

# Aerojet FAR Robotic Payload Blue Team



## Group 28

Justice Cordova	EE
James Ellison	CPE
Wesley Fletcher	CPE
Joshua Kissoon	CPE

# Agenda

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# Meet the Team

Justice  
Cordova

**Justice Cordova** is a senior at the University of Central Florida. He plans to graduate in May of 2022 with a Bachelor of Science Degree in Electrical Engineering. His interests include RF electronics and control systems, and he plans to continue his studies with a MSEE.

James  
Ellison

**James Ellison** is a senior at the University of Central Florida. He plans to graduate in May of 2022 with a Bachelor of Science Degree in Computer Engineering.

Wesley  
Fletcher

**Wesley Fletcher** intends to receive a Bachelor's in Computer Engineering in May of 2022. His interests include mobile robotics and large-scale autonomous systems. During his time at UCF, he served as the President of the Robotics Club. Currently working as an Autonomous Systems Engineering intern in the Applied Research division of a large defense contractor. After graduation, he will begin work as a Robotics Software Engineer for a consulting firm in MA while pursuing further education.

Joshua  
Kissoon

**Joshua Kissoon** is a senior at the University of Central Florida. He plans to graduate in May of 2022 with a Bachelor of Science Degree in Computer Engineering. After graduation, he plans to obtain his Masters.

# Team Structure and Responsibilities

James Ellison

<b>Task</b>	<b>Justice Cordova</b>	<b>James Ellison</b>	<b>Wesley Fletcher</b>	<b>Joshua Kissoon</b>
System Design	S	S	P	S
Power Systems	P			S
RF Communications	P	S		
PCB Design	P			S
Embedded Software			P	P
Ground Station (GUI)		S		P
Rover Electronics			P	
Rover Software			P	
Prototype Construction			P	

# Project Overview

Presenter(s): Wesley Fletcher, Justice Cordova

# Project Goals

Wesley Fletcher

Design and build a ground-based mobile robot for traversing short distances on uncontrolled terrain

Must satisfy FAR contest requirements and constraints:

- Capable of remote control from ground station and live video transmission
- Travel at least 10 feet
- Meet provided size and weight constraints

Handle potentially difficult communication conditions: high latency, long distances, lack of “real time” control, reliable transmission

# FAR 51025 Competition

Wesley Fletcher

- Rocketry competition – launch a rocket to 10K feet, with a robotic payload on board
  - UCF’s entry sponsored by Aerojet Rocketdyne Coleman Aerospace
  - 6 “payload” teams each designed a robotic payload, competing for a spot on the rocket.
- 
- Info on FAR 51025 Contest [here](#)



# Project Impact

Wesley Fletcher

Intended to emulate NASA Mars Exploration Rover Perseverance, a robotic system designed to handle harsh conditions at incredible (interplanetary) ranges

Mobile systems that can be trusted to work without real-time control are more robust to difficult operational conditions, have applications in search and rescue, planetary exploration, and extreme environments

This project acts as a “first step” into design of these systems, and provides a broadly capable platform for future development efforts

# Design Requirements

Wesley Fletcher

Trace #	Requirement	Value (if applicable)
R1.0	Mass and Dimensions	
R1.1	Payload assembly max weight (sled, canister, and payload combined)	<4.31kg
R1.2	Payload (rover) minimum weight	1kg
R1.3	Payload Canister dimensions	<=12.7cm diameter <=40.64cm length
R1.4	Payload-Sled Dimensions	Maximum 1.27cm depth on either side of payload

R4.0	Payload (Rover)	
R4.1	Rover shall travel the specified distance from the Payload Canister landing site starting position under its own power.	10ft
R4.2	Rover shall be radio-controlled.	N/A
R4.3	Rover shall transmit a live video feed back to the Ground Station at given range.	<=600meters
R4.4	Rover shall be dust resistant.	IP50
R4.5	Rover shall be able to determine position and orientation relative to Payload Canister starting position.	N/A
R4.6	Rover shall be able to generate and store a rough map of immediate surrounds	N/A
R4.7	Rover shall create a 360-degree horizontal panorama on command.	N/A
R4.8	Rover shall log all relevant sensor and control data during operation for later retrieval.	N/A
R4.9	Rover shall transmit real-time telemetry data back to ground station at defined intervals.	N/A

# Design Constraints

Justice Cordova

- Aerojet
- Economic and Time
- Environmental, Social, and Political
- Ethical, Health, and Safety
- Manufacturability and Sustainability

# Standards

Justice Cordova

- IEEE 830
  - System Interfaces
  - User Interfaces
  - Hardware Interface
  - Software Interfaces
  - Communication Interfaces
  - Memory Constraints
  - Design Constraints
- IEEE 1625
  - External Short Circuit Precautions
  - Overheating Precautions
  - Overcharge Precautions
  - Over-discharge Precautions
  - Overcurrent Precautions
  - Mechanical Stress Precautions
  - Precautions for cells connected in series and/or parallel to form a battery pack
- MIL-STD-901D – specifically for shock testing, but provides good insight into designing things for impact/vibration
  - Provide “sufficient slack” for wiring to avoid breaks, utilize strain relief techniques wherever possible
  - Using actual fasteners for components that must stay in place – don’t rely on Velcro or glue
  - Minimize clearances for screws/bolts to avoid excessive vibration or shearing

# Architecture and Critical Components

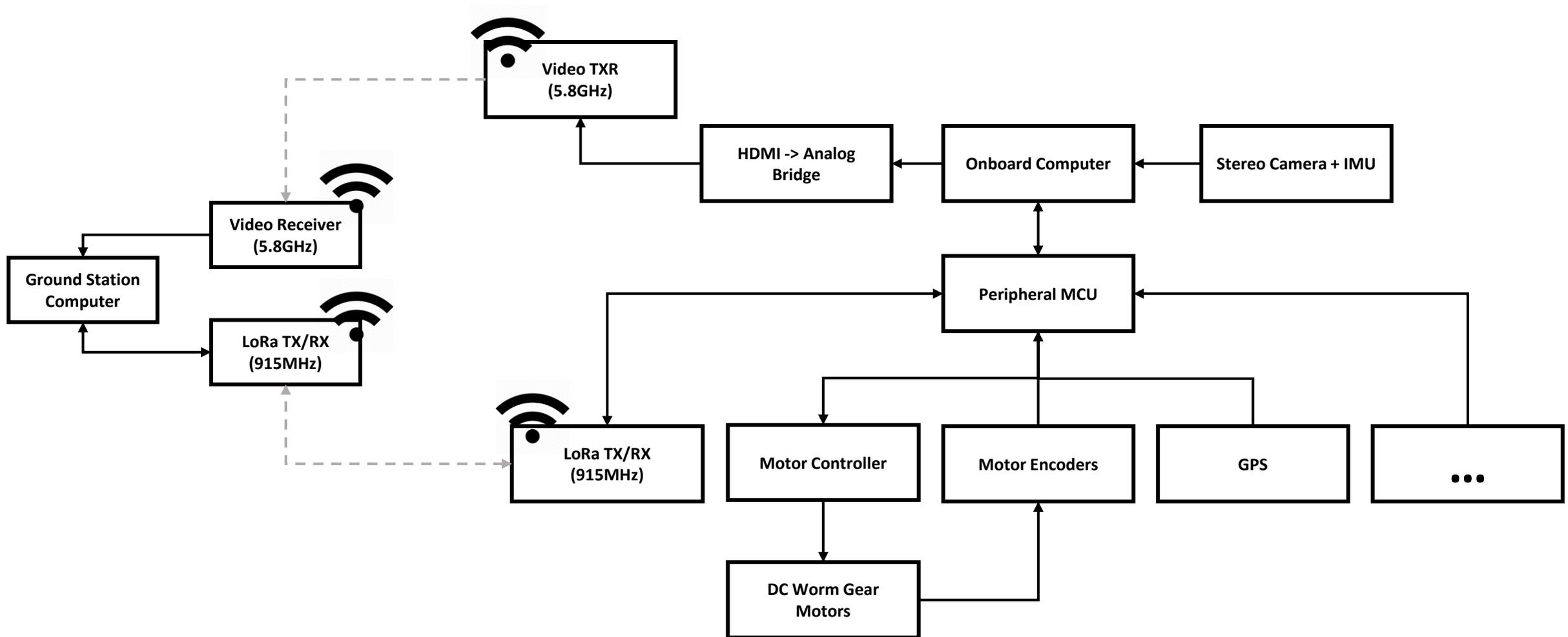
Presenter(s): All

# System Overview

Wesley Fletcher

# Component Block Diagram

Wesley Fletcher



# Parts Selection – SBC

Wesley Fletcher

- Single-board computer (SBC) on rover had to have sufficient performance for compute-intensive tasks like image processing, mapping, and ROS
- Selected **Jetson Nano** due to compute power, I/O, and **immediate availability**

Option	Price (MSRP)	Comparison
Jetson Nano Dev. Kit	\$99	<ul style="list-style-type: none"><li>• More powerful, potentially less energy-efficient, larger footprint</li><li>• Cheaper (since we already had one)</li><li>• Immediately available</li></ul>
Raspberry Pi 4 B (4GB)	\$55	<ul style="list-style-type: none"><li>• Smaller footprint, more power efficient,</li><li>• More expensive (since we didn't already have one)</li><li>• Potential back-order</li></ul>

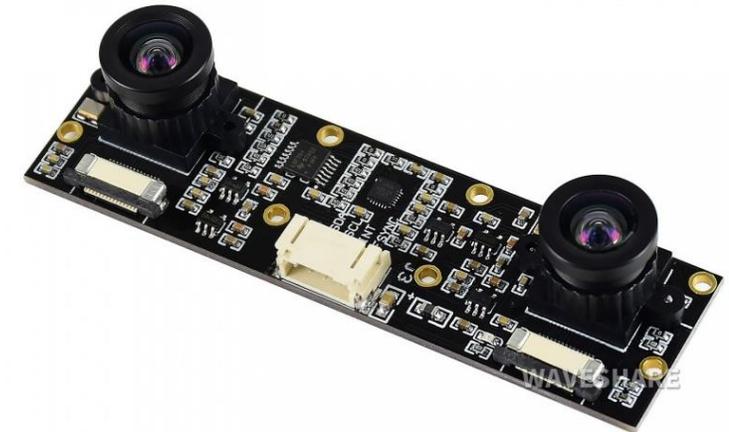


# Parts Selection – Camera

Wesley Fletcher

- Directly satisfies requirement R4.3 (in combination w/ 5.8GHz TX/RX)
- Selected **Waveshare Stereo Camera** due to:
  - easy interface w/ Jetson Nano (2x MIPI CSI-2 connectors on dev. kit)
  - possibility of depth cloud from stereo image disparities (bonus for mapping)
  - integrated IMU sensor (bonus for state estimation)

Option	Price (MSRP)	Comparison
Waveshare Stereo Camera	\$44.99	<ul style="list-style-type: none"><li>• Possibility of depth cloud through image processing (good for mapping environment)</li><li>• Requires 2 MIPI CSI-2 connectors, only Jetson provides 2</li><li>• Integrated IMU</li><li>• Most expensive option</li></ul>
Raspberry Pi Camera Module V2	\$25.00	<ul style="list-style-type: none"><li>• Requires only 1 MIPI CSI-2 connector (can be used with many SBCs)</li><li>• Single image stream, no depth cloud options</li></ul>
Leopard Imaging Camera - 136 degree	\$29.00	<ul style="list-style-type: none"><li>• Requires only 1 MIPI CSI-2 connector (can be used with many SBCs)</li><li>• Single image stream, no depth cloud options</li></ul>



