Group 20:
Semi-Autonomous Imaging Land Rover (SAILR)

Critical Design Review

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Project Sponsor: Barbara Streiffert

Project Advisor: Dr. Rafi

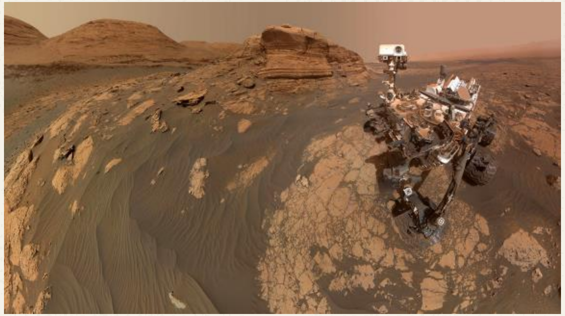
** Emphasized names correspond to presenting members

Project Motivation

Extreme environments not suitable for human exploration require the use of semi-autonomous rovers to surveil area and assess locations of interest.

Potential Applications:

- Space Exploration
- Natural Disaster Relief
- Law Enforcement



Curiosity's Selfie at Mont Mercou
Image Source: NASA JPL

NIFTi Unmanned Ground Vehicle (UGV)
Image Source: Advanced Robotics

Relevant Definitions

- **Typical Mission Environment:** Flat, dry terrain containing obstacles placed along the path from the ground station to the location of interest adhering to the requirements for the environment.
  - **Level 1**: 1 obstacle in environment
  - **Level 2**: 3 obstacles in the environment, spaced 10m apart or greater
- **Terrain:** The terrain will consist of either mowed grass, dry dirt, or concrete which may contain naturally occurring twigs no more than 0.5 inches in diameter. The terrain will contain no inclines or declines greater than 5° from horizontal.
- **Obstacles:** Obstacles include natural rocks and dense shrubs of a height greater than 2.5 inches and a diameter greater than 2.5 inches.

Relevant Definitions

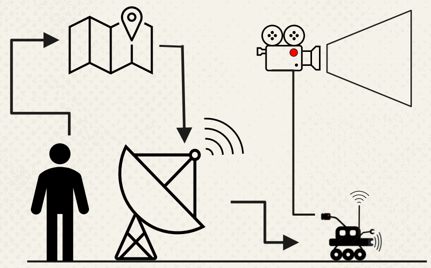
- **Ground Station:** The ground station will be an interface which displays images and video taken by the rover and displays the rover's location. The ground station will also provide a means for a user to input manual control commands and location of interest coordinates.
- **Location of Interest:** A set of GPS coordinates defined by the user indicating the location that the rover will navigate to. Location of interest coordinates must be within a 100-meter radius of the ground station.

Functional Requirements

Req. #	Requirements
FR.1	The rover shall move forwards, backwards and turn in any direction
FR.2	The rover shall transmit and receive data between the on-board computer and the ground station
FR.3	The rover shall utilize remote sensing subsystems to determine a path to a location of interest
FR.4	The power delivery subsystem shall be able to monitor and sustain the rover / ground station for the duration of the mission
FR.5	Rover shall have a footprint no larger than 1’ x 1’
FR.6	The ground station shall display video, images, and location of rover
FR.7	The ground station shall provide an interface to allow for input of manual commands from user

High-Level Mission CONOPS

Rover Continuously Communicating & Sending Video Packets to Ground Station

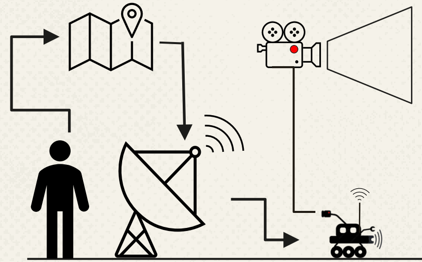


Initiate Rover

1. Setup ground station
2. Initialize rover and ground station communication
3. User sends location of interest through ground station to rover
4. Initiate rover video recording

High-Level Mission CONOPS

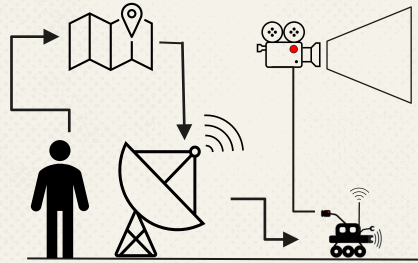
Rover Continuously Communicating & Sending Video Packets to Ground Station

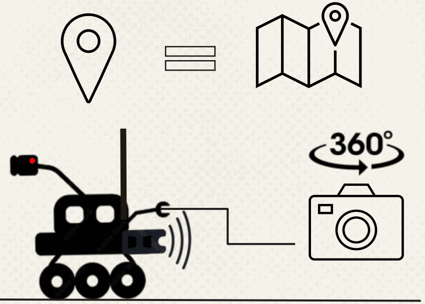


Initiate Rover	Autonomous Navigation
1. Setup ground station **2.** Initialize rover and ground station communication **3.** User sends location of interest through ground station to rover **4.** Initiate rover video recording	**5.** Rover navigates over small sticks autonomously **6.** Rover navigates around obstacles autonomously **7.** Rover transmits video to the ground station as it navigates

High-Level Mission CONOPS

⟵ Rover Continuously Communicating & Sending Video Packets to Ground Station ⟶





Initiate Rover

1. Setup ground station
2. Initialize rover and ground station communication
3. User sends location of interest through ground station to rover
4. Initiate rover video recording

Autonomous Navigation

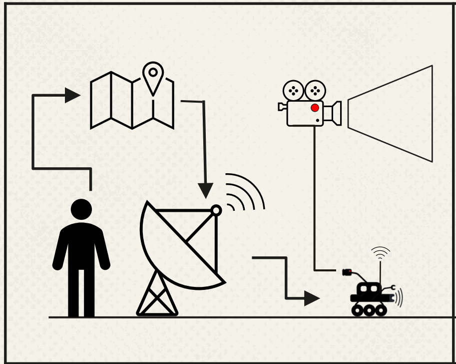
5. Rover navigates over small sticks autonomously
6. Rover navigates around obstacles autonomously
7. Rover transmits video to the ground station as it navigates

Reach Location of Interest

8. Rover reaches location of interest (up to 100m away from ground station)
9. Rover captures images of location of interest given user input
10. Rover transfers images to the ground station

High-Level Mission CONOPS

Rover Continuously Communicating & Sending Video Packets to Ground Station



Initiate Rover

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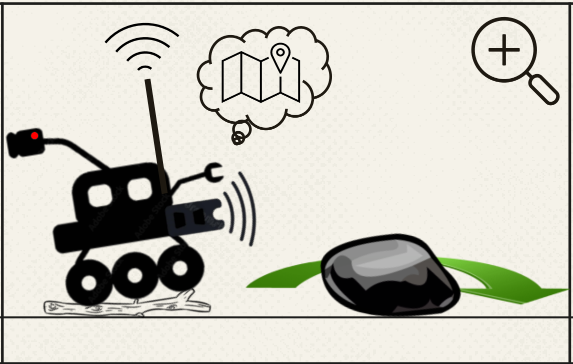

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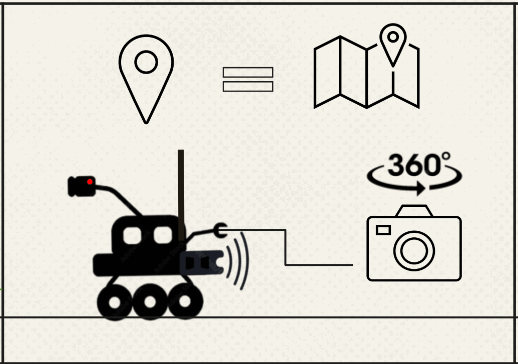

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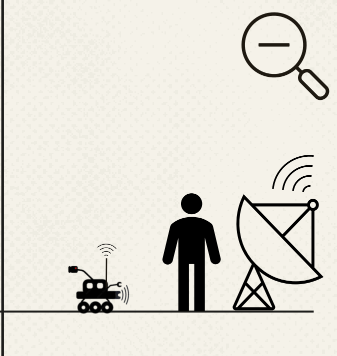


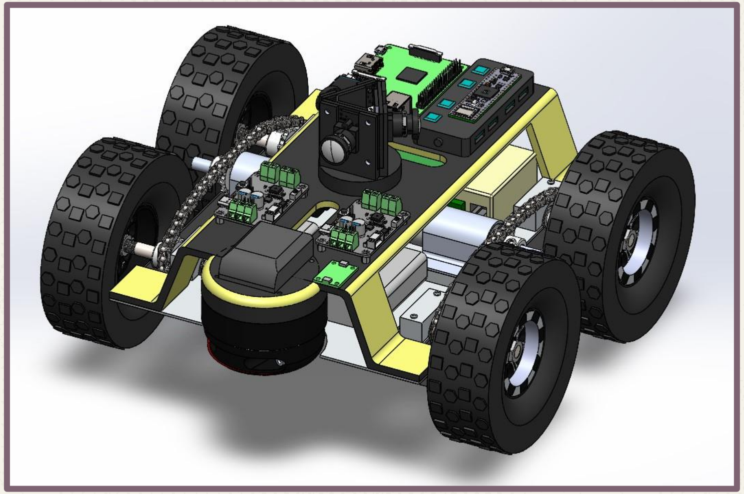
Return to Ground Station

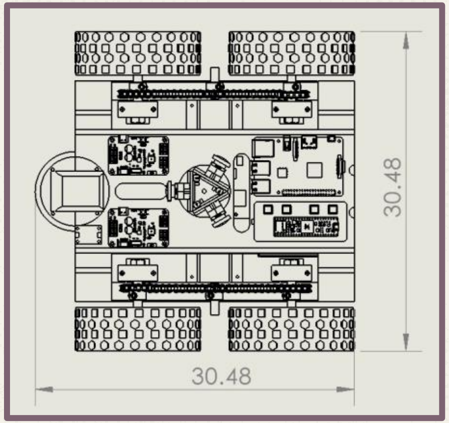
11. Rover autonomously navigates to ground station (steps 5,6,7)
12. Rover is collected and prepared for next mission

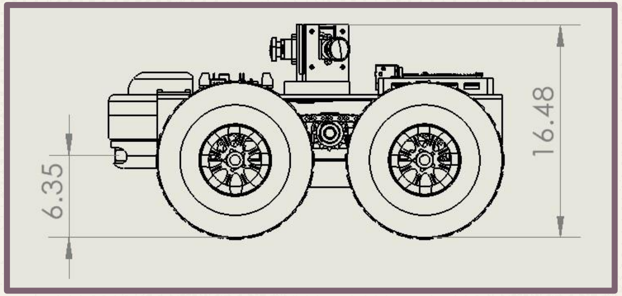
Design Solution Overview

Rover design overview, general component selection, hardware FBD, power FBD

Rover Design Solution



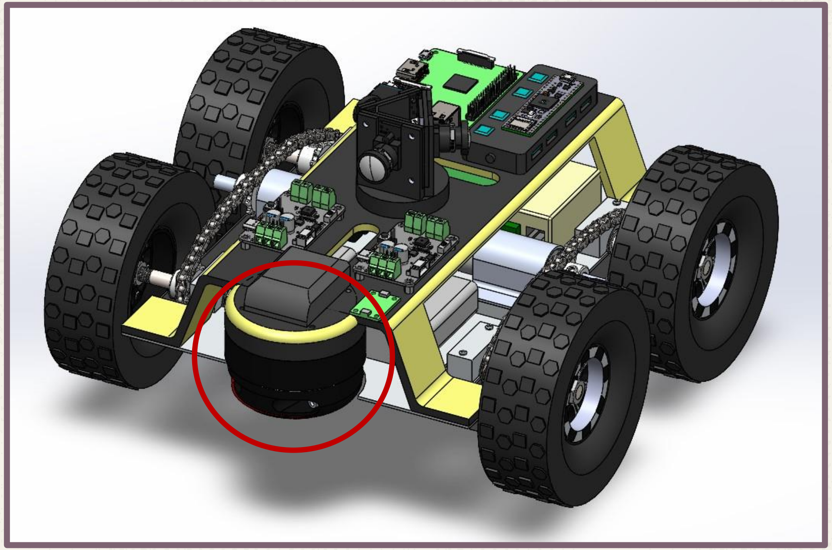


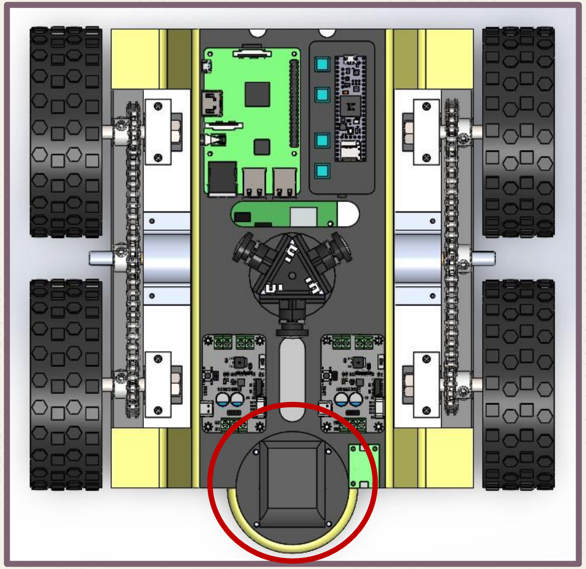


Predicted Rover Specs:

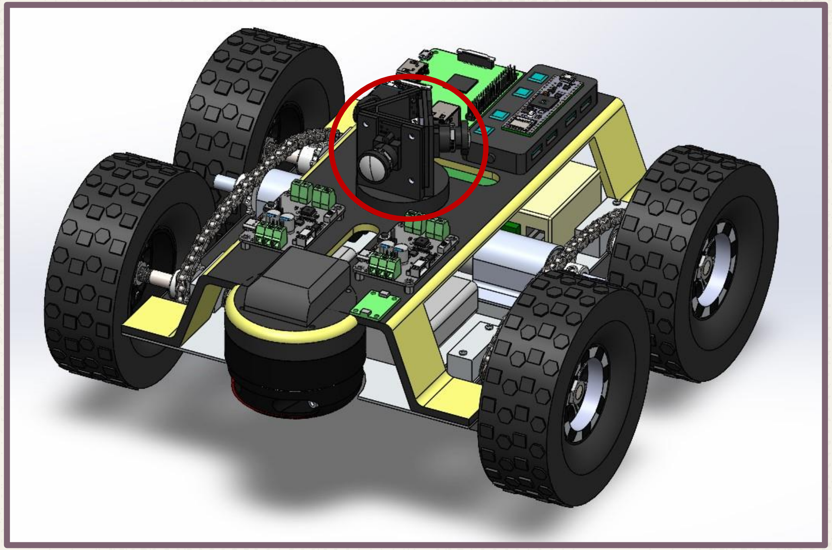
- Weight: 2.96 kg
- 30.48 x 30.48 x 16.5 cm (no antenna)

