Rocketry Team - Payload

EE 41430 Senior Design

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1 Introduction

Our Rocketry Payload design will be a planetary landing system (PLS) that fits the configuration constraints given to us by the National Aeronautics and Space Agency (NASA) for the NASA Student Launch competition, in which the Notre Dame Rocketry Team (NDRT) participates annually. This landing system will be launched inside of a rocket, deployed at a defined height, and land in an upright configuration. After the landing system reaches the ground, it will proceed to perform two pre-assigned tasks outlined in the requirements set forth by NASA in the NASA Student Launch Handbook (NSLH). The first mission the PLS will perform is having the system deploy a camera apparatus that will capture a 360-degree panoramic photo of the surrounding landscape. For the second task, the system will transmit this photo wirelessly to a host computer.

2 Problem Statement and Proposed Solution

The senior design team is tasked with building a PLS that will ascend with the rocket to an apogee set by the rocket team. Before launching the rocket, both the rocket and the PLS must be able to remain launch-ready on the launching pad for a minimum of two hours, as stated in requirement 2.7 in the NSLH. The PLS is then jettisoned from the rocket between 500 and 1000 feet above ground level (AGL). It must land either in an upright position or upright itself completely autonomously within a five-degree tolerance from vertical, and the team must record both the initial and final angles relative to the vertical position. After righting itself, the PLS will take a panoramic 360-degree picture and transmit it to the team for inclusion in a report at a later date. These requirements are all set forth in section 4.3 of the NSLH.

The system can be broken down into the following subsystems: Orientation Correction, Imaging, and Wireless Transmission. The first of these subsystems reorients the PLS so that it is upright, within a 5-degree margin from the vertical. The imaging subsystem is composed of the camera or cameras that will take the panoramic picture. Finally, the wireless transmission subsystem includes the wireless interface that will transmit this picture to the team.

3 System Requirements

Each required feature of the system directly contributes to the solution of the original problem. The first requirement is the launch of the PLS at competition, during which the system must be able to remain powered for at least two hours, and ascend safely in the rocket to then be deployed between 500 and 1000 feet AGL. The payload subsystem must also be no more than 10 inches in length, 6 inches in diameter, and 80 oz. in weight in order to fit inside of the rocket and deploy properly. The next requirement is the successful upright landing and reorientation of the PLS within a 5-degree tolerance with respect to vertical. Our properly designed orientation system includes multiple safeguards and mechanisms that will strongly aid in the ability for the system to land in an upright position. The upright position is necessary for the camera to be able to adequately take a panoramic photo. The third requirement is the taking of said photo, where the landing system actuates a grid of cameras and takes a panoramic photo. Our design has four cameras, each taking a photo which will be combined to form the continuous image, as opposed to using a rotating camera to capture a single panoramic picture. The next requirement is the transmission of the panoramic photo to the team for observation. The digital transmission will require radio frequency (RF) transmission. The final requirement is the overall success of the system. The launch will be overlooked by NASA and a successful demonstration is the combined function of the upright landing, capture of the photo and the transmission of the photo.

The nature of the required embedded intelligence is therefore one capable of taking four photos, combining them into one panoramic image, and transmitting the finalized image. The team has chosen a Raspberry Pi Zero system which is capable of performing these three essential tasks. Its small size, and consequently its low weight, were major factors when considering this particular component. The photograph will be captured utilizing four cameras, each at a 90-degree angle with respect to each other. This system, though larger and more electronically complex, will reliably capture an image of sufficient quality that can be easily ‘stitched together’. This system is also mechanically simpler than the considered alternatives (one camera with either a motor or a mirror), which translates into a more compact design. The chosen camera for this mission is the Raspberry Pi camera module with a wide-angle lens, which can easily connect to the Pi Zero. There are devices available that will allow us to split the singular camera port in the Pi Zero into four separate camera ports, which is ideal for our system.