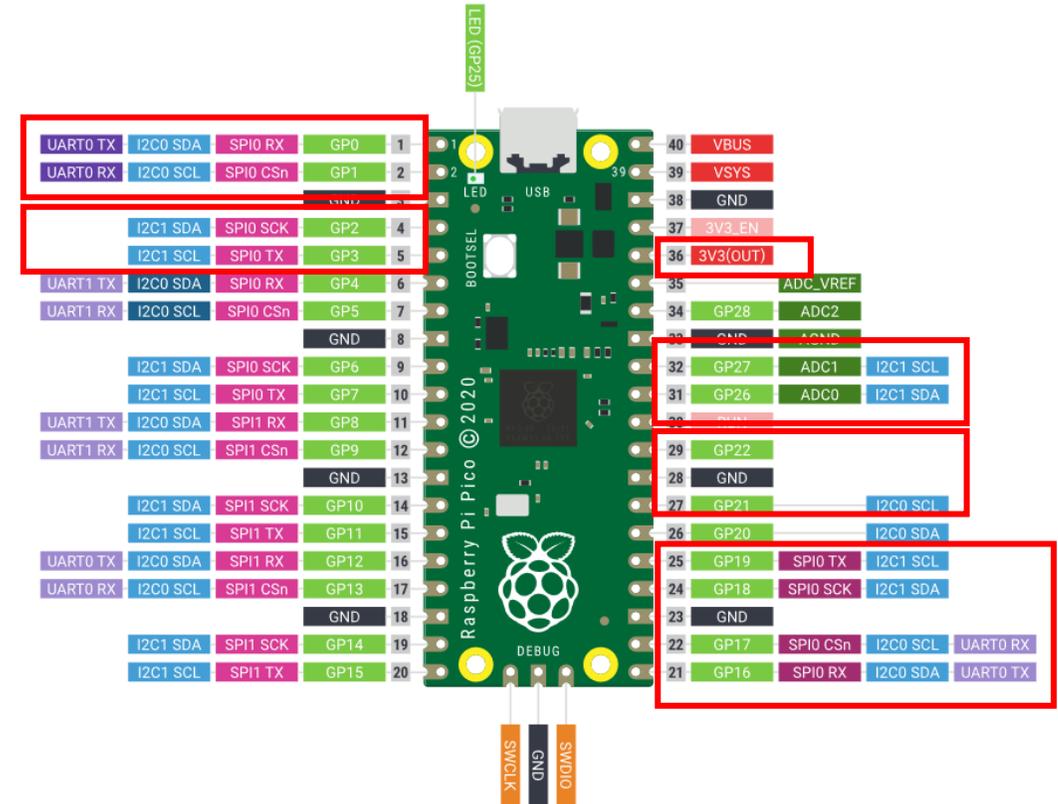
\* each of these options uses the IMX-219 sensor, no difference in resolution

# Parts Selection - Peripheral MCU

Wesley Fletcher

- Need peripheral MCU to:
  - increase I/O options and availability,
  - decouple I/O from Jetson in case of last-minute SBC changes (supply chain issues)
  - keep SBC GPIO available for last minute changes
- Selected **Raspberry Pi Pico** due to high clock speed, low cost, and easy availability

■	Power
■	Ground
■	UART / UART (default)
■	GPIO, PIO, and PWM
■	ADC
■	SPI / SPI (default)
■	I2C / I2C (default)
■	System Control
■	Debugging



# Parts Selection – DC Motors

Wesley Fletcher

- Selected **Greartisan 12V 250RPM 10Kg\*cm Worm Gear Motors**
- Pros:
  - worm gear motors have high torque to current ratio; low speed is a feature, not a bug
  - “brake by default” - when de-energized, they resist rotation to the point of mechanical failure
  - Dual output shafts allow for direct mounting of through-hole encoders without further hardware
- Cons:
  - Heavy, large footprint
  - Dual output shafts take up space inside of chassis



# Parts Selection - Motor Encoders

Joshua Kissoon

- Measures relative motor position using ticks
- MCU will receive ticks; SBC will convert to RPM
- CUI Devices AMT102-V selected
  - Incremental Capacitive
  - Inexpensive compared to absolute



# Parts Selection – LoRa (915MHz) Transceivers

Justice Cordova

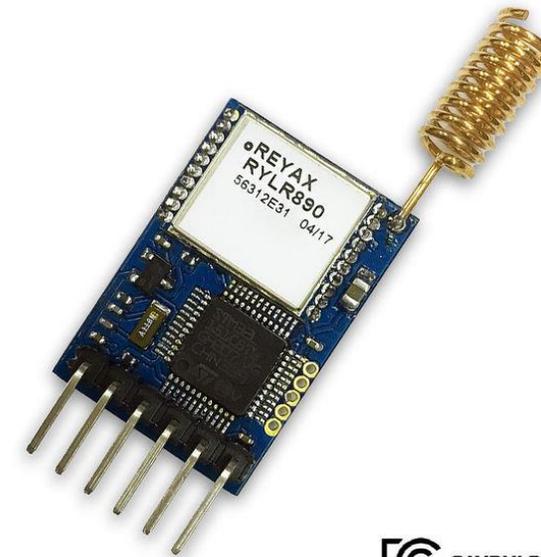
- Most important constraints are size and range
- ESP32 and LoRa considered
- LoRa selected to ensure rover meets range requirements

Option	Price (USD)	Comparison
Reyax RYLR896 LoRa RC Transceivers (2)	\$48.93	-UART -Uses LoRa modulation technique, based on chirp spread spectrum technology -operating voltage 3.3 V -max current draw of 43 mA -Range >1 km
LILYGO TTGO dev module WiFi + Bluetooth (2)	\$26.56	-I2C -Bluetooth and Wi-Fi protocols -ESP32 Commonly used in projects: lots of resources available online -Graphical Display for neat presentation of transmitted/received data -operating voltage of 3.3 V -max current draw of 67 mA -Range is limited to 300 m

# Parts Selection – Lora Transceivers

Justice Cordova

- Lora configured for 915 MHz operation: chosen to avoid operation on licensed bands and interference with rocket telemetry (430 MHz)
- Communicates using AT commands (AT commands translated by rover, ground station software)
- Receives RC commands, sends telemetry
- Range of >600m



FC QLYRYLR896

# Parts Selection - Video Tx/Rx

Justice Cordova

- Video TX cannot be achieved using LoRa
- With size constraints, options are severely limited for video TX
- Video TX will be biggest constraint on range of rover (~600m)
- **Hyperion TS5823** is selected- only available option that meets size, range constraints- operates at 5.8 GHz
- Skydroid receiver USB connects to ground station, broadcast to GUI



# Parts Selection – Batteries

Justice Cordova

- LiFePO4 vs LiPo
- Major considerations are safety and battery capacity
- Decision was made to go with LiPo
  - Protective casing should reduce risk of thermal runaway
  - Significantly higher energy density - LiFePo batteries could not be trusted to power all the rover modules

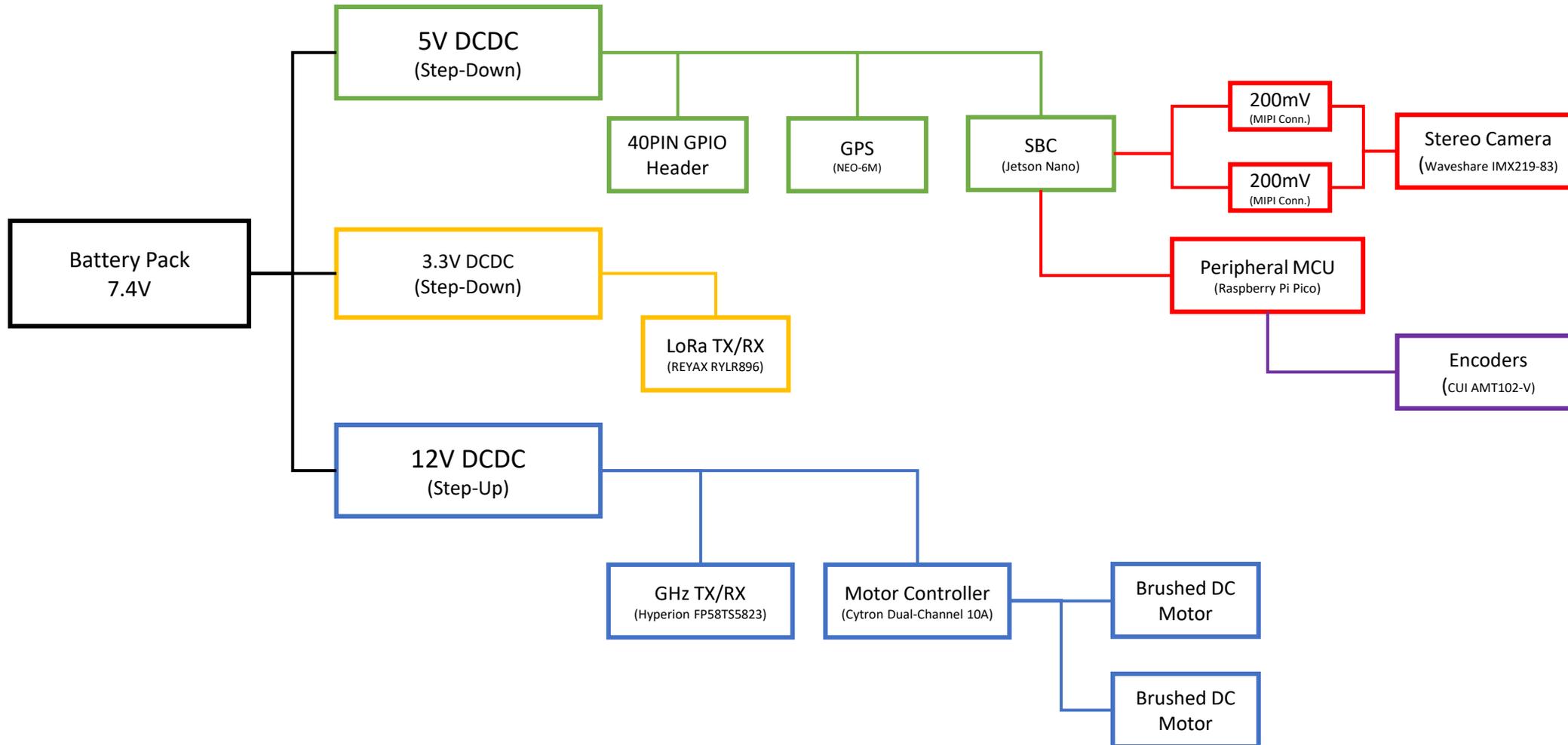
Option	Price (USD)	Comparison
LiFePo4 Battery (2s)	\$23.93	-Size is identical to LiPo -Voltage 6.4 V -Current capacity 900 mAh -Lower Risk of thermal runaway
LiPo Battery (2s)	\$27.89	-Identical size -voltage 7.4 V -Current capacity 4600 mAh -increased risk of thermal runaway

# Electrical Design

Presenter(s): Justice Cordova

# Power Tree

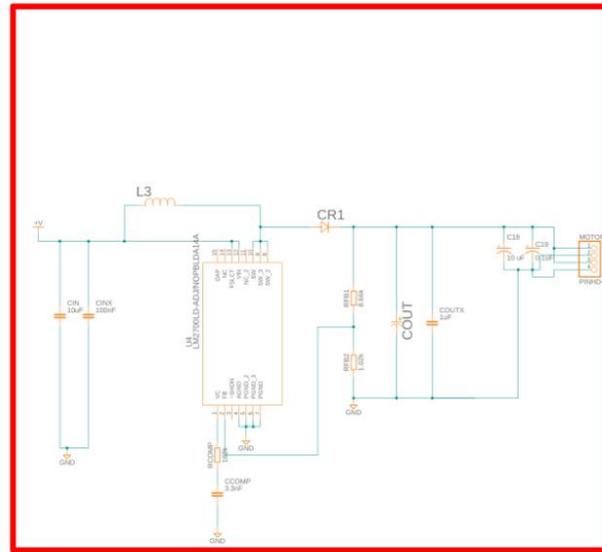
Justice Cordova



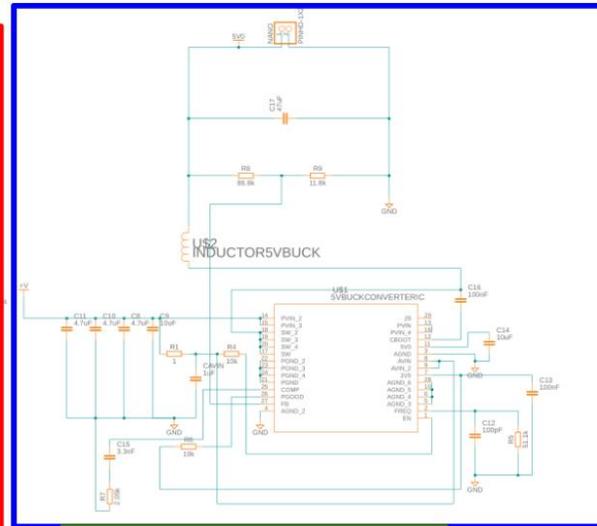
# Rover Electrical Design - PCB Schematic

Justice Cordova

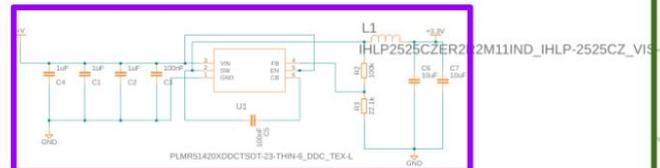
Boost Converter-Motor and Video TX



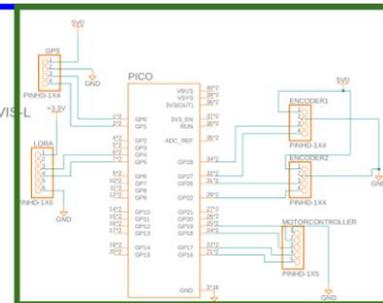
Buck Converter-Jetson/Peripherals



Buck Converter-LoRa

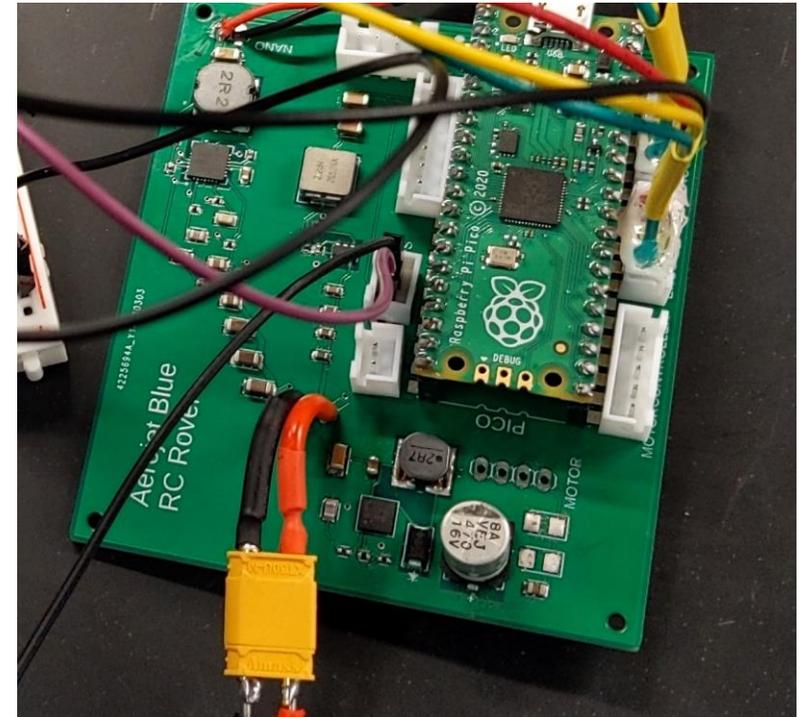
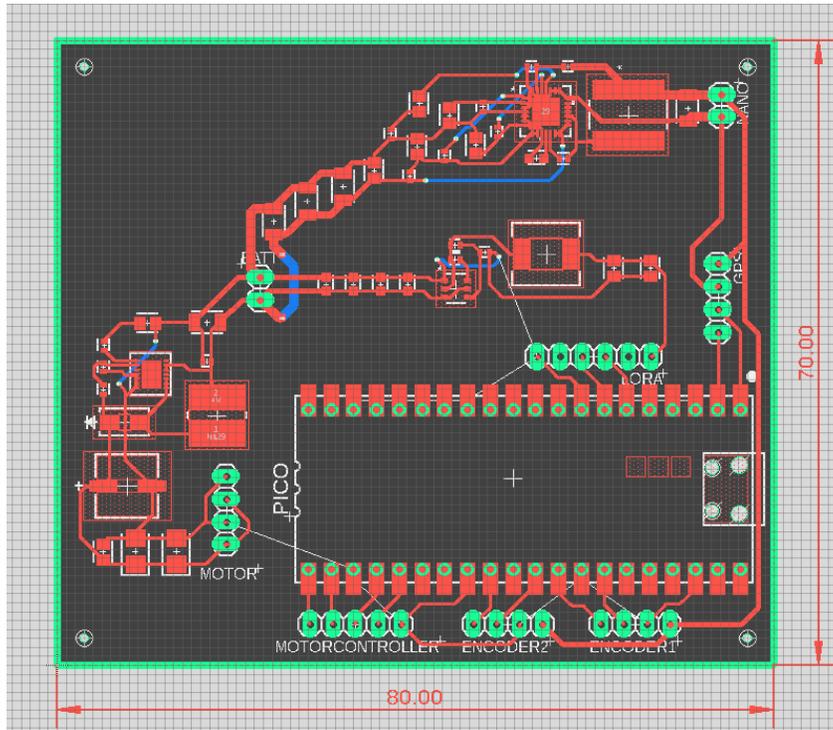


Raspberry Pi Pico



# PCB Layout and Assembly

Justice Cordova



# Software Design

Presenter(s): Wesley Fletcher, Joshua Kissoon, and James Ellison

# Peripheral MCU Program

[GitHub](#)

Wesley Fletcher

- Program provides the SBC a “single point of access” to all peripherals
- Communicates with SBC via serial (USB) protocol
- Multicore – core 0 is main program, core 1 communicates with LoRa transceiver
- Program handles:
  - GPS updates from GPS module
  - LoRa transmit/receive functionalities on second core
  - Wheel encoder tick updates
  - Motor control PWM

# Peripheral Comms. Summary

Wesley Fletcher

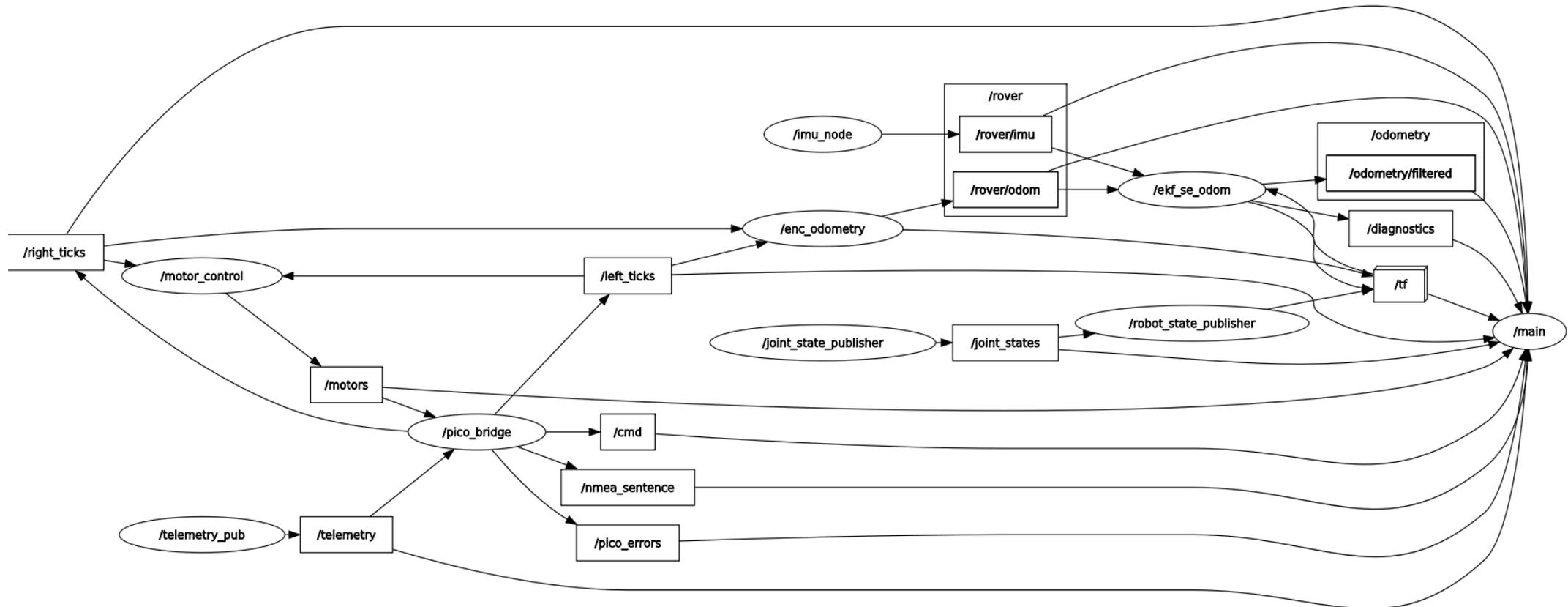
Component	Protocol	Method	Dir.	TX Mode	Approx. Freq.
SBC	Serial (USB)	Polling (Continuous)	IN/OUT	Half-duplex	20Hz
GPS	UART (9600-8-N-1)	IRQ	IN	Simplex	1Hz
LoRa TX/RX	UART (115200-8-N-1)	Polling (Continuous)	IN/OUT	Half-duplex	--
Wheel Encoders	GPIO	Polling (Timer)	IN	Simplex	250Hz
Motor Controller	PWM (GPIO)	PWM	OUT	Simplex	--

