University of Notre Dame

NDRT Payload
High Level Design

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Senior Design Project

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1. Introduction

Every year, the Notre Dame Rocketry Team (NDRT) competes in NASA's Student Launch Initiative and a team of electrical engineering seniors design their payload for the competition. Previous teams have built Unmanned Aerial Vehicles, an Unmanned Ground Vehicle, and a panoramic camera lander. This year, the senior design team will collaborate with members of NDRT to build a flight tracker that records data from an array of sensors during flight. After landing, that data will be used to calculate the rocket's final position relative to its launch site and both the launch site and the landing site will be mapped onto a satellite image of the landing zone with an overlaid grid. The grid location of landing will be transmitted from the payload to the ground station and submitted to NASA for scoring. This team will be designing, building, and maintaining the power delivery and wireless transmission systems of the payload and ground station.

2. Problem Statement

The problem statement provided by NASA is listed below. For the full list of payload mission requirements, see pages 13-14 of the 2022 NASA Student Launch Handbook.

4.1. College/University Division – Teams shall design a payload capable of autonomously locating the launch vehicle upon landing by identifying the launch vehicle's grid position on an aerial image of the launch site without the use of a global positioning system (GPS). The method(s)/design(s) utilized to complete the payload mission will be at the teams' discretion and will be permitted so long as the designs are deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge.

This senior design team will be responsible for designing the wireless transmission and power distribution systems of the payload and ground station. The team will operate as a sub-squad of the NDRT Payload team.

3. Proposed Solution

The NDRT Payload team is pursuing an inertial navigation system (INS) solution which will track the rocket's acceleration and rotation throughout flight to calculate its landing location. The rocket's landing location will be transmitted from the payload to the ground station for submission to NASA before verification.

This project, focusing on wireless transmission and power distribution, will consist of a custom printed circuit board integrating the power and radio circuitry. Identical boards will be used for both the payload and ground station, enabling a simpler assembly and repair process.

The radio transmission system will consist of a microcontroller and a radio transceiver communicating over SPI. The microcontroller interfaces with the INS over UART on the payload side, and with the host laptop over UART on the ground station side. The transceiver will have an external antenna located in the plastic nose cone of the rocket.

A single battery will be used to power the entire payload. The power distribution system will boost the battery voltage to 5V for each of the Raspberry Pi's in the INS. It will also regulate 3.3V for the microcontroller and transceiver.

4. System Requirements

NASA Requirements

- "2.23.8 Transmissions from onboard transmitters, which are active at any point prior to landing, will not exceed 250 mW of power (per transmitter).
- "2.23.9 Transmitters will not create excessive interference. Teams will utilize unique frequencies, handshake/passcode systems, or other means to mitigate interference caused to or received from other teams"
- "2.7 The launch vehicle and payload will be capable of remaining in launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board components, although the capability to withstand longer delays is highly encouraged"

