Senior Design Proposal: Lunar Rover Mission

Nasa Challenge Team

1 Introduction

Our project is loosely based off of the NASA Centennial Challenges Program (CCP) Space Robotics Phase 2 (SRC2)[1]. Though the original challenge is for virtual simulations of robotic systems, we will be building physical rovers. Essentially, our modified version of this project involves designing and constructing a system of two autonomous rovers capable of navigating through a partially unknown lunar environment, finding a predetermined object, and estimating the position of the object relative to the rovers' starting location.

2 Problem Description

As humans begin to spend more time in harsh, extraterrestrial environments, new technologies for applications often reserved for Earthbound missions must emerge. One such mission is the search and retrieval of some known object by a team of robots. We will focus on only the first segment of this mission: the search. This involves identifying the location of the object of interest and reporting the location back to Earth. Moreover, we focus specifically on the electrical engineering aspects of the mission and only require a trivial rover mechanical design. This simplified mission is largely directed by a couple of main design constraints.

Firstly, communication latencies between Earth and the rovers and the limited bandwidth that exist in such a channel dictate that the robotic system be able to function completely autonomously for long periods of time. While long distance communication between the Earth and Moon is outside the scope and budget of this project, we still require that the rovers be autonomous.

Additionally, the location of the object will likely be in a dimly lit or completely dark area (e.g. in a crater or on the dark side of the moon). So, the rovers must be able to function in these lighting conditions.

Furthermore, we consider a time sensitive mission, in which the object must be located as quickly as possible.

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[1] Official Rules Link

Lastly, NASA pays special attention to the radiation and thermal environments in which the device must operate. Both of these environmental hurdles will affect the processing and sensing capabilities of the solution. While thermal concerns are well within our scope, we do not have the resources to properly address radiation concerns, so we simplify this constraint by only requiring simple shielding.

3 Proposed Solution

We propose a two rover system to accomplish the mission outlined in the problem description. These two rovers work together to find and report the location of the object of interest in the following way.

First, each rover searches a different area of the moon for the target object while remaining within communication range of one another. Each rover navigates the environment, keeping track of its location relative to its starting location and avoiding obstacles detectable by a range finder.

Once the rover detects the object using object recognition technology, the rover reports the picture to Earth or a nearby lunar gateway for confirmation. Once the object in the image is confirmed to be the object of interest, the rover estimates the object's position using the rangefinder data and motor encoder data and transmits this location to the other rover.

When the other rover receives this signal, it travels to the communicated location, finds the object of interest, and makes its own estimate of the object’s location. Using these two independent estimates of the object’s location, a final estimate will be made and recorded. This concludes the mission.

An overview of a given rover in the system is illustrated in the figure below.

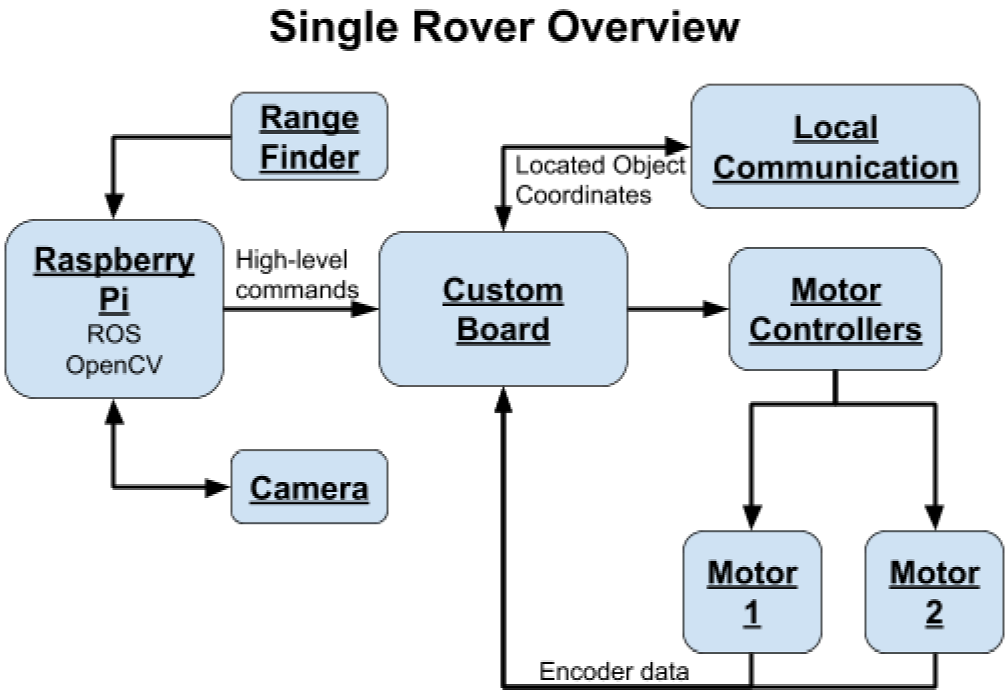

Figure 1. Proposed system overview of a single rover in the two-rover system

Usually, lunar missions would require the rovers to have a long term power supply (generally nuclear). However, we consider the question of a reliable long term power source outside the scope of our project since our focus is on object identification, autonomy, and communication.

We will address radiation and temperature concerns by operating our rovers only on the dark side of the moon. Since the rovers are already expected to operate in dark environments, this is a reasonable simplification. The dark side of the moon will shield us from the moon's higher temperatures and most of the strongest radiation from the sun. With only low temperatures and ambient radiation to worry about, we can reasonably use simple radiation shielding and escape the need for electronics working at high temperatures.

We will demonstrate basic swarm communication by creating two robots to communicate with each other. In theory if two robots can work together, a larger swarm could communicate in the same general way. Although we do not know which communication system would be best, we plan to research and experiment with zigbee, bluetooth, and wifi communication between the bots. We will choose a system that would theoretically scale well for larger swarms.

