Project Proposal

Notre Dame Rocketry Team Telemetry System

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1. Introduction

The Notre Dame Rocketry Team (NDRT) has communicated a desire to report data from their rocket during its launch, such that the status of the rocket can be observed and understood in real time. This requires the design and implementation of a sensor system as well as a radio link between the rocket and a ground station. Using concepts from engineering domains such as RF, communications, and embedded systems, a reasonable and robust solution can be developed to address NDRT's goals.

2. Problem Description

The primary consideration in this project will be the radio link and the conditions in which it must operate. In terms of range, the rocket reaches its apogee at approximately 4,900ft and must communicate information to a ground station a few hundred feet from the launch site. It will also reach a maximum speed of 590ft/s during its flight, with a maximum acceleration of 222 ft/s^2. Additionally, the rocket will change orientation throughout its launch, descent, and landing. This means that the transmitter aboard the rocket must be able to transmit data consistently regardless of orientation and up to the maximum range.

There are additional constraints on the size and location of the system, as it must fit into the nose cone of the rocket. The nose cone is 3-D printed and is therefore RF transparent, so all components, including the antenna, can be located inside. All sensors that report useful data must also be located in the top portion of the rocket since the rocket breaks apart during descent.

NASA requires GPS data to be logged during the launch, but the NDRT also wants to measure altitude, measure acceleration, and be able to observe these values on the ground in real time. This requires transmitting, receiving, and processing packets of data, as well as developing a user interface for the ground station.

3. Proposed Solution

The proposed solution for the telemetry hardware involves a dipole antenna placed in the rocket to communicate with a ground station. NDRT proposed the hardware to reside in the Fin Can or Nose Cone. The Fin Can is made of carbon fiber, so antennas and GPS would need to be mounted on the outside; however, the 3D printed nose cone is RF transparent, so the telemetry components can be inside the rocket there. As a result, we have chosen to locate our system in the nose cone.

The proposed frequency of operation is 915 MHz. This is a commonly used frequency in the ISM band, meaning there are many compatible components, and it is a lower frequency than other popular choices (e.g. 2.4 GHz, 5 GHz), soit has lower propagation losses. Also, operating in this band means we can transmit without a license. At 915 MHz, the antenna length is 6.5”.

For a dipole antenna, the radiation pattern is more favorable than that of a quarter-wave monopole antenna for ascent, descent, and lying on the ground. The symmetry of the dipole radiation pattern, as opposed to that of a finite ground plane monopole, is useful given the large variation in rocket orientation. Additionally, using a dipole antenna involves only one antenna, making it a simpler solution than more directive solutions that involve multiple antennas. As a result, a dipole antenna was selected for our proposed solution.

Furthermore, because of the unique structure and trajectory of the rocket, we are proposing designing our own RF circuitry rather than buying a commercial solution because we require more flexibility in design. One concern is whether commercial products will be able to compensate for the doppler shift resulting from the high speed of the rocket during flight. We also require precise control over the transmit power, components used in the transmitter and receiver, and packetization methodology. Lastly, to adhere to NASA’s rules best, we are considering using a spread spectrum technique. For these reasons, we believe designing our own RF circuitry will allow for our design to be more robust given the harsh operating environment.

At the rocket’s maximum possible apogee of 4,900ft, the angle between the rocket and the ground station would be approximately 86° if the ground station is 300ft away from launch. Using a dipole antenna at this angle would result in extremely low received power due to the dipole’s radiation pattern. To address this issue, we plan to implement a relay station located further away from the launch, such that it will be at a more favorable angle in the dipole’s radiation pattern. This relay station will serve as an intermediary between the rocket and the ground station by receiving data transmitted from the rocket and forwarding it to the ground station.

The ground station will consist of a commercial radio link receiver connected to a laptop. A custom-made receiver on the relay station will give data to a commercial transmitter via a wired connection, and the commercial transmitter will forward the data to the commercial receiver at the ground station that is connected to a laptop. Software on the laptop will pull data from the link, process it, and display relevant data in a GUI. We propose using a commercial solution for the ground-to-ground communication for simplicity, since it is not a unique environment. Specifically, we plan to use the Flex Gecko Wireless SoC Starter Kit, discussed further in Section 5.

4. Demonstrated Features

On demonstration day in May we expect to demonstrate the functional radio link between the stationary rocket and the ground station. This will show that the embedded system, transmitter, receiver, and ground station software all work in real time, although the data will be relatively static since the rocket will no longer be under test. More specifically, we plan on demonstrating that the system is able to collect data on the acceleration and altitude of the rocket and transmit it to the ground via our custom transmitter. We will also demonstrate that the relay station is able to receive this data via the custom receiver and send it on to the ground station via the commercial transmitter. Finally, we will demonstrate that the ground station is able to receive this data from the commercial receiver, send it to a computer, and display the data in an easily-interpreted manner in real time.

The launch, of course, happens much earlier than the demonstration date in May. In May, then, we will also demonstrate that our system functions were successful during the launch by locally storing the sensor readings from the rocket and confirming that data with the data received at the ground station. This will allow us to determine the reliability of our telemetry link during the rocket's flight by directly comparing the data collected by the sensors in the rocket to the data received by the ground station after transmission. This data can also be fed into our UI on demonstration day and the live feed from the launch day can be replicated and observed.

5. Available Technologies

See Appendix A for links to the distributor's website for each part.

For tracking the location and altitude of the rocket, a GPS receiver module will be integrated into our system. There are several different options for modules that contain the GPS antenna built-in.
CAM-M8C-0-10 - 10Hz update rate, 29mA current draw, SPI or UART interface, $25
SL869GNS115T001 - 10Hz update rate, 43mA current draw, UART or I2C interface, $23.16
Adafruit Mini GPS PA1010D - 10Hz update rate, 30mA current draw, UART or I2C interface, $29.95

For measuring acceleration of the rocket, an accelerometer will be incorporated into the system.
Adafruit BNO055- 9 DOF with built in orientation calculations, I2C interface, $34.95
Adafruit LSM303 - 3 axis accelerometer and 3 axis magnetometer, I2C interface, $14.95
KX222-1054 - 3 axis accelerometer with large input ranges, I2C/SPI interface, $9.41

For measuring accurate altitude, a barometer will be incorporated into our system. It will have access to the outside of the rocket via a sealed tube to measure the barometric pressure.
Adafruit MPL3115A2 - 0.3m resolution, altimeter calculation, no calibration required, I2C interface, $9.95
Adafruit BMP388 - 0.5m resolution, no built in altitude calculation, calibration required, I2C or SPI interface, $9.95

The radio transmitter onboard the rocket and the receiver at the relay station will be based on the superheterodyne radio, constructed using RF ICs from Analog Devices (see link in Appendix A). While we have not selected exact parts for the radio, we plan to use the components laid out in Figure 1 such as amplifiers, a mixer, a local oscillator, tunable filters, and a demodulator. Additionally, our mentor, Dr. Chisum, has evaluation boards for many of the parts we will be using which will allow us to conduct rapid prototyping before developing our custom PCB.

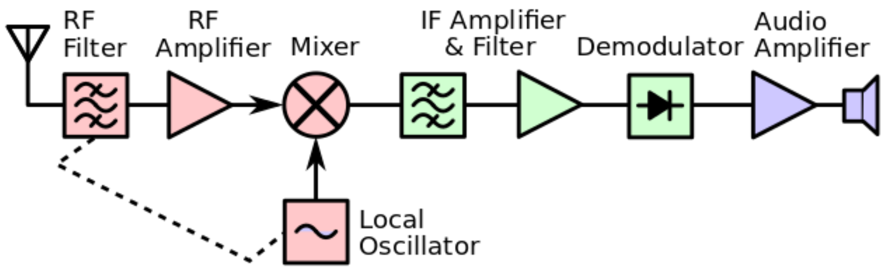

Figure 1. Superheterodyne radio diagram (wikipedia.com)

The ground-to-ground radio link can be easily implemented using commercial radio boards. Silicon Labs offers a development kit with two mainboards and two EFR32 Flex Gecko radio boards which can operate in the sub-GHz band (see link in Appendix A). This package comes with a software development kit that allows data to be sent across the link efficiently and is easily configurable.

The sensor suite, microcontroller, and radios will all need to be powered by batteries. The total flight time will be on the order of two minutes, so a trade off between weight and maximum stored energy will be made when our team is given a specific weight budget by NDRT.

As a final note, RFICs and any evaluation boards that are not available from the EE department will be more expensive than normal chips. We expect that our cost will be high, but NDRT has pledged an additional $500 to our budget. Additionally, NDRT is working with 4pcb to sponsor the team.

6. Engineering Content

This project has a large RF component. We plan to develop our own radio link, including the designs of antennas, transmitter, and receiver. With Dr. Chisum's guidance, we will base our system off a superheterodyne radio. This will involve choosing various RF components, constructing a "breadboard" prototype of our design using evaluation boards, and designing the layout of the printed circuit board to ensure that the radio will function as intended.

Another component is the Embedded Systems and Communications aspect. A microcontroller will be used to gather data from all sensors. This will involve designing a system that will allow the microcontroller to properly communicate with each sensor IC. We will need to write software to pull data from each sensor on a regular interval using serial communication protocols, as well as packetize the data before sending it to the radio transmitter. An especially difficult challenge will be developing a physical layer protocol that will allow us simultaneously to handle the doppler distortion we expect during the mission and use the 915 MHz ISM band in a way that will not interfere with other competing teams. On the ground, the relay station will need to be designed to pull the rocket's data from the custom radio receiver and then send it to the commercial transmitter that will forward it to the ground station. This will involve designing the hardware to allow proper communication between the receiver and commercial transmitter, and writing software to properly send data between them. The ground station will be designed to receive data via the commercial radio receiver, unpack it, and then send it to the computer to be further processed and displayed by the UI . Each of these systems will need to incorporate all IC's into one printed circuit board that will need to be custom designed to fit their various size and weight requirements.

This is also a component of Computer Science involved. We will work with NDRT members to develop a UI to elegantly display the transmitted data on a ground station computer located close to the launch site. This will involve writing software on the computer to pull the data from the ground station electronics, perform the necessary calculations to determine the state of the rocket, and display the data collected in an easily-interpretable manner. This software will need to operate fast enough to display the data in real time during the flight of the rocket.

7. Conclusions

Our proposed system will provide a new capability for NDRT that will allow them to receive the status of their rocket in real time. We plan on working closely with NDRT throughout our design process to ensure that we are meeting all of their requirements and providing them with a system that will be most useful for them. As they have never attempted this before, this project will be used by NDRT as a basis for future telemetry systems, making a large impact on their future capabilities. Since this system has the potential to be fairly elaborate, we are prepared for the potential challenges that arise and are excited to tackle the complex problems that lie ahead.

Appendix A: Links to Possible Parts

GPS
CAM-M8C-0-10: https://www.digikey.com/product-detail/en/u-blox-america-inc/CAM-M8C-0-10/672-CAM-M8C-0-10CT-ND/6150677
SL869GNS115T001:
https://www.digikey.com/product-detail/en/telit/SL869GNS115T001/943-1029-ND/5056809
Adafruit Mini GPS PA1010D:
https://www.adafruit.com/product/4415

Accelerometer
Adafruit BNO055
https://www.adafruit.com/product/2472
Adafruit LSM303 https://www.adafruit.com/product/1120
KX222-1054https://www.digikey.com/product-detail/en/kionix-inc/KX222-1054/1191-1062-1-ND/10186945

Altimeter
Adafruit MPL3115A2
https://www.adafruit.com/product/1893
Adafruit BMP388
https://www.adafruit.com/product/3966

Custom Radio Link Parts (Analog Devices)
https://www.analog.com/en/products/rf-microwave.html

Commercial Radio Link (ground-to-ground)
Flex Gecko EFR32
https://www.silabs.com/products/development-tools/wireless/proprietary/slwstk6062b-efr32-flex-gecko-490-mhz-2-4-ghz-and-sub-ghz-starter-kit

Additional Evaluation Boards Available Through Dr. Chisum
PLL/VCO
MAX287x (2870, 2871, 2874) : https://www.maximintegrated.com/en/products/comms/wireless-rf/MAX2871.html
HMC820: https://www.analog.com/en/products/hmc820.html

Variable Gain Amplifier
- HMC681: https://www.analog.com/en/products/hmc681a.html

Mixer
- LTC5510: https://www.analog.com/en/products/ltc5510.html

Quadrature Demodulator
- ADL5380: https://www.analog.com/en/products/adl5380.html

4-to-1 Switch
- ADG904: https://www.analog.com/en/products/adg904.html