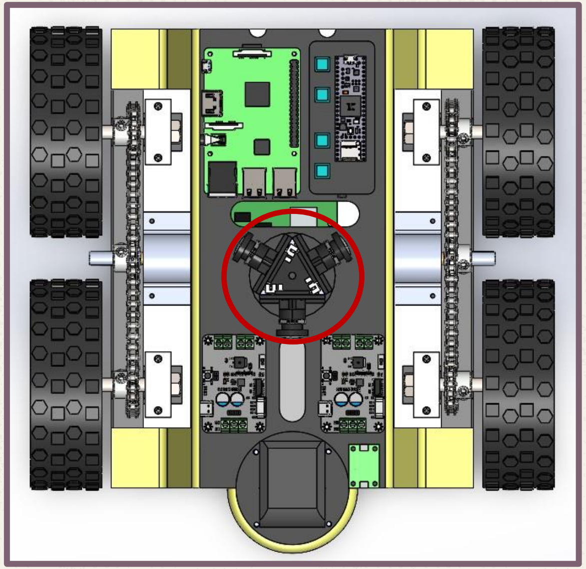
Critical Components
-LiDAR-





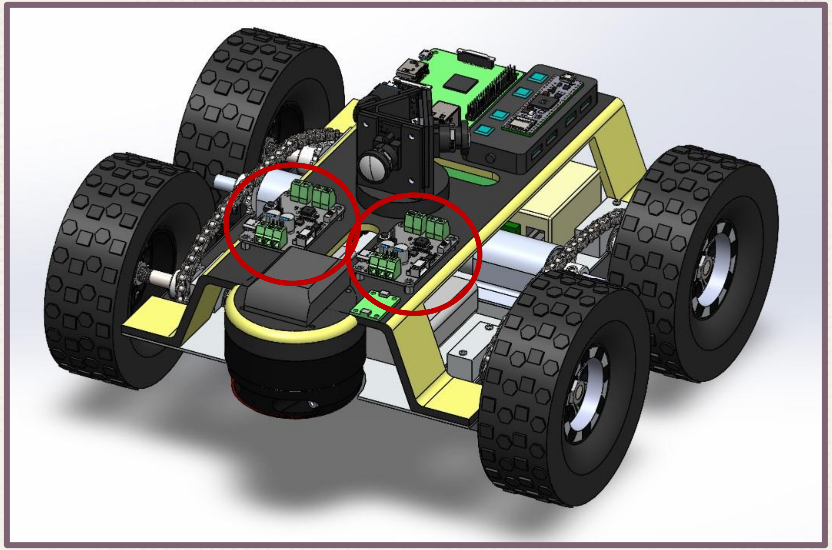
Critical Components
-Camera System-

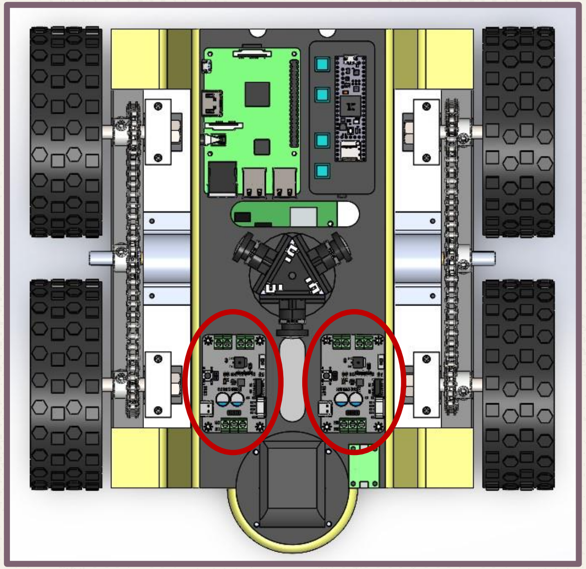




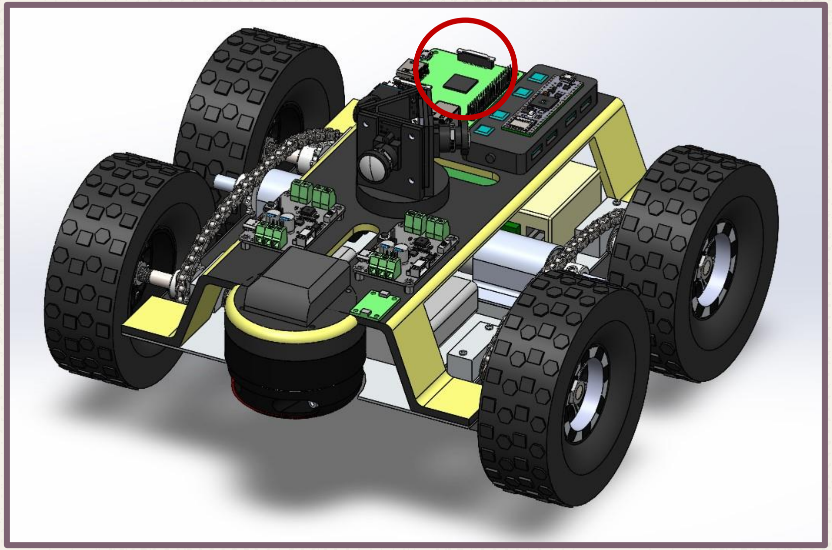
Critical Components

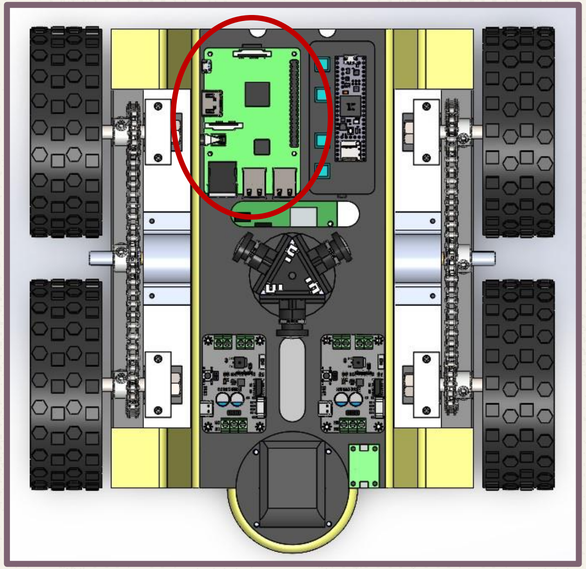
-ESC-





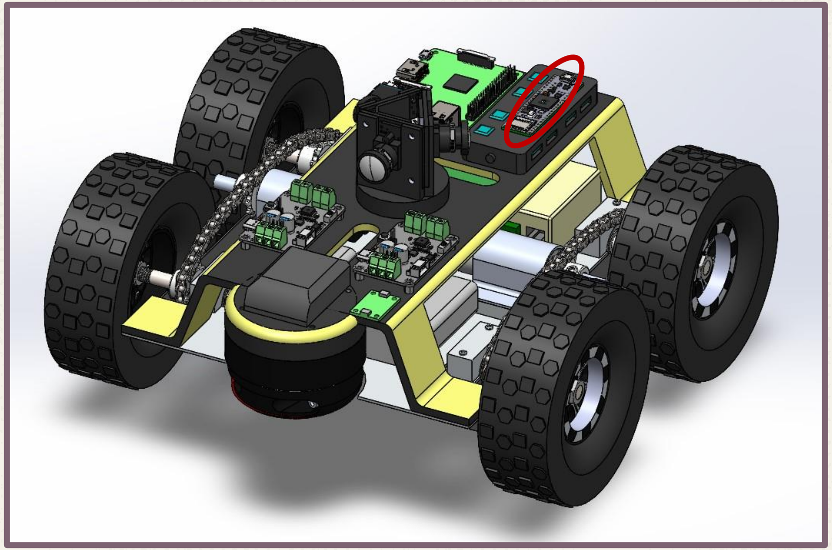
Critical Components
-Onboard Computer-

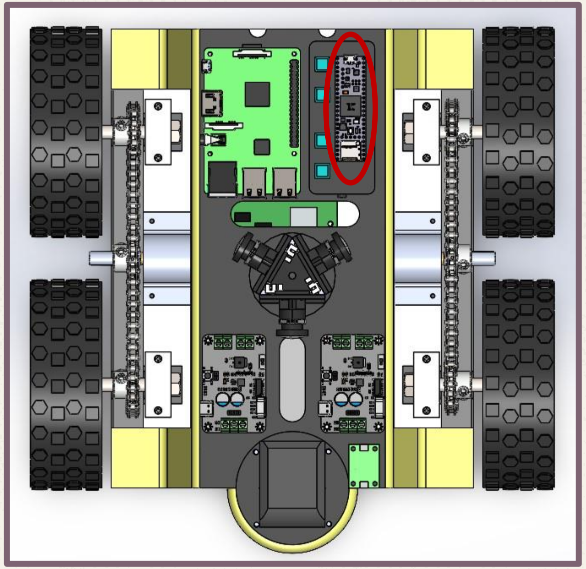




Critical Components

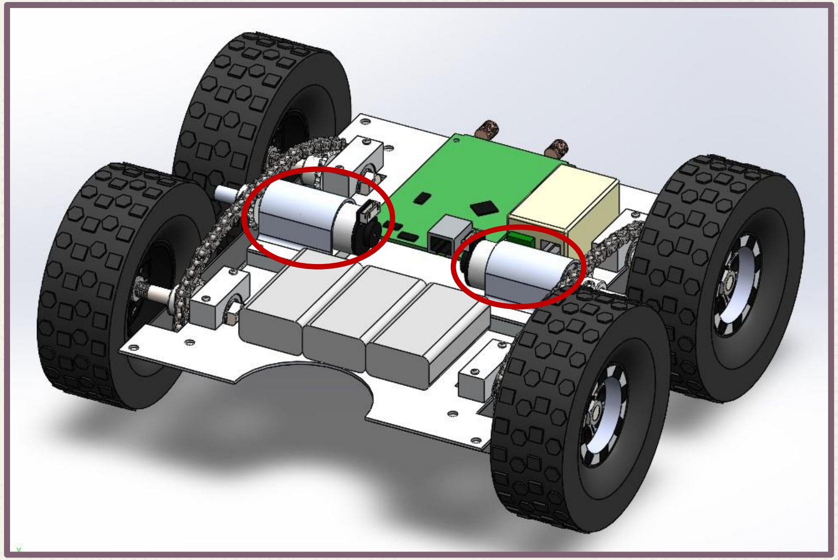
-Micro Controller-

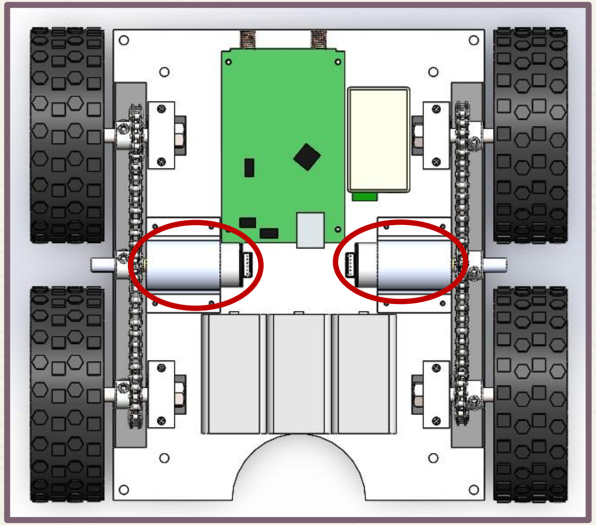




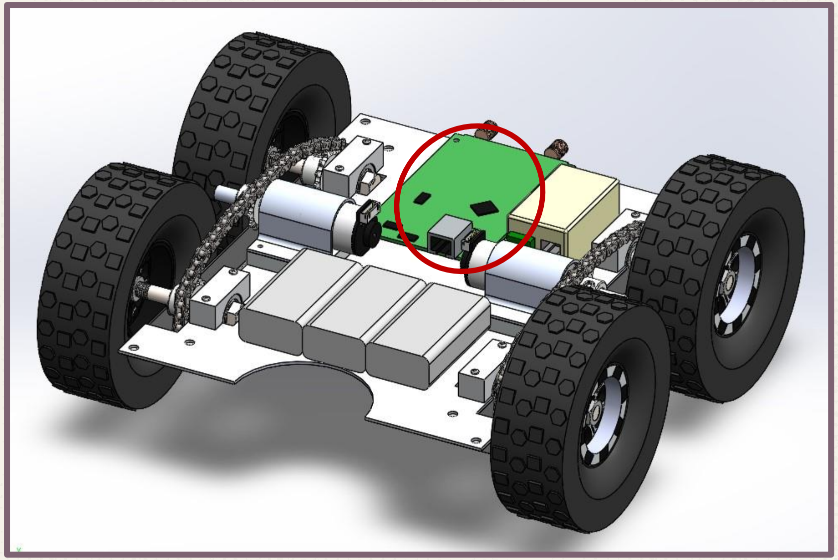
Critical Components

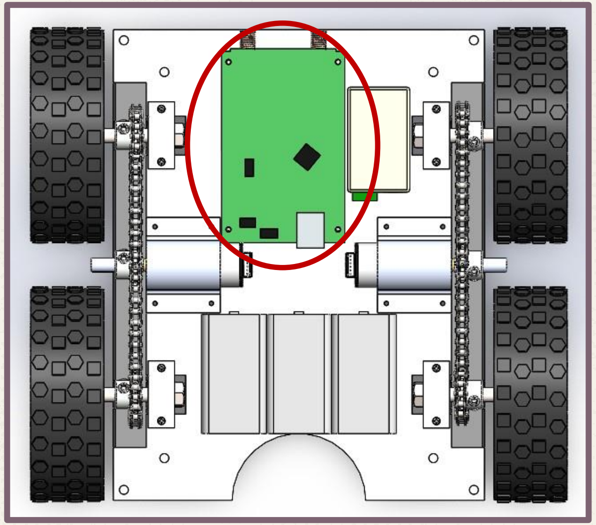
-Motors-



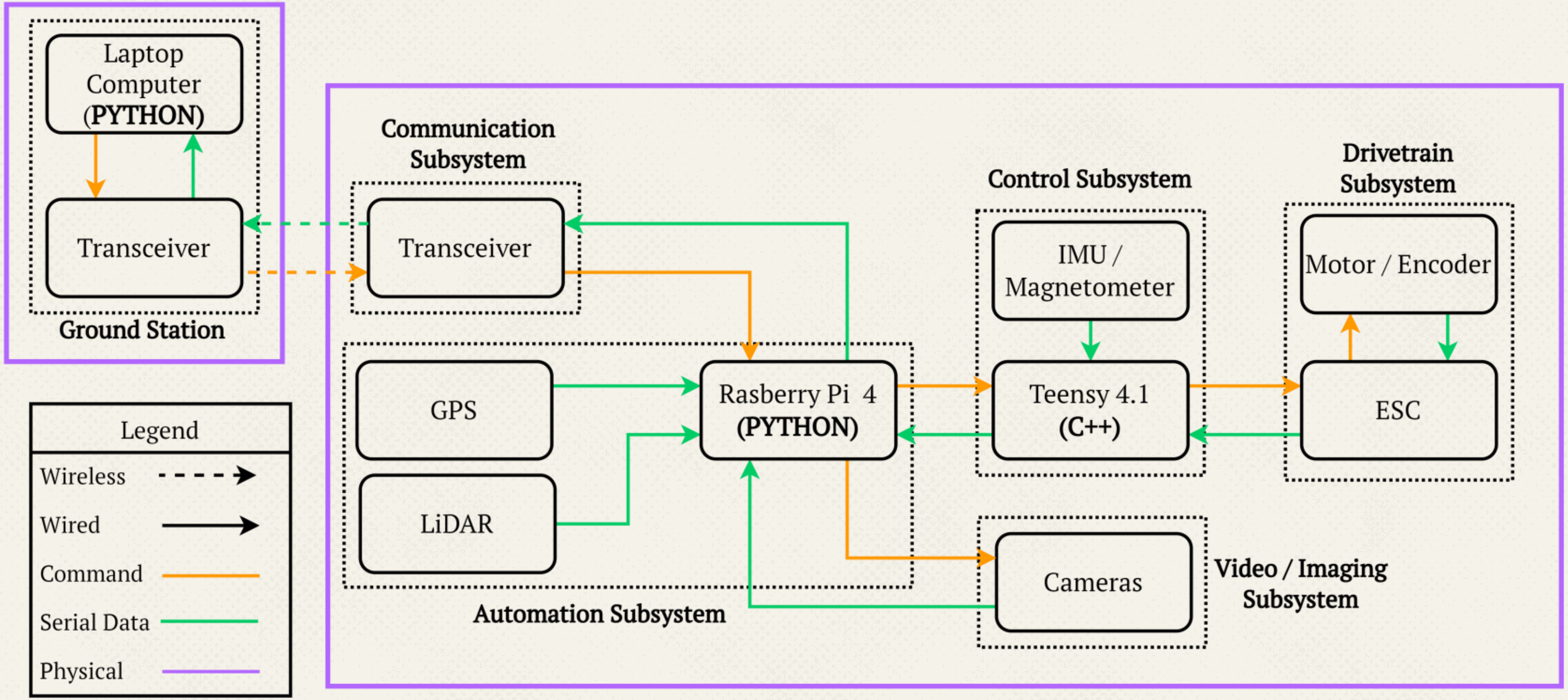


Critical Components
-Wireless Transceiver-

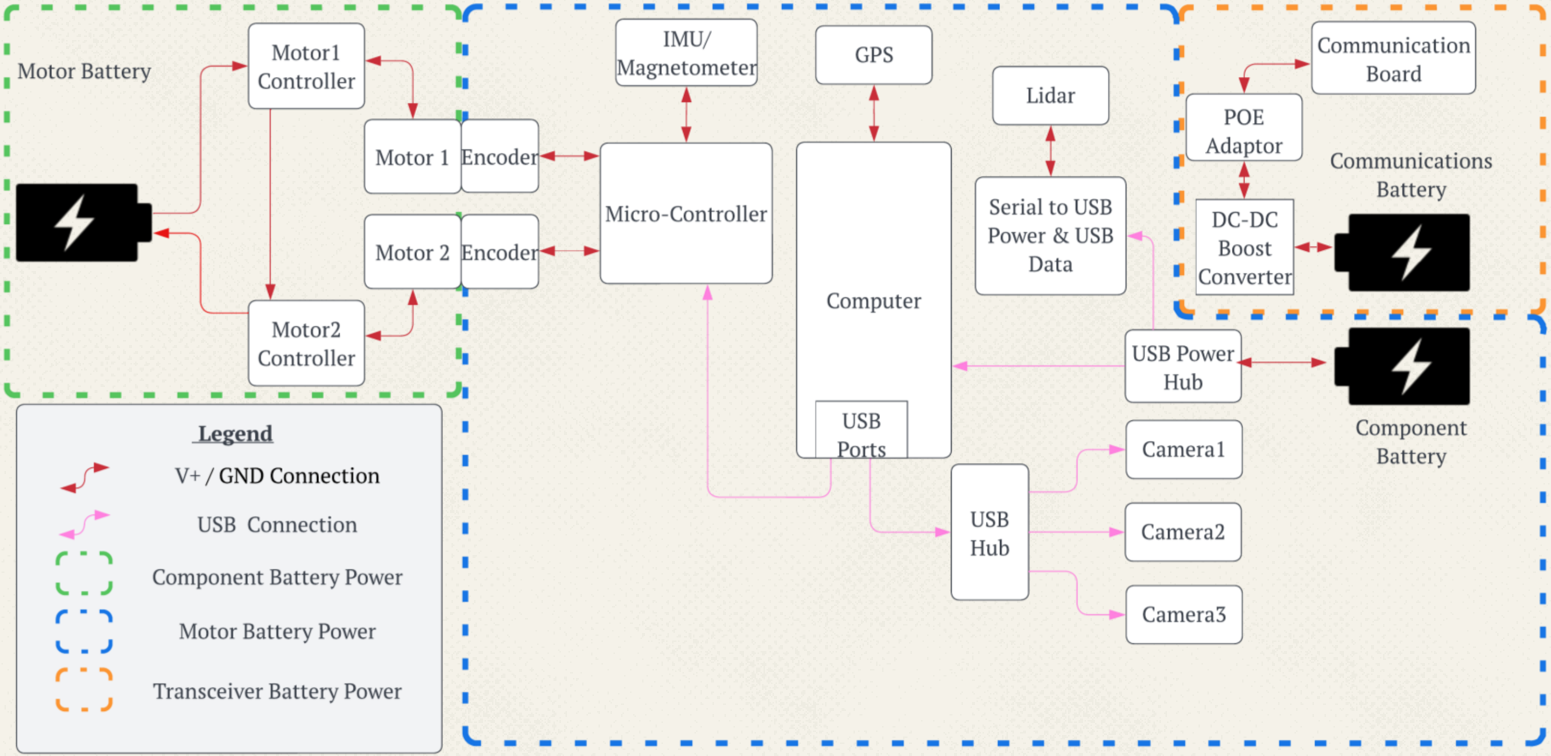




Functional Block Diagram



Power Functional Block Diagram



CPEs and Risk Analysis

Critical project elements, unmitigated risk analysis, risk mitigation strategies, mitigated risk analysis

Critical Project Elements

CPE #	Subsystem	Critical Project Element (CPE) Description	FR #
1	**Locomotion**	The rover needs a method of locomotion which allows it to successfully navigate in the typical mission environment to reach the location of interest. If the rover cannot successfully reach the location of interest, it cannot satisfy its mission.	1
2	Command and Control - Manual	A backup manual control system will be implemented as a safeguard in the event that the autonomous control of the rover fails. This element of manual control is necessary in the case of automation failure or required operator interaction.	2,7
3	**Command and Control – Autonomous**	The rover must be able to use autonomy to navigate itself to the location of interest. This involves sensing its environment, making path planning decisions to define its next motion, and then controlling that motion to make progress towards the location. The rover must also be able to use automated control to navigate back into range of communication.	2,3
4	Video and Imaging	Streaming live video to the operator is essential for manual control of the rover, when the rover is not in line of sight of the operator. The rover's mission is also to collect images of a location of interest, making imaging an essential function of the rover.	2,6
5	Ground Station	The ground station shall provide a method of communication between the operator and the rover. The ground station will allow the exchange of video, images, and manual control.	6,7
6	**Power/Endurance**	The battery must be capable of powering all systems for the duration of a typical mission.	4
7	Integration into Rover	Integration pertains to integrating all of the previous critical project elements into a single rover, and the successful interaction of the elements.	5

Risk Matrix: Unmitigated

Probability					
Very Likely	(Watch)	(Watch)	(Unacceptable)	(Unacceptable)	(Unacceptable)
Likely	(Acceptable)	(Watch)	(Watch)	(Unacceptable)	1. Rover autonomy failure (Unacceptable)
Possible	(Acceptable)	(Acceptable)	(Watch)	(Watch)	2. Rover stuck in environment (Unacceptable)
Unlikely	(Acceptable)	(Acceptable)	(Acceptable)	(Watch)	3. Insufficient rover battery (Watch)
Very Unlikely	(Acceptable)	(Acceptable)	(Acceptable)	(Acceptable)	4. Loss of communication (Watch)
	Negligible	Minor	Moderate	Significant	Severe

Impact

Risk Level:	Acceptable	Watch	Unacceptable

Risk Mitigation

Risks	Pre-Mitigation	Mitigation Strategy
1. Rover autonomy failure	• Autonomy most difficult CPE • Potential for autonomy to unsuccessfully navigate around obstacle OR unsuccessfully navigate to location of interest	• Manual override contingency
2. Rover stuck in environment	• Possibility of small sticks in typical mission environment • Chain drive exposed to sticks	• Protection for the rover to prevent sticks and other objects from entering the drivetrain
3. Insufficient rover battery	• Significant power pull from motors, wireless communication, and onboard computer	• Optimize path to reduce total distance travelled • Optimize rover speed to most efficient motor speed
4. Loss of communication	• Max distance of 100 meters • Potential signal interference through obstacles	• Navigate back into communication contingency • Design choices have large factor of safety considering our obstacles and environment

Risk Matrix: Mitigated

Probability					
Very Likely					
Likely			1.		1.
Possible					2.
Unlikely					2. 3.
Very Unlikely			4.		4. 3.
	Negligible	Minor	Moderate	Significant	Severe

Impact

Risk Level:	Acceptable	Watch	Unacceptable

Risk Matrix: Mitigated

Probability					
Very Likely					
Likely			1. Rover autonomy failure		
Possible					
Unlikely					2. Rover stuck in environment
Very Unlikely			4. Loss of communication		3. Insufficient rover battery
	Negligible	Minor	Moderate	Significant	Severe

Impact

Risk Level:	Acceptable	Watch	Unacceptable

Modeling

Relating to CPEs #1,3,6

Mechanical/Controls Design Solutions

CPE #1: Locomotion

Design Requirements: Mechanical

Verification Method: D = Demonstration, I = Inspection, A = Analysis, T = Test

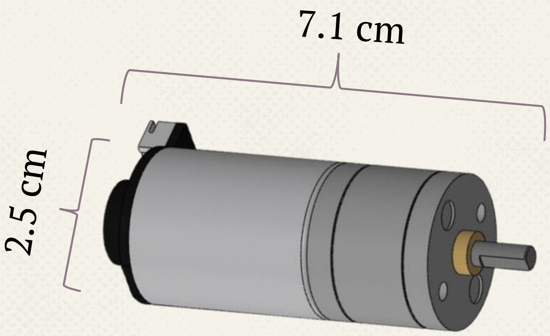
FR. 1: The rover shall move forwards, backwards and turn in any direction.

Requirement	Verification
1.9.1: Rover shall be able to move within 100 m radius from ground station.	D
1.9.2: Rover shall be able to move forward	D
1.9.3: Rover shall be able to move backward	D
1.9.4: Rover shall be able to turn 360 degrees	D

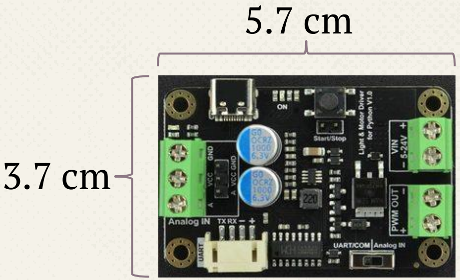
FR. 5: Rover shall have a footprint no larger than 1’ x 1’

Requirement	Verification
1.1.1: Rover structure shall physically contain all subsystems (excluding ground station) on the rover	I

Motor & ESC Selection



DF Robot DC Geared Motor

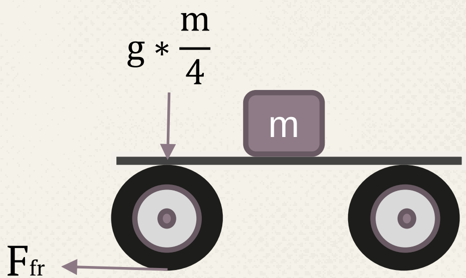


DF Robot Motor Controller

- **Purpose:**
  - To manipulate power to the drivetrain, propelling the rover
- **Procurement or Production:**
  - Purchase 2x motors and 2x ESC (one for each motor)
- **Specifications**
  - **Motor:** 6 V input, max 210 rpm, max 0.98 Nm torque, 3.1 W draw
  - **ESC:** 5-24 V max, 10 A max, analog input pins

Drivetrain Satisfaction:
Torque Requirements

System Free Body Diagram:



Governing Equations:

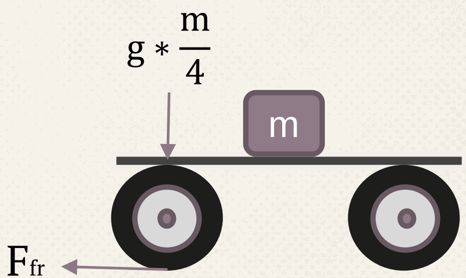
$$\tau = r \times F_{fr} \qquad F_{fr} = \mu * g * \frac{m}{4}$$

- **Assumptions:**
  - Weight is evenly distributed throughout the system
  - All internal resistances are negligible
- Estimated required torque per wheel = **0.21 N•m**
- Available torque from each motor = **0.98 N•m**

**Equation nomenclature is located in corresponding subsystem backups*

Drivetrain Satisfaction:
Torque Requirements

System Free Body Diagram:



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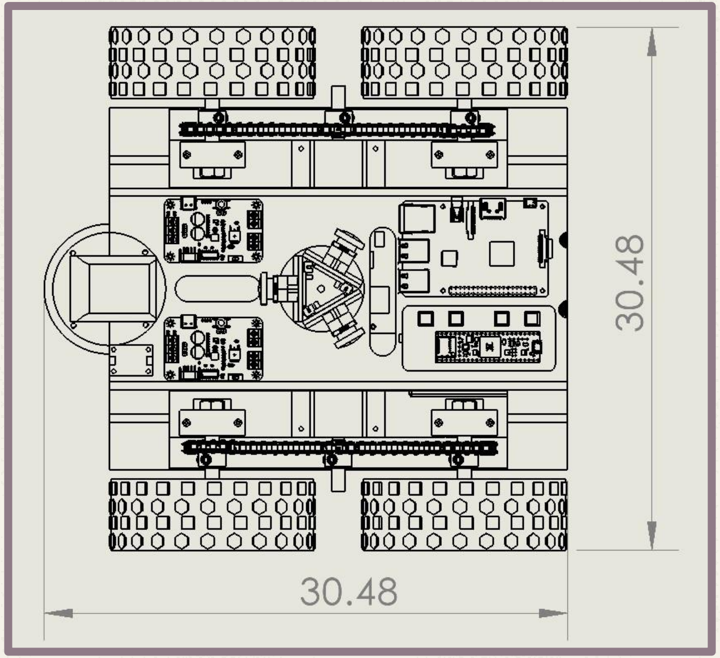
Satisfies FR. 1: "The rover shall move forwards, backwards and turn in any direction" and all subsequent design requirements

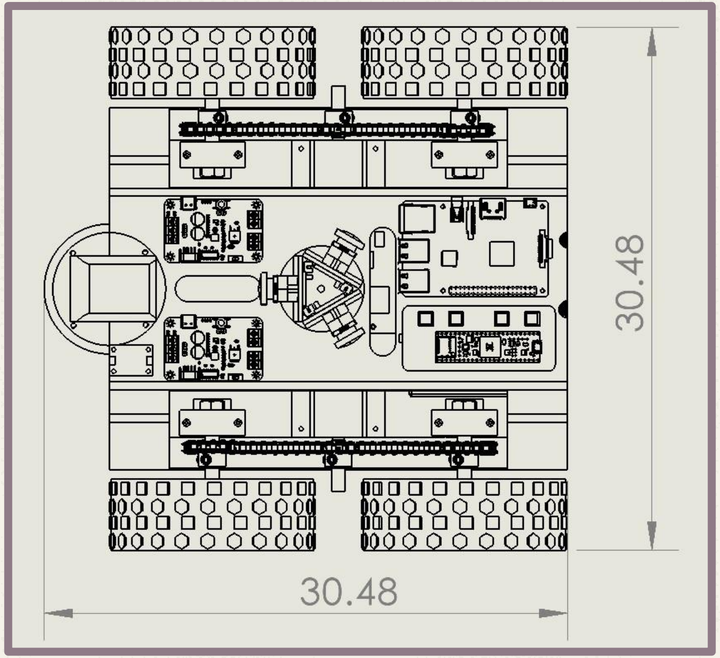
Drivetrain Satisfaction:
Dimension Requirements



**All units in cm*

- **Size:**
  - Rover maximum dimensions: 30.48 cm x 30.48 cm
- **Drivetrain Orientation:**
  - Two independent motors (left and right side)
  - Independent motor control
    - Allows for turning in place

Drivetrain Satisfaction:
Dimension Requirements



*All units in cm

Satisfies FR. 5: "Rover shall have a footprint no larger than 1' x 1'" and all subsequent design requirements

- **Size:**
  - Rover maximum dimensions: 30.48 cm x 30.48 cm
- **Drivetrain Orientation:**
  - Two independent motors (left and right side)
  - Independent motor control
    - Allows for turning in place

Satisfies FR. 1: "The rover shall move forwards, backwards and turn in any direction" and all subsequent design requirements

