Notre Dame Rocketry Team (NDRT) Payload
360° Rotating Optical Imager (TROI)

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1 Introduction

The purpose of this project is to design and create an electronic controller according to the annual rocketry competition that NASA hosts every year. Our team is operating within the greater Notre Dame Rocketry Team as a dedicated group of senior electrical engineers to produce the controller. To complete this project within the context of the entire launch mission, the team is working with an interdisciplinary group of engineering students.

2 Problem Statement and Proposed Solution

The problem is described by NASA in their student launch handbook. In summary, once the rocket has been launched and then lands, the payload component of the rocket must deploy a camera unit that (a) is capable of swiveling 360º about the z-axis, (b) is in accordance with certain pre-established camera parameters such as field of view, (c) receives radio frequency (RF) commands in the band 144.90-145.10 MHz through Automatic Packet Reporting System (APRS), (d) executes each received command to its desired effect, and (e) saves the images taken by the camera with a timestamp. Some examples of these commands are to swivel the camera in 60º increments clockwise and counterclockwise, to apply image-distorting filters, and to change the image from full-color to grayscale.

The proposed solution is referred to as the 360º Rotating Optical Imager (TROI), and consists of an electronic system, alongside a series of lead screws and small stepper motors. The bulk of the electronics will be mounted on a board at the base of the TROI, although the camera will be placed on a rotating arm to allow rotation around the z-axis.

The entire TROI will fit inside the rocket's interior during flight. During the rocket's flight, the nose-cone will be removed, creating an opening in the tube, in front of the payload system. After the rocket has landed, the TROI will deploy the camera out of the rocket tube via a stepper motor and telescoping arm, while the rest of the electronics will remain inside of the rocket tube (the tube will be designed not to interfere with RF transmission). Once the camera is deployed, the electronics system will receive RF commands, rotate the camera, and save images according to the specific challenges given at the time of competition.

3 System Requirements

Payload Experiment Requirements

All payload designs shall be approved by NASA. NASA reserves the authority to require a team to modify or change a payload, as deemed necessary by the Review Panel, even after a proposal has been awarded.

1. College/University Division—Teams shall design a payload capable upon landing of autonomously receiving RF commands and performing a series of tasks with an on-board camera system. The method(s)/design(s) utilized to complete the payload mission shall be at the team's discretion and shall be permitted so long as the designs are deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge. An additional experiment (limit of 1) is allowed, and may be flown, but will not contribute to scoring. If the team chooses to fly an additional experiment, they will provide the appropriate documentation in all design reports so the experiment may be reviewed for flight safety.

2. Radio Frequency Command (RAFCO) Mission Requirements

    2.1. The launch vehicle shall contain an automated camera system capable of swiveling 360º to take images of the entire surrounding area of the launch vehicle.

        2.1.1. The camera shall have the capability of rotating about the z axis. The z axis is perpendicular to the ground plane with the sky oriented up and the planetary surface oriented down.

        2.1.2. The camera shall have a FOV of at least 100º and a maximum FOV of 180º.

        2.1.3. The camera shall time stamp each photo taken. The time stamp shall be visible on all photos submitted to NASA in the PLAR.

        2.1.4. The camera system shall execute the string of transmitted commands quickly, with a maximum of 30 seconds between photos taken.

    2.2. NASA Student Launch Management Team shall transmit an RF sequence that shall contain a radio call sign followed by a sequence of tasks to be completed. The list of potential commands to be given on launch day along with their radio transcriptions which shall be sent in an RF message using APRS transmission in no particular order are:

    A1—Turn camera 60º to the right

    B2—Turn camera 60º to the left

    C3—Take picture

D4—Change camera mode from color to grayscale

E5—Change camera mode back from grayscale to color

F6—Rotate image 180º (upside down).

G7—Special effects filter (Apply any filter or image distortion you want and state what filter or distortion was used).

H8—Remove all filters.

2.2.1. An example transmission sequence could look something like, "XX4XXX C3 A1 D4 C3 F6 C3 F6 B2 B2 C3." Note the call sign that NASA will use shall be distributed to teams at a later time.

2.3. The NASA Student Launch Management Panel shall transmit the RAFCO using APRS.

2.3.1. NASA will use dedicated frequencies to transmit the message. NASA will operate on the 2-Meter amateur radio band between the frequencies of 144.90 MHz and 145.10 MHz. No team shall be permitted to transmit on any frequency in this range. The specific frequency used will be shared with teams during Launch Week. NASA reserves the right to modify the transmission frequency as deemed necessary.

2.3.2. The NASA Management Team shall transmit the RAFCO every 2 minutes.

2.3.3. The payload system shall not initiate and begin accepting RAFCO until AFTER the launch vehicle has landed on the planetary surface.

2.4. The payload shall not be jettisoned.

2.5. The sequence of time-stamped photos taken need not be transmitted back to ground station and shall be presented in the correct order in your PLAR.

3. General Payload Requirements

3.1. Black Powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Energetics shall not be permitted for any surface operations.

3.2. Teams shall abide by all FAA and NAR rules and regulations.

3.3. Any secondary payload experiment element that is jettisoned during the recovery phase will receive real-time RSO permission prior to initiating the jettison event, unless exempted from the requirement of the CDR milestone by NASA.

3.4. Unmanned aircraft system (UAS) payloads, if designed to be deployed during descent, will be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given permission to release the UAS.

3.5. Teams flying UASs will abide by all applicable FAA regulations, including the FAA's Special Rule for Model Aircraft (Public Law 112–95 Section 336; see https://www.faa.gov/uas/faqs).

3.6. Any UAS weighing more than .55 lbs. shall be registered with the FAA and the registration number marked on the vehicle.

4 System Block Diagram

4.1 Overall System

The electronic system within the payload will need to determine when the rocket has landed, receive RF commands, control motors to deploy and rotate the camera system, and process images from the camera. These tasks will require an accelerometer, RF receiver, camera, two motors (one for deploying the camera system and another for rotating it), and microcontroller. Component selection began with the microcontroller, which will be an ESP32 with a custom PCB. Additional component selections were made based on size constraints, durability, availability, and compatibility with the ESP32. Trade studies were also conducted to make final decisions on the specific models to use. Table 1 below summarizes the selections for each electronic component.

Table 1. Component List

Component	Microcontrollers	Battery	Accelerometer	Camera	RF Receiver	Stepper Motor
Selection	ESP32 with custom PCB ESP32-CAM	MIKROE -4475	DFRobot Gravity 12C	OV2640	DRA818V	NEMA 8 McMaster-Carr Stepper Motor with Linear Actuation

4.2 ESP32 Main

The first ESP32 microcontroller within the payload will be referred to as "Main." It will coordinate (1) detection of vehicle landing, (2) RF reception of APRS commands, (3) stepper motor actuation for deploying the camera apparatus and camera rotation, and (4) send commands to the ESP32-CAM subsystem via ESP-NOW. In order to detect the vehicle landing, the subsystem will require an accelerometer capable of interfacing with the ESP32 microcontroller. Readings from the accelerometer will inform the microcontroller when the vehicle has landed, so that the microcontroller can initiate camera deployment and RF reception.

Because the RF communication requirement involves reception of ARPS commands, not transmission, the subsystem's RF transceiver will only need to receive messages. As a result, the transceiver shall only be wired for receiving on a GPIO pin on the ESP32. The transmission pin shall be shorted as a precaution to prevent accidental transmissions.

In order to deploy and rotate the camera, the microcontroller must also interface with the stepper motors responsible for each action. One motor will control the camera deployment, while a separate motor will control camera rotation during and after deployment. These motors will work together, but the microcontroller must manage them independently, so two motor interfaces will be required.

The fourth component of the ESP32 Main subsystem's responsibilities, involving communication with the ESP32-CAM subsystem, will be accomplished via a wireless interface, described in Section 4.3, below. Additionally, the ESP32 Main will require batteries for the microcontroller and any other devices requiring power. These batteries must be capable of providing sufficient power at the proper voltage, and must fit easily inside the payload assembly within the vehicle.

4.3 Wireless Interface & ESP-NOW

The ESP32-CAM subsystem will connect to the ESP32 Main subsystem via a wireless connection in order to simplify wiring and prevent problems that the camera's rotation might cause for a wired connection. This wireless connection will be used in the payload to send commands involving image capture and image processing. The connection must be two-way, well suited for low-power and close-range communications, and ideally it should be easy to implement with ESP32 systems as well. The ESP-NOW wireless protocol meets all of these requirements, and is described in Section 5.2.

4.4 ESP32-CAM

The ESP32-CAM subsystem will be responsible for (1) capturing images, (2) image processing, and (3) data storage. The camera must be compact and meet the minimum field of view requirement of 100º (and the maximum FOV requirement of 180º). Additionally, this system will consist of its own board, connected to the ESP32 Main subsystem via a wireless connection, as mentioned above. The ESP32-CAM subsystem will receive commands from the Main subsystem, and will be responsible for capturing, processing, and saving images. Specifically, the subsystem must be able to filter and timestamp images.

4.5 Future Enhancements

In the future, adding post-processing to the images taken by the camera would be beneficial. Creating software that ensures the image is not overexposed and is in focus would allow for better quality pictures.

The addition of gyroscopic leveling for the camera arm would also increase the image quality. With the current design of our system it is possible for the photos to not be level. If a gyroscope was added to the arm this issue would be resolved.

Autonomous capabilities can be added for image capture. An improved payload could use image recognition software such as OpenCV to determine areas of interest to photograph. This would aid researchers interested in gathering image data in locations not easily accessed by humans.

5 High Level Design Decisions

5.1 ESP32 Main

As discussed in section 4.2, the ESP32 Main subsystem is responsible for (1) detection of vehicle landing, (2) RF reception of APRS commands, (3) deploying the camera apparatus and rotating the camera via stepper motor actuation, and (4) send commands to the ESP32-CAM subsystem via ESP-NOW. For detection of vehicle landing, a DFRobot Gravity 12C accelerometer will be used. This device will interact with the microcontroller via an I2C interface.

The RF reception will be conducted through a DRA818V transceiver. As discussed in Section 4.2, the transceiver will be wired only for receiving commands, with the transmission pin shorted. Additionally, the transceiver will connect to a GPIO pin on the microcontroller, using a UART interface.

The stepper motor responsible for camera deployment will be the McMaster-Carr Stepper Motor with Linear Actuation. The NEMA 8 motor will be used for camera rotation. Both will connect to the microcontroller via SPI interfaces. To power the subsystem, two series 3.7 V MIKROE-4475 LiPo batteries will be used

5.2 Wireless Interface & ESP-NOW

The wireless interface between the ESP32-CAM subsystem and the ESP32 Main subsystem will be done using the ESP-NOW protocol. This is a wireless communication protocol developed by Espressif to enable two-way communication between ESP32 systems. It operates over a 2.4 GHz carrier frequency and is similar to other low-power, close-range communication protocols like Bluetooth. Messages sent over ESP-NOW are constrained to 250 bytes, which is sufficient for sending commands related to image capture and processing.

5.3 ESP32-CAM

The subsystem's camera will be the OV2640, connected to the ESP32-CAM with internal pins on the board. The ESP32-CAM board is sufficiently compact, and the additional OV2640 module provides a lens that meets the field of view constraints. Image processing libraries for the ESP32, such as the "esp32-camera" and "ESP32-Cam-Text-overlay" libraries, will be used for image filtering and timestamping within the subsystem. Once the image processing has concluded, each image will be saved on a microSD card, which comes self-contained in the ESP32-CAM module.

6 Open Questions

The TROI must be capable of detecting the landing and orientation of TROI, processing RF commands, and then executing those commands by controlling the camera and motors. These devices are not used in the EESD coursework and therefore will require outside research on how to program.

Testing will require a variety of evaluations including: test bench, simulated flight, and flight testing. We have a limited number of flight tests and therefore must verify the performance of our device prior to takeoff. This will require simulating the different conditions and orientations our system may encounter.

The NDRT project has an early deadline as the payload must be fully functional with all testing completed before the payload demonstration flight deadline of March 6th. Launch day is scheduled for April 15th.

7 Major Component Costs

Table 2. Project Component Costs

Component	Cost	Link
ESP32 with custom PCB	$50-$75	
ESP32-CAM	$17.99	---------------
MIKROE-4475	$21.90	---------------
DFRobot Gravity 12C	$13.90	---------------
NEMA 8	$26.50	---------------
1 "EASY DIGI™" UV-5R INTERFACE for laptops and desktops	$33.25	---------------
2 of the DRA818V ---	$9.98	---------------
2 of the Baofeng ---	$21.00	---------------
TOTAL	~$200	

Note that the Notre Dame Rocketry Team also has a budget for the payload. While this budget will be used for other mechanical components and materials to build the payload, it will likely also cover the cost of the two stepper motors.

8 Conclusion

TROI will allow for the capture of photos from the payload tube by rotating 360 degrees. TROI will actuate the camera out of the tube using stepper motors. An accelerometer will be used to ensure proper orientation, and custom PCB will be designed to control TROI. Capture and orientation will be commanded through RF communication. TROI is essential to this year's rocketry design. It fulfills the requirements set by NASA and provides a solution to the challenge of taking photos of unexplored locations.

References

1. 2023 NASA Student Launch Handbook - https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwibkeD3iun7AhVAhXIEHeY-CNwQFnoECAsQAQ&url=https%3A%2F%2Fwww.nasa.gov%2Fsites%2Fdefault%2Ffiles%2Fatoms%2Ffiles%2F2023_slhandbook_508.pdf&usg=AOvVaw1Lz9Xl3n1gAbGWvwd4nqCf
2. NDRT 2022-2023 Preliminary Design Review - see the PDF attached with this submission