Notre Dame Rocketry Team Payload High Level Design

EE 41430 Senior Design 1

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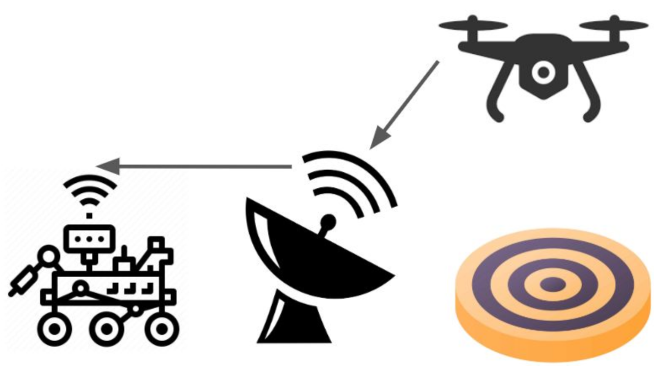

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Introduction

The purpose of our project is to support the Notre Dame Rocketry Team's electrical design for the 2020 NASA Student Launch competition payload. The official competition description per NASA's website is as follows:

"The NASA Student Launch (SL) is a research-based, competitive, and experiential learning project that provides relevant and cost-effective research and development."

Specifically, our team will work to design the communication protocols, controls, software, and power distribution for the rover that will be responsible for retrieving a simulated lunar ice sample consisting of a bead like material. We will also be working with other groups within the ND Rocketry Team to integrate our system with their mechanical design and communications for payload deployment and data transmission.

For further information about the Notre Dame Rocketry Team such as contact information, technical documents, and social media updates please see the team's website at the following link:

http://sites.nd.edu/aiaa-club/notre-dame-rocket-team/

Problem Statement and Proposed Solution

Problem Description:

The Notre Dame Rocketry Team's payload will be required to exit the rocket after a successful landing, navigate to one of five predetermined sample locations that are each 3 feet in diameter with a colored tarp 10 feet in diameter surrounding the sample area, and collect at least 10mL of a simulated lunar ice that could be as much as two inches below the ground. After the sample is recovered, the payload vehicle must transport the sample at least ten linear feet away from the chosen recovery area. Any hardware that is used to collect the sample must be launched within the rocket and may not be physically touched by team members after landing. Our team will be working to design the electrical systems to accomplish these tasks and comply with the rules set forth by NASA. The official rules set forth by NASA for the general payload requirements are outlined in the competition handbook accessible online at the following link:

https://www.nasa.gov/sites/default/files/atoms/files/2020-sl-handbook.pdf

Proposed Solution:

The Notre Dame Rocketry Team's payload team has designed a two part solution. The system will consist of two payload vehicles: a UAV which will use an on board camera and computer vision algorithms to identify one of the target locations and transmit the GPS coordinates of the sample area to a ground station, and a rover which will receive the GPS coordinates from the ground station and using on board GPS determine the direction it needs to drive. Once the desired direction is calculated, the software loaded on the rover's embedded systems will autonomously control the drive motors to drive to the sample area and upon arrival activate motors for the sample retrieval system which will consist of an archimedes screw. Upon successful collection of the sample, the rover will then drive 10 feet away from the target area. By utilizing both a UAV and a rover, the team is accepting the experimental challenge of two payload vehicles to more closely simulate a lunar environment where location information would be transmitted from a satellite or similar system to the rover on the ground.

System Requirements

The Rover Electrical System must be reliable, robust, and meet the requirements given in the 2019 NASA Student Launch competition. It must be able to withstand the environments of the launch and deployment stages.

Control Requirements

The system must be able to operate both autonomously and under manual control. The rover must be able to autonomously navigate to the sample recovery area based on the GPS coordinates transmitted by the ground station. The rover must be capable of responding to environmental disturbances that may require changing the course of travel.

In addition, as stipulated by NASA, the rover must be able to switch to manual control at any time. The manual control must be over a wireless communication that can operate reliably over a range of at least 30 feet as team members are allowed to walk alongside the rover during manual control.

Power Requirements

The rover power system must supply sufficient power to the rover for two hours which is the approximate time allocated between launch windows at competition. This accounts for both idle time on powered on the launch pad and active time in which the motors are active with increased current draw. On board batteries need to provide enough voltage and current to power the two drive motors, the microcontroller and sensors, and the two sample retrieval servo motors throughout the mission. The drive motors selected have a recommended operating voltage of 12 V. The servo motors selected have a recommended operating voltage of 5 V. The microcontroller requires a voltage of 3.3 V. The sensors used all require 3.3 V. Thus a 3.3 V and 5 V voltage regulator will be required to convert the 12 V power supply to acceptable levels for the microcontroller electronics and servo motors.

Mechanical Requirements

The electronics and power system of the rover must fit within the size and weight requirements stipulated by the Notre Dame Rocket Team. The rover as a whole must weigh less than 3 lbs. The rover must fit within the nosecone of the rocket with dimensions of 16 in. length and 7.75 in. diameter. The electronics and power system must add minimal weight to the rover and fit within the surface area given on the rover. Preliminary designs for the team’s rover are shown in Fig. 1 and Fig. 2. The design utilizes an eccentric crank mechanism which will allow the rover to better traverse and climb the uneven terrain expected in the launch fields.

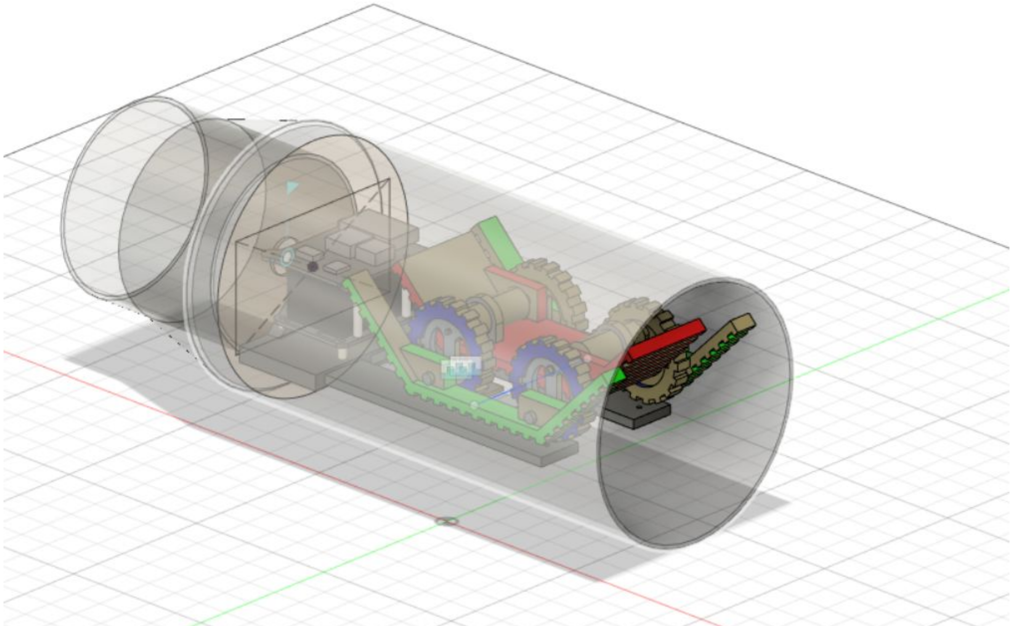


Fig. 1: CAD Model of Rover in Nosecone

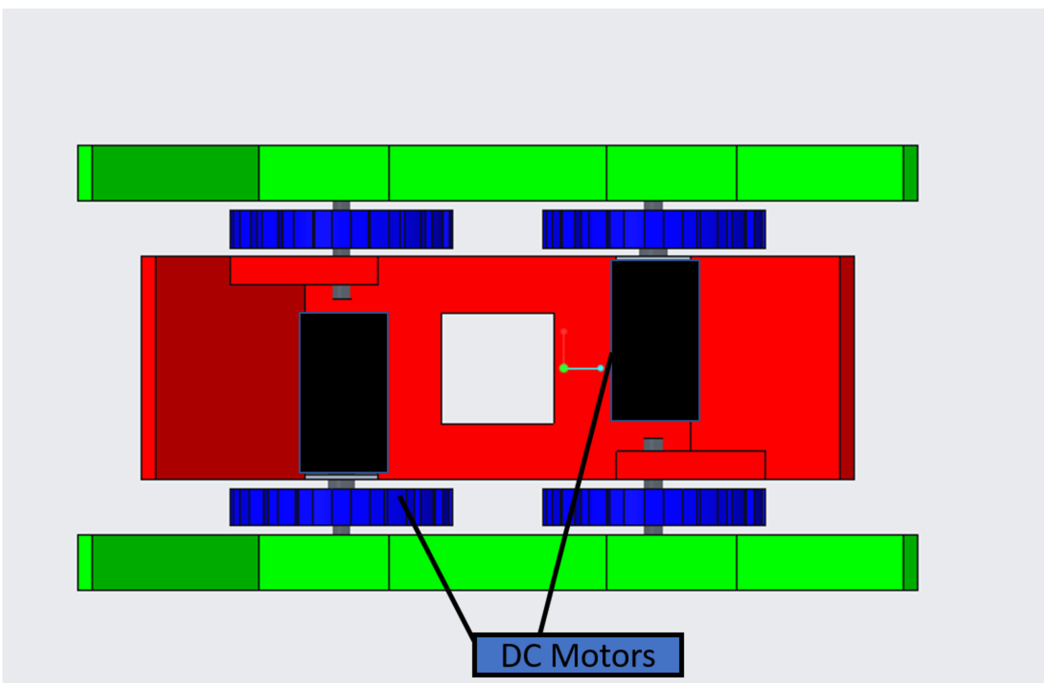


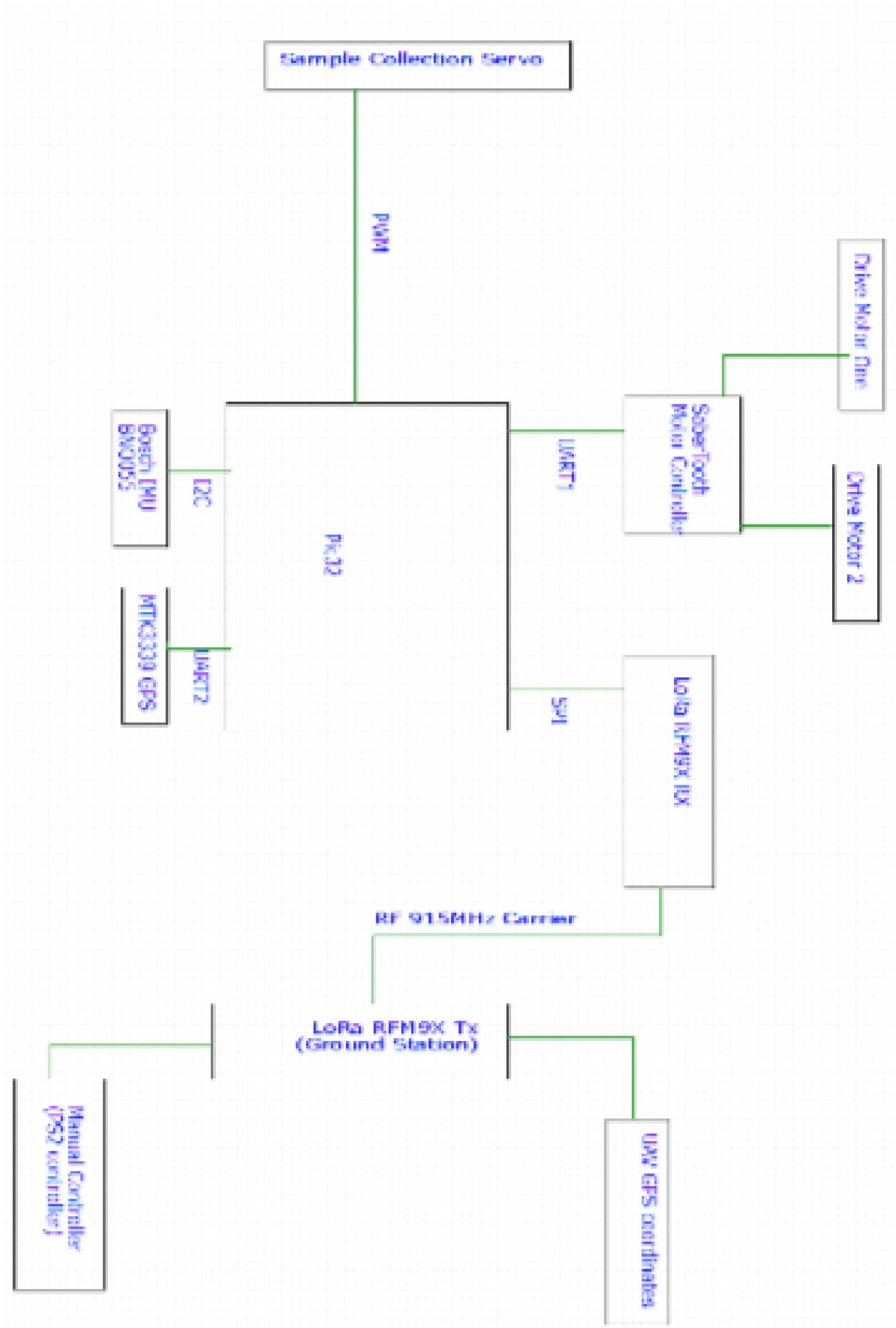
Fig. 2 Top-Down View of Rover Model

User Interface Requirements

The rover must be able to interface with the ground station and the manual controller. As of the current design, it is undecided whether the manual controller will be through the ground station or a separate controller package. This interface will likely rely on a simplified arduino system since it's only functionality is to act as a transceiver and will use the same transceiver as the rover to transmit data.

System Block Diagram

Overall System



Subsystem and Interface Requirements

Navigation Subsystem

-IMU: This subsystem will allow for compliance to the requirements of our project outlined in the NASA student launch handbook, by enabling the rover to sense direction and to tell if the motor power is being applied to the ground.

- The accelerometer will be used to run a control system to give power to the wheels. If there is power being sent to the wheels but the accelerometer does not sense linear motion of the rover, then the motor may be stalled and needs to be sent a stop command.
- The geomagnetic sensor will be used in conjunction with the GPS module to give the orientation of the rover.

-GPS: This subsystem will be used to give the rover its location, allowing it to automatically navigate to the sample site. The GPS sensor will aid the geomagnetic sensor in orienting the rover.

Communication Subsystem

-RF Transceiver: This subsystem will allow for communication from the ground station with the rover, feeding back data and feeding forward to the rover.

Embedded Intelligence Subsystem

-PIC32: This subsystem will integrate the sensors, and give commands to the modules. The logic for the control system for power delivery to the skids (wheels) will run here, as well as the navigation to the sample site. Power delivery to the motors is controlled by the PIC32 as well.

Motor Control Subsystem

-Sabertooth MC: The motor controller will respond to either a PWM or serial signal from the PIC32.

-Servos: The sample retrieval servos must respond to a PWM signal from the PIC32 in order to rotate and operate the mechanism.

Future Enhancement Requirements

The launch in Huntsville is the only foreseeable release of our product. As a result, all requirements specified by NASA and the Notre Dame Rocket Team must be verified and fulfilled in the first version. However, it would be interesting for future releases to explore methods of powering the rover that would make the rover self-sustaining, such as solar panels mounted to the rover. Finally, future designs of the rover could include expanded communication with the ground station, including data acquired from sensors, status updates on location, and images of what the rover “sees.”

High Level Design Decisions

Subsystems:

- Sabertooth 2x5 Motor Controller

Our motor control system will be utilizing the Sabertooth 2X5 motor controller. This controller is able to provide up to 5 amps continuous current to a brushed DC motor, and up to 10 amp peaks for short durations. This fits the current needs perfectly, and then some, for our motors.

The Sabertooth 2X5 has a number of different input/motor control options. The basic operation is that there are two input ports, S1 and S2, that control motors 1 and 2 respectively (generally). The control options most useful to us would either be:

Full, independent analog: two analog signals from 0 to 5 volts, applied independently to S1 and S2 to control motion (0=full reverse, 2.5=stop, 5=full forward), simplified serial: A 9600, 8N1 data stream applied to S1 only (1= full reverse for motor one, 64 full stop motor 1, 127 full forward for motor 1, 128 full reverse for motor 2, 192 stop for motor 2, 255 full forward for motor 2, 0 special character that stops motors)

Packetized serial: A serial packet sent with the format of: address byte, command byte, data byte, and then a seven bit checksum.

The most likely candidate for control right now will be simplified serial. It will work best with the options we have. The motor controller will hold the previous input, so we can send drive information to control one motor, and while it is holding, send drive information to control the other motor. Information will be sent plenty fast enough that we will have sufficient granularity in separate control.

The benefits of this configuration is that we can control and limit the current in software. So long as we don't get close to the 3.8 amp stall current that would damage the motors, we will be just fine. We can operate at a slightly slower speed overall to avoid sending too much continuous current through the motors, so max current ever sent will be, for example, 3 amps.

Additionally, we can monitor movement in software by comparing drive commands we are sending to the motors against our measured velocity and determine if we are stuck. If we do get stuck, the Sabertooth motor controller will aid in preventing motor burnout, and we can perform evasive maneuvers.

The only hiccups with using simplified serial is that the input to the Sabertooth is looking for 5V TT logic, while the MCU we're using is 3.3V CMOS. We will need a level shifter to get it to work.

If there are any other issues we encounter along the way, it is certainly possible to employ our own D2A converter and use the analog input on the Sabertooth. We will be doing essentially the same thing as with the simplified serial, except that we will be taking care of the D2A. We can even figure out packetized serial if we find it necessary.

- Li-Ion Battery

The two batteries of the rover are necessary to provide power to the on board electronics as well as the two drive motors and two sample retrieval servo motors. The primary design constraints when selecting motors are the capacity, max continuous current supply, size and weight. The selected drive motors have a maximum stall torque of 3.8 A so a minimum discharge current of 5 A was selected such that the battery has a 1.3 factor of safety for current supply to avoid overdrawing the batteries and risking damage to the battery.

- 900 MHz Antenna + Connector

The 900 MHz band was chosen because of its long range and unlicensed transmission. One of the major considerations is that the RF Senior EE team communicating on the 433 MHz band, so we wanted to be on different bands to avoid interference. However, the amount of bandwidth that is needed for data transfer is minimal compared to the RF team, and therefore the impact will be negligible. The range, found experimentally, is 1500 feet. This will be more than enough to communicate across the expected NASA defined distance of 100m.

- Microcontroller - PIC32MX795F512H

The PIC32MX795F512H was chosen for its increased featureset, as opposed to the PIC32MX1XXFX series. The PIC32-795 has better performance, memory, clock speed and more options for the pin-outs. The PIC32-795 will more than serve our needs, and moreover we are familiar with the architecture and modules.

- IMU - Bosch IMU BNO055

The primary reason that the Bosch sensor was chosen is because there are three sensors included in the package; the gyroscope, accelerometer, and geomagnetic sensor.

The package will communicate over I2C, and there is an on-chip interrupt controller. The interrupt controller is motion based, with the triggers corresponding to:

-any-motion (slope) detection
-slow or no motion recognition
-high-g detection

To reduce the total power consumed by the package, the individual sensors' configuration bits can be assigned to several settings such as sleep mode, fast boot, high accuracy and a few others.

This subsystem will allow for compliance to the requirements of our project outlined in the NASA student launch handbook, by enabling the rover to sense direction, and to tell if the motor power is being applied to the ground.

- GPS - MTK3339

The GPS module will be used to automatically guide the rover to the sample site, which is above and beyond the NASA student launch handbook requirements. The GPS module has an impressive sensitivity of -165dBm, and conveniently comes with automatic antenna switching functionality. The power draw is also lower than the competition, at around 70mW. Another advantage of this package is that it has a high-refresh rate of 10Hz.

- RF Transceiver Module - LoRa RFMNX Tx

The RF transceiver module will be used to communicate with the rover remotely, allowing for autonomous navigation. The effective bitrate of the module is 018 - 37.5 kbps, depending on the bandwidth. This is more than enough for our needs. The power draw of the module is 100mW maximum, well within the 250mW maximum given by NASA requirements.

Open Questions

The target that the rover is autonomously navigating to is a 10ft diameter tarp but the GPS is only accurate within 3 meters. Inside of the tarp, the actual sample retrieval section is only 3ft diameter, so it is very unlikely that the rover will be able to obtain sample fully autonomously. The open question is whether we can incorporate another method so that the rover can autonomously collect the sample even if the GPS is not accurate enough. Currently the plan is to switch to manual control mode and have someone guide the rover the rest of the way with a controller. Ideally, we would like to have the option of using the UAV to takeoff for another flight and use its camera feed to direct the rover the last couple feet to the sample. This is still an open question if it will work because we don't know how long it will take for the UAV to identify the sample site so there might not be enough energy left in the battery for another flight. We also would need to allocate time to coordinate programming with the UAV team to take on this extra task.

Major Component Costs

Our Team has financial support from the Rocketry team in addition to the funds available from senior design some of our parts will be able to be bought by the Rocketry team. The parts that are used for mechanical aspects such as the motors will be bought by the team while the sensors and antennas needed for our specific functions will be bought with senior design funds. With our current part selection, we are on track to spend approximately $300 of the senior design funds. This is 60% of the allocated $500 available, which is a good margin to allow for increased costs in the event of damage to a part or a need to redesign the board.

Part Name	Quantity	Total cost	Supplier Link
Sabertooth 2x5 Motor Controller	1	$57.95	Link
Li-Ion Battery	2	$83.98	Link
900 MHz Antenna + connector	3	$40.50	Link

PIC 32 Microcontroller	1	$8.80	Link
Inertial Measurement Unit (IMU)	1	$11.16	Link
GPS	1	$29.99	Link
RF Transceiver Module	2	$27.14	Link
Board Manufacturing Funds	1	$50.00	Estimate
Total Cost	N/A	$309.52	N/A

Conclusions

The specifications given by the Notre Dame Rocket Team are broad enough that many different solutions exist to address the task. We believe that our proposed solution is a creative and efficient way to achieve the goals set by the NASA Student Launch competition. During the upcoming Critical Design Review as part of the competition the team shall outline further requirements and testing plans to ensure successful functionality of electronics components and the integration with the rest of the payload's functionality. The team is currently working on the design of a board to integrate all of these components on the rover and hopes to order them in time to test early in the next semester in preparation for test launches in February and March in preparation for the competition launch April 4th.

References

a. Sabertooth 2x5 Motor Controller
b. Li-Ion Battery
c. 900 MHz Antenna + connector
d. PIC 32 Microcontroller
e. Inertial Measurement Unit (IMU)
f. GPS
g. RF Transceiver Module