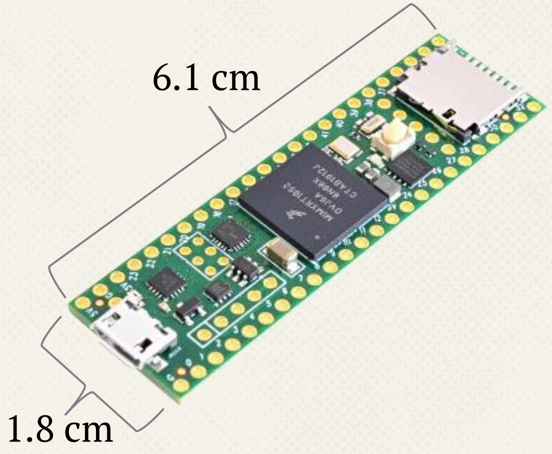
Design Requirements: Controls

Verification Method: D = Demonstration, I = Inspection, A = Analysis, T = Test

FR. 1: The rover shall move forwards, backwards and turn in any direction

Requirement	Verification
1.5.1: Rover control subsystem shall receive commands from automation subsystem	D
1.5.2: Rover control subsystem shall receive manual control commands from the ground station	D
1.5.3: Rover control subsystem shall control the rover motors	I
1.5.4: Rover control system shall override autonomous commands with manual control commands when manual control commands are received.	D,T

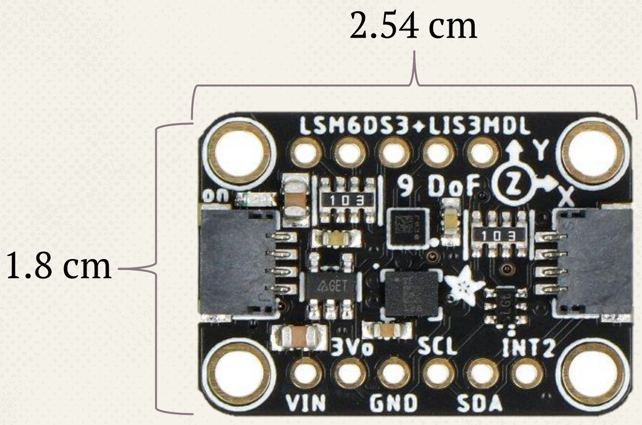
Micro-controller Selection



Teensy 4.1 Micro-controller

- **Purpose:**
  - To control the voltages supplied to motors to produce desired rover motion
- **Procurement or Production:**
  - Purchase a Teensy 4.1 Development Board
- **System Specifications:**
  - 18 analog input pins
  - 35 PWM output pins
    - Compatible with ESC
  - C-based programming

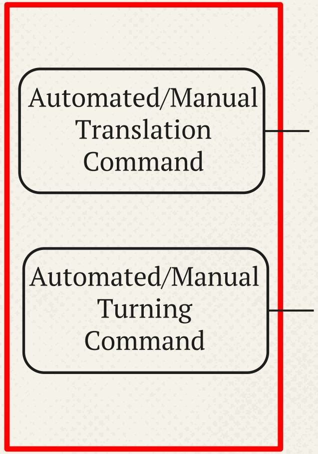
IMU/Magnetometer Selection



Adafruit LSM6DS3TR IMU and LIS3MDL Magnetometer

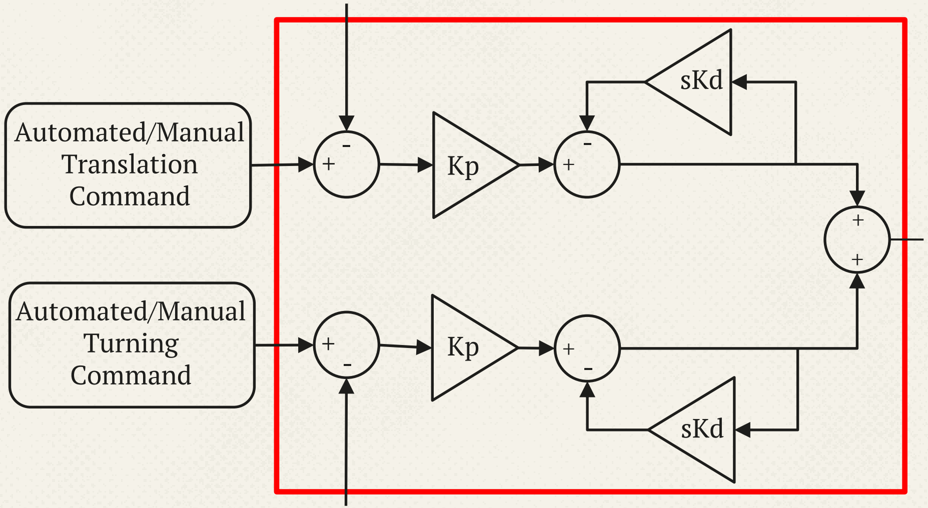
- **Purpose:**
  - To provide translation and rotation position, velocity, and acceleration data for use in feedback control
- **Procurement or Production:**
  - Purchase an Adafruit LSM6DS3TR and LIS3MDL breakout.
- **System Specifications:**
  - 6 DoF accelerometer/3 axis magnetometer on a single board
  - Up to 1.6 kHz sampling rate
  - Teensy 4.1 compatible

Controls Flow Chart



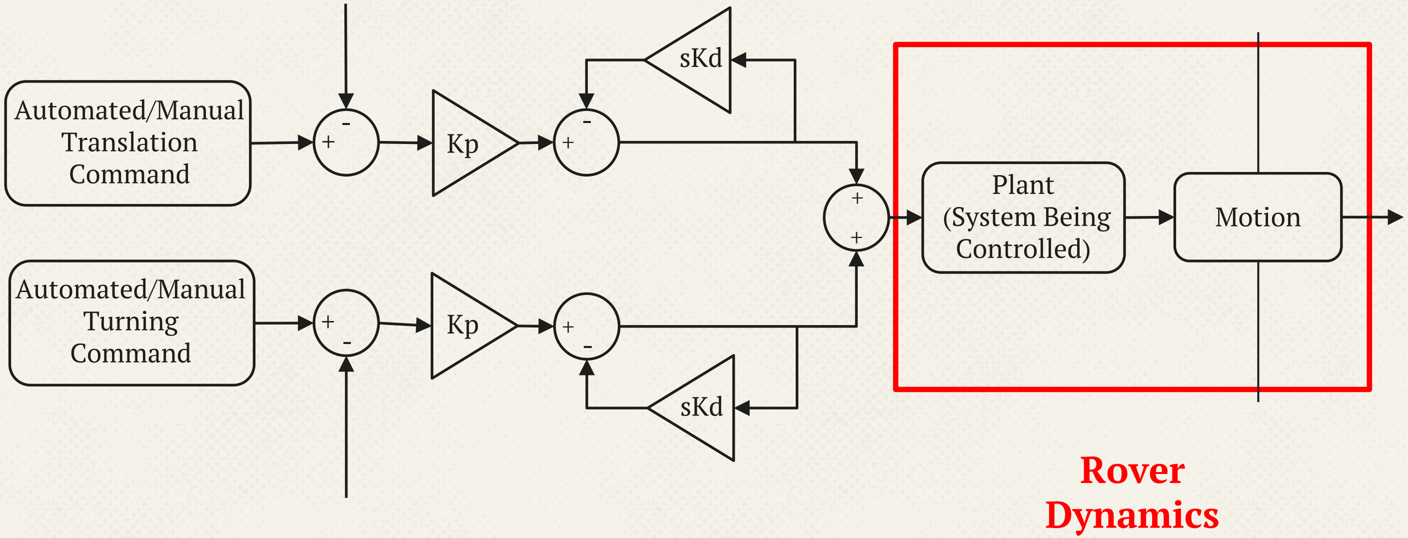
Commands from SBC

Controls Flow Chart



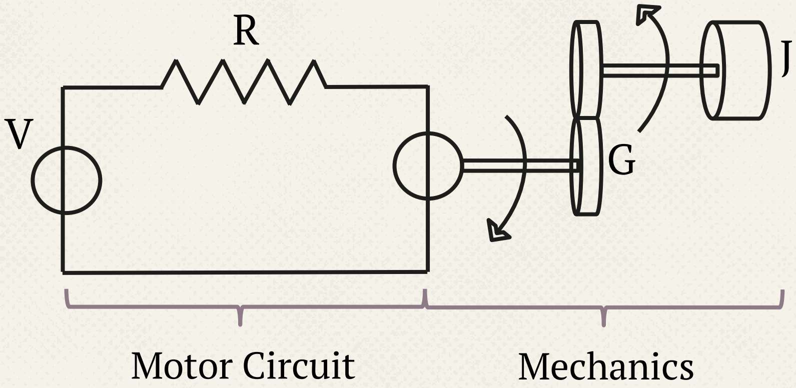
Control Elements

Controls Flow Chart



Controls Satisfaction:
Rover Dynamics

System Schematic:



Simplifying Assumptions:

- Drivetrain components impose negligible friction (bearings, chain links, etc.)
- Motors are ideal and identical
- Wheels can be approximated as hoops

**Equation nomenclature is located in corresponding subsystem backups*

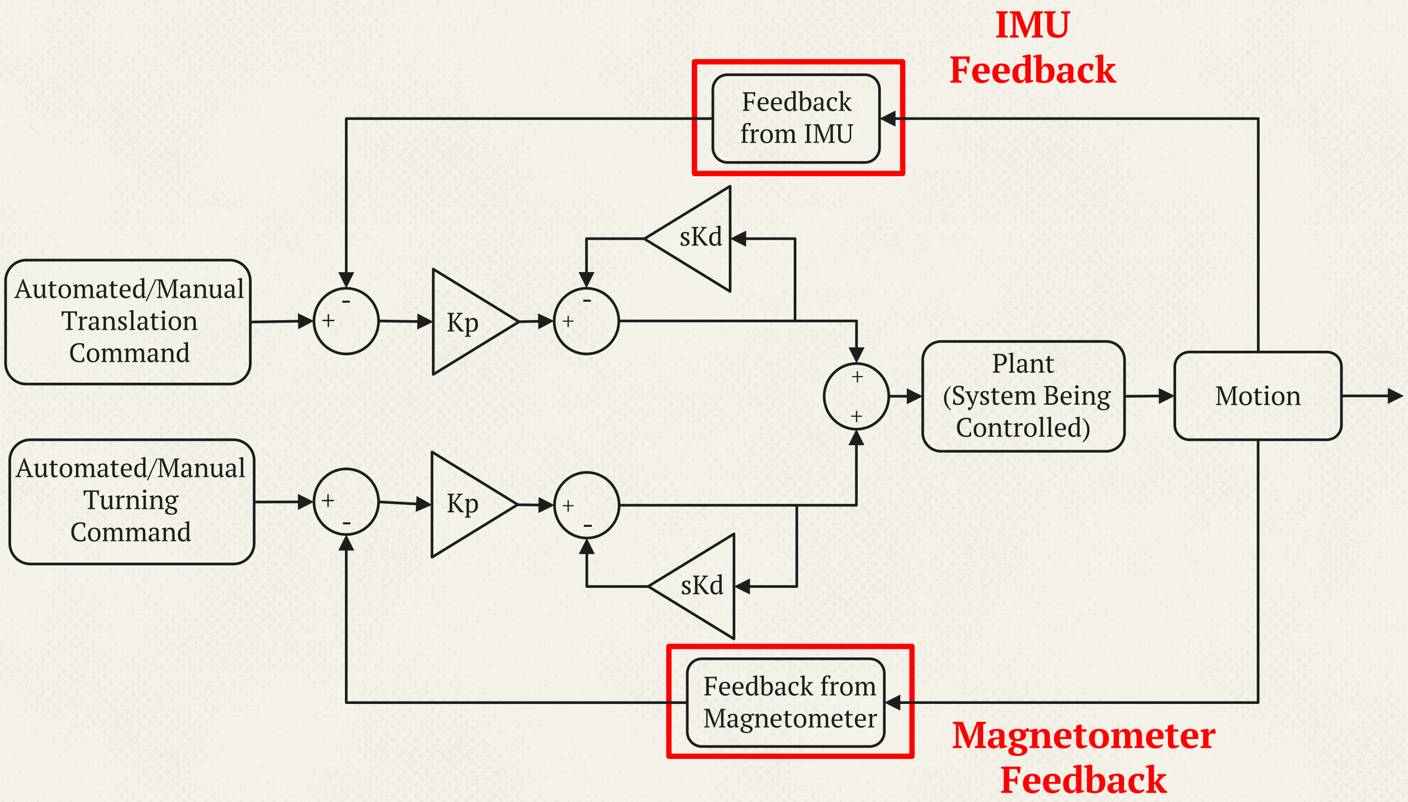
Governing Equations:

$$\dot{\omega} = \frac{GK_t}{RJ}V - \frac{G^2K_t}{K_vRJ}\omega$$

$$\bar{V} = \frac{(\omega_{fL} + \omega_{fR})r_f}{2}$$

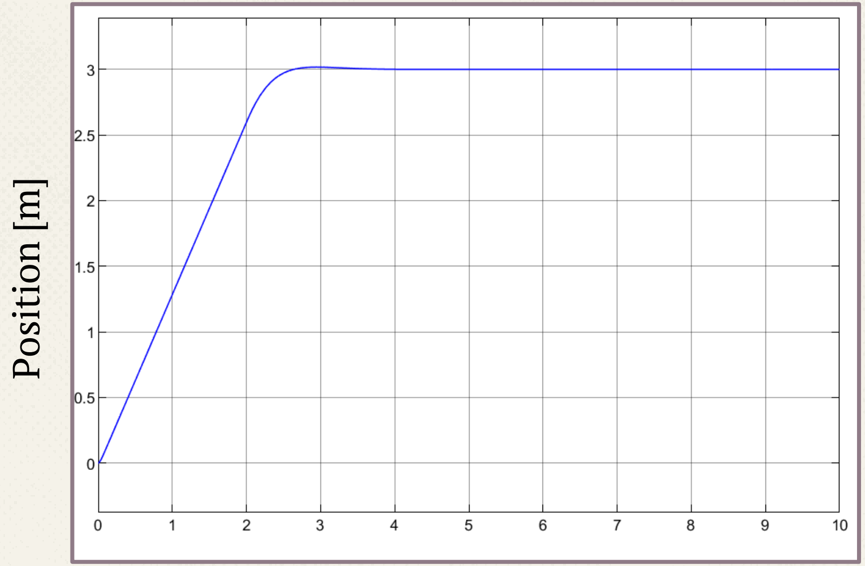
$$\omega_t = \frac{\omega_{fL} * r_f}{r_d} + \frac{\omega_{fR} * r_f}{r_d}$$

Controls Flow Chart



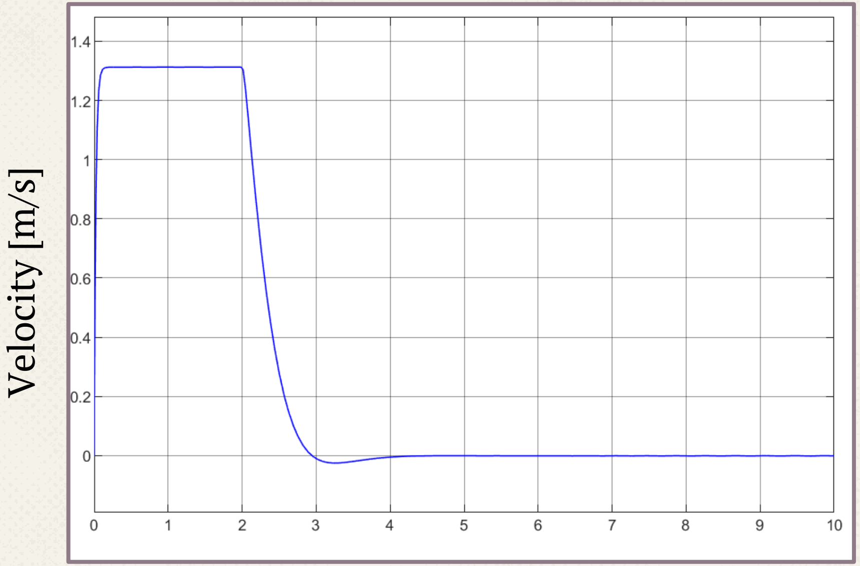
Controls Satisfaction:
Simulink Model

Position vs Time



Time [s]

Velocity vs Time

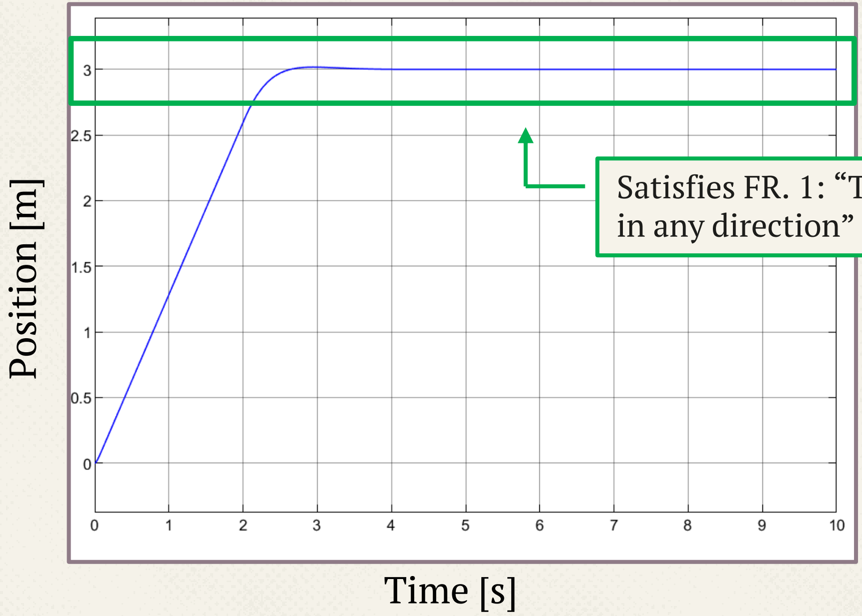


Time [s]

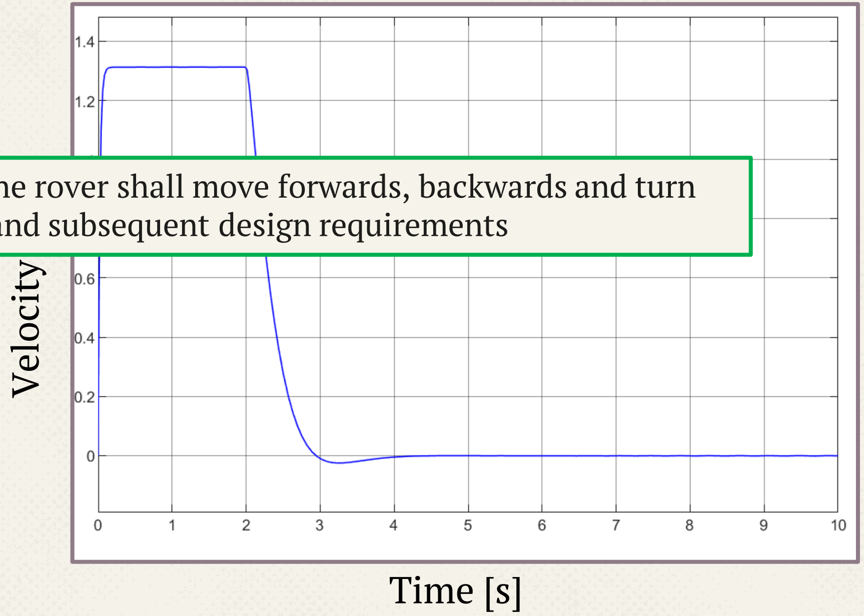
Command: Move forward 3 meters

Controls Satisfaction:
Simulink Model

Position vs Time



Velocity vs Time

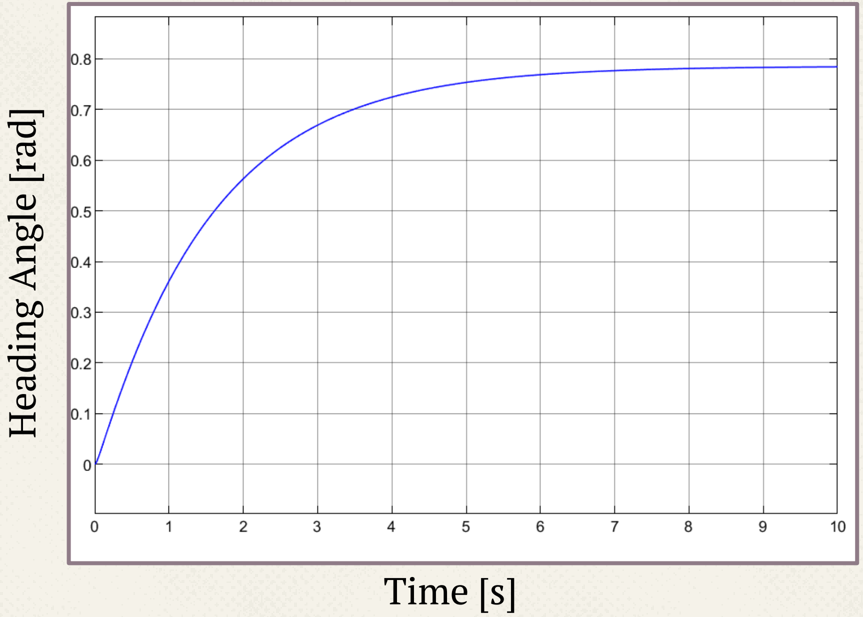


Satisfies FR. 1: “The rover shall move forwards, backwards and turn in any direction” and subsequent design requirements