# Rover Autonomy Software [GitHub](#)

Wesley Fletcher

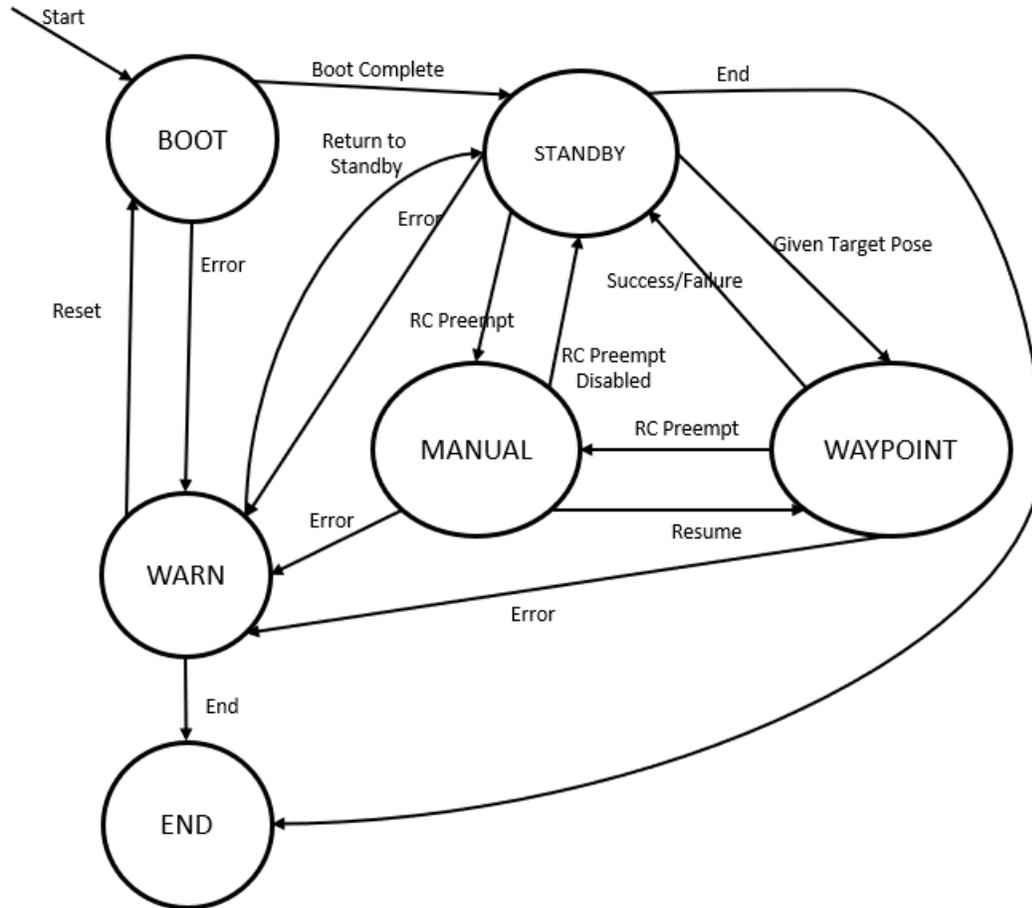
- High-level software implements the advanced functionality of rover
  - Waypoint navigation
  - Real-time telemetry and logging
  - Image processing
- Finite state machine for executing advanced behaviors
- Leverages the Robot Operating System
  - Custom message definitions
  - Software nodes using ROS API and paradigms

# A (Partial) Map of Rover Software

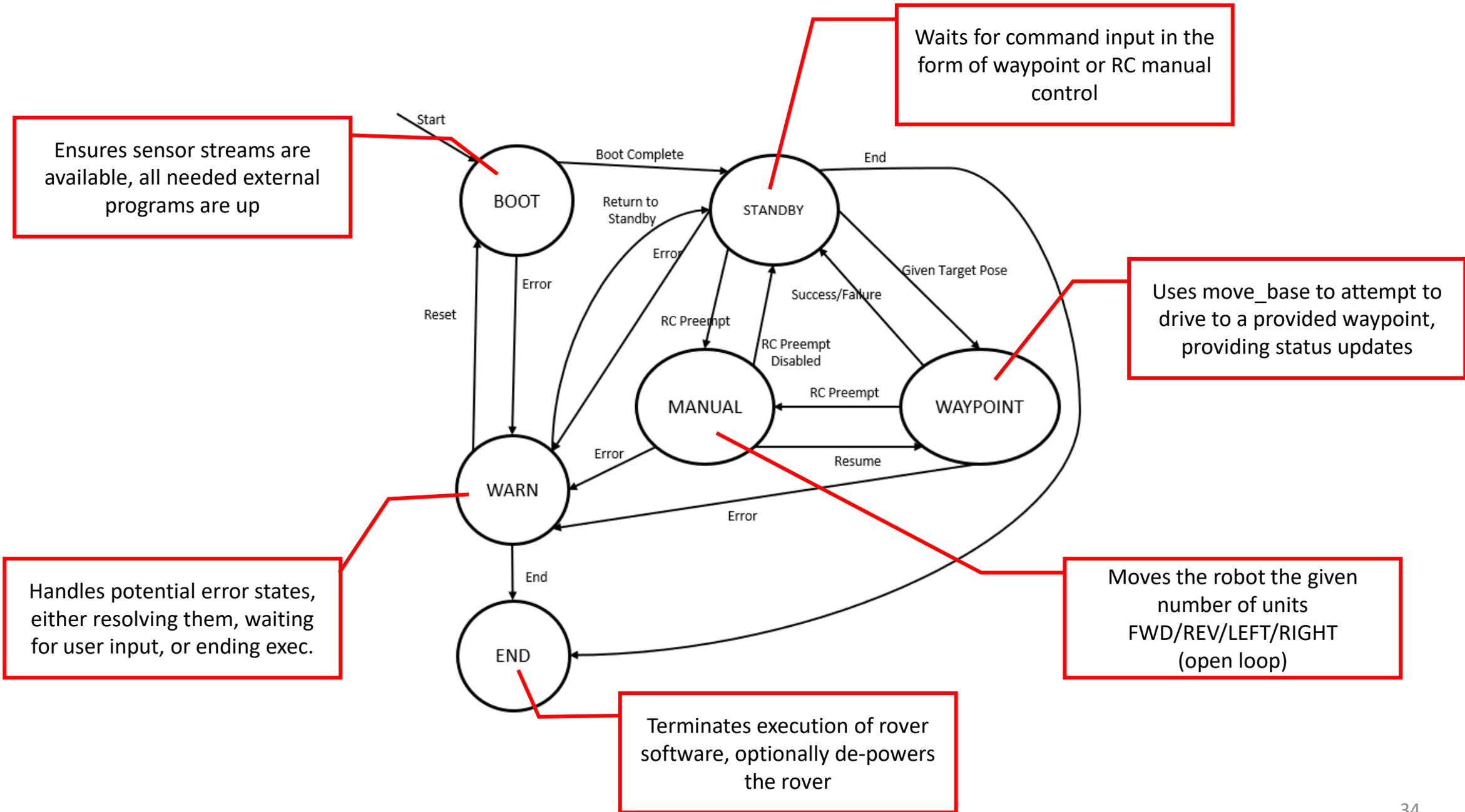


# Finite State Machine

Wesley Fletcher



- Handles rover behaviors depending on context/stage of lifecycle
- Rigid, but simple to debug and adjust as needed
- FSM makes decisions on behaviors based on sensor and user inputs from other parts of the system



# Additional Software Nodes

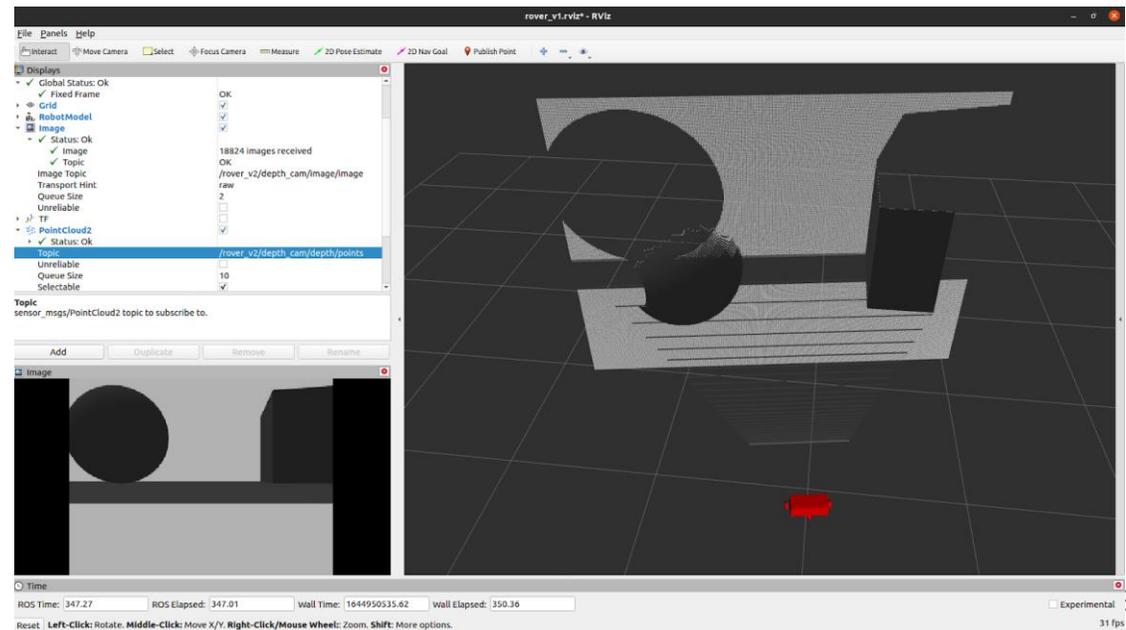
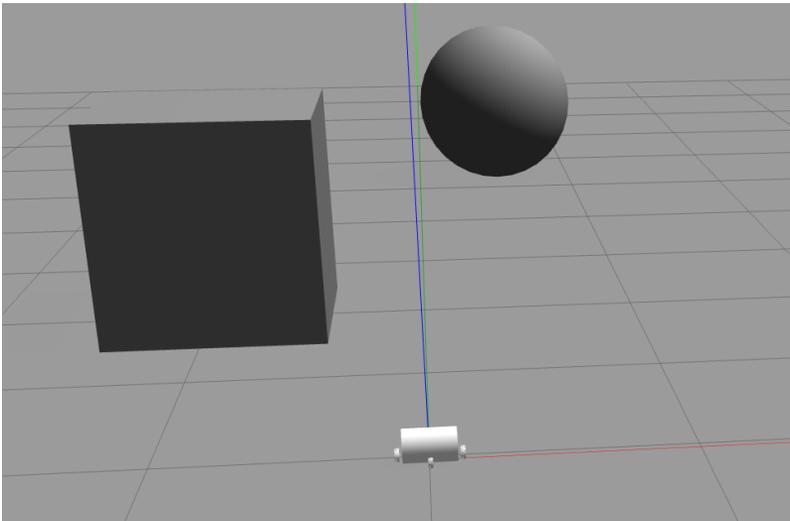
Wesley Fletcher

- `pico_bridge`: Python program that acts as SBC side of the MCU->SBC connection; reads input from Pico and dispatches to other nodes
- `telemetry_pub`: gathers information about state of rover, sends it to `pico_bridge` to be sent to the Pico for transmission
- `motor_control`: converts velocities to PWMs for our motor controller; assumes a linear relationship between PWM and speed
- `encoder_odom`: generates odometry from wheel encoder ticks and velocities; a.k.a. my pride and joy -> Requirement 4.5

# Rover Simulation

Wesley Fletcher

- Developed high-fidelity robotic simulation in Gazebo to develop and test the robot software stack
- Gazebo works "out-of-the-box" with ROS; software written in the simulation environment works in real-world with few modifications



# Ground Station [GitHub](#)

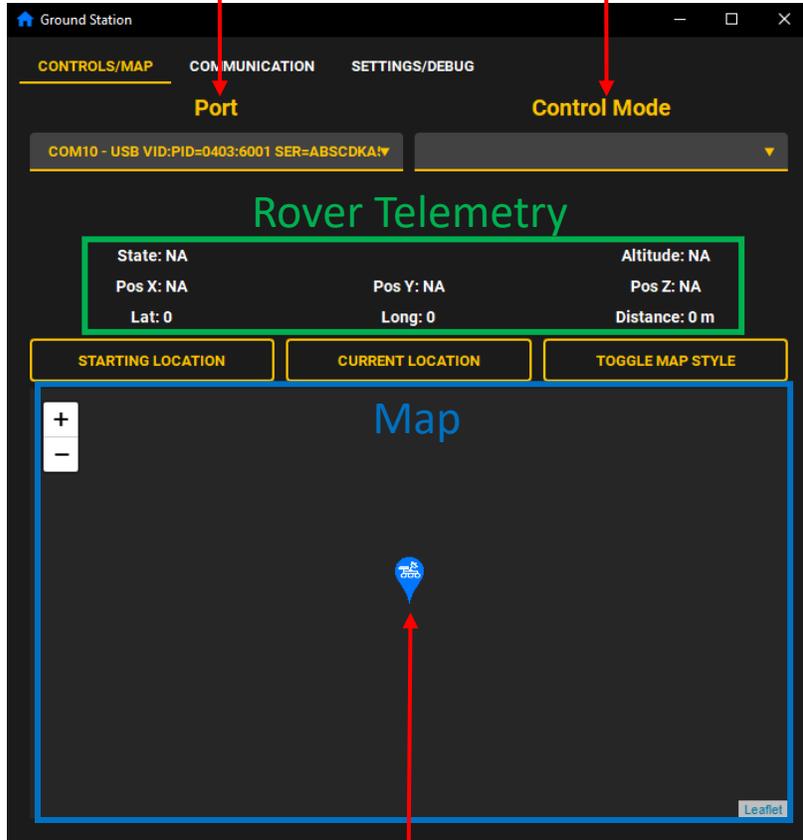
Joshua Kissoon

- The Ground Station is the command center. It will relay instructions to the rover and retrieve live video and GPS data.
- The host machine will be a laptop running Ubuntu 20.04 LTS.
- A 5.8 GHz FPV receiver and LoRa transceiver will be connected via USB.
- We will control the rover and receive telemetry using our custom GUI.
  - Used Python for application development and PyQt5 for creating the GUI.
  - Telemetry – GPS coordinates, altitude, rover state, rover position
  - View rover's journey using PyQtlet – interactive map library.
- VLC will be used to view the video feed.

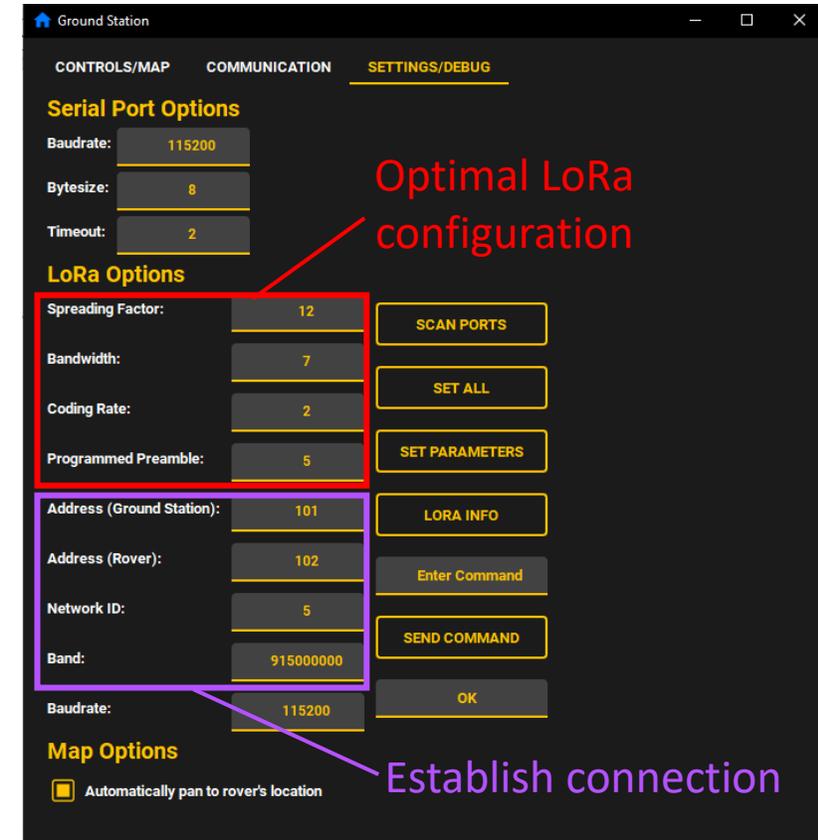
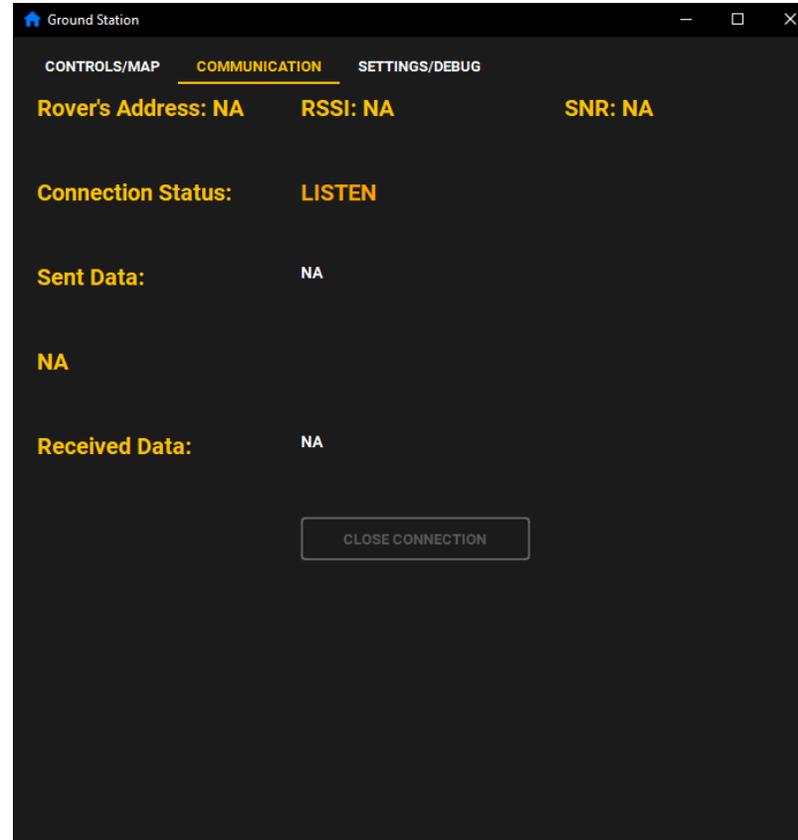
# Graphical User Interface

Joshua Kissoon

1. Select LoRa Port
2. Select Control Mode



Rover Position



Optimal LoRa configuration

Establish connection

# Control Modes

Joshua Kissoon

**Port** **Control Mode**

COM10 - USB VID:PID=0403:6001 SER=ABSCDKA!▼ Blind Drive ▼

Latitude Longitude TRAVEL

**Port** **Control Mode**

COM10 - USB VID:PID=0403:6001 SER=ABSCDKA!▼ Manual 2 ▼

Forward 0

Left 0 Reverse 0 Right 0

SEND COMMAND

**Port** **Control Mode**

COM10 - USB VID:PID=0403:6001 SER=ABSCDKA!▼ Manual 1 ▼

X 0 Y 0 Z 0

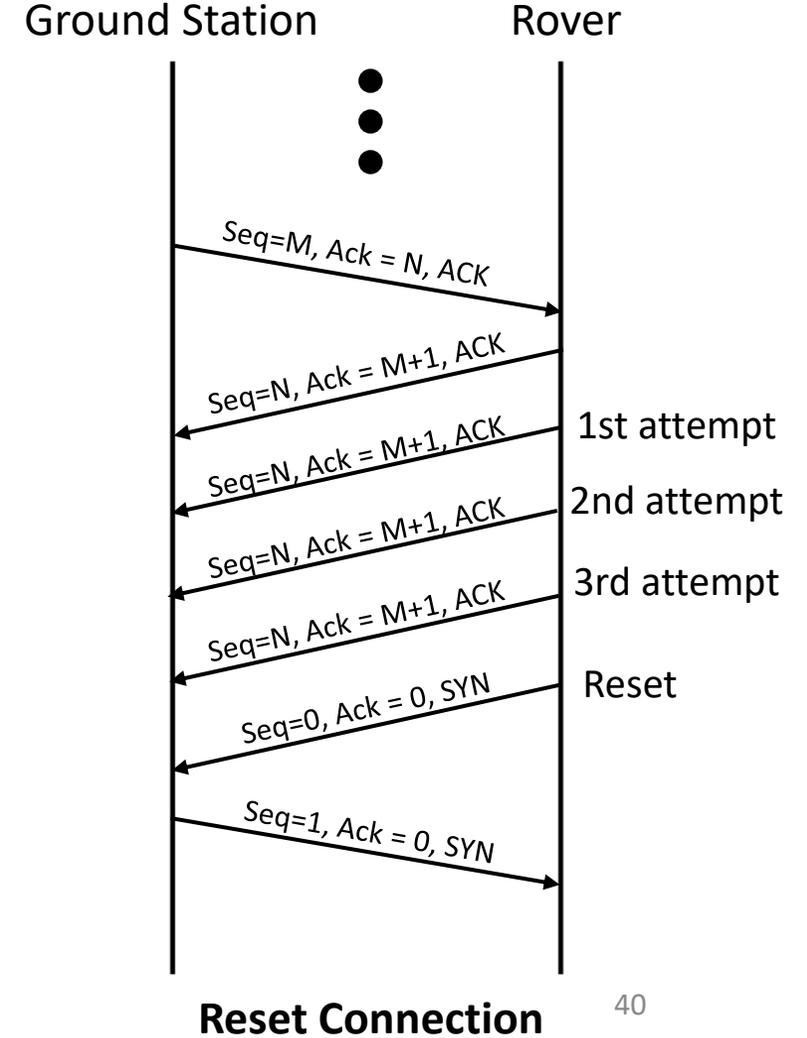
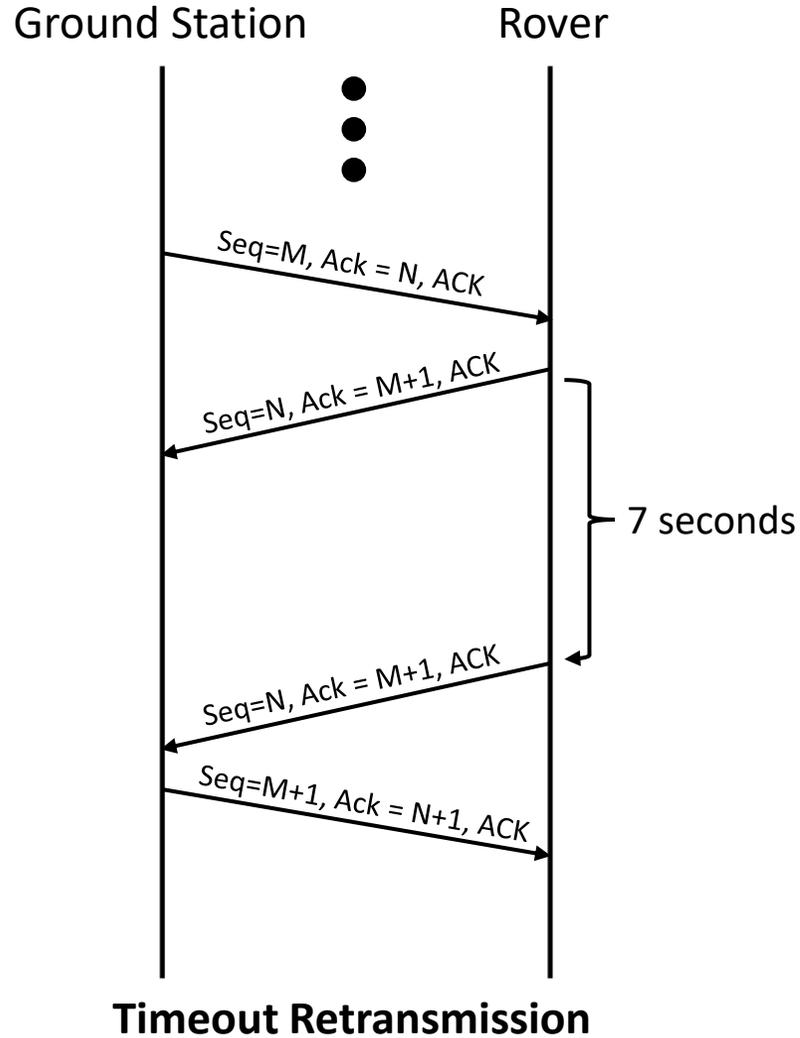
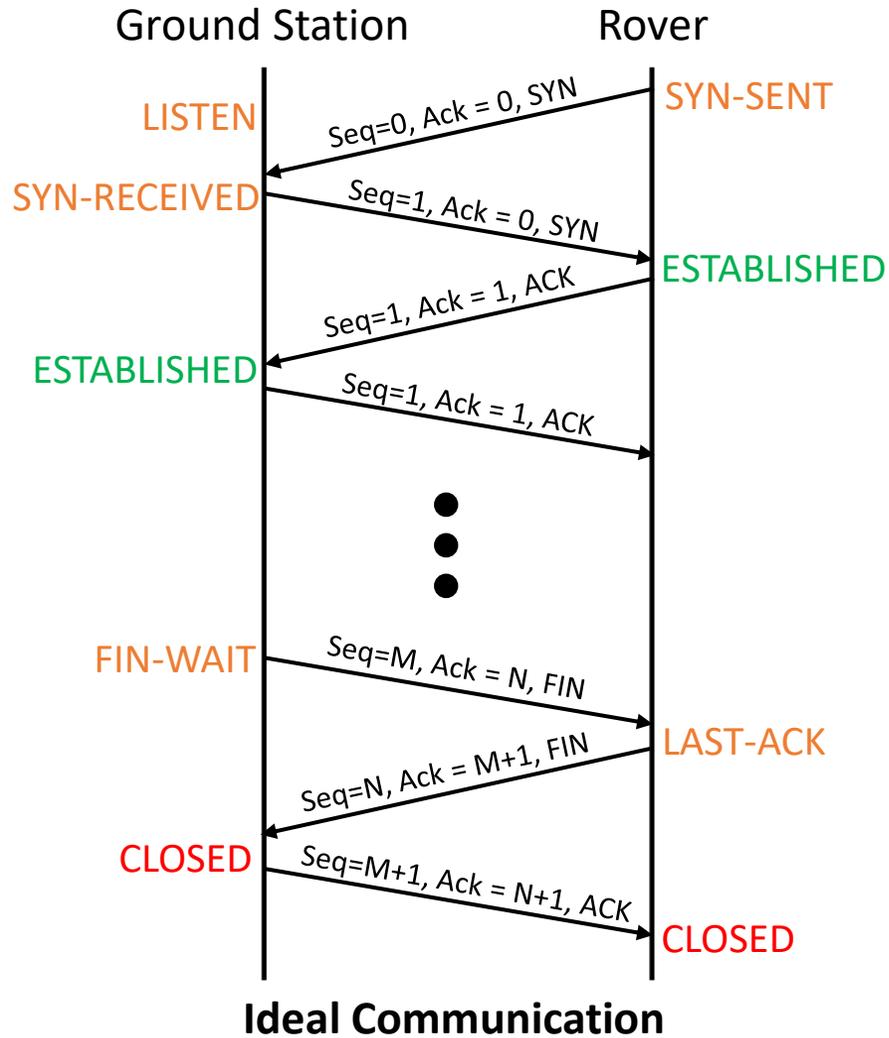
Start Cancel Shutdown RC Preempt Pose Preempt

False ▼ False ▼ False ▼ False ▼ False ▼

SEND COMMAND

# Communication

Joshua Kissoon



# The Prototype

Presenter(s): Wesley Fletcher

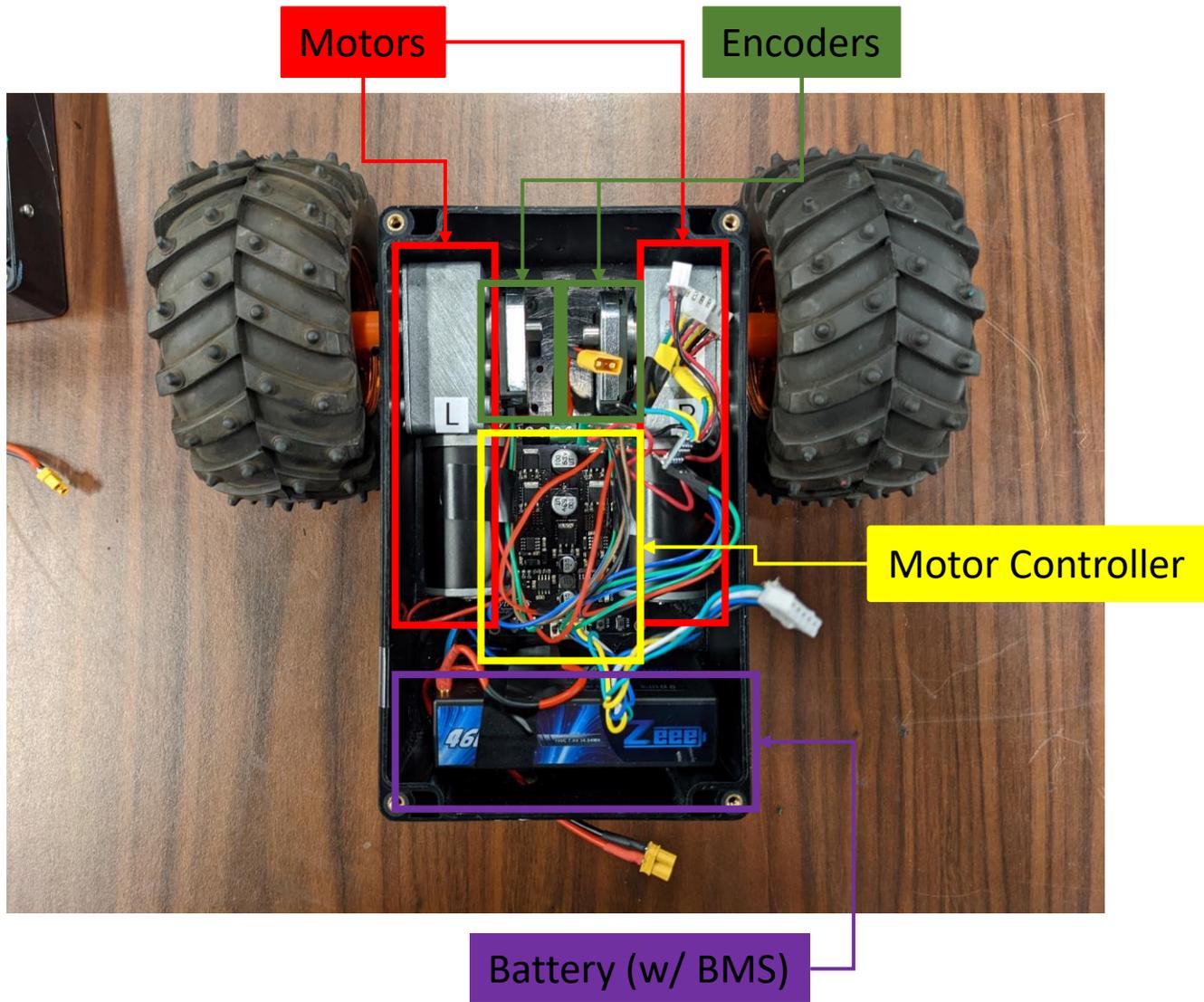
# Prototype – “Cpt. Petard”

Wesley Fletcher

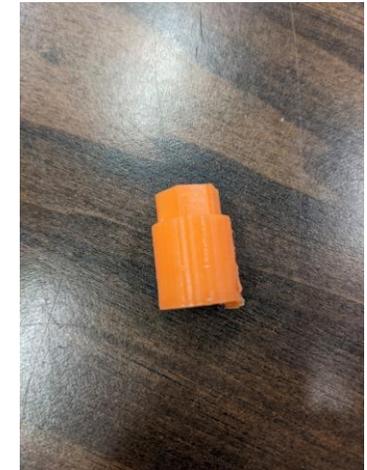
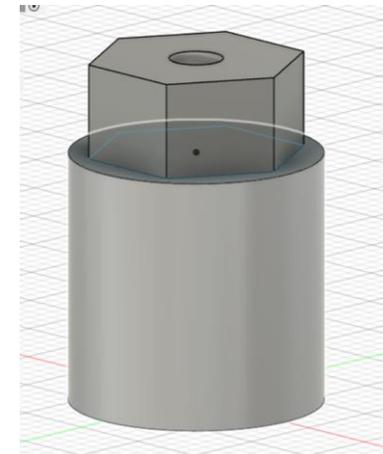


# Bottom Level – Drivetrain and Power

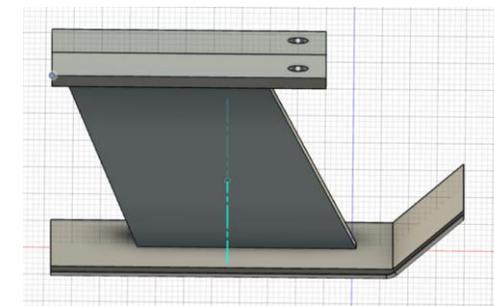
Wesley Fletcher



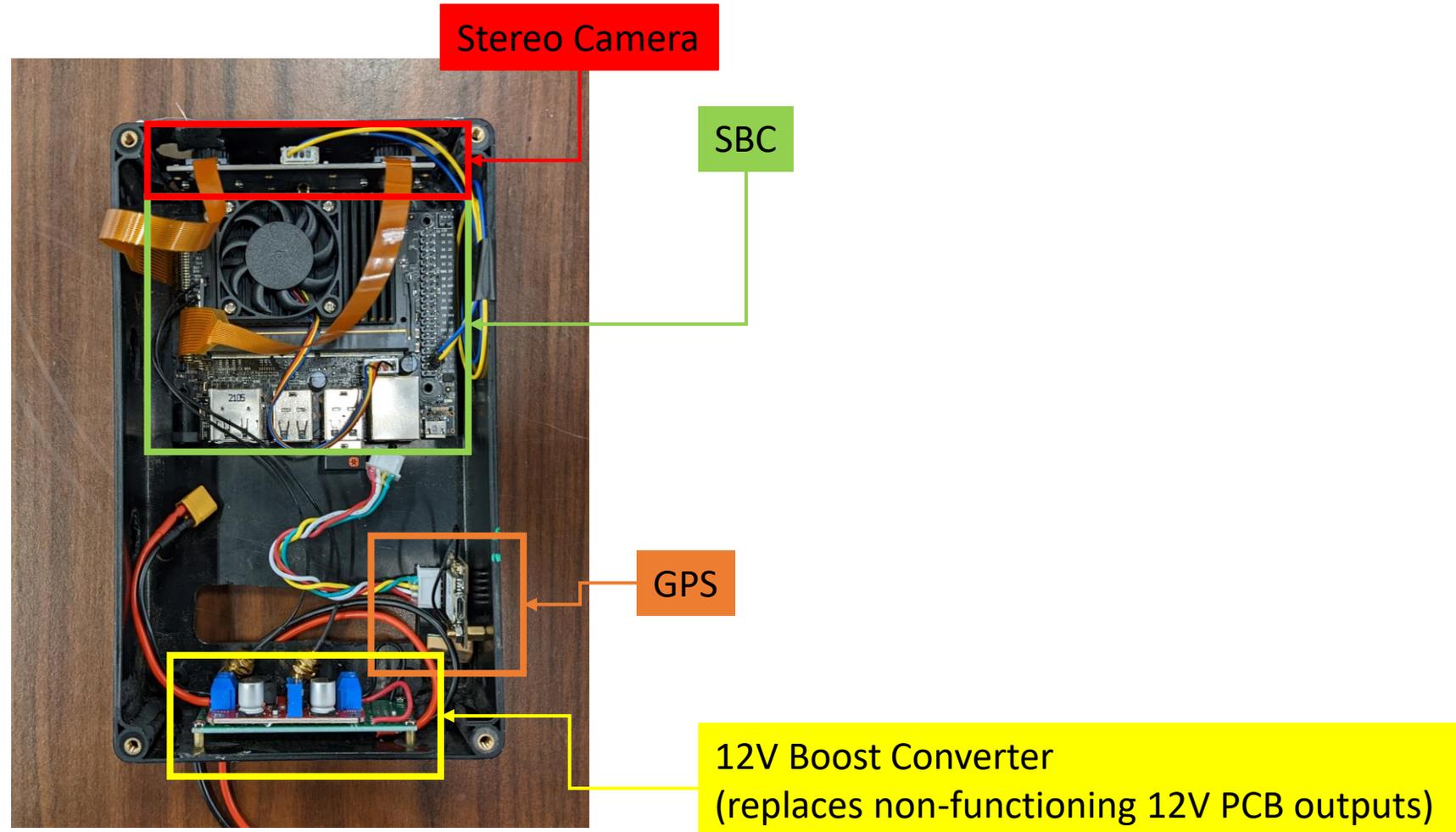
3D printed custom shaft adapters



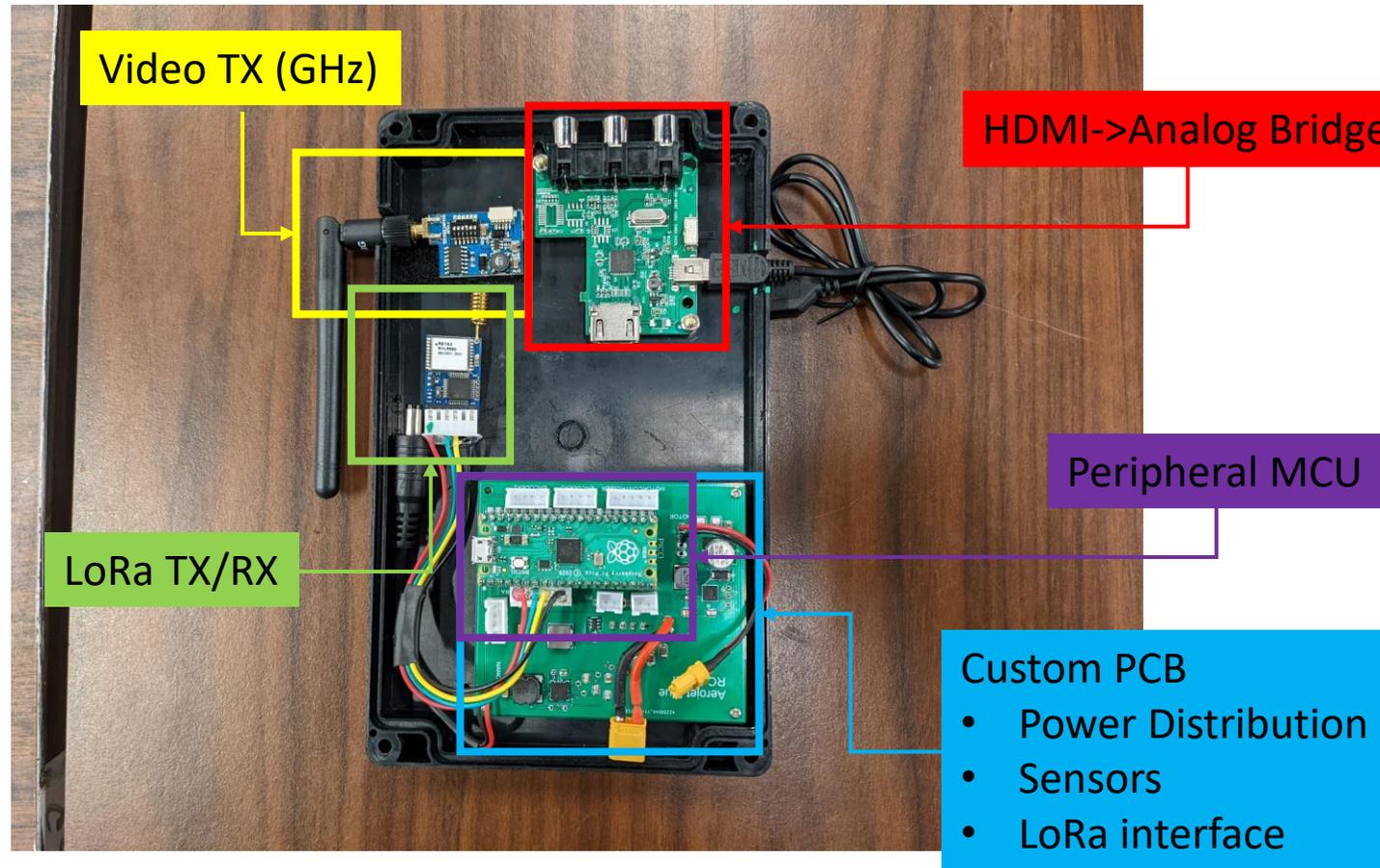
“Skis” for sand



# Top Level – SBC and Sensors



# Lid – MCU and Communications



# Results

Presenter(s): Wesley Fletcher

# Results

Wesley Fletcher

- Final weight of payload prototype including battery, wheels, and “skis” was 2.041Kg -> requirements R1.1 and R1.2 satisfied
- Fitting all components was a challenge, plans for rev. 2 fell through
  - diameter of prototype exceeds the requirement at about 9.4in diameter. -> requirement R1.3 not satisfied

# Results (Cont.)

Wesley Fletcher

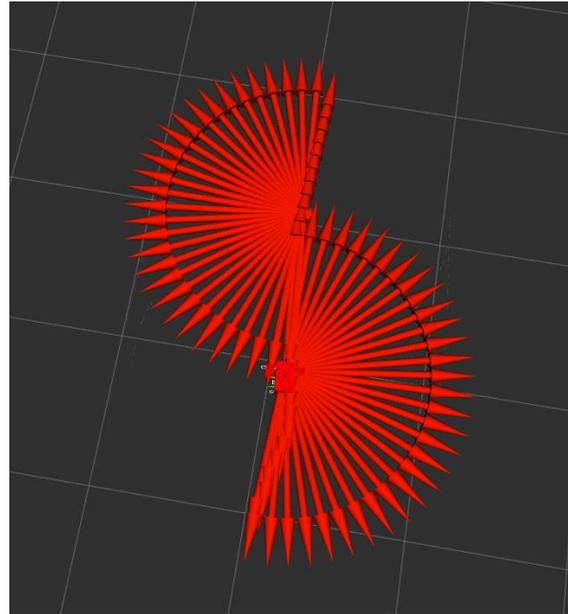
- Robot is capable of driving under its own power, and easily exceeds 10ft of range -> requirement R4.1 satisfied
- We were able to send LoRa (RC) commands from the Ground Station (GS) to the Rover using the GUI -> requirement R4.2 satisfied
- We can transmit live video from Jetson to GS, but:
  - we didn't have space/the correct connectors to actually transmit live video from the rover as it drove around
  - We only successfully range tested it to 500m, 100m shy of requirement
  - Requirement R4.3 not fully satisfied
- Rover is constructed from IP67-compliant materials, but cannot be closed fully and so cannot be called truly dust-resistant -> R4.4 not satisfied

# Results - Odometry

Wesley Fletcher

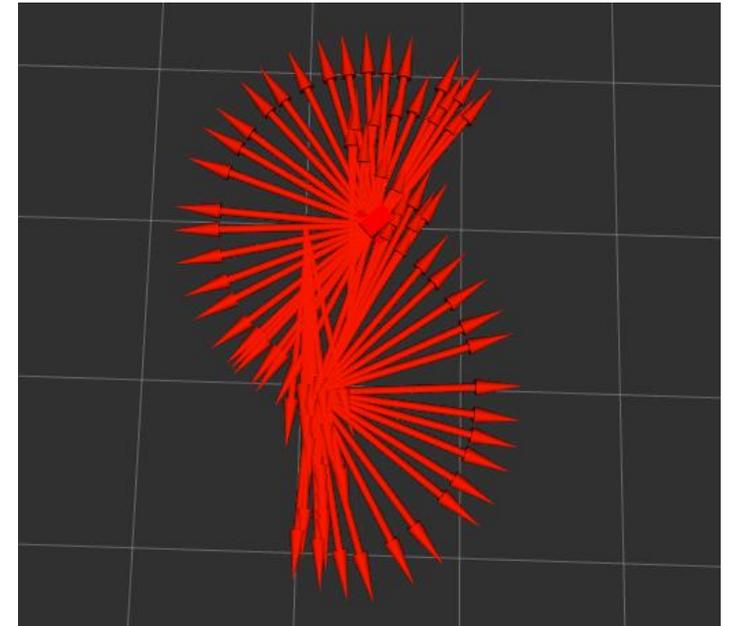
- Drive same path on real-life and simulated robot, measure the difference; repeat ad nauseum
- Results: MIXED
  - Knows position to within 0.2m
  - Has especially tough time tracking rotations
  - Likely due to right-wards drift when driving straight
- Requirement R4.5 satisfied (mostly)

Simulation



Average Final Position:  
 $X = -0.10\text{m}$ ,  $Y = -0.11\text{m}$

Real-world



Average Final Position:  
 $X = 0.169\text{m}$ ,  $Y = -0.2589$

# Results (Cont.)

Wesley Fletcher

- Rover couldn't map surroundings due to latency issues with the stereo camera not generating a depth cloud -> requirement R4.6 not satisfied
- R4.7 was for generating panoramas, but this wasn't functionality we actively pursued this semester
- Rover does log all relevant sensor data, storing those ROS topics in .bag files, where they can be played back -> R4.8 satisfied
- Rover does transmit real-time telemetry data to the ground station using LoRa communications -> R4.9 satisfied

# Conclusions

Presenter(s): All

# Skills Gained

## Wesley Fletcher

- Electronics
  - Soldering
  - Crimping/solder connectors
  - Working with LiPo batteries
- Embedded/MCU
  - Pi Pico SDK
  - IRQs, timers, void pointers,...
- Programming:
  - Deeper work in C, C++
- Robotics
  - Sensor selection, sensor input conditioning
  - Kinematic models/odometry
  - Mobile base control
- Mechanical
  - 3D CAD w/ Fusion 360
  - 3D printing
  - Fasteners, prototype assembly

## James Ellison

- RF Communications
  - LoRa Protocol
  - Integration Testing-Video Tx
- Programming
  - Python
  - PyQt GUI design

## Justice Cordova

- Electronics
  - Soldering
  - PCB design
  - PCB Assembly
  - Electronics Rework
  - Electronics Troubleshooting
- RF Communications
  - LoRa Protocol
  - Integration Testing-Video Tx

## Joshua Kissoon

- Electronics
  - Soldering
  - PCB design
- Embedded/MCU
  - Pi Pico SDK
  - Multicore
- Programming
  - Python
  - PyQt GUI design
- Mechanical
  - 3D CAD w/ SolidWorks
  - Ansys simulation

# Lessons Learned

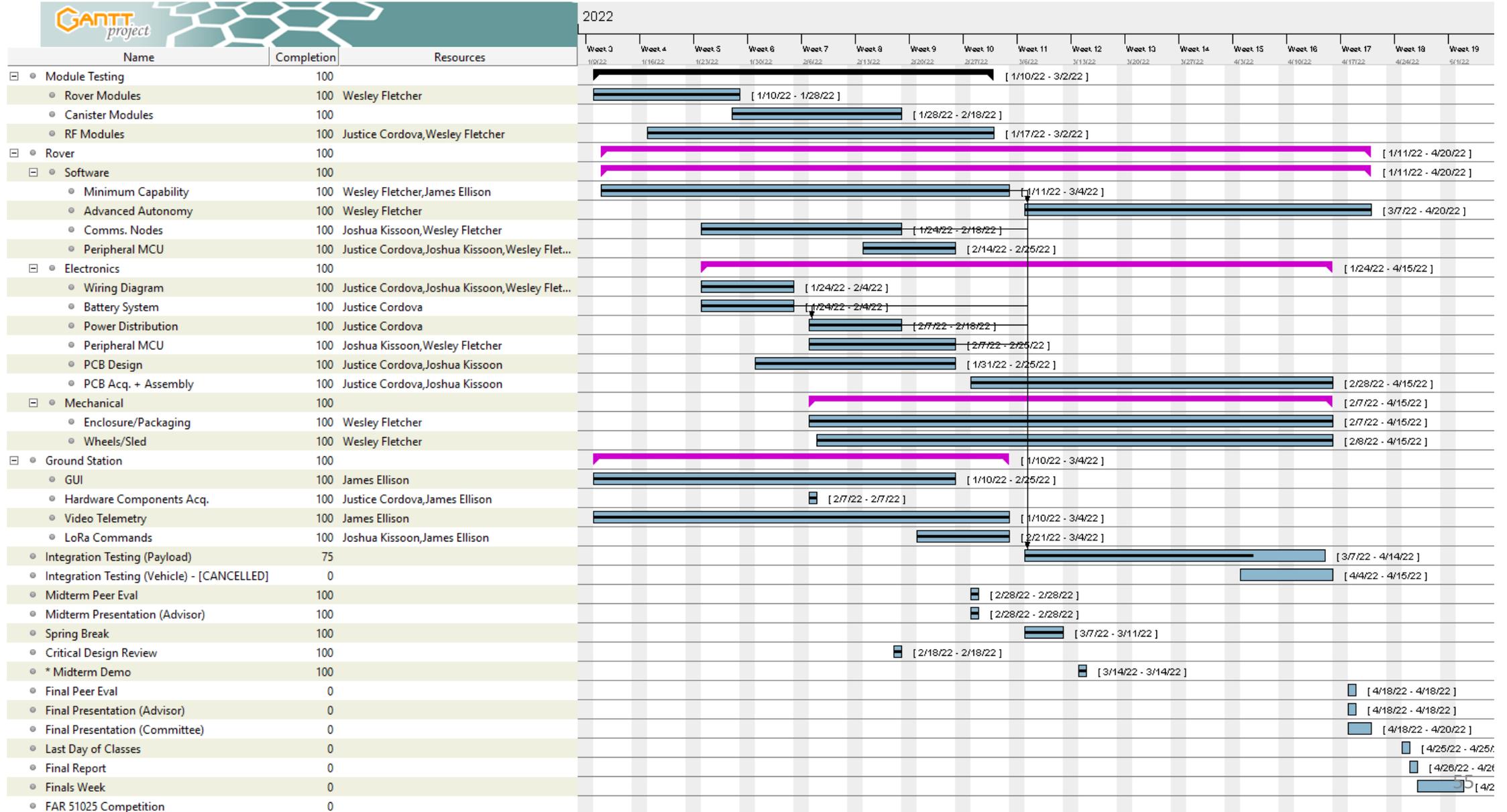
- Requirements
  - Push back against unrealistic expectations and deliverables
  - Ensure that requirements are clear, specific, and **testable**
- Don't obsess over the first iteration – sometimes it's faster to do it wrong and fix it in the next revision
- Push for basic functionality first; don't try to build every feature in parallel

# Administrative Content

Presenter(s): James Ellison

# Gantt Chart

James Ellison



# Budget

James Ellison

- This project was sponsored by Aerojet Rocketdyne Coleman Aerospace
- Each payload team was given ~\$500 for their project; anything else would come from personal funds
- We remained well within budget by:
  - Using "scavenged" parts from the Robotics Club lab
  - Selecting items that we already had (like the Jetson) for our design
  - Using personal funds for last-minute purchases

# Bill of Materials

James Ellison

PCB

Rover

Function	Name	Price/unit	Quant.	Total Price	Cust. Cost
SBC	Jetson Nano 4GB Dev. Kit *	\$99.00	1	\$99.00	\$0.00
Camera	Waveshare Stereo Camera	\$44.99	1	\$44.99	\$0.00
MCU	Raspberry Pi Pico	\$3.60	1	\$3.60	\$0.00
GPS	GPS NEO-6M	\$11.59	1	\$11.59	\$0.00
Motor Driver	Cytron Dual Channel 10A	\$21.18	1	\$21.18	\$0.00
Motors	Greartisan DC 12V 250RPM Worm Gear	\$28.99	2	\$57.98	\$0.00
Wheel Encoders	ENC-AMT102-V	\$23.86	2	\$47.72	\$47.72
Wheels	Dagu Wild Thumper Wheels 120x60mm *	\$17.95	2	\$35.90	\$0.00
Batteries	Zeee 2s 7.4V 4600mAh LiPo	\$27.89	1	\$27.89	\$0.00
BMS Circuit	ACEIRMC 4A 2S BMS *	\$2.00	1	\$2.00	\$0.00
Boost Converter	ACEIRMC XL6019 5A DCDC *	\$3.33	1	\$3.33	\$0.00
Enclosure	Zulkit ABS Project Box IP65	\$9.99	2	\$19.98	\$0.00
LoRa TX/RX	RYLR896 LoRa	\$24.47	2	\$48.94	\$0.00
Video TX	TS5823 Transmitter	\$8.99	1	\$8.99	\$8.99
Video RX	5.8 GHz downlink Receiver	\$24.60	1	\$24.60	\$24.60
HDMI->Analog	HDMI2AV Upscaler (modified)	\$10.99	1	\$10.99	\$0.00
Connector	JST-XH 2.54mm Connector Kit *	\$8.99	1	\$8.99	\$0.00
Connector	Amass XT30U Pair	\$1.10	5	\$5.50	\$0.00

\* parts were scavenged, rather than purchased

**Total \$483.17 81.31**

Part	Manufacturer	Part Number	Quantity	Price (\$)	Footprint (mm <sup>2</sup> )	Description
Ccomp	TDK	C2012C0G1H332J060AA	1	0.03	6.75	Cap: 3.3 nF
Cin	MuRata	GRM31CR61C106KA88L	1	0.08	10.92	Cap: 10 μF
Cout	Panasonic	EEV-FK1E102Q	1	0.43	263.5	Cap: 1 mF
Coutx	Kemet	C0805C105K4RACTU	1	0.02	6.75	Cap: 1 μF
D1	Fairchild	SS24FL	1	0.05	11.7	Schottky
L1	MuRata	1255AY-2R7N=P3	1	0.18	68.89	L: 2.7 μH
Rcomp	Vishay-Dale	CRCW0402133KFKED	1	0.01	3	133 kΩ
Rfb1	Vishay-Dale	CRCW04021K02FKED	1	0.01	3	1.02 kΩ
Rfb2	Vishay-Dale	CRCW04028K66FKED	1	0.01	3	8.66 kΩ
U1	TI	LM2700MTX-ADJ/NOPB	1	1.65	58.8	
Cinx	MuRata	GRM155R71A104KA01D	1	0.01	3	Cap: 100 nF
C2v5	AVX	08053C104JAZ2A	1	0.06	6.75	Cap: 100 nF
C5v0	Samsung	CL10A106MQ8NNNC	1	0.02	4.68	Cap: 10 μF
Cavin	Kemet	C0805C105K4RACTU	1	0.02	6.75	Cap: 1 μF
Cboot	MuRata	GRM155R71C104KA88D	1	0.01	3	Cap: 100 nF
Ccomp	TDK	C2012C0G1H332J060AA	1	0.03	6.75	Cap: 3.3 nF
Cin	Kemet	C1206C475K4PACTU	3	0.06	10.92	Cap: 4.7 μF
Cinx	MuRata	GRM21BR61E106MA73L	1	0.05	6.75	Cap: 10 μF
Cout	MuRata	GRM31CR60J476ME19L	1	0.23	10.92	Cap: 47 μF
Csync	Samsung	CL21C101JBANNNC	1	0.01	6.75	Cap: 100 pF
L1	Bourns	SRN8040-2R2Y	1	0.27	100	L: 2.2 μH
Ravin	Vishay-Dale	CRCW04021R00FKED	1	0.01	3	1 Ω
Rcomp	Vishay-Dale	CRCW04022K15FKED	1	0.01	3	2.15 kΩ
Ren	Yageo	RC0201FR-0710KL	1	0.01	2.08	10 kΩ
Rfbb	Vishay-Dale	CRCW040211K8FKED	1	0.01	3	11.8 kΩ
Rfbt	Yageo	RC0201FR-0786K6L	1	0.01	2.08	86.6 kΩ
Rpg	Yageo	RC0201FR-0710KL	1	0.01	2.08	10 kΩ
Rt	Vishay-Dale	CRCW040251K1FKED	1	0.01	3	51.1 kΩ
U1	TI	LM21305SQX/NOPB	1	2.42	49	
Cboot	MuRata	GRM155R71C104KA88D	1	0.01	3	Cap: 100 nF
Cin	TDK	C1608X7R1V105K080AC	3	0.05	4.68	Cap: 1 μF
U1	TI	LMR51420YDDCR	1	0.6	14.82	
Cout	Kemet	C0805C106K8PACTU	2	0.03	6.75	Cap: 10 μF
Cinx	MuRata	GRM188R71H104KA93D	1	0.02	4.68	Cap: 100 nF
L1	Vishay-Dale	IHLP2525CZER2R2M11	1	0.67	75.04	L: 2.2 μH
Rfbb	Vishay-Dale	CRCW040222K1FKED	1	0.01	3	22.1 kΩ
Rfbt	Vishay-Dale	CRCW0402100KFKED	1	0.01	3	100 kΩ
PCB	JLCPCB		5	19.4		PCB
Total				26.78		