To successfully identify and locate the prespecified object of interest, the rovers will patrol their paths and use a camera and flash light to identify obstacles and potential objects. The distance between the rover and obstacle or object will be determined by implementing a laser rangefinder (see figure 1). If a potential candidate for the object of interest is found, a picture will be taken for identification purposes. A convolutional neural net will be taught to identify the specific object of interest; we plan to use OpenCV for this step and train it using simulated pictures. If the target is determined to be the object, then it’s location will be recorded and communicated to the other rover.

While the rover is travelling through the partially known terrain, there may be some objects in the rovers path that the rover needs to avoid. We plan on using the laser rangefinder as the obstacle detection for the rover. The laser rangefinder will be directed at obstacles in the rover’s path so the rover knows the location of the obstacles and can take the proper measures to avoid unknown obstacles.

We plan on having the rovers cover a partially known terrain which means the rover can have a predetermined path programmed in. The rovers will be deployed from a known starting location. The partially known environment will have the basic topology of the moon so we can avoid mountains and craters for our rover paths. We will have the rover traverse this terrain while avoiding any obstacles that may come up and then moving back to the programmed path.

4 Demonstrated Features

Our two rover swarm will find and identify the location of the object of interest within a +/- 2 meter range. The object of interest will be prespecified but the location will be unknown.

The rover will be able to correctly identify the object from a subset of given possibilities.

With our swarm solution, we will be able to obtain a better estimate of object location than individual estimates. Using the location of the two rovers and their individual estimates we can better triangulate the location of the object of interest.

Rovers do not hit objects larger than the rover is capable of surmounting. The robot will follow its predetermined path while correctly avoiding obstacles and identifying objects of interest.

The swarm locates the object of interest with greater accuracy and faster than individual rover could.

The swarm maintains uninterrupted communication link with other agents throughout the search.

5 Available Technologies

The following is a list of the estimated components and cost of our project:

- Camera with flash ($25 each, $50 total)[2]
- Raspberry Pi (previously owned)
- Zigbee/WiFi/Bluetooth module (~$20 each, $40 total)[3]
- 2 cars (chassis and motors w/ encoders) for adaptation ($12 each, $22)[4]
- Assuming boards cost $75 each
- DC Motor Controllers ($7 each, $14 total)[5]
- Battery (previously owned)
- Laser rangefinder (~$20 each, $40 total)[6]
- Total cost ~$316

We will be leveraging a number of existing technologies to design our lunar rovers. In the camera functional block, we will be using Raspberry Pi camera modules ($25 each) and a currently-owned Raspberry Pi for image processing. These systems will be connected to one another via a ribbon cable. We would also like to illuminate the path along which the camera is aimed with a simple flashlight.

Once the object is found, we intend to use a laser rangefinder to better estimate its position. We have settled on a laser rangefinder because an ultrasonic sensor likely would not work in the vacuum of space.

In the communication block, we will be using two ZigBee, Bluetooth, or WiFi modules, which will cost up to $20 each. We will use one of these standards to communicate essential information between rovers, including positions of objects and of each rover. When one rover believes it has found the object, it will call the other rover over to provide a second estimate of the location of the object.

Within our motor control block, we will need two DC motor controllers, which we have found for around $5 each. These will allow us to precisely control two DC motors per rover ($18 each), which will be equipped with speed encoders to give our MCU information about distance travelled and current position. Furthermore, our power block

[2] Camera flash link
[3] Zigbee module link
[4] Chassis link
[5] Motor Controller link
[6] Laser rangefinder link

will require two batteries, to which we already have access. Our other costs will include two chassis with pre-attached wheels ($12 each).

6 Engineering Content

First and foremost, our team will need to design a custom PCB that can handle both wireless communication and motor control. Hosting both of these applications onboard one PCB will require careful pin selection and layout planning.

We will also have a functional block consisting of a forward-facing camera, flashlight, laser rangefinder, and MCU whose purpose is object image capturing and analysis. We will likely host this processing on a Raspberry Pi, because it is computationally intense, and the MCU on our own board will be occupied with communication and motor control. This poses the issue of interfacing our own MCU with that onboard the Raspberry Pi to pass back and forth control information.

Furthermore, since this rover is intended for long-term use in space, it needs to operate over a wide range of temperatures and have a long-term power source. We must be careful in our selection of components, ensuring that we limit current draw and that our components have an adequate operating temperature range. Temperature concerns also require us to manage heat efficiently using heat sinks.

Another design concern is the rover body. We will likely need to 3D model and print these housings, ensuring that they are large enough to fit our systems while balancing weight.

To test the performance of the robotic system, will need to construct a simulated lunar environment. This simulated environment will only need to test our proposed features and not provide a more realistic lunar environment with radiation, lower gravity, etc. Our environment will consist of low lighting conditions, lunar rock-like obstacles, and specified crater locations. Rocks will be used to test the obstacle avoidance capabilities of the robot system and will be placed at random locations. A designated area of the environment will be defined as a crater the robot can not get out of, and the robot system will seek to avoid this known area. We will ensure that this is a modular setup and construct the environment in an available/reserved classroom for testing. Lastly, the object of interest for the search and retrieval mission will be 3D printed and placed in the environment.

7 Conclusions

This project will be challenging but our proposed solution will adequately demonstrate a distributed autonomous robotic system capable of navigation, path and motion planning, and object detection. In addition it will be implemented within the given budget of $500. The rover design will make use of a combination of commercial hardware, custom board designs, and custom and open source software. Our multi-robot solution will also be scalable with the potential for the addition of more rovers to explore and search larger areas and provide a more accurate position estimation of the desired object.