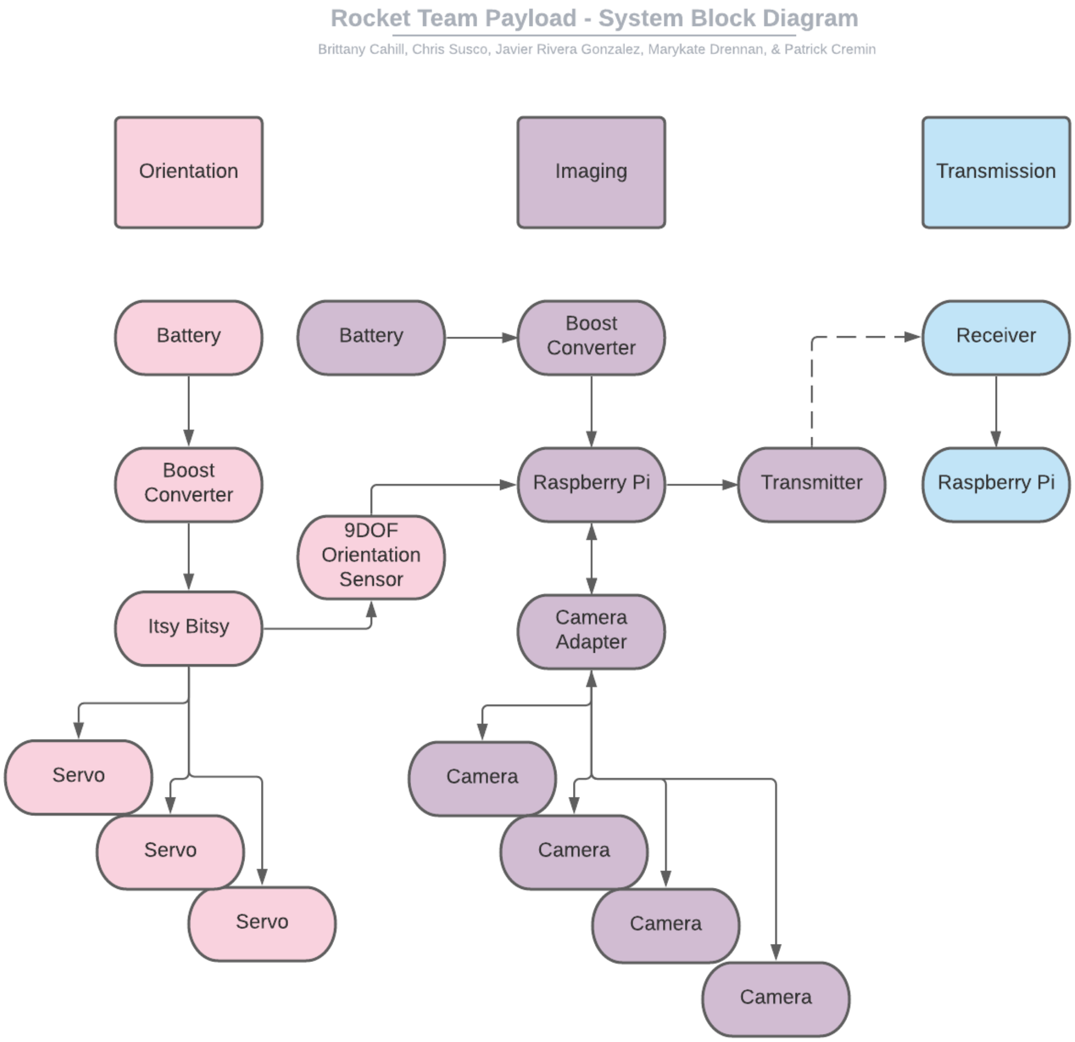
We will require a wireless interface between the team and our landing system so that the system has the ability to transmit the photograph captures it has performed over a minimum distance of 6000ft. The team has chosen an RF transceiver pair that can transmit well over 500m. An antenna is also needed to accomplish this. We will need to learn about different types of antennas in order to design an optimal communication system. A preliminary analysis has shown that a dipole antenna might work well, due to the fact that our lander will be righting itself in a consistent manner. We will need to explore other options such as horn, clover, circle, and monopole antennas to make a final decision. This interface needs only to support the Raspberry Pi, which is transmitting the photo, and the secondary Raspberry Pi that is receiving the photo.

Since it is easier to have two Raspberry Pi’s communicate with each other than any alternative, using the secondary Raspberry Pi will make the user interface easier to operate. This base computer connected to the secondary Raspberry Pi is the user interface: it receives the photo and uses the secondary Raspberry Pi to communicate with the main Raspberry Pi in the payload system.