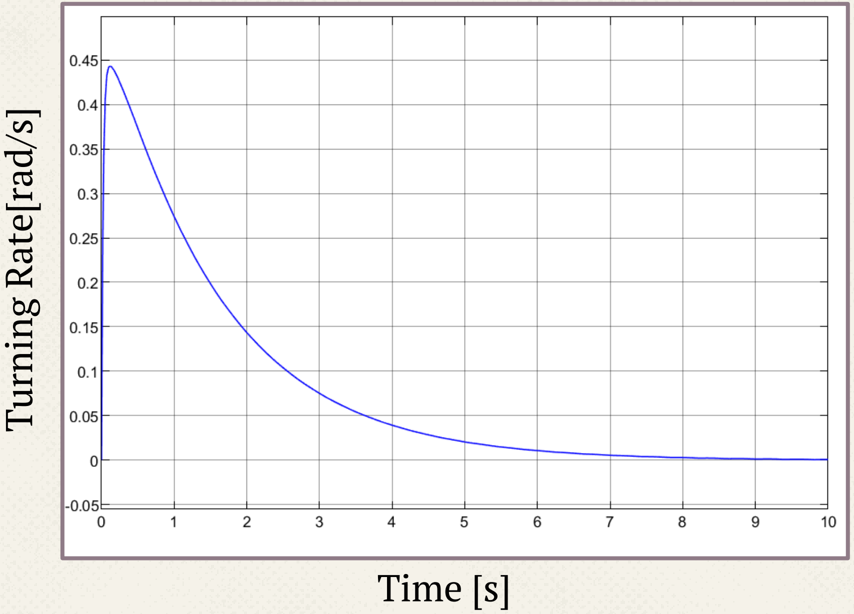
Command: Move forward 3 meters ✓

Controls Satisfaction:
Simulink Model

Heading Angle vs Time



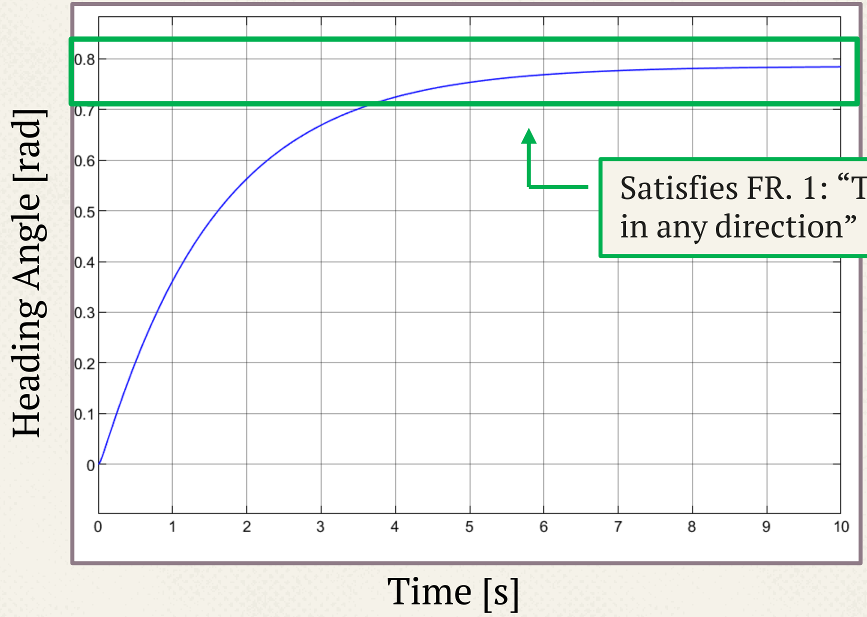
Turning Rate vs Time



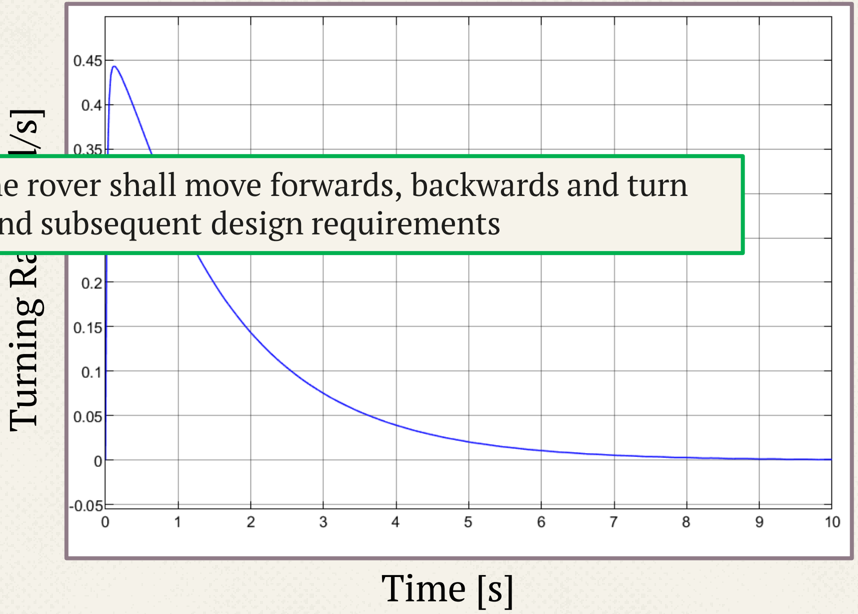
Command: Turn 45 degrees (.78 rad)

Controls Satisfaction:
Simulink Model

Heading Angle vs Time



Turning Rate vs Time



Satisfies FR. 1: “The rover shall move forwards, backwards and turn in any direction” and subsequent design requirements

Command: Turn 45 degrees (.78 rad) ✓

Locomotion Verification:
Test Plan

FR. 1: The rover shall move forwards, backwards and turn in any direction.
FR. 5: Rover shall have a footprint no larger than 1’ x 1’

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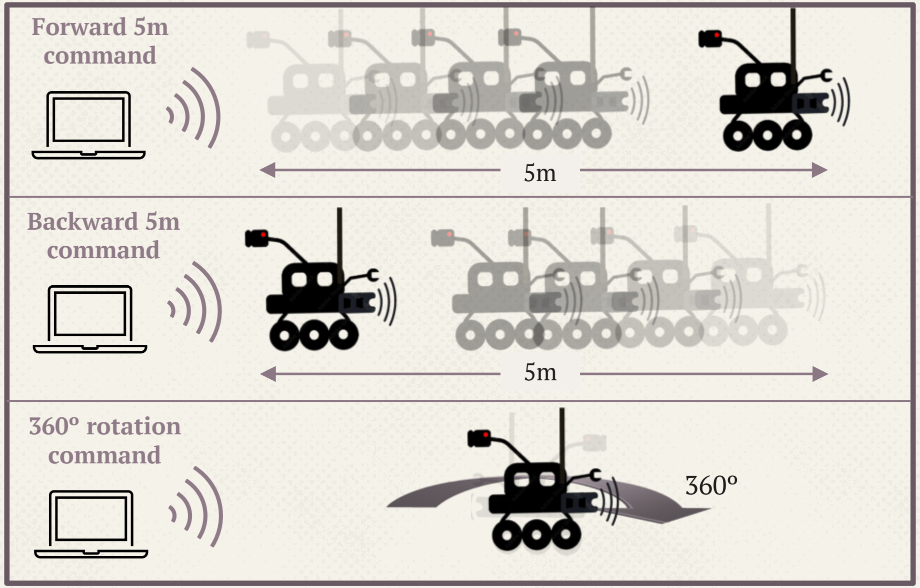


- **Objective:**
  - Verify integration of drivetrain and controller is successful in translating rover forward and backward as well as turning 360º
- **Test Plan:**
  - Command drivetrain to move forward 5m
  - Command drivetrain to move backward 5m
  - Command drivetrain to turn in place 360º
- **Data Collected:**
  - Rover distance traveled
  - Rover degrees of rotation
- **Pass Criteria:**
  - Rover travels 5m forward/backward after receiving the respective command
  - Rover rotates in place complete 360º after receiving the command

Electrical Design Solutions

CPE #6: Power/Endurance

Design Requirements:
Electrical

Verification Method: D = Demonstration, I = Inspection, A = Analysis, T = Test

FR. 2: The electrical subsystem shall be able to monitor and sustain the rover / ground station for the duration of the mission

Requirement	Verification
1.10.1: The electrical subsystem shall provide sufficient power for the autonomy subsystem specifications	A,D
1.10.2: The electrical subsystem shall provide sufficient power for the communication subsystem specifications	A,D
1.10.3: The electrical subsystem shall provide sufficient power for the control subsystem specifications	A,D
1.10.4: The electrical subsystem shall provide sufficient power for the mechanical subsystem specifications	A,D
1.10.5: The electrical subsystem shall provide sufficient power for the video/imaging subsystem specifications	A,D

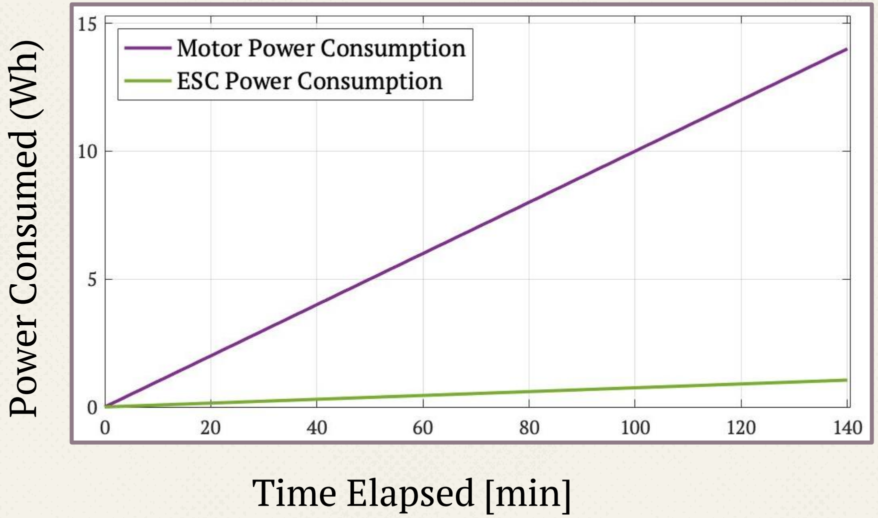
Battery Selection

LI-2S1P-2200 Battery

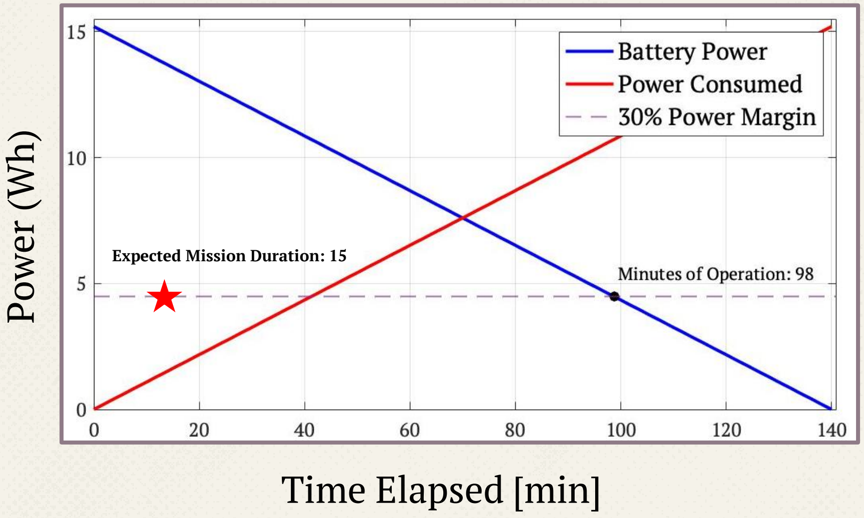
- **Purpose:**
  - Provide power for all on-board rover subsystems
- **Procurement or Production:**
  - Purchasing 3X LI-2S1P-2200 battery
- **System Specifications:**
  - Minimum voltage on discharge: 6.0V
  - Minimum power: 12.9Wh
  - Maximum discharge: 3A
  - Continuous discharge: 2.4A

Battery Satisfaction:
Drivetrain Subsystem

Component Power Consumption vs. Time



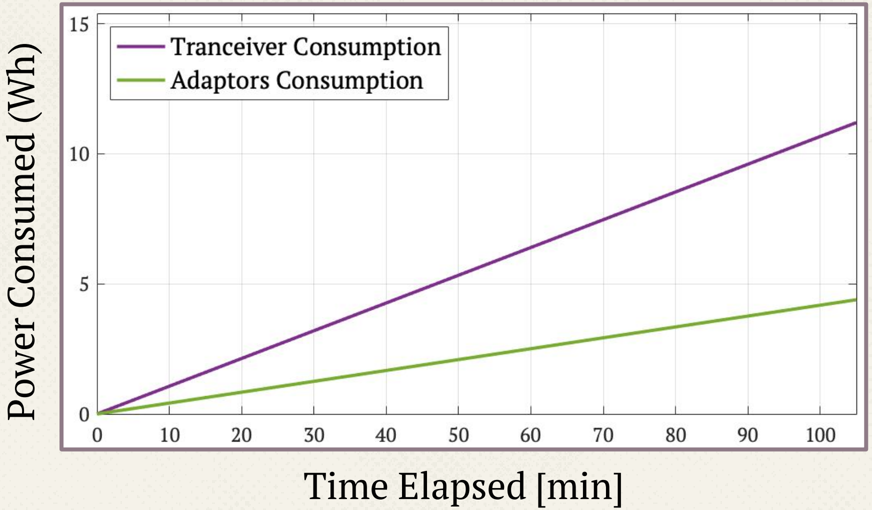
Motor Battery Power & Consumption vs. Time



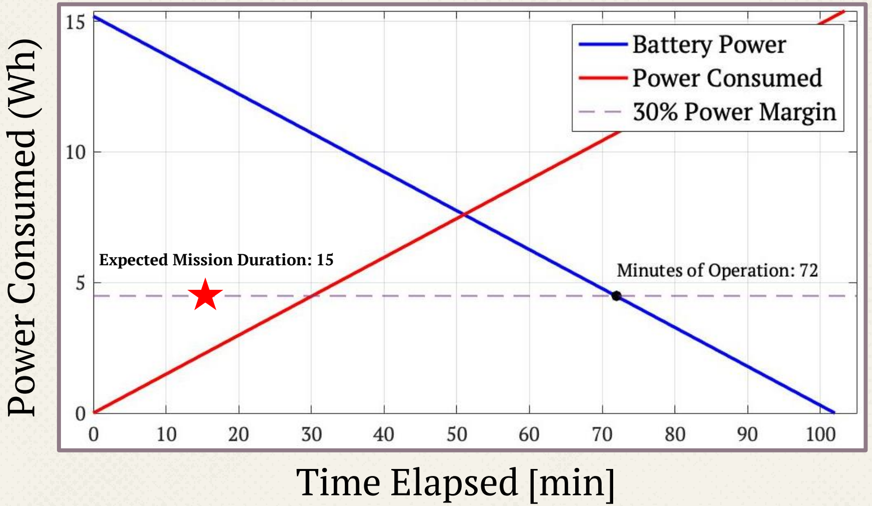
- Max battery discharge rate: 3A
- Max current demand: 1.7A
- Sustainable battery discharge rate: 2.4A
- Average current demand: 1.15A

Battery Satisfaction: Communication Subsystem

Communication Battery Power Consumption vs. Time



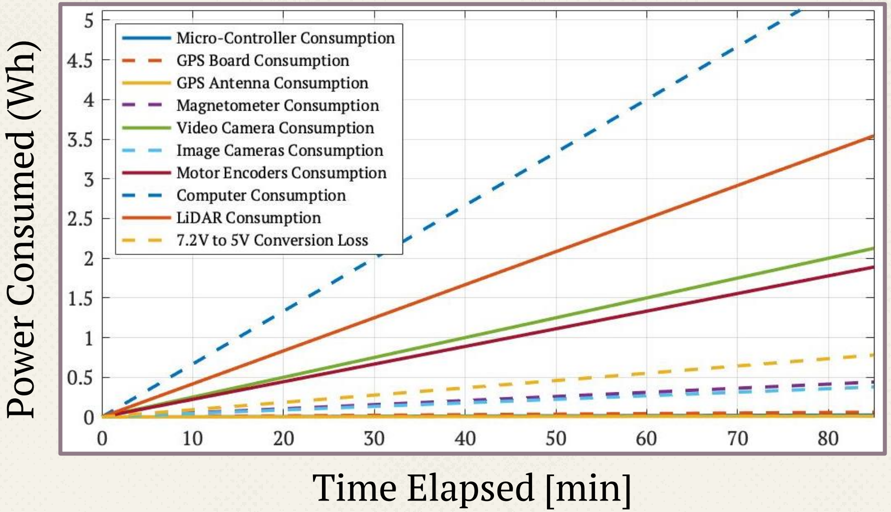
Communication Battery Power & Consumption vs. Time



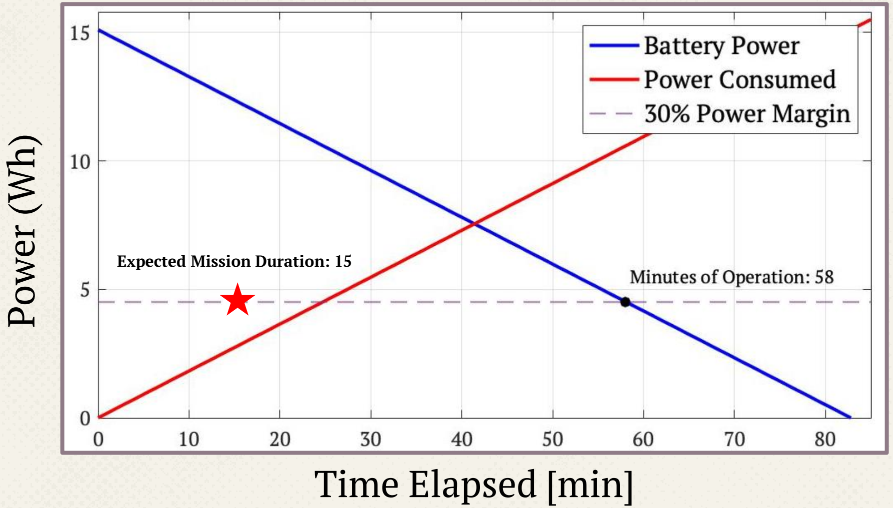
- Max battery discharge rate: 3A
- Max current demand: 1.63A
- Sustainable battery discharge rate: 2.4A
- Average current demand: 1.25A

Battery Satisfaction:
All Other Components

Component Battery Power Consumption vs. Time



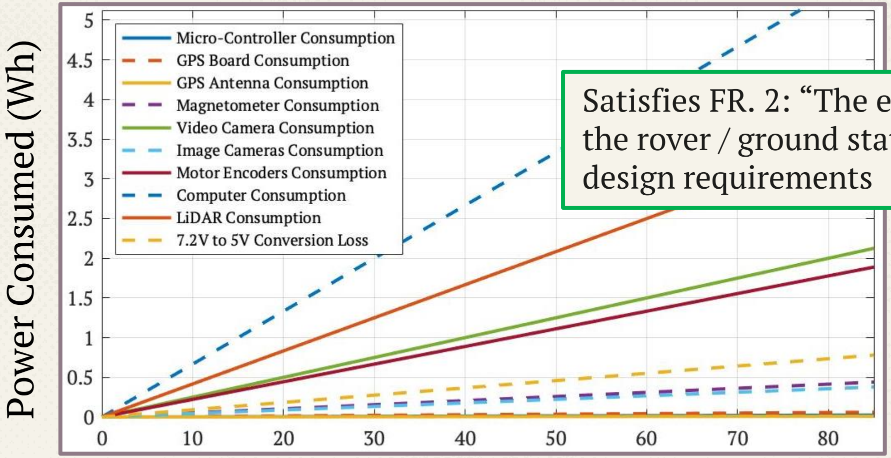
Component Battery Power & Consumption vs. Time



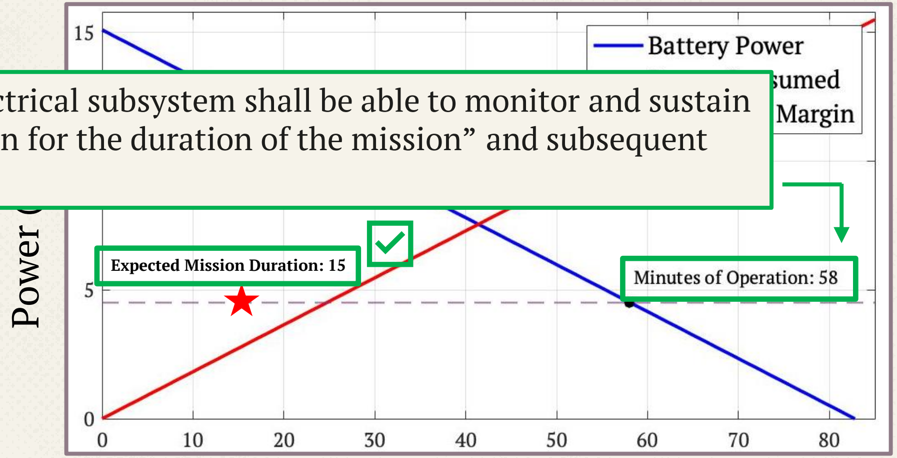
- Max battery discharge rate: 3A
- Max current demand: 2.07A
- Sustainable battery discharge rate: 2.4A
- Average current demand: 1.61A

Battery Satisfaction: All Other Components

Component Battery Power Consumption vs. Time



Component Battery Power & Consumption vs. Time



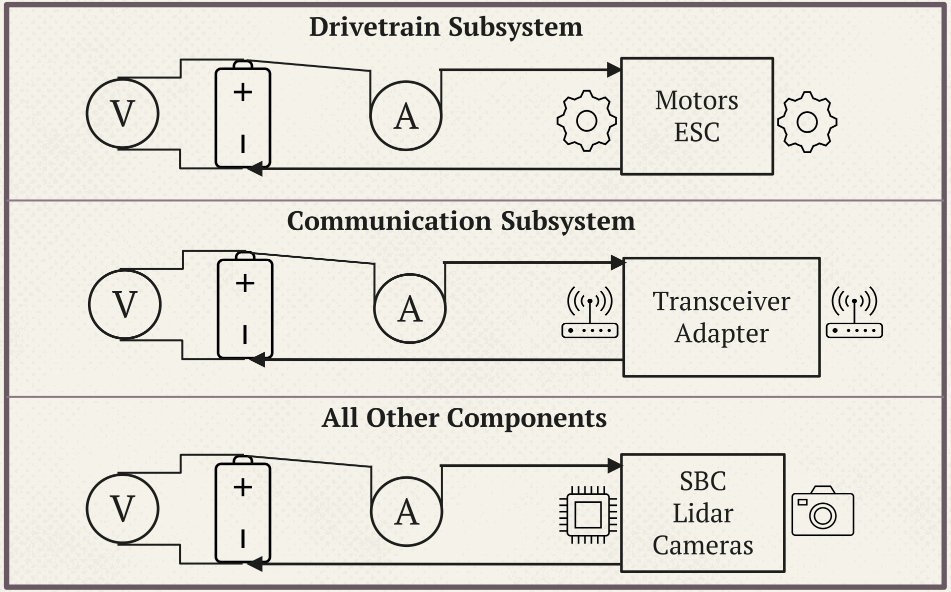
Satisfies FR. 2: "The electrical subsystem shall be able to monitor and sustain the rover / ground station for the duration of the mission" and subsequent design requirements

- Max battery discharge rate: 3A
- Max current demand: 2.07A
- Sustainable battery discharge rate: 2.4A
- Average current demand: 1.61A

Power Verification:
Test Plan

FR. 2: The electrical subsystem shall be able to monitor and sustain the rover / ground station for the duration of the mission

Ann and H.J. Smead Aerospace Engineering Sciences Pilot Lab



Objective:
- Verify batteries will sustain all onboard components for mission duration

Test Plan:
- Run each battery with respective components
- All components will be under full loading conditions for test duration (ex: motors have friction)

Data Collected:
- Battery capacity and voltage over time
- Component functionality during test

Pass Criteria:
- All components maintain functionality for 1.5x factor of safety of expected mission duration (15 minutes)
- 30% power margin is maintained for 15-minute expected mission duration

Autonomous Design Solutions

CPE #3: Command and Control – Autonomous

Design Requirements:
Autonomy

Verification Method: D = Demonstration, I = Inspection, A = Analysis, T = Test

FR. 3: The rover shall utilize remote sensing subsystems to determine a path to a location of interest

Requirement	Verification
1.6.1: The autonomy subsystem shall determine a path to location of interest	D
1.6.2: The autonomy subsystem shall receive data from the remote sensing subsystem	T
1.6.3: The autonomy subsystem shall send commands to the control subsystem	D,T
1.6.4: The autonomy subsystem shall determine a path to the back to the ground station after taking a panoramic image at the location of interest	D
1.6.5: The autonomy subsystem shall determine when the rover has reached the location of interest	T

Microprocessor Selection

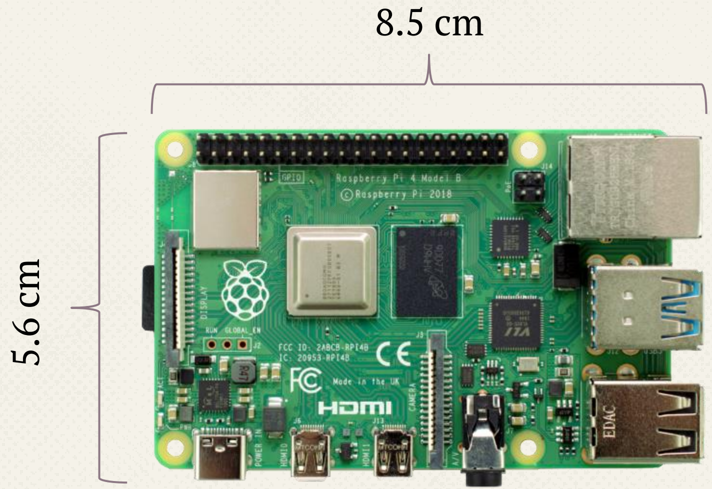
8.5 cm

5.6 cm

Raspberry Pi 4 Model B

- **Purpose:**
  - Serve as the primary processor for the onboard automation and communication subsystems
- **Procurement or Production:**
  - Purchase Raspberry Pi 4 Model B
- **System Specifications:**
  - 2x USB 2.0, 2x USB 3.0
  - Ethernet
  - 4 GB Ram

Microprocessor Selection

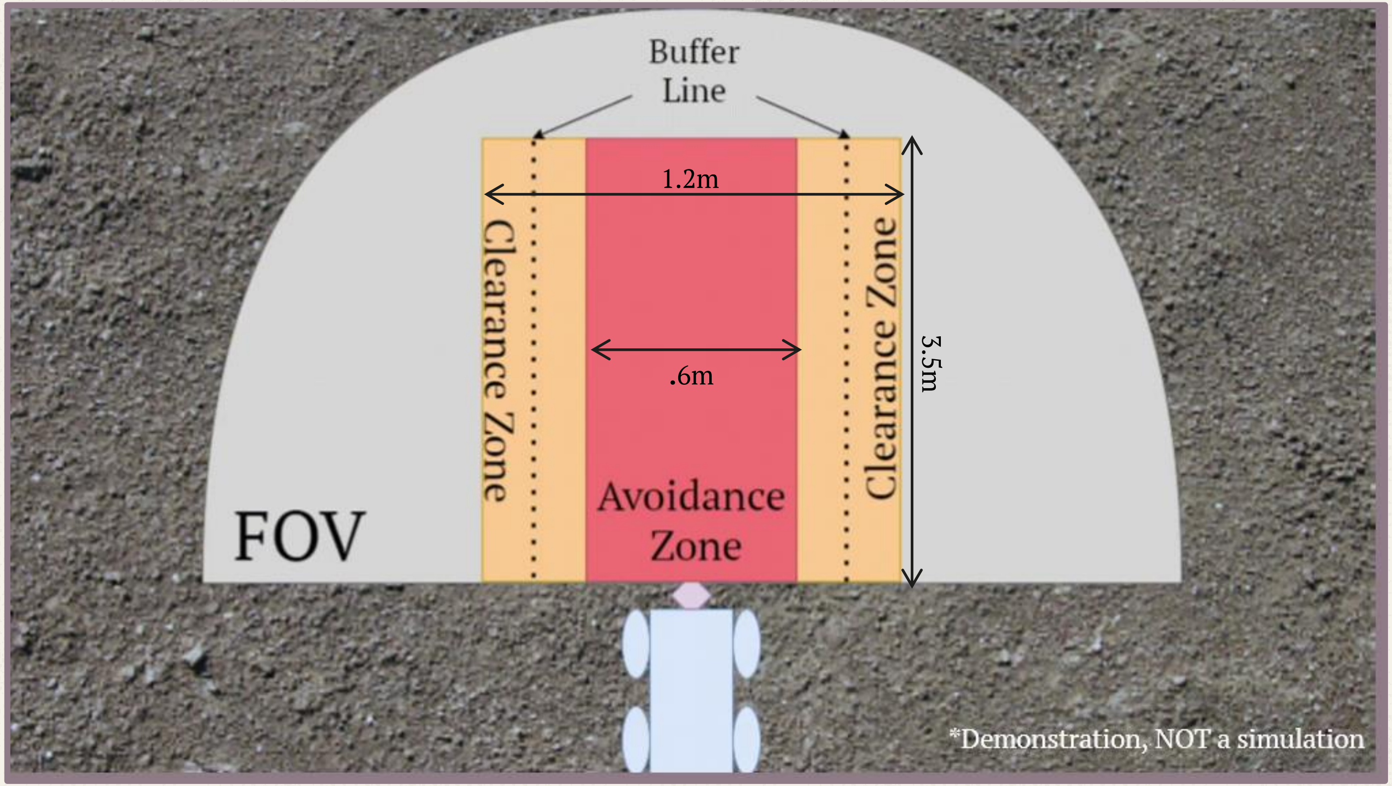


Raspberry Pi 4 Model B

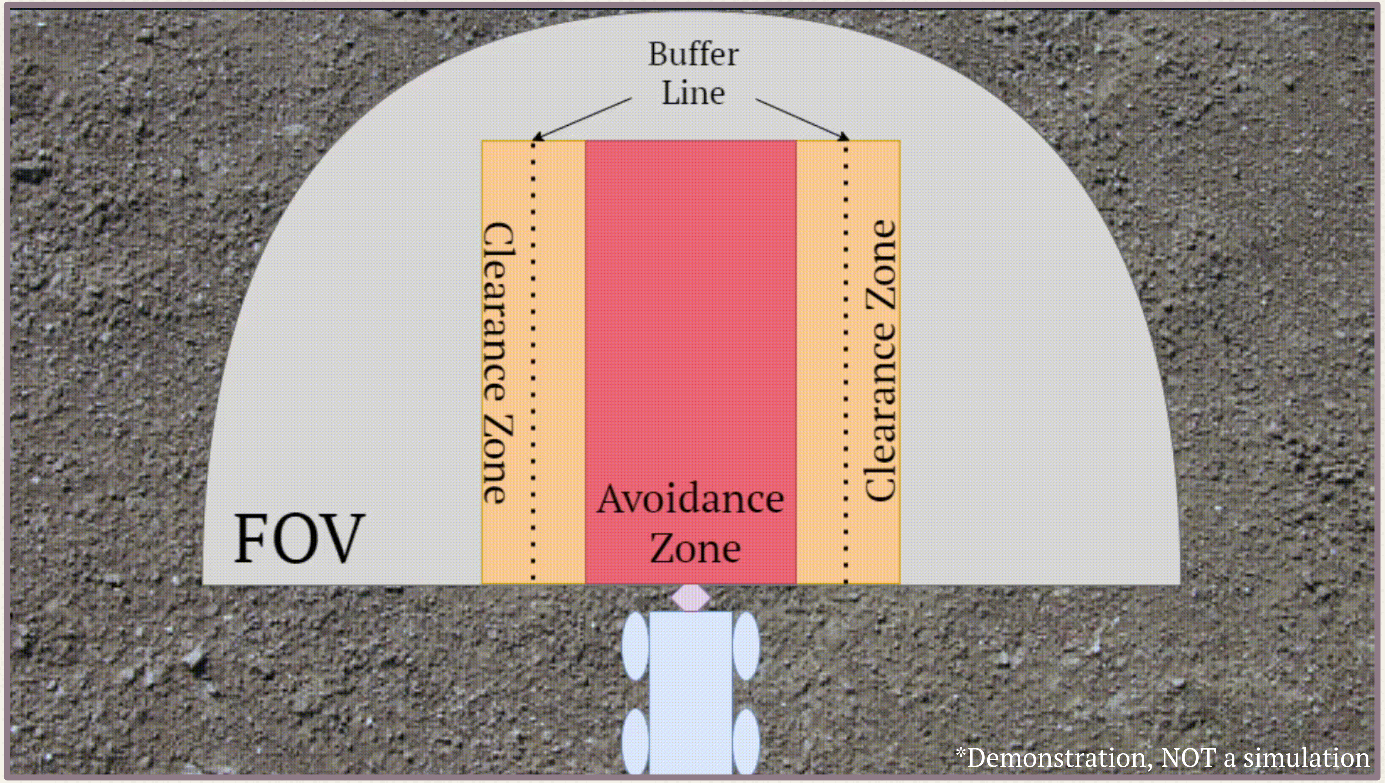
- **Purpose:**
  - Serve as the primary processor for the onboard automation and communication subsystems
- **Procurement or Production:**
  - Purchase Raspberry Pi 4 Model B
- **System Specifications:**
  - 2x USB 2.0, 2x USB 3.0
  - Ethernet
  - 4 GB Ram

Satisfies "FR. 3: The rover shall utilize remote sensing subsystems to determine a path to a location of interest" and all subsequent design requirements

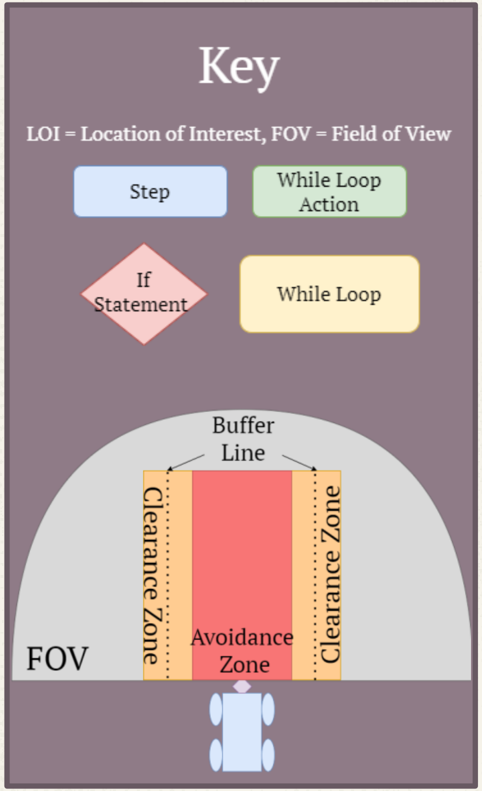
Autonomy Animation

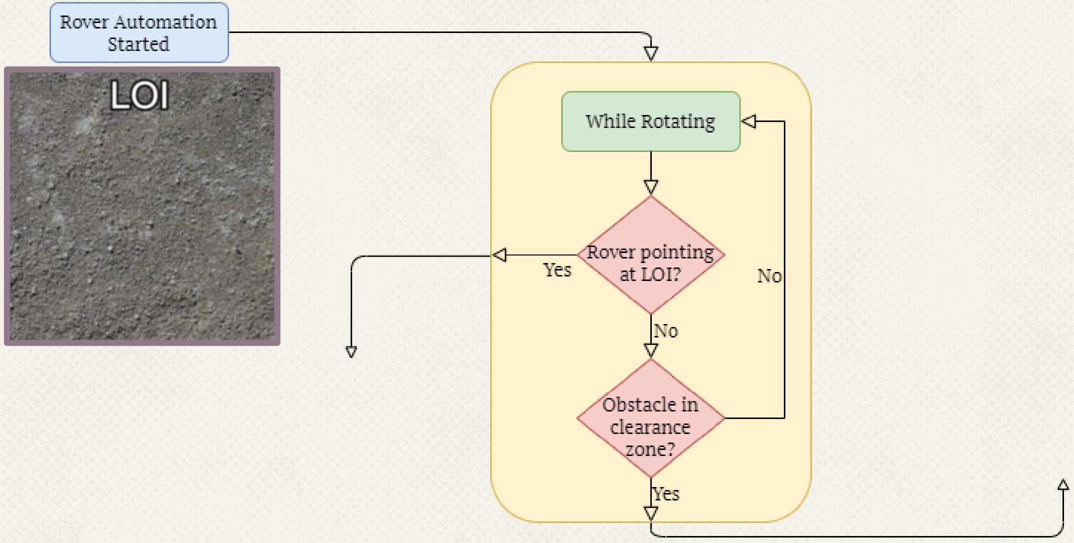


Autonomy Animation



Autonomy Algorithm Flow Chart





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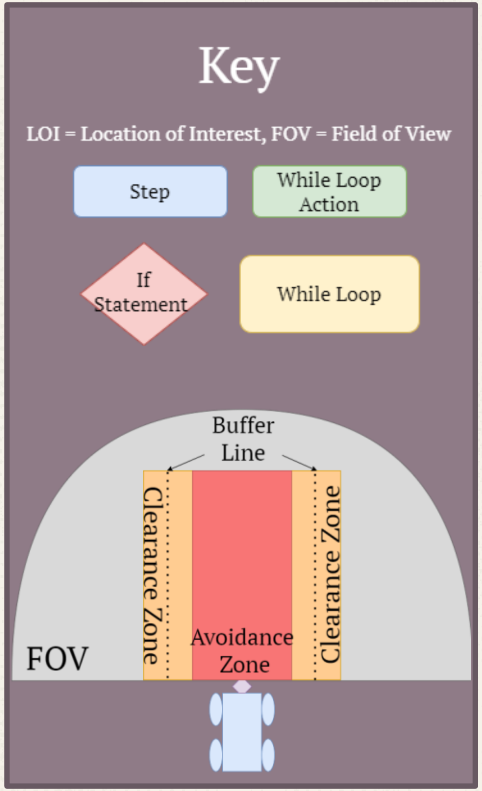

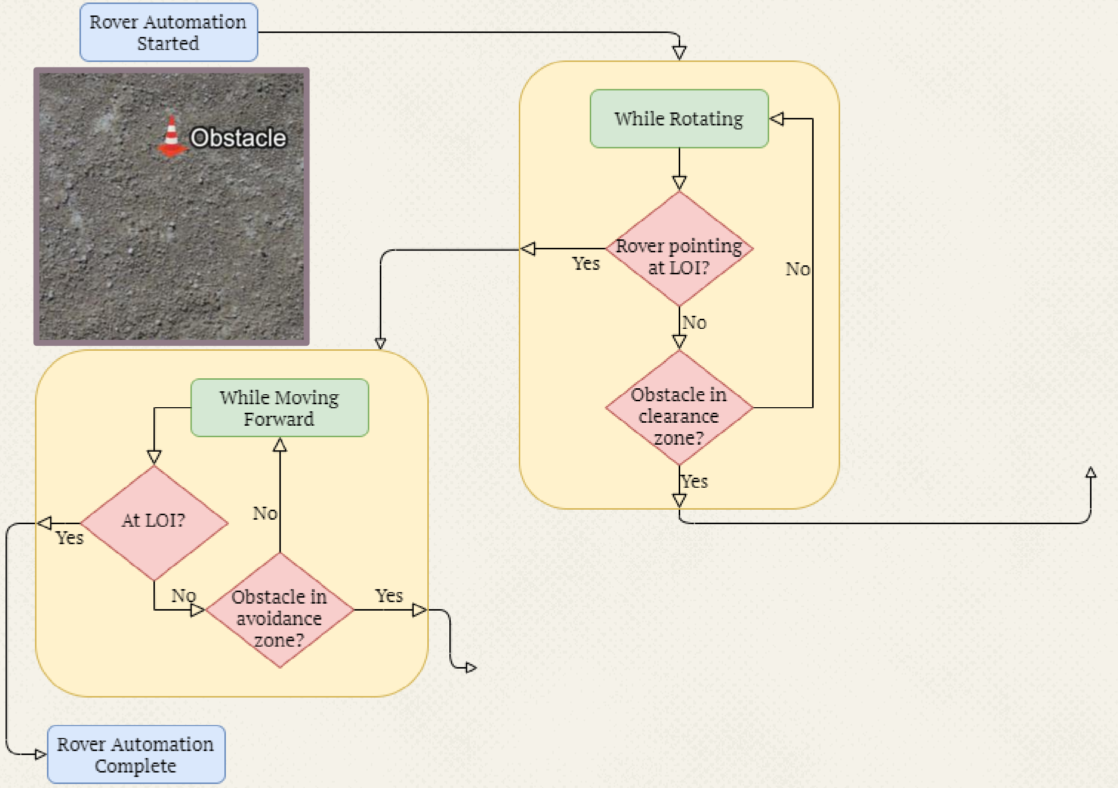

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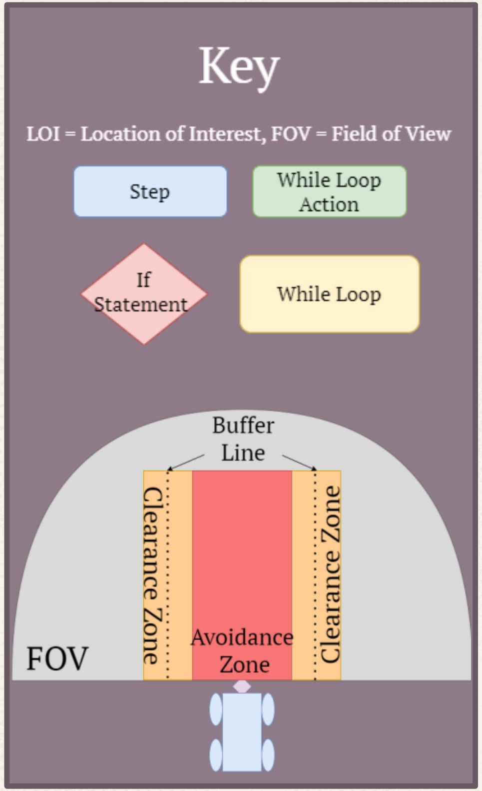

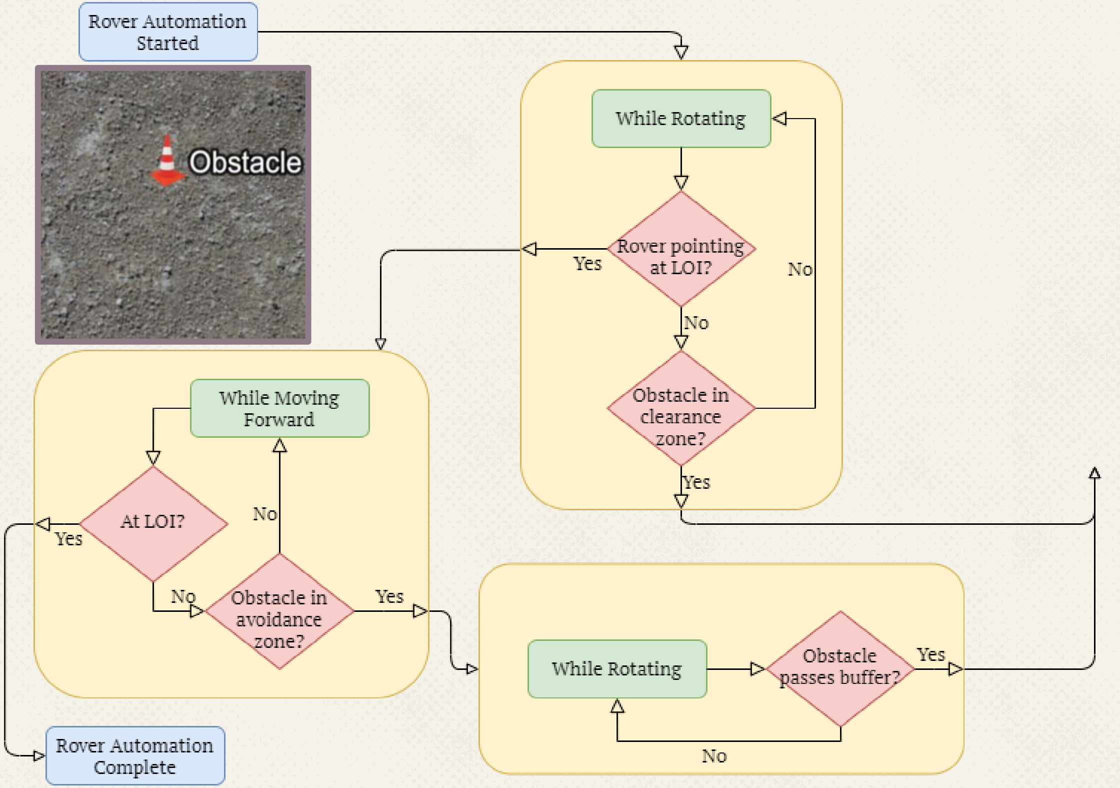

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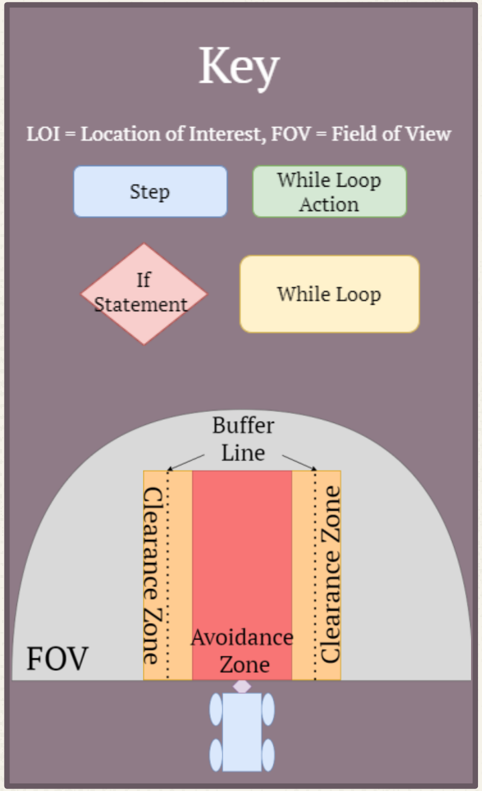

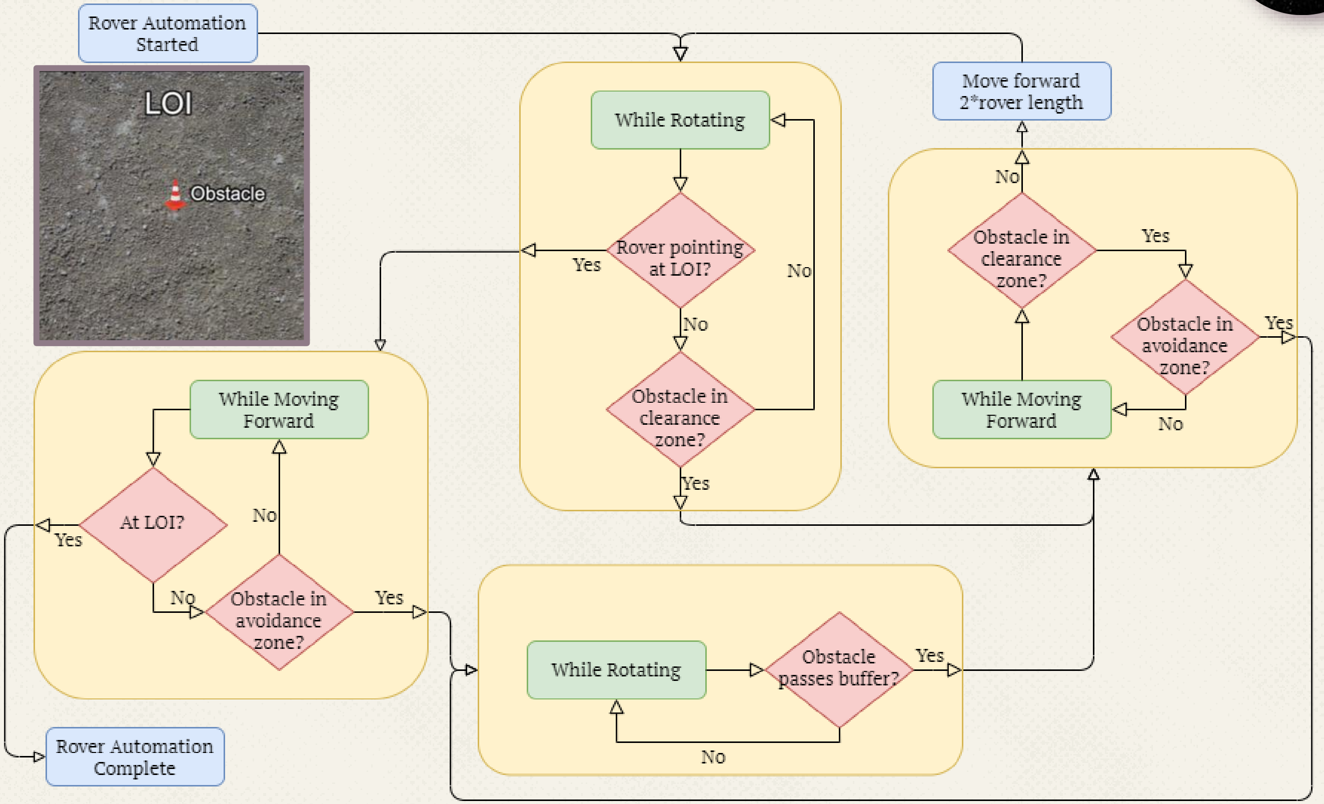

Design Requirements: Autonomy Continued

Verification Method: D = Demonstration, I = Inspection, A = Analysis, T = Test

FR. 3: The rover shall utilize remote sensing subsystems to determine a path to a location of interest

Requirement	Verification
1.7.1: The remote sensing subsystem shall detect objects defined as obstacles	D,T
1.7.2: The remote sensing subsystem shall have a horizontal FOV of at least 120 degrees	A
1.7.3: The remote sensing subsystem shall send data to the autonomy subsystem	T
1.8.1: Rover shall determine its location to an accuracy of 10 m or less	D,T
1.8.2: Rover shall communicate its location to the ground station at least once every 5 meters of distance travelled	D

LiDAR Selection

RPLIDAR A2M8

- **Purpose:**
  - To detect obstacles in the mission environment.
- **Procurement or Production:**
  - RPLIDAR A2M8 sensor acquired from previous team. No purchase needed.
- **System Specifications:**
  - Angular resolution: ~1 deg
  - Max range: 12 m
  - FDA Class I laser (Non-hazardous to unassisted eye)
  - Field of View: 360 deg (180 deg effective)
  - Capable of detecting 6cm wide objects at 3 meters distance

LiDAR Selection

RPLIDAR A2M8

Satisfies "DR. 1.7.1: The remote sensing subsystem shall detect objects defined as obstacles" and "DR. 1.7.2: The remote sensing subsystem shall have a horizontal FOV of at least 120 degrees"

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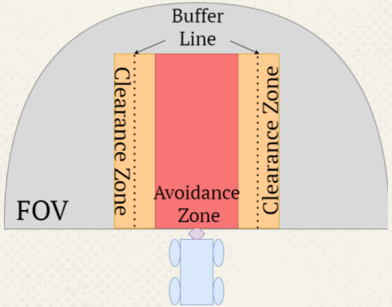
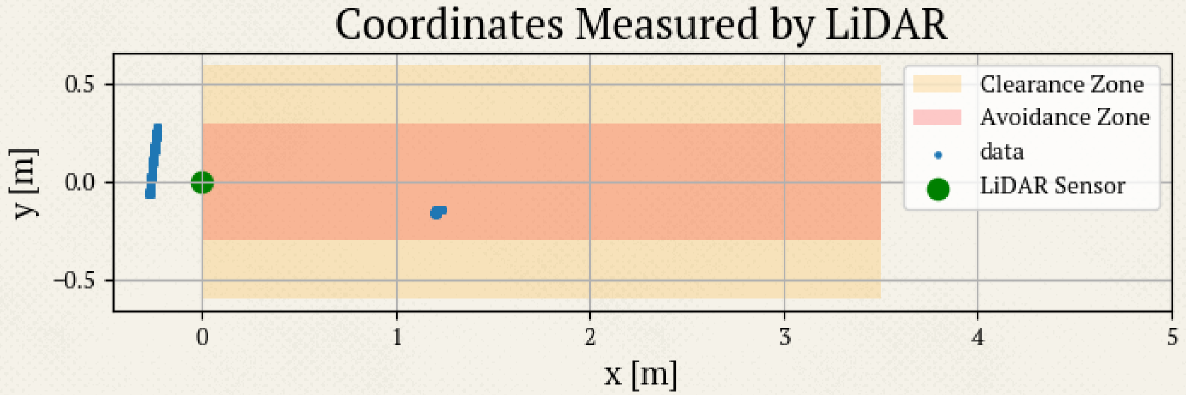
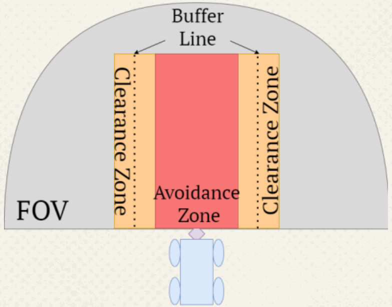
LiDAR Satisfaction & Preliminary Testing



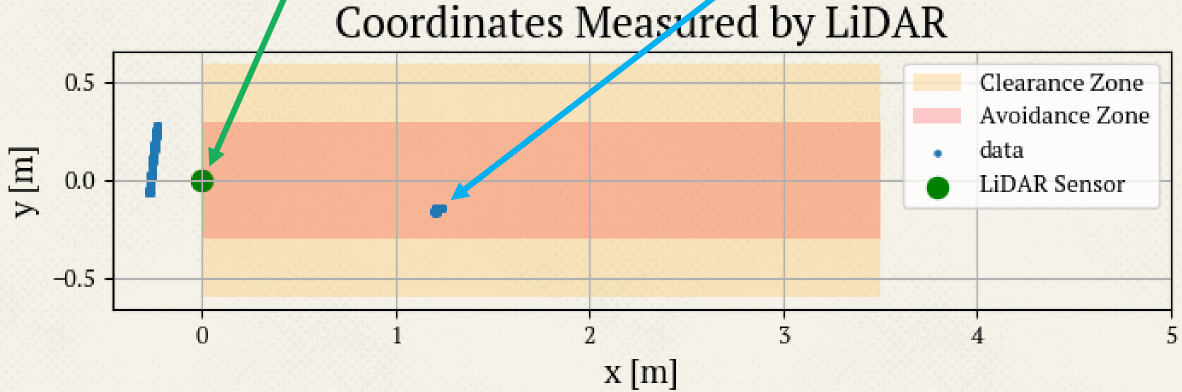


LiDAR Satisfaction & Preliminary Testing

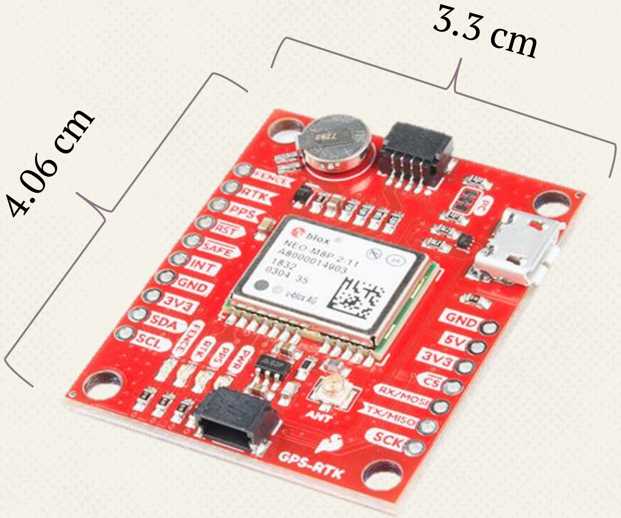


LiDAR
Sensor

Test object
(mulch)



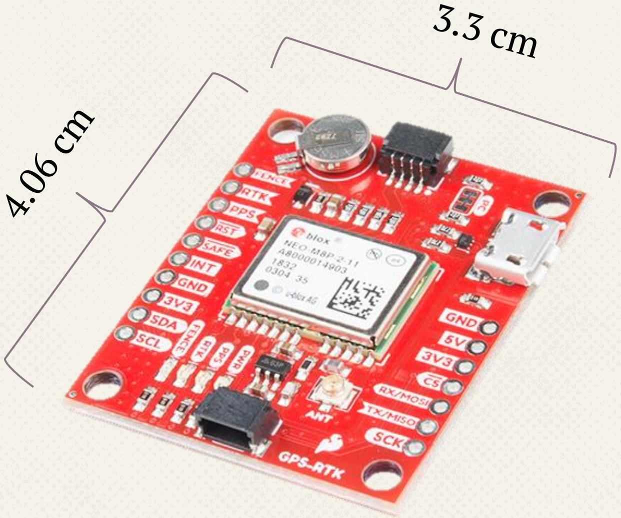
GPS Selection



SparkFun GPS-RTK Board - NEO-M8P-2

- **Purpose:**
  - To provide Earth fixed coordinates of the rover for navigation to and from the location of interest
- **Procurement or Production:**
  - SparkFun GPS-RTK Board - NEO-M8P-2 acquired from previous team. No purchase needed.
- **System Specifications:**
  - Max sampling rate: 10 Hz
  - Horizontal accuracy: 2.5 m without RTK
  - Operating voltage: 3.3 V

GPS Selection



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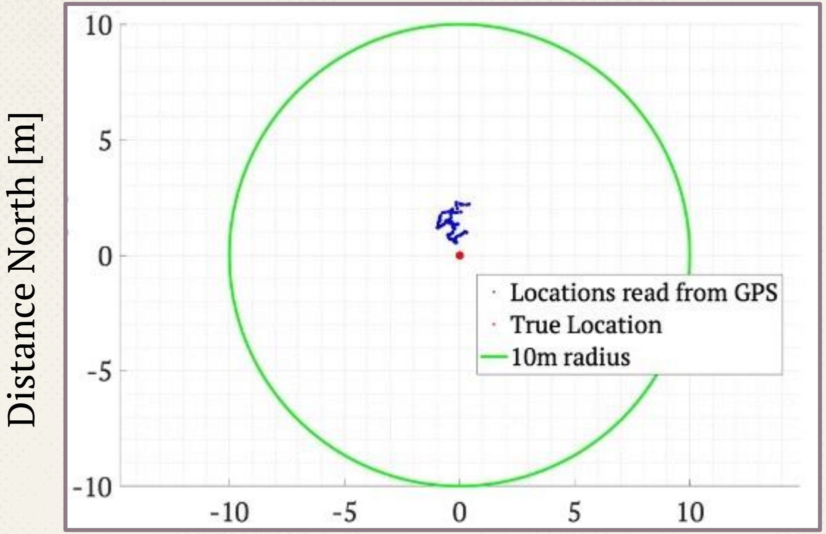
  - Operating voltage: 3.3 V

Satisfies "DR. 1.8.1: Rover shall determine its location to an accuracy of 10 m or less" and "DR. 1.8.2: The rover shall communicate its location to the ground station at least once every 5 meters..."

GPS Satisfaction & Preliminary Testing

GPS Accuracy Analysis at 40.004N, 105.2607W

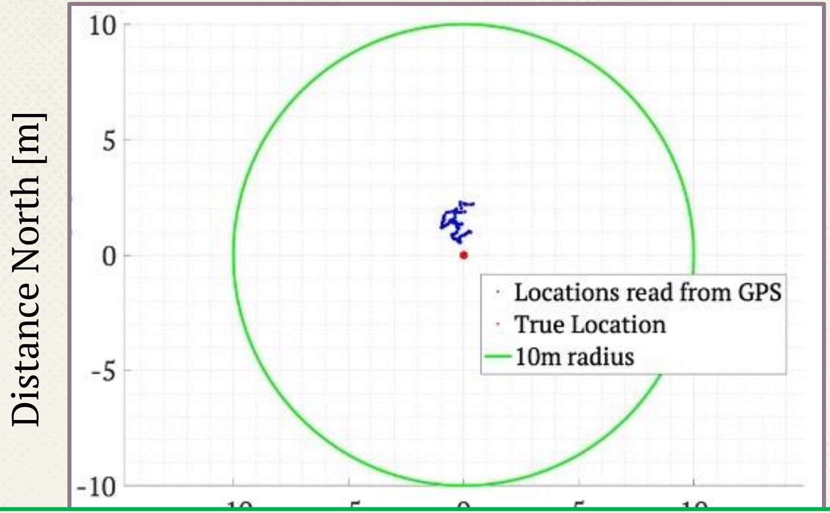


Distance East [m]

- **Preliminary Test Observations:**
  - Max distance error: 2.2895 m
  - Mean distance error: 1.4127 m
  - Standard deviation: 0.46 m
  - Precision: $\pm$ 1.15 m
- **Preliminary Test Results:**
  - GPS accuracy is at worst 3.39 meters.
  - Rover will stop within 4.54 meters from the target

GPS Satisfaction & Preliminary Testing

GPS Accuracy Analysis at 40.004N, 105.2607W



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Satisfies "DR. 1.8.1: Rover shall determine its location to an accuracy of 10 m or less" and "DR. 1.6.5: The autonomy subsystem shall determine when the rover has reached the location of interest"

Autonomous Verification:
Test Plan

FR. 3: The rover shall utilize remote sensing subsystems to determine a path to a location of interest

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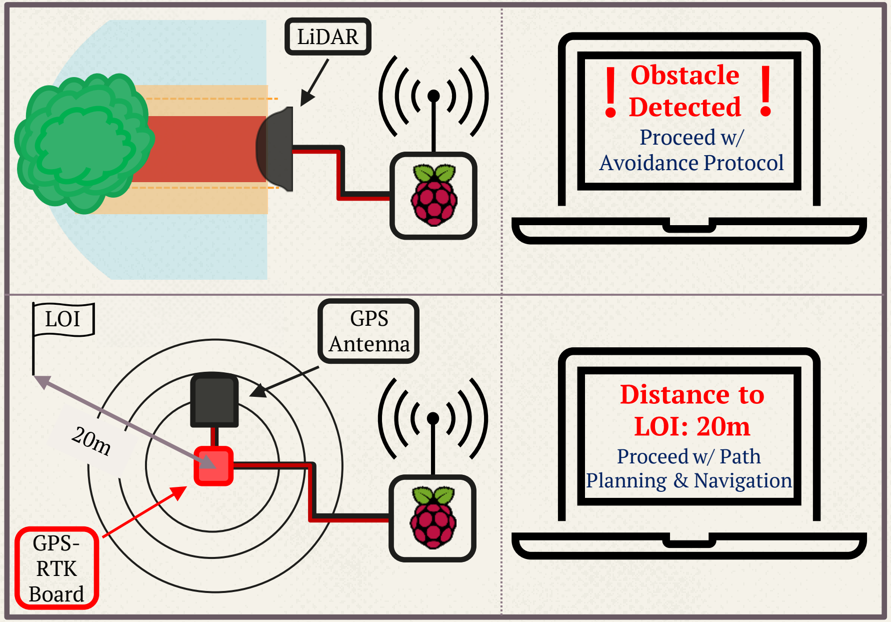


- **Objective:**
  - Verify autonomous path planning algorithm functionality utilizing object detection and location determination components.
- **Test Plan:**
  - Place obstacle in LiDAR red avoidance zone
  - Move GPS sensor/antenna 20m from specified location
- **Data Collected:**
  - LiDAR data points
  - GPS coordinates (translated to distance between LOI and GPS components)
- **Pass Criteria:**
  - Obstruction detected and avoidance commands prompted by automation software
  - Distance between LOI and GPS components calculated with path planning continuing until LOI is reached

Project Planning

“Day in the Life” test plan, work plan, spring schedule, cost plan

"Day in the Life" Test Plan

Test Site:

- Pleasant View Sports Complex
  - Public access
  - 100m of unobstructed mowed grass

Test Objective:

- Execute primary CONOPS to assess final system integration functionality in defined mission environment

Test Equipment:

- Rover & ground station
- Obstacles to satisfy system objectives

Test Criteria:

- All functional and design requirements must be validated according to their indicated test method

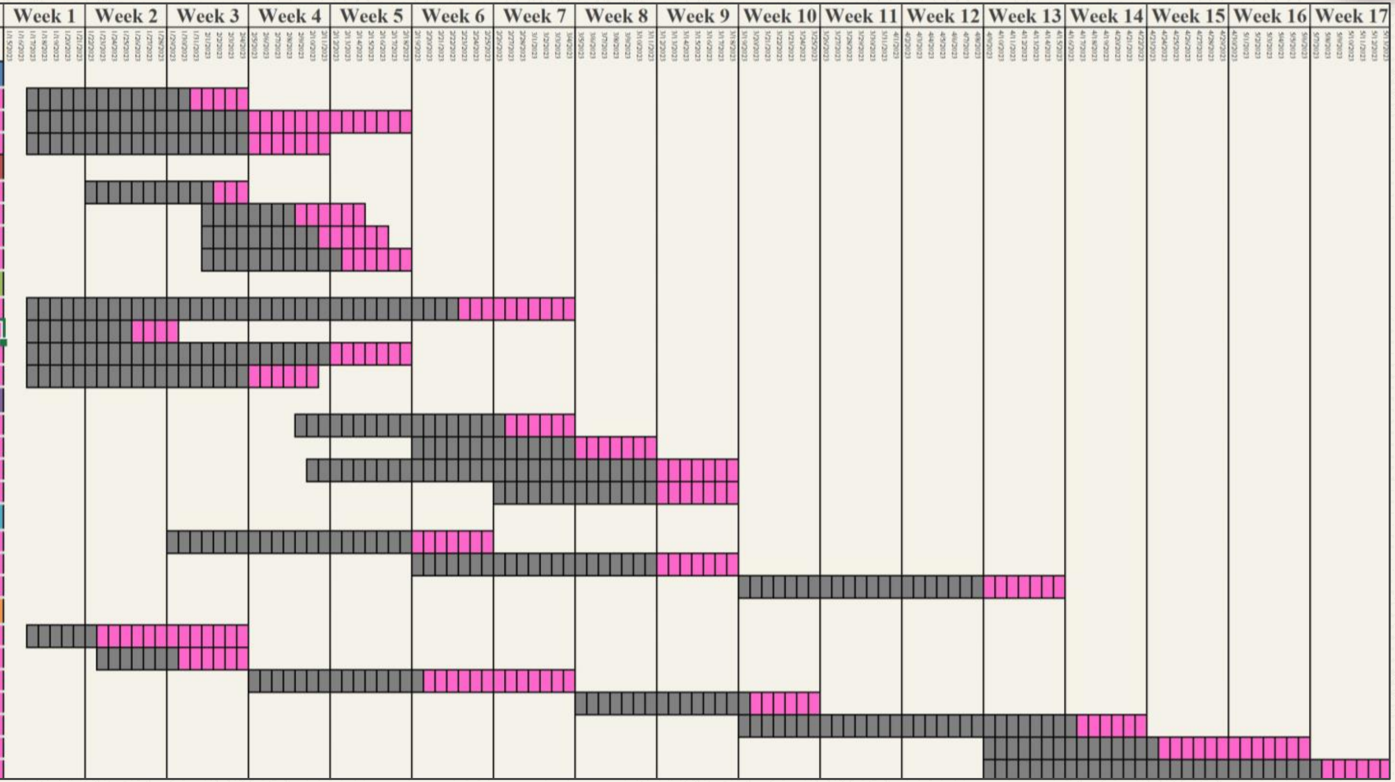
Work Plan

SAILR

- **Management**
  - CDR Presentation
  - Fall Report
  - TRR Presentation
  - AIAA Conference Paper
  - Spring Final Review
  - Final Report
- **Electrical & Software**
  - Electronics Procurement
  - Final Ground Station Code
  - Final Comms Code
  - Final Controls Code
  - Final Autonomy Algorithm Code
- **Mechanical**
  - Raw Material Procurement
  - Fastener Procurement
  - Mech. Component Procurement
  - Structure Fabrication
  - Custom Mount Fabrication
  - Drivetrain Fabrication
- **Integration & Test**
  - Structural Integration
  - Electrical Integration
  - Motion/Controls Testing
  - Comms/Ground Station Testing
  - Automation/ Sensor Testing
  - Day In The Life Functional

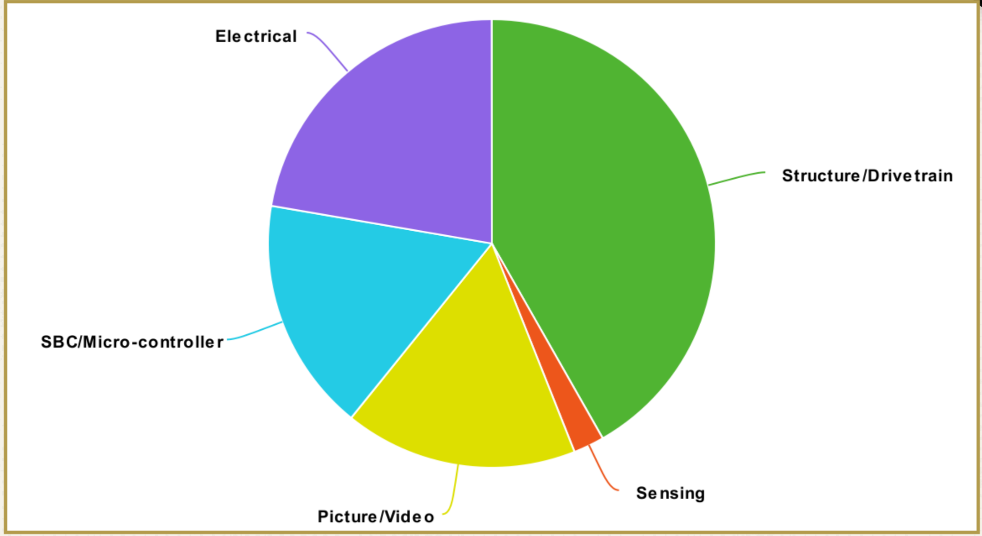
GANTT Chart

TASK	Start	End	Margin
Acquisition			
Raw Materials/Fasteners	1/17/2023	1/30/2023	2/4/2023
Electronic Components	1/17/2023	2/4/2023	2/18/2023
Mechanical Components	1/17/2023	2/4/2023	2/11/2023
Fabrication			
Reviews / Setup	1/22/2023	2/1/2023	2/4/2023
Rover Structure	2/1/2023	2/8/2023	2/14/2023
Custom Mounts	2/1/2023	2/10/2023	2/16/2023
Custom Drivetrain	2/1/2023	2/12/2023	2/18/2023
Software			
Automation Code	1/17/2023	2/22/2023	3/4/2023
Ground Station	1/17/2023	1/25/2023	1/29/2023
Communications Code	1/17/2023	2/11/2023	2/18/2023
Controls Code	1/17/2023	2/4/2023	2/10/2023
Integration			
Physical Integration	2/9/2023	2/26/2023	3/4/2023
Electrical Integration	2/19/2023	3/4/2023	3/11/2023
Software Integration	2/10/2023	3/11/2023	3/18/2023
Final Integration	2/26/2023	3/11/2023	3/18/2023
Testing			
Component Testing	1/29/2023	2/18/2023	2/25/2023
Subsystem Testing	2/19/2023	3/11/2023	3/18/2023
"Day in the Life"	3/19/2023	4/8/2023	4/15/2023
Deliverables			
Internal Design Reviews	1/17/2023	1/22/2023	2/4/2023
AIAA Abstract	1/23/2023	1/29/2023	2/4/2023
Test Readiness Review	2/5/2023	2/19/2023	3/4/2023
AIAA Paper	3/5/2023	3/19/2023	3/25/2023
Symposium	3/19/2023	4/16/2023	4/22/2023
Spring Final Review	4/9/2023	4/23/2023	5/6/2023
Final Report	4/9/2023	5/7/2023	5/13/2023



Cost Plan

Subsystem(s)	Cost
Structure/ Drivetrain	$380.17
Sensing	$19.95
Picture/Video	$150
SBC/Micro-controller	$150.49
Electrical	$198.78
Total	$899.39



- All GPS and communications components obtained from past projects
- Uncertainty in SBC cost due to supply chain issues

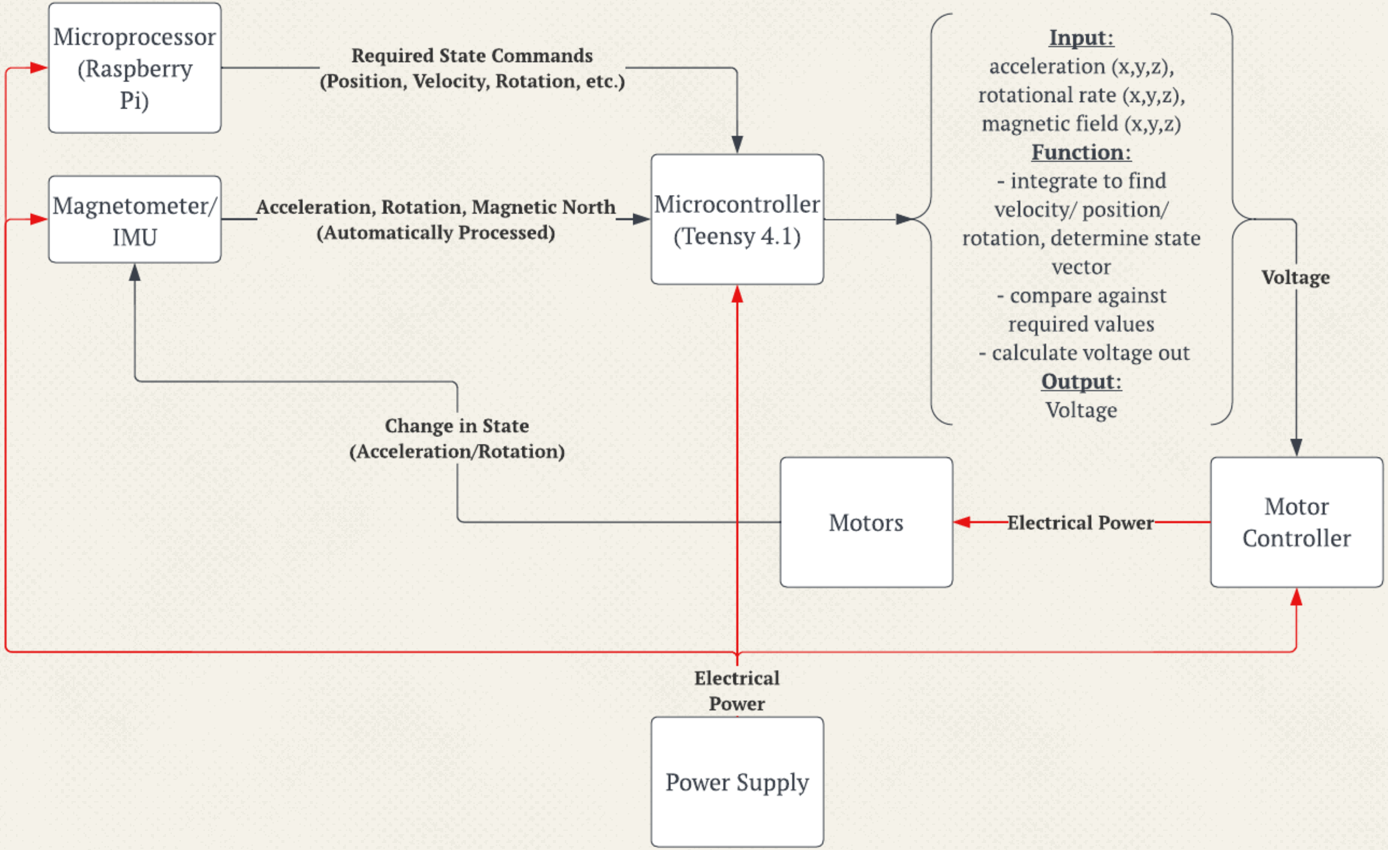
Questions?

Subsystem Backups

Controls, autonomy, communications, video/imaging, ground station, electrical, mechanical

Controls Backups

Controls Diagram



Equation Nomenclature

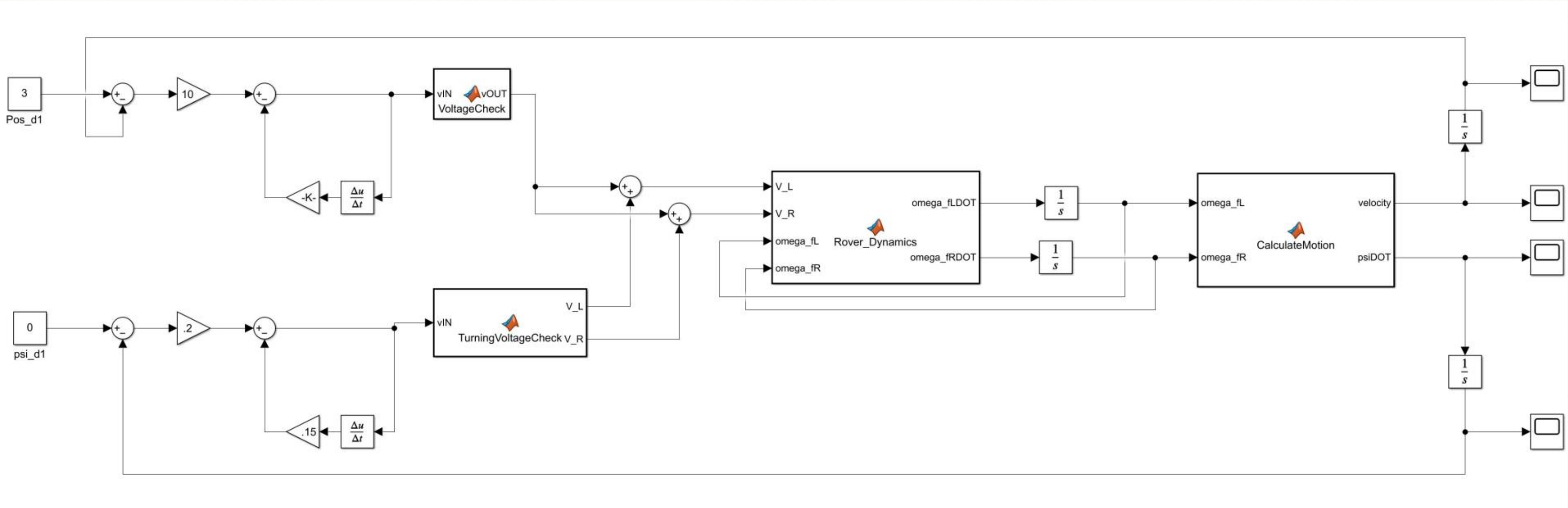
$$\dot{\omega} = \frac{GK_t}{RJ}V - \frac{G^2K_t}{K_vRJ}\omega$$

$$\bar{V} = \frac{(\omega_{fL} + \omega_{fR})r_f}{2}$$

$$\omega_t = \frac{\omega_{fL} * r_f}{r_d} + \frac{\omega_{fR} * r_f}{r_d}$$

- G = motor gear ratio
- J = drivetrain moment of inertia [kg*m2]
- K_t = motor torque constant [N*m/A]
- K_v = motor angular velocity constant [rad/s*V]
- R = motor resistance [ohms]
- V = voltage applied to motor [V]
- $\bar{V}$ = rover linear velocity [m/s]
- r_f = rover wheel radius [m]
- r_d = rover drivetrain radius [m]

Simulink Model



Mechanical Component Validation Testing

Component(s) Being Tested	Equipment Required	Test Description	Passing Metrics	Design Requirements
Micro-controller	1. Ground station 2. SBC 3. Microcontroller 4. Motor Interface	1. Send motion commands from ground station and SBC separately and observe response 2. Attempt to overwrite SBC commands with manual commands and observe response	1. Drivetrain moves after receiving commands and automated commands can be overwritten by manual commands	1.9.1, 1.9.2, 1.9.3, 1.9.4, 1.5.1, 1.5.2,1.5.3, 1.5.4
Magnetometer/IMU	1. Magnetometer/ IMU board 2. Laptop/ desktop computer 3. Compass	1. Collect accelerometer and magnetometer data at different orientations 2. Simultaneously collect data from a compass	1. Accelerometer and magnetometer data are accurate within 10%	1.9.4
Motor/ESC	1. Power supply 2. ESC/ motor 3. Drivetrain Assembly	1. Connect motors to drivetrain 2. Power motors and observe drivetrain	1. Drivetrain moves rover forward and backward 2. Drivetrain turns rover	

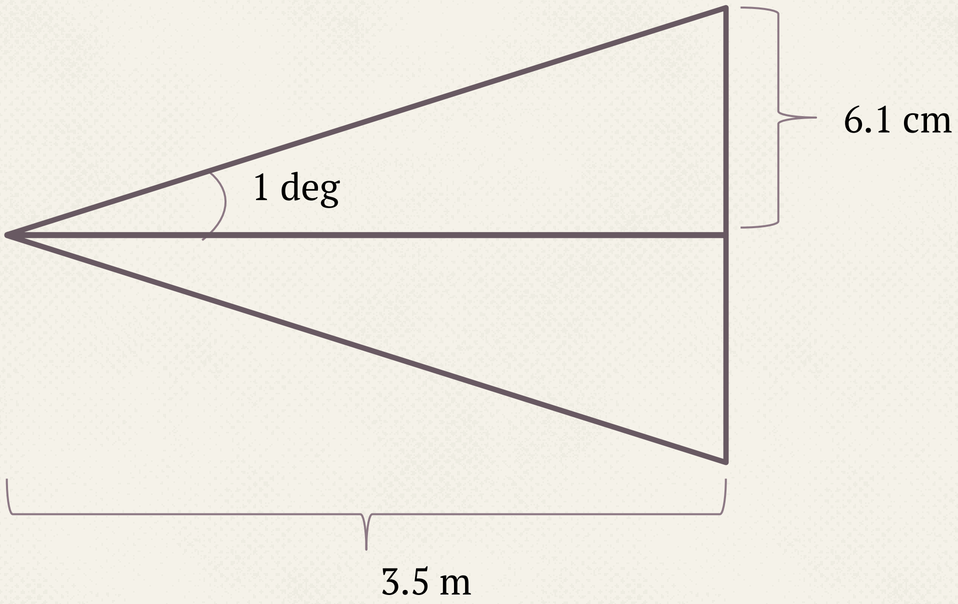
Autonomy Backups

Microprocessor/ Microcontroller Selection

	SBC	Microcontroller
Processing power required(25%)	93.66 Mbps	980.4 Kbps
Memory required(25%)	349.96 MB	172.8 KB
Processing power required(100%)	374.63 Mbps	3921.6 Kbps
Memory required(100%)	1399.86 MB	691.2 KB

- 25% number is calculated from what is known so far – video storage, sensor baud rate, etc.
- 100% number is a margin factor of 4 to account for unknown requirements.
- SBC selection (Raspberry Pi 4) is 4GB(4000MB) and 1.5GHz 64-bit.
- Microcontroller (Teensy 4.1) is 7936KB and 600MHz 32-bit.

Automation Zoning Satisfaction



Obstacles:

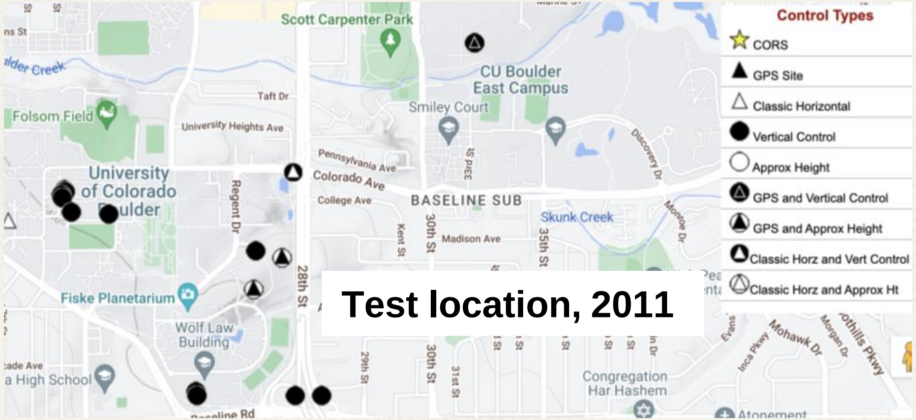
- Minimum of 2.5 in width
- Sense as far away as possible so we can optimize path

Lidar Resolution

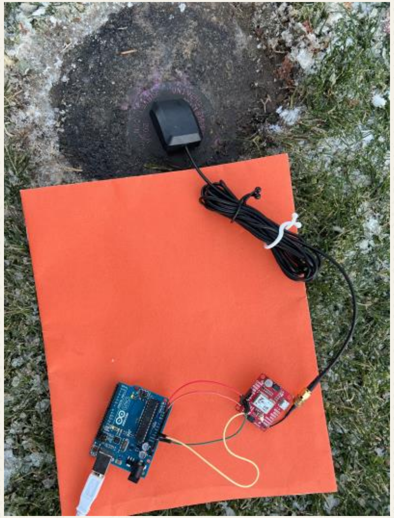
- 1 degree resolution
- Geometry defines that 2.5 inch objects can be detected 3.5 meters away

GPS Satisfaction Process

1. Identify known coordinates

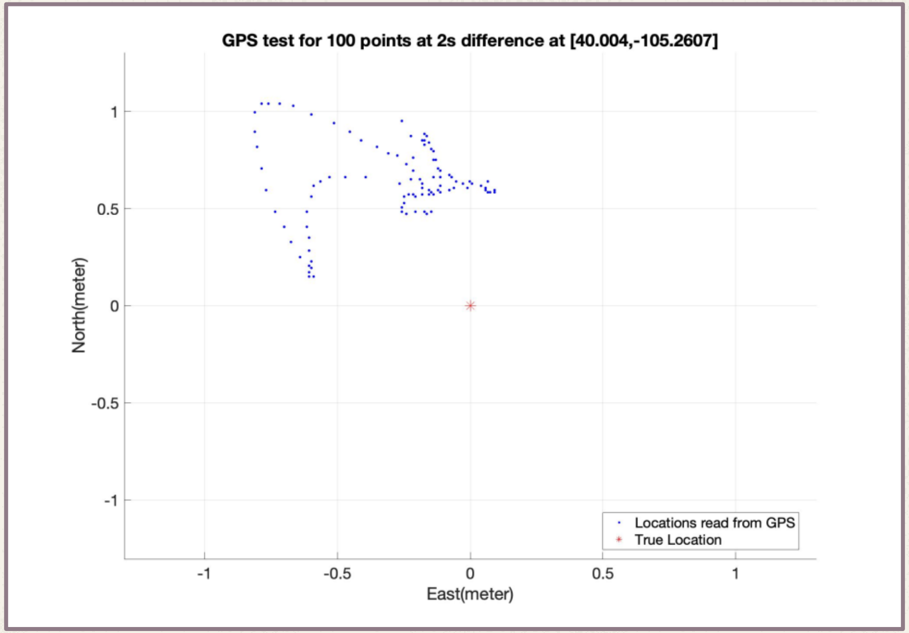


2. Collect GPS data



GPS Satisfaction Process

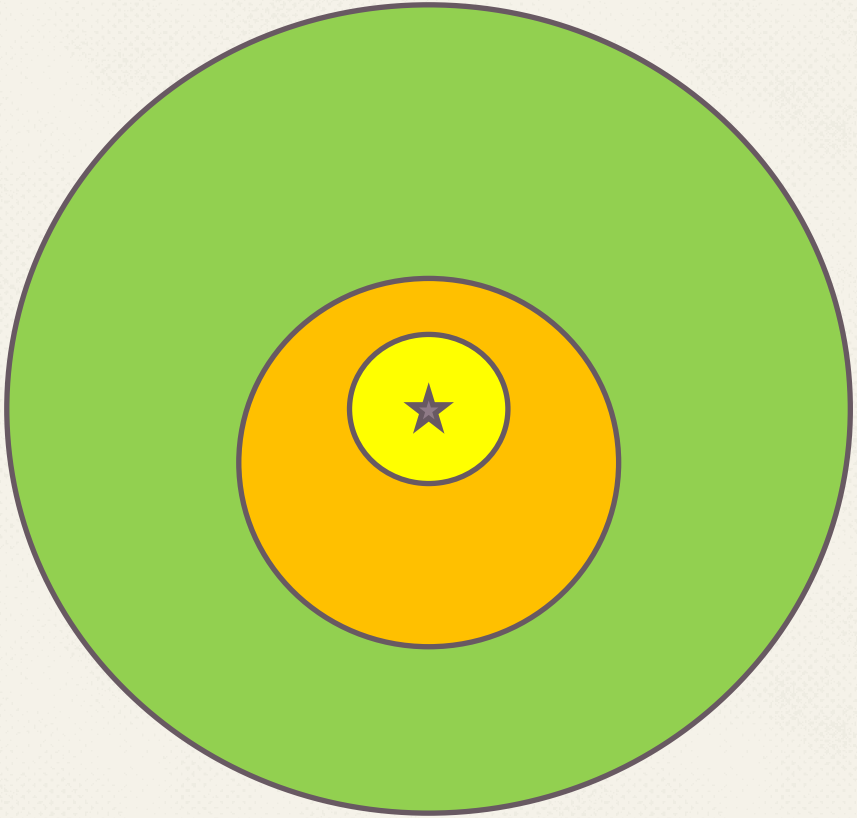
3. Conduct accuracy analysis on collected data



Optimal Case (Satellites in View >=15)

- Max distance error: 1.3031 m
- Distance error mean: 0.75604 m
- Standard deviation: 0.19 m
- Precision: +/- 0.63 m
- Satellites in view: 15-16

GPS Satisfaction



Key:

- Star – target
- Green – 10m radius
- Yellow – 1.15m radius (stop radius)
- Orange – 3.39m radius (rover location radius)

Maximum distance from target when the rover stops:
1.15m + 3.39m = 4.54m

Autonomy Component Validation Testing

Component(s) Being Tested	Equipment Required	Test Description	Passing Metrics	Design Requirements
LiDAR Sensor	1. LiDAR 2. Rock/ Shrub	1. Run LiDAR sensor in mission environment to sense the placed obstacle	1. 24 number of data points detected by LiDAR sensor indicating an obstacle in line of motion.	1.6.2, 1.7.1, 1.7.2, 1.7.3
GPS Chip/GPS Antenna	1. GPS chip 2. GPS antenna 3. Raspberry Pi	1. Set up GPS at least 20 meters from the simulated target with known coordinates 2. Start collecting GPS data 3. Approach the target until algorithm signals to stop (decided by stop radius) 4. Measure distance from the target	1. GPS antenna is within 10 m from the target when stops	1.6.2, 1.6.5, 1.8.1, 1.8.2

Communications Backups

Design Requirements:
Rover Communications

Verification Method: D = Demonstration, I = Inspection, A = Analysis, T = Test

FR. 2: The rover shall transmit and receive data between the on-board computer and the ground station

Requirement	Verification
1.3.1: The communication subsystem shall receive location of interest coordinates from ground station	D,T
1.3.2: The communication subsystem shall send telemetry data to ground station	D
1.3.3: The communication subsystem shall send video to the ground station	D
1.3.4: The communication subsystem shall send images to the ground station	D
1.3.5: The communication subsystem shall receive manual control commands from the ground station	D,T
1.3.6: Rover shall send video to ground station at least every 15 seconds	D

Communications Configuration

Rocket M2

- **Purpose:**
  - Transmit and receive data between ground station and on-board computer
- **Procurement or Production:**
  - Procured Rocket M2s and Antennas from heritage project(s)
- **System Specifications:**
  - Operating Frequency: 2.4 GHz
  - Power: 24V, 1A PoE
  - Size: 160 x 80 x 30 mm
  - Minimum Data Rate: 36 Mbps
  - @ -80dBm

Communications Satisfaction

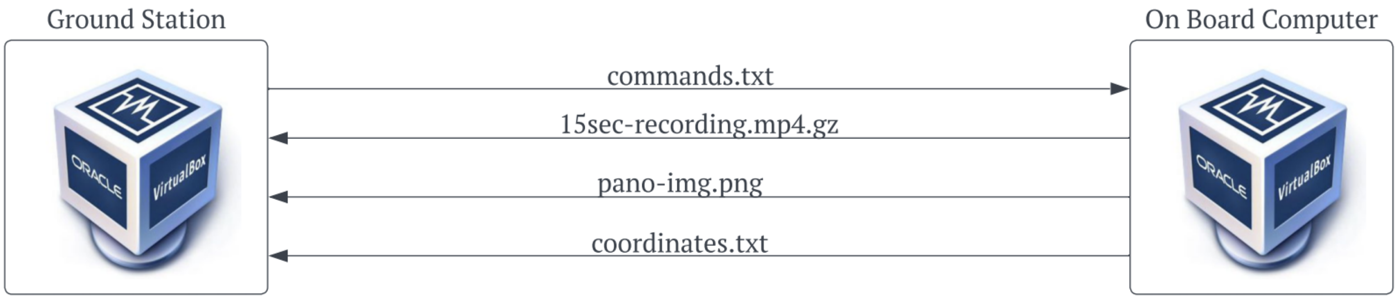
Structure: Utilize rsync over secure shell (ssh) to continuously synchronize files that contain necessary data and commands between ground station and on-board computer

Data flow structure:

- The commands file will update based on user input to the ground station UI which will be transmitted to the on-board computer
- The updated commands file will be read on the on-board computer and the necessary command will be applied
- The on-board computer will sync .png and .mp4.gz files to the ground station when created

Communications Satisfaction

Initial proof of concept: Connected two virtual machines together on local machine (laptop) and transmitted changes to a .txt, an added .png file, and an added .mp4 file



commands.txt	=> updated commands file
15sec-recording.mp4.gz	=> synced video file (compressed)
pano-img.png	=> synced image from panoramic stitching script
coordinates.txt	=> gps coodinates of rover

Communications Satisfaction

Initial proof of concept modeling results: Testing sending sample image and video files

```
[root@onboardcomputer comms-gs]# rsync -v /root/comms-gs/Pano.jpg 192.168.56.101:/root/comms-gs/Pano.jpg
root@192.168.56.101's password:
Pano.jpg

sent 190,302 bytes  received 35 bytes  54,382.00 bytes/sec
total size is 190,180  speedup is 1.00
[root@onboardcomputer comms-gs]#
```

```
[root@onboardcomputer comms-gs]# rsync -v /root/comms-gs/SampleVideo_720x480_30mb.mp4.gz 192.168.56.101:/root/comms-g
s/SampleVideo_720x480_30mb.mp4.gz
root@192.168.56.101's password:
SampleVideo_720x480_30mb.mp4.gz

sent 31,487,927 bytes  received 35 bytes  8,996,560.57 bytes/sec
total size is 31,480,141  speedup is 1.00
[root@onboardcomputer comms-gs]#
```

Communications Satisfaction

Initial proof of concept modeling results:

Convey automatic sending of updated .txt between VMs

root@onboardcomputer:~/comms-gs

```
[root@onboardcomputer comms-gs]# python3 obcfile
sync.py
sending incremental file list
test.txt

sent 151 bytes  received 41 bytes  128.00 bytes/
sec
total size is 57  speedup is 0.30
sending incremental file list
test.txt

sent 188 bytes  received 41 bytes  458.00 bytes/
sec
total size is 95  speedup is 0.41
sending incremental file list
test.txt

sent 226 bytes  received 41 bytes  534.00 bytes/
sec
total size is 132  speedup is 0.49
sending incremental file list
test.txt

sent 263 bytes  received 41 bytes  202.67 bytes/
sec
total size is 169  speedup is 0.56
sending incremental file list
test.txt

sent 299 bytes  received 41 bytes  226.67 bytes/
sec
total size is 205  speedup is 0.60
```

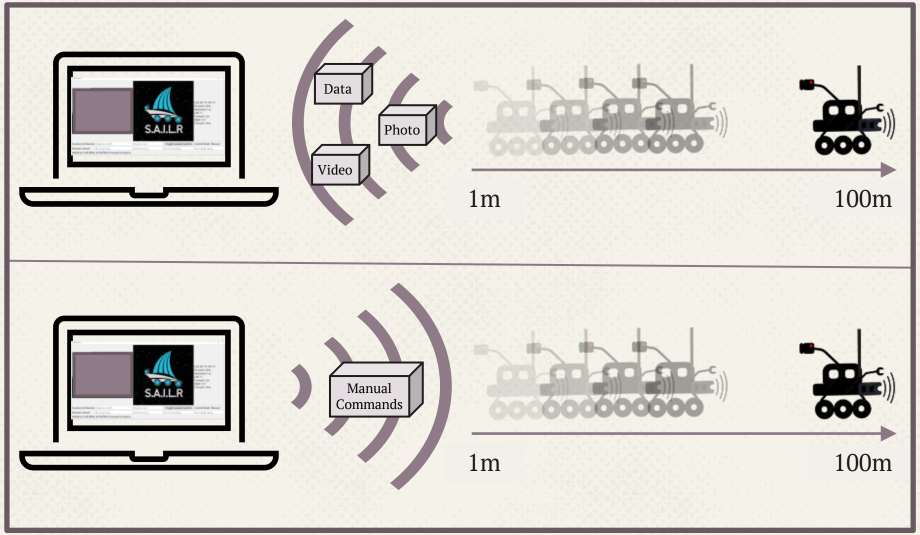
root@groundstation:~/comms-gs

```
[root@groundstation comms-gs]# python3 gsfilesync
.py
sending incremental file list
test.txt

sent 131 bytes  received 41 bytes  344.00 bytes/s
ec
total size is 38  speedup is 0.22
sending incremental file list
test.txt

sent 170 bytes  received 41 bytes  140.67 bytes/s
ec
total size is 76  speedup is 0.36
sending incremental file list
test.txt

sent 206 bytes  received 41 bytes  494.00 bytes/s
ec
total size is 113  speedup is 0.46
sending incremental file list
test.txt

sent 245 bytes  received 41 bytes  572.00 bytes/s
ec
total size is 151  speedup is 0.53
sending incremental file list
test.txt

sent 281 bytes  received 41 bytes  214.67 bytes/s
ec
total size is 187  speedup is 0.58
```

Comms Verification:
Test Plan

FR. 2: The rover shall transmit and receive data between the on-board computer and the ground station

Pleasant View Sports Complex



Objective:
- Verify transfer of data, image, and video files between ground station and rover communication system

Test Plan:
- Utilize rsync capabilities to transfer test files for the three data types
- Utilize rsync capabilities to transfer manual command from rover to ground station

Data Collected:
- Data throughput on airOS
- Latency via script

Pass Criteria:
- Communication is sustained between ground station and OBC when translating the rover from 1m to 100m in the mission environment
- All files are received following transmission from one rocket M2 to the other

Comms Component Validation Testing

Component(s) Being Tested	Equipment Required	Test Description	Passing Metrics	Design Requirements
Rocket M2	1. Ground Station Rocket M2 2. OBC Rocket M2	1. Set up bridge network between ground station Rocket M2 and on-board computer Rocket M2 2. Monitor data throughput on airOS and latency via script 3. Verify rsync capabilities of sending sample files at one meter distance: .txt, .png, .mp4.gz 4. Utilize ground station UI to update file and trace transmission of change made to file via rsync	1. Communication is sustained between ground station and OBC when translating the rover from 1m to 100m in the mission environment	1.3.1, 1.3.2, 1.3.3, 1.3.4, 1.3.5, 1.3.6

Video / Imaging Backups

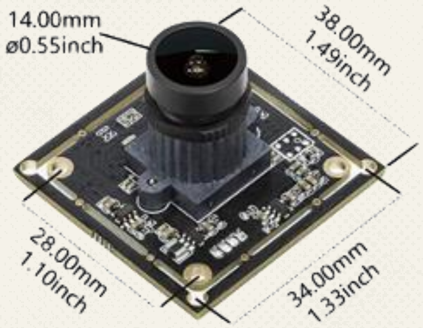
Design Requirements: Video / Imaging

Verification Method: D = Demonstration, I = Inspection, A = Analysis, T = Test

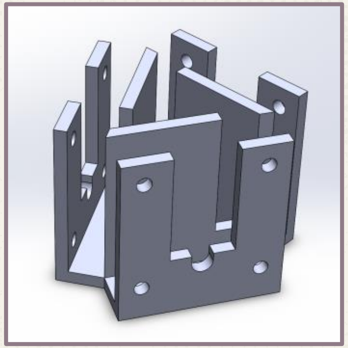
FR. 2: The rover shall transmit and receive data between the on-board computer and the ground station

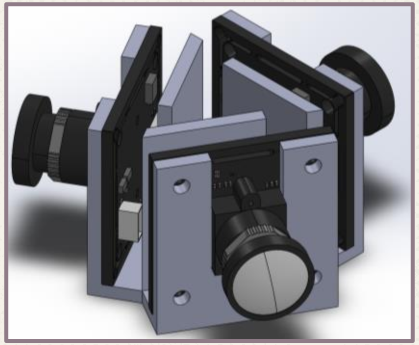
Requirement	Verification
1.4.1: Rover video subsystem shall have at least a 100 degree field of view	D
1.4.2: Rover video subsystem shall take video at a minimum 15 frames per second	D
1.4.3: Rover video subsystem shall take video at a minimum resolution of 640 x 360	D
1.4.4: Rover imaging subsystem shall have a 360 degree field of view	D
1.4.5: Rover imaging subsystem shall take image at a minimum resolution of 1920 x 360	D
1.4.6: Rover imaging subsystem shall take a panoramic image when it reaches the location of interest	D,T

Video / Imaging Configuration



Arducam 1080P Fisheye Camera





- **Purpose:**
  - The primary purpose of this subsystem is to record video and take 360 degree panoramic images
- **Procurement or Production:**
  - Purchasing three widescreen fisheye cameras
- **System Specifications:**
  - Frame rate: 30 FPS
  - Resolution: 1920x1080
  - FOV: 160 degrees (diagonal)

Video / Imaging Satisfaction

Camera

- Sensor: 1/2.8" IMX291
- Resolution: 2MP 1945H x 1109V
- Data Format: MJPG/YUY2/H.264
- Frame Rate: H.264 30fps@1920 x 1080; MJPG 30fps@640×320, 30fps@640×360, 30fps@800×600, 30fps@848×480, 30fps@960×720, 30fps@1024×576, 30fps@1280×720, 30fps@1920×1080; YUY2 30fps@640×320, 30fps@640×360, 30fps@800×600, 30fps@848×480, 30fps@960×720, 30fps@1024×576, 30fps@1280×720, 30fps@1920×1080
- Dynamic Range: 80dB
- USB Connector: B4B-ZR(LF)(SN)

Lens

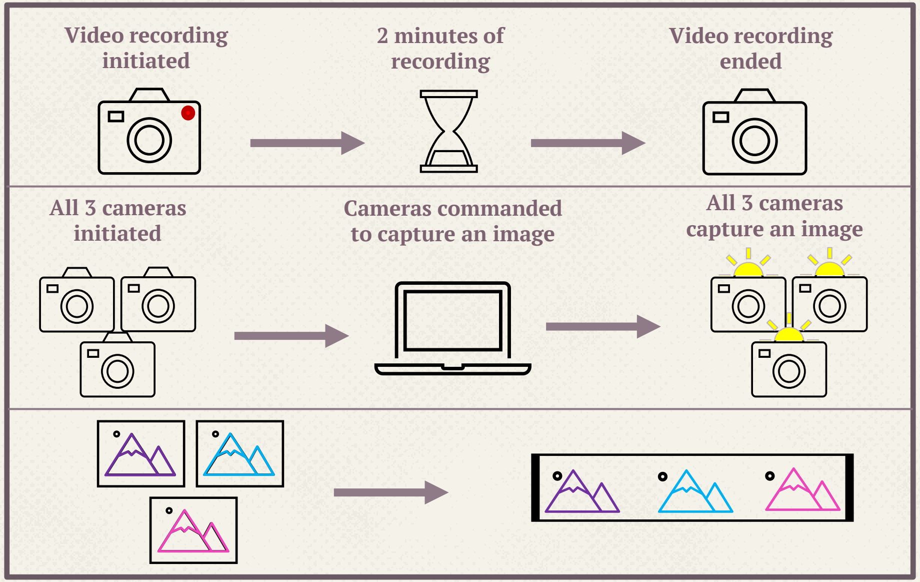
- Field of View (FOV): D= 160°
- Lens Mount: M12
- Focusing Range: 6.56ft (2M) to infinity
- IR Sensitivity: Integral IR filter, visible light only

Fig 1. Spec sheet verification of FPS, Resolution and FOV requirements

Video/Imaging Verification:
Test Plan

FR. 2: The rover shall transmit and receive data between the on-board computer and the ground station

Ann and H.J. Smead Aerospace Engineering Sciences Building



Objective:
- Verify video files and panoramic images are captured during respective mission phases

Test Plan:
- Command camera to begin recording video and stop recording after 2 minutes
- Command all three cameras to capture a single image
- Utilize image splicing code to form a single panoramic

Data Collected:
- Video file
- Three images

Pass Criteria:
- Camera is successful in beginning and ending video recording at specified interval
- All cameras capture an image when commanded
- Image splicing results in a single 360° panoramic

Comms Component Validation Testing

Component(s) Being Tested	Equipment Required	Test Description	Passing Metrics	Design Requirements
Arducam 1080P Fisheye Camera (Imaging)	1. 3 Arducam cameras 2. Ground Station	1. Assemble three cameras with camera mount and USB adapter 2. Command each camera to take a photo simultaneously	1. 3 images captured 2. Images spliced into a single 360° panoramic with a minimum resolution of 1920 x 360	1.4.4, 1.4.5, 1.4.6
Arducam 1080P Fisheye Camera (Video)	1. 1 Arducam cameras 2. Ground Station	1. Assemble three cameras with camera mount and USB adapter 2. Command one camera to start recording video 3. After 2 minutes command same camera to stop recording	1. A single 100° FOV video with a minimum resolution of 640 x 360 at a minimum of 15 frames per second	1.4.1, 1.4.2, 1.4.3

Ground Station Backups

Design Requirements:
Ground Station

Verification Method: D = Demonstration, I = Inspection, A = Analysis, T = Test

FR. 6: The ground station shall display video, images, and location of rover

Requirement	Verification
1.2.1: Ground station shall send coordinates of location of interest to the rover	D,T
1.2.2: Ground station shall receive rover telemetry data from the rover	D
1.2.3: Ground station shall receive panoramic images from the rover at a minimum resolution of 1920 x 360	I
1.2.4: Ground station shall receive video from the rover at a minimum resolution of 640 x 360	I
1.2.5: Ground station shall display images and video within 10 seconds of receiving them	D,T
1.2.6: Ground station shall display rover telemetry within 2 seconds of receiving it	D,T
1.2.7: Ground station shall display panoramic images at a minimum resolution of 1920 x 360	I
1.2.8: Ground station shall display video at a minimum resolution of 640 x 360	I

Design Requirements: Ground Station Continued

Verification Method: D = Demonstration, I = Inspection, A = Analysis, T = Test

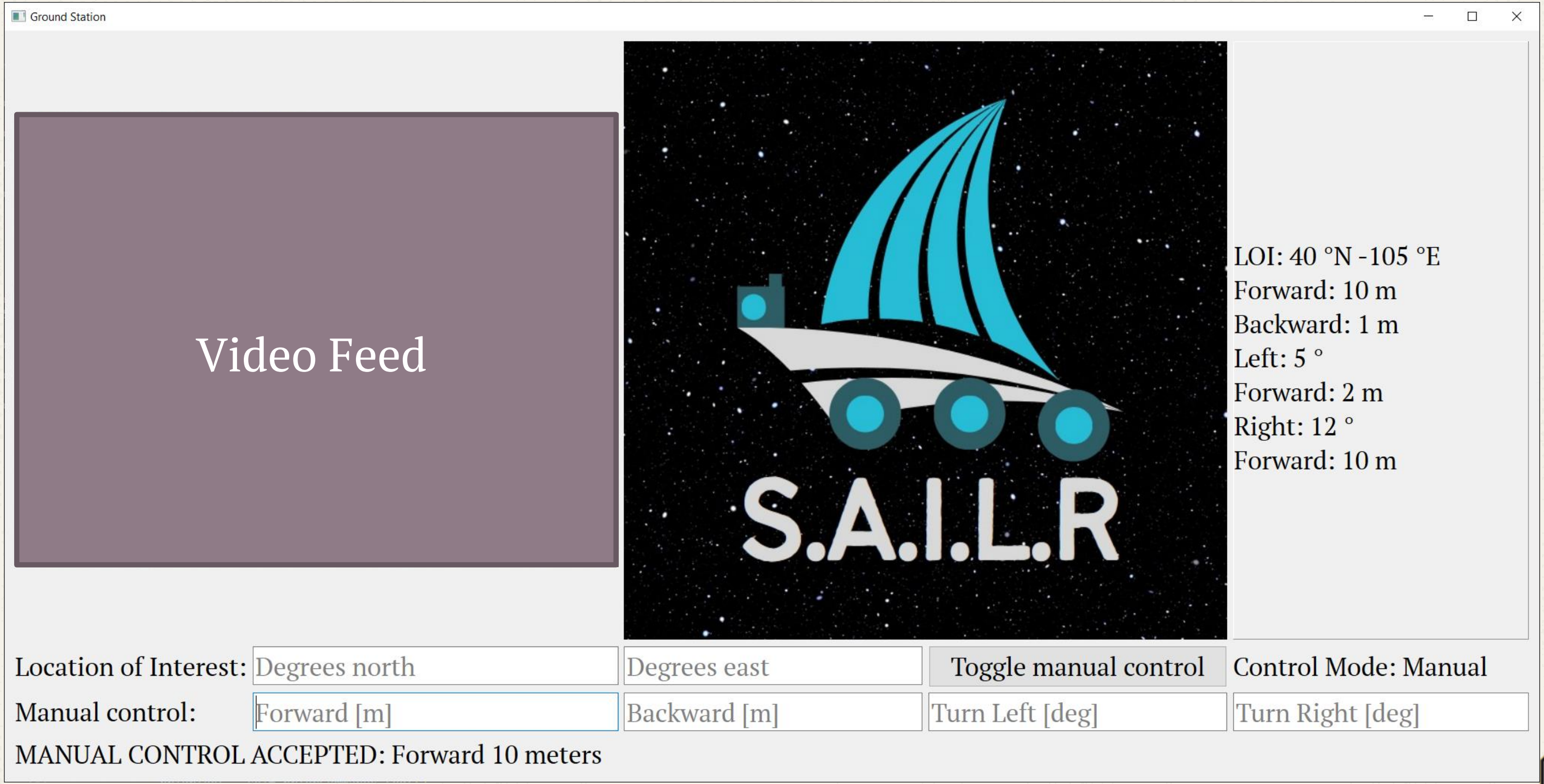
FR. 7: The ground station shall provide an interface to allow for input of manual commands from user

Requirement	Verification
1.2.9: Ground station shall receive manual control commands inputs from user	D
1.2.10: Ground station shall transmit manual control commands to the rover	D,T

Ground Station Configuration

- **Purpose:**
  - The primary purpose of these subsystem is to display video and images taken by the rover, the rover location, and accept user inputs
- **System Description:**
  - Our ground station consists of a laptop, a radio, and an antenna
  - For this subsystem we will be using the 20dBi directional panel antenna and Rocket M2 radio utilized in the previous year's rover project (AEROSS)
  - An aerospace department laptop has been checked out for the duration of the semester

Ground Station Satisfaction



*Rover Location to be added

Ground Station Satisfaction

Legend:

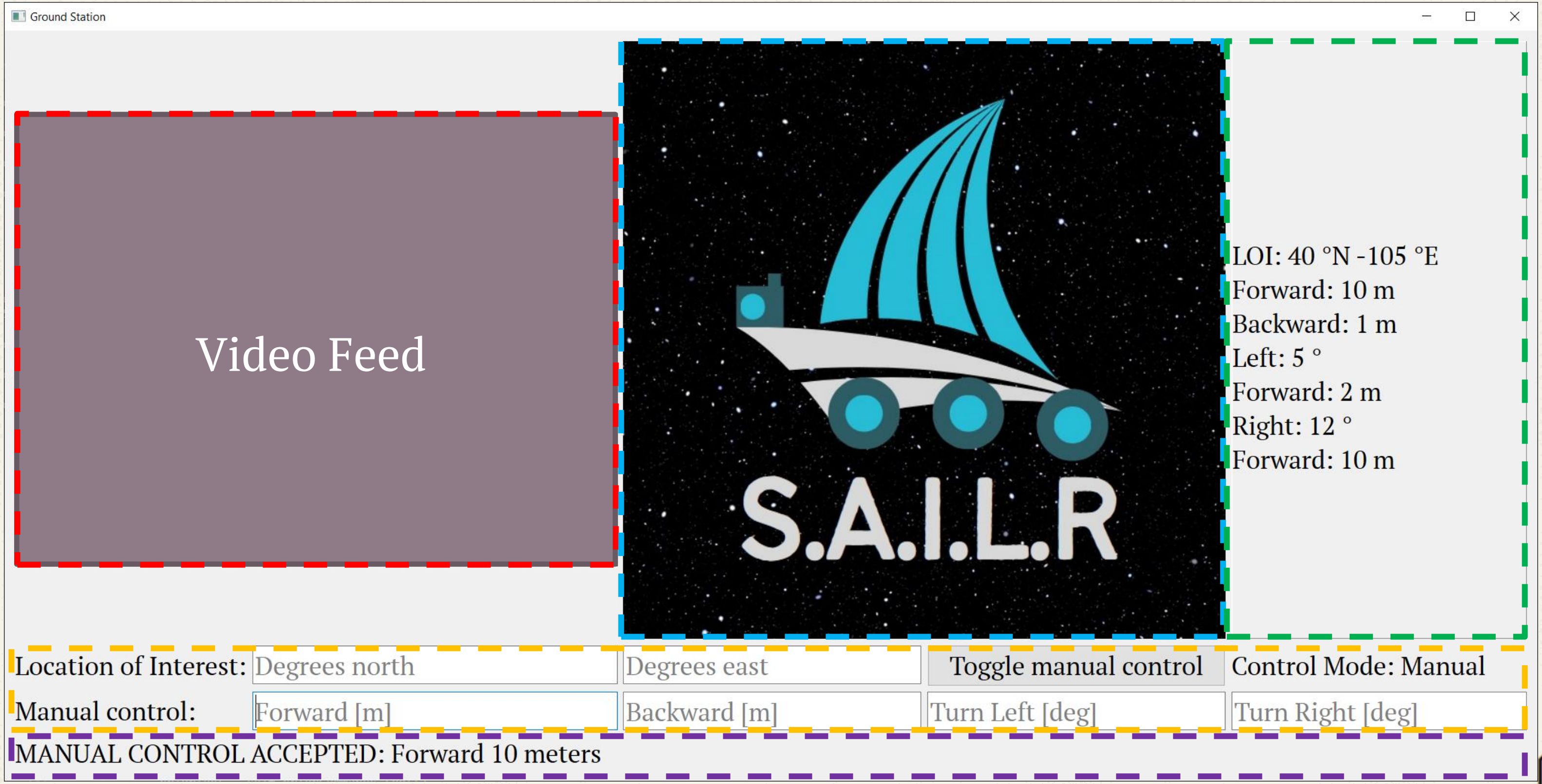
Video Feed

Images

Accepted Commands

Manual Inputs

Console



*Rover Location to be added

Ground Station Test Overview

Telemetry 1.2.1, 1.2.2, 1.2.6	Image 1.2.3, 1.2.5, 1.2.7	Video 1.2.4, 1.2.5, 1.2.8	Manual Controls 1.2.9, 1.2.10
1.2.1 (I)- Ground station will write LOI input to text file and send to rover	1.2.3 (A)- Rover will send captured images to ground station through radio which will be analyzed to determine if resolution is at least 1920 x 360	1.2.4 (A)- Rover will send captured video to ground station through radio which will be analyzed to determine if resolution is at least 640 x 360	1.2.9 (I)- Ground station will provide user interface for user to input manual controls
1.2.2 (I)- Rover will write current location to text file and send to ground station	1.2.5 (T)- Ground station will display image received within 10 seconds as compared to timer	1.2.5 (T)- Ground station will display video received within 10 seconds as compared to timer	1.2.10 (I)- Ground station will write manual control commands to text file and send to rover
1.2.6 (T)- Ground station will display rover location sent in text file within 2 seconds as compared to timer	1.2.7 (A)- Ground station will display images which will be analyzed to determine if resolution is at least 1920 x 360	1.2.8 (A)- Ground station will display images which will be analyzed to determine if resolution is at least 640 x 360	

Ground Station Test Plan

- **Necessary Hardware:** 2 Rocket M2 radios, 2 laptops, ground station panel antenna, and rover omnidirectional antennas
- **Test location:** Outdoors, flat area with no obstructions and negligible interference
- To test sending from rover to ground station: Video, images, and rover location
- To test sending from ground station to rover: Manual controls, control mode input, and location of interest input

Electrical Backups

Drivetrain Power Budget

Motor Subsystem

Component	Operating Voltage (V)	Input Voltage (V)	Estimated Current Draw (mA)	Estimated percent time of operation	Operating Watts (W)	Losses (W)	Loss Notes
Motor 1	6	6	600	0.85	3.06	0	Losses will have already occured in ESC
Motor 2	6	6	600	0.85	3.06	0	x
ESC 1	6	7.2	50	0.85	0.255	0.051	7.2Vin, operates at 6V, 1.2V drop @ 600mA
ESC 2	6	7.2	50	0.85	0.255	0.051	x

Total Power (W)	6.732
Max Current Draw (mA)	1700
Estimated Avg Current Draw:	1105

Computer Power Budget

Computer Subsystem	(Used for calculations of Component Subsystem)						
Component	Operating Voltage (V)	Input Voltage (V)	ESTIMATED CURRENT DRAW (mA)	OPERATION DURATION /MISSION DURATION	OPERATING WATTS (W)	Losses (W)	Loss Notes
Micro-Controller	3.3	5	100	1	0.33	0.34	5Vin, operates at 3.3V, 1.2V drop @ 100mA (MC)+100mA (magnetometer)
GPS Board	3.3	5	27	0.2	0.01782	0.00918	5Vin, operates at 3.3V, 1.2V drop @ 27mA
GPS Antenna	3.3	5	15	0.2	0.0099	0.0051	5Vin, operates at 3.3V, 1.2V drop @ 15mA
Magnetometer	3.3	3.3	100	1	0.33	0	see micro-controller loss notes
Encoder 1	3.3	3.3	200	1	0.66	0	x
Encoder 2	3.3	3.3	200	1	0.66	0	x
Camera 1	5	5	300	1	1.5	0	x
Camera 2	5	5	300	0.1	0.15	0	x
Camera 3	5	5	300	0.1	0.15	0	x
Total Power (W)	4.162						
Max Current Draw (mA)	1542	Shouldnt ever occur if cameras operate one at a time					
Estimated Avg. Current Draw	908.4						

Component Power Budget

Component Subsytem

Component	Operating Voltage (V)	Input Voltage (V)	Estimated Current Draw (mA)	OPERATION DURATION /MISSION DURATION	OPERATING WATTS (W)	Losses (W)	Loss Notes
Computer	5	5	800	1	4	0	x
Computer-Powered Components	Varyied	5	908.4	1	4.162	0.35428	See Computer Subsytem Notes
Lidar	5	5	500	1	2.5	0	x
USB Power Hub	5	14.4	2208.4	1	0	0.5521	0.95% effecieny @ 11.042W = 0.5521 Loss

Avg. