Senior Design Project: Notre Dame Rocketry Club Deployable Rover

Vinolin Anbalagan, John Speier, Chris St. George, Kevin Yokum

1. Introduction

For our senior design project, we will be working with the Notre Dame Rocketry Club. Specifically, we will be entirely responsible for all of the electrical (and assisting with much of the mechanical) functionality of Notre Dame's 2018 NASA Student Launch Deployable Rover Experiment.

2. Problem Description

The requirements provided by NASA for the deployable rover determined the problem description for this project. First, the rover must be a custom design that will deploy from the internal structure of the launch vehicle. Second, the rover must be deployed from the rocket using a trigger that is remotely activated by the team upon the rocket's landing. Third, the rover must autonomously move at least 5 feet in any direction from the launch vehicle once it has been deployed. Finally, the rover must deploy a set of foldable solar cell panels once it has reached its final destination.

3. Proposed Solution

The rover will be deployed from the second piece of the rocket, this will be accomplished using black powder to eject the nose cone then retract the studs that hold the rover in place. This will be accomplished using the LoRA modem network to remotely deploy the rocket and set the nose cone charge. The rover will then read the GPS beacons in each of the sections of the rocket to ascertain its exact position relative to the rest of the rocket. It will move autonomously using the LiDAR sensor for object avoidance. The solar cells will be deployable using a servo motor controlled by the PIC microcontroller, The servo will operate a rack-and pinion system, which will extend a post on either side of the rocket, expanding the folded solar panel array.

4. Demonstrated Features

4.1. Object Avoidance

In order for the rover to move autonomously once it has been deployed from the rocket, an object avoidance system will be implemented. This will involve the use of a LiDAR sensor to recognize objects and determine their locations and distances. These data will be received by our microcontroller and used to determine how the wheels of the rover should move to avoid the detected obstacles.

4.2. Radio Communications

The rover will be deployed using a radio signal from the ground station.

4.3. Position Triangulation

In order for the rover to end up at least 5 feet in any direction from the pieces of the rocket, a position triangulation system will be implemented. This will involve the use of GPS beacons in each of the three main sections of the rocket body, which will separate from each other in the air as the rocket descends.

These GPS beacons will send signals that will be received by the rover and processed by the microcontroller. By determining the change in the strength of the signals as the rover moves in a particular direction, the rover can determine whether it is moving toward or away from the sections of the launch vehicle. If the rover determines that is it moving toward a section or sections of the launch vehicle, it can change its direction so that it is moving away from the sections of the launch vehicle.

4.4. Solar Panel Deployment

The solar cells will be deployable using a servo motor controlled by the PIC microcontroller, The servo will operate a rack-and pinion system, which will extend a post on either side of the rocket, expanding the folded solar panel array.

4.5. Relevant Data Communication (i.e. ground station)

As part of the rocket, it is necessary to take a lot of data throughout the entire length of the launch. The rover will continuously send gyroscope orientation data, acceleration data and altitude data all through the launch via radio communications. After the rover has been deployed, the rover will continue to continuously update the base station on its current position.

5. Available Technologies

5.1. PIC32 Microcontroller

For the processor, a PIC32MX795 microcontroller will be used as the control unit for the rover and rocket as a whole. The PIC will be used to complete the major goals of the rover, object avoidance, autonomous movement from the rocket, and communication of important parameters to the ground station.

The PIC was chosen due to the convenience of the IDE, as well as its comparatively low cost and larger number of remappable pins and greater options for customizations. The PIC32MX795 was chosen over other types of PIC's for its large data memory (128 KB), program memory (512 KB). A PIC24 was considered, however some of the sensors require 8 byte data streams, therefore the PIC32 was necessary.

For object avoidance, the PIC will have interface with the LiDAR sensor using I^2C. This comes with a JST 6 pin connector, and will be used to reliably connect to the board. In addition, the microcontroller will interface with the other sensors (GPS, altimeter, gyroscope) using SPI. On the first board, I^2C communications will be used in the interest of using fewer wires and simpler troubleshooting; however, in the final printed board, SPI communications will be used wherever possible due to much lower power consumption and easier programming. Using a series of relays and the built in i/o ports, the PIC will also interface with the motors and control the motion of the rover.

5.2. Sensors

5.2.1. LiDAR Sensor

In order for the rover to be able to sense and avoid obstacles while moving autonomously after it is deployed, a LiDAR sensor will be used. The LiDAR sensor will measure the distance and location of any objects by sending out a pulsed laser light that will reflect off any objects and then measuring the reflected pulses. A LiDAR sensor was chosen for obstacle avoidance rather than a sensor such as ultrasonic sensor because LiDAR sensors do not have the same problems with noise interference or adverse conditions that ultrasonic sensors do. Since the conditions during the launch could vary, an ultrasonic sensor whose data could be affected by external noise, wind, rain, fog, or other conditions would not be as robust as a LiDAR sensor.

The LiDAR sensor that will be used is a LiDAR Lite v3 manufactured by Garmin. The dimensions for the sensor are 20 x 48 x 40 mm. This sensor has a range of up to 40 m and a resolution of +/- 1 cm, which will allow for the recognition of many obstacles that could impede the motion of the rover. The LiDAR Lite v3 is powered by a 5 Vdc supply and weighs 22 g.