The system is powered by a 3.7 V Lithium-Poly Battery. The system needs to be able to run on the battery for at least two hours while waiting for launch in addition to the launch, landing, and photo transmission time. Since we are working with low voltages, there are not notable, additional safety measures. While there could be a risk of fire due to movement of the lithium ion batteries or failed electrical connections, we plan on fully charging and securing the batteries in the payload, keeping circuitry off until just prior to launch, and testing all electronic components separately prior to launch.

4 System Block Diagram

4.1 Overall System:



4.2 Subsystem and Interface Requirements:

4.2.1 Orientation Correction

Our team will be working closely with the other subsystem team responsible for orientation correction. This is because it is required that the payload record orientation data before and after reorientation. Initially this was planned to be a passive subsystem; a gyroscope mechanism was going to be responsible for the orientation of the payload. This was changed after the team's Preliminary Design Review with NASA - even though our design fulfilled all of the initial requirements, they still were not satisfied with our design. They wanted a more active system, so the team needed to take a new approach to the problem.

The active reorientation of the payload will be controlled by a new microcontroller - an ItsyBitsy. This is a very compact microcontroller that will allow us to have a high level of control of the subsystem, without overloading the Raspberry Pi. This will then be actuated by 3 or 4 continuous servos, that will be attached to a lead screw mechanism to increase/decrease the angle of the legs. Altering the angle of each of the legs will allow the team to have a high level of control over the orientation of the payload.

The current orientation will be tracked by a 9DOF inertial measurement unit (IMU), that utilizes an accelerometer, magnetometer, and gyroscope to provide orientation data. This data will be sent into a feedback loop, which will be the driving force behind these legs. The specific algorithm has yet to be developed, but the mechanical engineers on the team will assist us in implementing this control system.

4.2.2 Imaging

As determined via trade study, an imaging subsystem with four individual cameras will be utilized in order to comply with NASA requirements to give the highest chance of success. The four-camera design involves having all of the cameras attached to a single microcontroller, hence requiring additional hardware.

The microcontroller selected for use in the system is a Raspberry Pi Zero, which has a singular slot for a camera serial interface (CSI) input. Therefore it is necessary to multiplex this singular port across four cameras. This will be done with an ArduCam multi-camera adapter module.

This module takes one input and splits it into four CSI inputs, which is ideal for this system design. Furthermore, this device can be daisy-chained to incorporate up to 16 cameras on a single Raspberry Pi. This could be useful if we decides to incorporate a level of redundancy in the system.

The camera itself will use the base Raspberry Pi camera board and connector, but the image sensor and lens itself will need to be switched out for an Arducam ultrawide lens camera. The lens will need to have a minimum field of view of 90 degrees, ideally with some room of overlap to assist the image stitching algorithm. Arducam has several lenses that fit this profile, but more research will need to be done to determine which fits best.

By adding these two devices to the Raspberry Pi, the team will have the necessary tools to develop a 360-degree panoramic picture. Further research will need to be done to determine if redundancy is necessary, or if this system will be reliable enough to only utilize four cameras.

4.2.3 Wireless Transmission

The successful completion of the payload experiment is contingent upon the transmission of the captured 360-degree image to the team. This image must be transmitted from onboard the vehicle to the team's receiver, which will be located either within the prep or viewing area. To successfully transmit the image, we decided the chosen hardware must be able to transmit within a range of 6000 ft. Furthermore, the transmitter must be able to send a GPS location and record and store orientation data from an IMU. Ultimately, the results of the trade study show that the commercial transceiver pair is best suited for our needs. Despite its slightly higher cost, this transceiver pair bests its custom-made counterpart in weight, reliability, and ease of use. Choosing a commercially available transceiver pair would save the team the considerable amount of effort needed to design, build, and test a custom one. In particular, these are already optimized to function at a large range and often operate well below 250mW of RF power. Furthermore, even though the custom transceiver would be designed specifically to interface with the rest of the electronics in the system, interfacing between the commercial transceiver and the Raspberry Pi does not imply a significant difficulty to outweigh the other aforementioned benefits of using such a component.