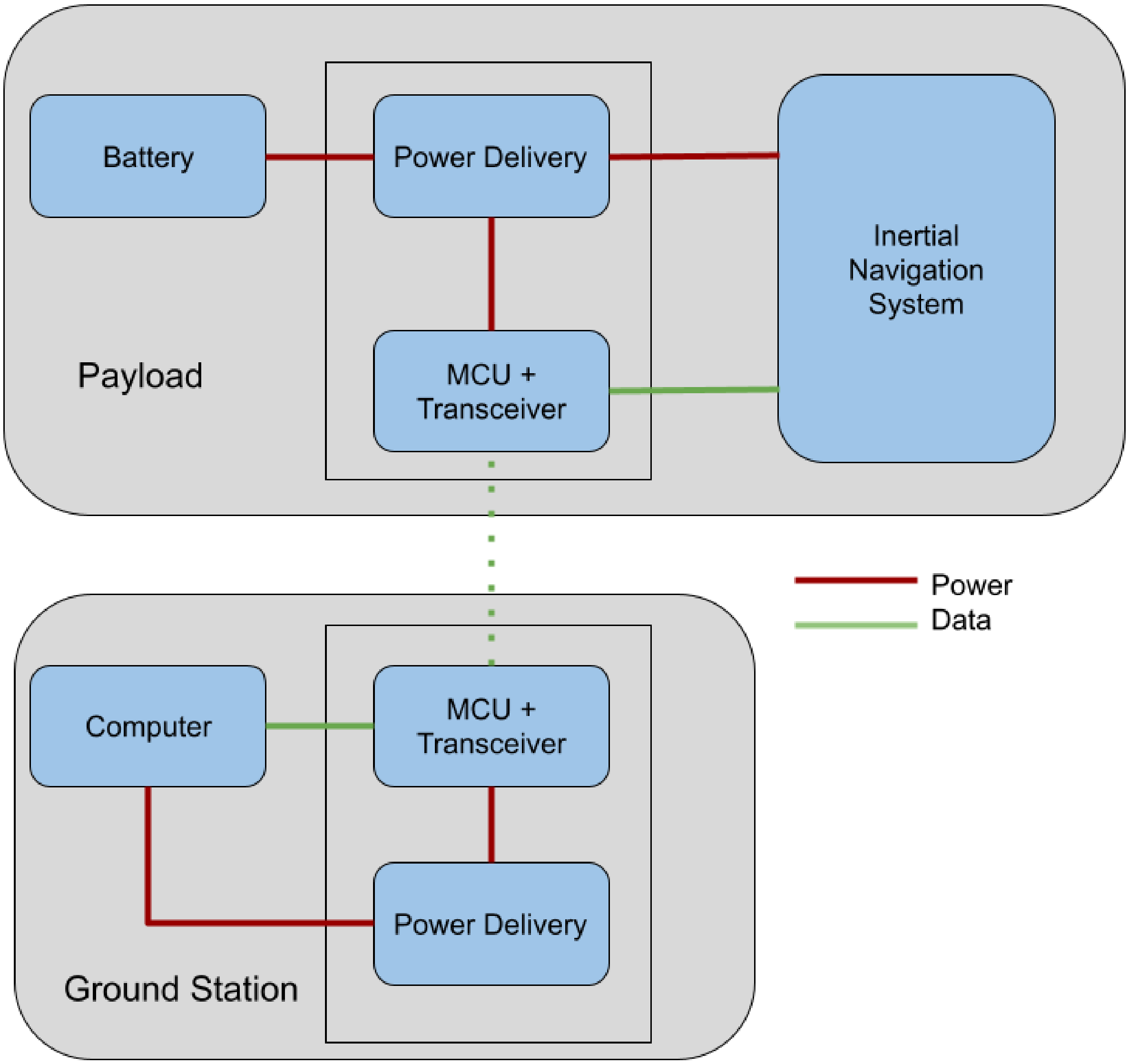
Hardware Requirements

- Total payload mass does not exceed 90 oz or 2.551 kg.
- Power delivery system delivers sufficient power to each peripheral Raspberry Pi, microcontroller, and transceiver.

- Embedded intelligence interfaces with INS, ground station, and transceiver. It passes a message received on one interface through to the other.
- Operates in outdoor temperatures between 20°F and 100°F.
- Withstands acceleration on the order of 40 Gs.
- Transmits within ISM Frequency Bands.
- Receives transmission at distances of up to 2500 feet.

5. System Block Diagram

5.1. Overall System



5.2. Subsystem and Interface Requirements

Battery Requirements

a. Has capacity for at least 2 hours idle while system is powered
b. Capable of outputting 4.5A peak current

Power Tree Requirements

a. Regulates a 5V $1A_{max}$ rail for each Raspberry Pi in the INS
b. Regulates a 3.3V $500mA_{max}$ rail for the microcontroller and transceiver

Transmitting Microcontroller Requirements
a. Receives a short message string from the INS
b. Passes message through to transceiver

Receiving Microcontroller Requirements
a. Receives a short message from transceiver
b. Passes message through to host laptop

Wireless Transceiver Requirements
a. Sends/receives data to/from microcontroller
b. Transmits within an ISM band
c. Outputs at a minimum transmit power of 250mW

5.3. Future Enhancement Requirements

A future iteration of this project should integrate the sensors and compute hardware of the INS into a single board to improve its reliability and footprint.

Though not implemented in this cycle, the wireless communication system could be used to transmit and receive telemetry data from the rocket during flight. This data would help the team analyze flight data in the field and make more precise flight-to-flight adjustments.

6. High Level Design Decisions

<u>Battery</u>

A 1S2P 3.7V 18650 Lithium-ion battery is selected because of its high capacity and ability to output over 6A peak current.

<u>Power Tree</u>

Boost converters will be used to regulate the battery voltage up to 5V, providing power to the Raspberry Pi’s. Parts will be selected which allow for a max current draw of 500mA + 1A × the number of Raspberry Pi’s.

A LDO will regulate 5V to 3.3V, providing power to the microcontroller and transceiver.

Microcontroller

No wireless microcontrollers could be found in stock which had the desired package type and met the system requirements, so a microcontroller + transceiver layout was chosen.

A microcontroller will be selected which supports 1x UART and 1x SPI. It will operate on 3.3V and have a minimal footprint and current draw. The UART interface will be used to connect the microcontroller to the INS or host laptop. SPI will be used to connect the microcontroller to the transceiver.

Transceiver

The 915MHz ISM band was selected for the purpose of maximizing transmission range. The transceiver will interface with the microcontroller over SPI. It will transmit at a minimum of 250mW. A transceiver with frequency modulation is preferred for the purpose of improving reliability at long range.

7. Open Questions

LDO or Buck/Boost for microcontroller power

Which of the following solutions is best suited for powering the microcontroller and transceiver:

1. LDO from 5V rail regulates down to 3.3V
2. Buck/Boost from battery regulates to 3.3V

The 3.3V rail will draw very low current for the majority of the time. Current will peak during transmission but that will last for a relatively short time. An LDO would be simpler, cheaper, and lower noise, so this is the design that is currently planned.

Where to find USB-to-UART interface IC

The CP2102 IC on the 695 and 795 boards in the lab is out of stock at Digikey, where the rest of our components are coming from. Are there any suppliers that don’t charge shipping or are we stuck paying the $8 shipping for a $2 part?

8. Major Component Costs

Part Name	Manufacturer	Description	Unit Price	Count	Total Cost
RFM95W-915S2	RF Solutions	RF Transceiver	$13.44	2	
PIC32MX110F	Microchip	Microcontroller	$2.67	2	
MIC3775-3.3YMPIC32MX110F016B-I/ML Microchip Technology | Integrated Circuits (ICs) | DigiKey	Microchip	LDO to power microcontroller	$2.07	2	$4.14
TPS61032RSAR	Texas Instruments	High-current (3.6A) 5V boost regulator	$3.13	1	$3.13
AS1325-BSTT-50	AMS	5V boost regulator	$1.36	1	$1.36
CP2102N-A02	Silicon Labs	UART-to-USB adapter	$2.16	1	$2.16
TBS LongShot 915MHz	Team BlackSheep	Ground station antenna	$24.95	1	$24.95
RST-W1B6	Raltron Electronics	Flight antenna	$4.64	1	$4.64
SMA Connector	Linx Technologies	Antenna-PCB connectors	~$3	2	~$6

9. Conclusions

The system will accept data from a processor onboard the rocket and transmit it to a ground station located up to half a mile away. The battery must contain enough energy to power the entire system for at least two hours of idle time on the launch pad followed by a complete successful flight and transmission, and the components must survive the high acceleration expected during a successful flight. The system will be deemed successful if the ground station receives the coordinates computed by the rocket's onboard processor following a successful flight.

References:

NASA Student Launch Handbook:
https://www.nasa.gov/sites/default/files/atoms/files/2022_nasa_students_launch_handbook.pdf

FCC ISM Band Regulations:
https://afar.net/tutorials/fcc-rules/