line in front of it looking for obstacles, either rocks or drop-offs.

Hyperion measures speed, voltage and current on all its motors so that it can monitor their performance and determine it motion. It has roll and pitch inclinometers for determining motions.   The robot has numerous sensors to monitor power generation and consumption. There are temperature sensors spread throughout to monitor critical components.

How is Hyperion powered?

All of Hyperion's energy comes from the sun. Its solar cells supply its power bus, which runs computers and sensors, drives the wheels and charges its batteries. The output of the solar panels depends on the solar flux which is a function of the orientation of the panel and atmospheric conditions. The overall power tracking system is 11% efficient so if 600 W/m^2 of solar energy (a typical value) falls on the 3.5m^2 panels then Hyperion will have about 200W to use. Any excess power is put into a bank of lead-acid batteries so that Hyperion has capacity to can climb a steep slope, drive over an obstacle, or take a shortcut through a shadow or away from the sun when necessary. It's battery capacity is 32Ahr at 24V.

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Won't the wind blow Hyperion over?

Hyperion has a solar panel that stands up like a sail. Wind on the panel does exert a force that could tip Hyperion. Like a sailboat, Hyperion's upright panel is lightweight (about 20kg) compared to the weight of its body (136kg). Calculations show that Hyperion is stable in a 30KPH (20mph) wind on Earth.

On the Moon, there is no atmosphere and therefore, no wind to apply force to a rover. On Mars, the atmosphere is much less dense than on Earth so the force applied by the wind is much less. Although wind speeds on Mars can be high (over 100KPH) the force is applied is still low. On Earth we must monitor the weather and choose conditions appropriate for robot operation.

How does Hyperion know where it is?

To determine its position and orientation Hyperion carries a pair of GPS (global positioning system) receivers and odometric sensors. It computes the position of the each individual antenna and then determines its orientation from the known, relative position of the individual antennae. Hyperion also incorporates odometric sensing on its wheels so that it can estimate its motion by integrating information from its wheels. This is important beyond the Earth where GPS is not available; odometry combined with star, sun, or terrain landmark tracking would form the basis of estimating position and orientation.

How does Hyperion avoid shadows and know where to go?

To navigate sun-synchronously Hyperion must have a map of the terrain, an estimate of where it is located, and a measurement of the current time. Digital elevation maps at 100m resolution or better are available for most of the Earth. Maps of this resolution or better are or will soon be available for interesting areas of the Moon and Mars. Hyperion uses a combination of GPS and odometry to determine its location and an accurate onboard clock to know the current time.

With a map and a clock Hyperion can determine the relationship between the sun and terrain to compute where shadows will fall. By knowing its location relative to the map it can determine where the shadows are and how they will move over time. The difficult problem is then to make decisions that optimize the efficiency and safety of the path while reconciling the need to maintain adequate power all the time.

How does Hyperion avoid obstacles like rocks and slopes?

To travel through terrain Hyperion uses a pair of cameras, like eyes, and computer algorithms to see, measure and model obstacles in its immediate surroundings. It then evaluates multiple possible paths that avoid the obstacles, selecting a path that heads toward its goal while collecting sufficient solar energy to proceed. Hyperion can miss seeing an obstacle under certain conditions so it also carries a laser scanner to act as a "virtual bumper". If something, like a dirt-covered rock, appears in front of it, Hyperion stops immediately and sends a message indicating that it has been surprised and may have a problem.

Is Hyperion autonomous?

The answer is sometimes yes and sometimes no. Hyperion's control system is designed for what is sometimes called "sliding autonomy." It can smoothly slide from direct teleoperation where a human operator tells it everything to do, through modes of control where the operator and robot share decision making, to full autonomy where Hyperion decides for itself how to perform a given mission, where to go and when.

Hyperion has a health monitoring capability that enables it to decide when it needs help. If it can't find it's way, thinks the mission is impossible, or detects strange behavior from its sensors, it sends a message to human operators about what has happened and if it has decided to stop and wait for instructions. When everything is okay it can decide to pick up and continue on its own.

How will Hyperion explore?

Hyperion must move with the sun to collect the energy that it needs to survive. As it explorers it can conduct science investigations on the fly, collecting data and seeking evidence of specific phenomena: biological, hydrological or geological, while it is traveling. Although Hyperion does not currently posses any specialized scientific instruments, in principle when it needs to stop for science operations, for example close inspections or sample collection, it must either accumulate sufficient energy reserves or park so as to collect energy to sustain itself and then get back onto its sun-synchronous schedule. Exploration becomes more complicated because of the sometimes conflicting goals of scientific interest and power consumption but ultimately the advantage is that Hyperion can cover great distances and survive for a long time. In exploration both of these factors increase the chance of finding something interesting.

How much does Hyperion cost?

The components that make up Hyperion cost less than US$100,000. The larger cost is the development of software that enables it to sense the environment and navigate through terrain while reasoning about the sun. This work is done by scientists, engineers and graduate students who are supported by NASA.

Will Hyperion ever go to the Moon or Mars?

No. Hyperion is a concept vehicle and designed for operation Earth. On other planets or moons, different components would be used, for example space-qualified motors and computers, and some parts would be sized differently. Beyond the Earth, its solar panel would be smaller. Hyperion incorporates some commercially available components because they are readily available and are optimized for performance here on Earth.

Devon Island panorama, northwest of Haughton Crater

Where will field experiments of Hyperion be conducted?

Hyperion will be tested on Devon Island in the Territory of Nunavut in the Canadian arctic in July 2001. Devon island is the largest uninhabited island on Earth, with a surface area of approximately 66,800km^2. The flat-topped plateau characterizing much of Devon Island's surface is an ancient erosional surface. Devon Island is outside the region of permanent ice pack and much of its surface is free of snow in midsummer.

Haughton Crater is located at 75.35°N, 89.68°W on Devon Island. It is notable for the lunar-like impact breccia inside the crater and Mars-like terrain to the northwest of the crater. We will conduct experiments in these terrains to characterize Hyperion's performance on Earth and to collect data to study potential performance beyond Earth

Why Haughton Crater?

There are three reasons why Devon Island and the Haughton Crater area were selected. First, the site receives 24 hour sunlight during the Northern summer. Importantly, Haughton Crater is far enough north of the Arctic Circle so that the sun remains high in the sky (more than 5° above the horizon) well into July when weather conditions are favorable for experimentation.

Second, this area of Devon Island has terrain and soil that is analogous to what rovers might encounter on Mars and, in the area inside the crater, to the Moon. In mid-July snow has melted (see panorama above) and all of this terrain is revealed. This provides an idea environment for taking measurements that will allow us to predict rover performance beyond Earth.

Third, through the NASA/SETI Haughton-Mars project operating with the Canadian Polar Continental Shelf program, the logistical support structure has been established for field operations in this area of the high Arctic. We will be able to quickly and effectively access this site and conduct the experiments needed to evaluate the sun-synchronous navigation concept.

When will the experiments be conducted at Haughton Crater?

The field experiments with Hyperion will be conducted during the narrow window of time when the snow has melted in mid-July and when the sun begins to drop below surrounding hills in late July. The field experiment is expected require several weeks both because we will need to characterize subsystems and incrementally advance toward the complete sun-synchronous experiments and because experience shows that many days on site in polar environments are not suitable for experimentation.

The current schedule call for experimentation to commence on July 10, 2001 when the sun's minimum elevation (at midnight) is 7.5° above the nominal horizon and conclude by July 22 when it is barely 5° above the horizon at its minimum.

What else is happening at Haughton Crater?

There are several research groups working in or near Haughton Crater in 2001 because it presents both Mars-analog and Lunar-analog features. Some groups are studying the biology and geology of this unique site, some are considering human exploration, and others, like the Sun-Synchronous Navigation project, are researching robotic exploration.

The Mars Society is studying the human exploration of Mars at Haughton Crater. We are not collaborating because our objectives do not overlap. We won't need to conduct joint experiments and will be physically quite separated as well because the Flashline MARS habitat is in an area unsuitable for our experiments.

We are collaborating with the NASA/SETI Haughton-Mars project. We are both funded by NASA and will share logistics support. The Sun-Synchronous Navigation project has been approved by the Canadian government for our experiments under the auspices of the NASA/SETI project which is now entering its fourth year of study at Haughton Crater.

We collaborate with scientists from NASA Ames Research Center to make measurements of rover performance at specific scientific data collection tasks. We intend to collect measurements of time required for various tasks (survey area, approach specific target) under various conditions (amount of visual information, communication bandwidth, etc.) We will be studying performance of rovers and remote human operators with an eye to upcoming Mars rover missions.

Why are we conducting these experiments?

The Earth represents a particularly challenging environment for a solar powered robot because the available solar radiation and gravity conspire to provide barely enough power to propel the robot with today's technology. If a robot can succeed with sustained operation on Earth then the approach may be feasible on the Moon, Mars, or Mercury. At Haughton Crater we find Mars and Lunar-like terrain and conditions of sunlight for long duration tests. We will be measuring power and performance characteristics necessary to scale these values and predict performance beyond the Earth.

How can I get more information?

For more information you can visit our website at:

http://www.frc.ri.cmu.edu/sunsync

or contact Dr. David Wettergreen by telephone at: +1-412-268-5421 or email at: dsw@ri.cmu.edu

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