4.3 Future Enhancement Requirements

Future enhancements are not applicable to rocket team systems because we strictly abide by NASA requirements. Furthermore, the payload required by NASA changes each year.

5 High Level Design Decisions

5.1 Microcontroller & Cameras

The embedded intelligence must be capable of taking four photos, combining them into one panoramic image, and transmitting the finalized image. The team has chosen a Raspberry Pi Zero system which is capable of performing these three essential tasks. Its small size, and consequently its low weight, were major factors when considering this particular component. The photograph will be captured utilizing four cameras, each at a 90-degree angle with respect to each other. This system, though larger and more electronically complex, will reliably capture an image of sufficient quality that can be easily ‘stitched together’. This system is also mechanically simpler than the considered alternatives (one camera with either a motor or a mirror), which translates into a more compact design. The chosen camera for this mission is the Raspberry Pi camera module with a wide-angle lens, which can easily connect to the Pi Zero. There are devices available that will allow us to split the singular camera port in the Pi Zero into four separate camera ports, which is ideal for our system.

5.2 Wireless Interface

We will require a wireless interface between the team and our landing system so that the system has the ability to transmit the photograph captures it has performed over a minimum distance of 6000 feet. The team has chosen an RF transceiver pair that can transmit overly roughly 2 kilometers. An antenna is also needed to accomplish this. We will need to learn about different types of antennas in order to design an optimal communication system. A preliminary analysis has shown that a dipole antenna might work well, due to the fact that our lander will be righting itself in a consistent manner. We will need to explore other options such as horn, clover, circle, and monopole antennas to make a final decision. This interface needs only to support the Raspberry Pi, which is transmitting the photo, and the secondary Raspberry Pi that is receiving the photo. Since it is easier to have two Raspberry Pi's communicate with each other than any alternative, using the secondary Raspberry Pi will make the user interface easier to operate. This base computer connected to the secondary Raspberry Pi is the user interface: it receives the photo and thus uses the secondary Raspberry Pi to communicate with the main Raspberry Pi in the payload system.

5.3 Power

The system is powered by a 3.7 V Lithium-Poly Battery. The system needs to be able to run on the battery for at least two hours while waiting for launch in addition to the launch, landing, and photo transmission time.

6 Open Questions

While we know that the Raspberry Pi is capable of stitching the four images taken with its cameras, as this played a role in selecting these components, we are not actually familiar at this time with how to have it perform this action. This is something that we will have to educate ourselves on before we can write the code. We are also unfamiliar with the process of parsing and viewing of wireless transmission data. Since these actions are common with the Raspberry Pi Zero, we anticipate having many resources available to help us with this. Additional testing equipment will not likely be necessary.

7 Major Component Costs

The costs of system components and a rough cost estimate of the project are outlined in Table 1.

Table 1. Anticipated Expenses

Item	Quantity	Cost per unit
Raspberry Pi Zero	2	$5.00
Raspberry Pi Camera Module	4	$28.99
Multicam Adapter Module	1	$50.00
RF Transceiver Pair	1	$19.95
Antenna	1	$0
9-DOF Absolute Orientation Sensor	1	$34.95
3.7 V Lithium-Poly Battery	2	$25.00
Boost Converter	2	$20.00
Servos	3	$40.00
Total	**17**	**$223.89**

8 Conclusions

We are very fortunate to have the opportunity to collaborate with the NDRT on a multi-part project that requires a lot of coordination and cooperation. There are some limitations that we will have to work around, such as our budget and the ability to work in a physical space due to COVID-19, but these will push us to be more adaptable and regardless still lead to a highly technical experience throughout the whole process. Our three goals of landing, photographing, and transmitting are our technical goals, but our overall goals are to grow as a team and be able to learn skills that we can apply to whatever projects we work on in the future. Although we will face challenges during the implementation of this design, our teamwork and communication will allow us to persevere in these exciting electrical engineering applications.

References of Project Components:

RF Transceiver:

https://www.electrodragon.com/product/433m-rf-wireless-module-a-pair-of-receiver-and-transmitter/

Raspberry Pi Zero:

https://www.pishop.us/product/raspberry-pi-zero/?src=raspberrypi

9-DOF Sensor:

https://www.adafruit.com/product/2472

Wide Angle Camera Module:

MultiCamera Adapter Module