5.2.2. Gyroscope and Accelerometer

In order for the orientation of the rover to be determined once the rocket lands, a gyroscope will be used. This gyroscope will also include a built-in accelerometer that will be able to continuously relay data to the ground station concerning the motion of the rover and, thus, the rocket. The data from the accelerometer will be used to determine when the rocket has landed and come to a complete stop so that the rover can be deployed. Meanwhile, the data from the gyroscope will be used to determine whether the rover is oriented right-side-up or upside-down as it prepares to exit the rocket. The orientation of the rover needs to be known so that the wheels will rotate in the correct direction (clockwise or counterclockwise) for the rover to exit the rocket and then move autonomously away from the rocket before deploying its solar panels.

The gyroscope/accelerometer package that will be used is an LSM9DS1 manufactured by STMicroelectronics which combines a 3D accelerometer, a 3D gyroscope, and a 3D magnometer. This sensor utilizes an analog supply voltage of 1.9 to 3.6 V and has SPI and I2C serial interfaces that will be used for communicating data.

5.2.3. Altimeter

The altimeter will be used to communicate the current altitude of the rocket to the ground station. The data from the altimeter will be used to check the whether the correct altitude has been attained, and whether the rocket has reached the ground again.

The rocket will use the altimeter MPL3115A2, which was chosen due to its wide operating range, from 20kPa to 110kPa, its high acquisition rate, up to once per second, and its easy I^2C interface.

5.2.4. GPS

Each section of the rocket will have an integrated GPS chip in order to check that the rover has moved an adequate distance from the body of the rocket. For the GPS tracking chip, the titan X1 GPS module will be used. It was chosen for its high sensitivity, up to -165dBm. This will allow for very precise location measurements for each of the sections of the rocket. The GPS module will communicate with the microcontroller via a SPI interface.

5.2.5. Radio Communications [LoRa™ Modem Network]

The rover deployment will need to be remotely activated. To achieve this, the rover will be equipped with a Microchip RN2903 LoRa™ Modem operating at 868 MHz. The Base Station, consisting of a LoRa Gateway and Laptop (located at the launch site) will communicate with the RN2903 in the rover, commencing deployment operations. The RN2903 in the rover will then be able to continuously update the ground crew at the base station on the rover's status as it autonomously exits the cargo tube and moves away from the landing site to where it will deploy the solar panels.

5.3. Power Control System

The Power Control System is the subsystem that powers the rover. It needs to provide enough voltage and current to drive the four motors and the microcontroller. The motors selected have a max voltage rating of 8V. The microcontroller requires a voltage between 3.3 and 5V. All the sensors used have similar voltage ranges. The LiDAR sensor requires 5V, the Gyroscope and Accelerometer needs between 1.9 to 3.6V, the GPS module requires 3.3V, the Altimeter needs between 1.6 and 3.6V, and the LoRa Modem requires 3.3V.

In addition to supplying the necessary power, this subsystem also has to meet other design parameters such as size, weight, durability, and safety requirements. The system should also be transportable so batteries are an obvious choice. The battery system should be compact, lightweight, and robust enough to withstand vibrations and pressure from the rocket launch.

To meet all these requirements, the Tracer 12V 8Ah Lithium Polymer Battery Pack was selected. This battery has dimensions of 80 x 153 x 49 mm which is well within the size for the rover. The pack weighs only 600 grams and will be able to supply power to the rover for over two hours. The pack comes in a hard shell that protects it from impact. Another nice feature of this battery pack is that it comes with a built in fuel gauge to check the remaining power level. And, more importantly, the pack is UN38.3 certified safe which includes several safety features such as overcharge and over-discharge protection, thermal, protection, overcurrent and short circuit protection.

5.4. Base Station

The base station will consist of a LoRa Gateway, which will communicate with the RN2903 in the rover and communicate via serial connection with the base station PIC32. The PIC32 will communicate via serial connection with a laptop for easy display of the rover's status as well as a location where the command to the rover to begin deployment can be entered.

6. Engineering Content

This project is comprised of several functional blocks that interface with each other. The base station setup must be designed so that it can communicate with robot for remote deployment. The bluetooth beacons that communicate with the robot is another functional block that must be designed. The mechanism for deploying solar panels is a function block that must be built. An algorithm needs to be developed for rover mobility, object avoidance, and solar panel deployment. The circuit board with the microcontroller and sensors needs to be designed and tested.

7. Conclusions

While some of our proposed solutions are fairly expensive, with our combined budget and the rover budget from rocket team, we should have no problem incorporating more robust yet more expensive sensors such as the LiDAR. This will allow us to be more confident about our current configuration working without having to worry about potential pitfalls such as weather or other interference that a cheaper device like sonar would have. This will be a significant advantage for us to implement our vision for this project. Additionally, working on a cross-functional team of aerospace, electrical, computer, and mechanical engineers will give us an experience that we may not have had otherwise. Overall, this is an interesting project, with interesting design constraints that will need to be overcome to adequately solve the engineering problem discussed.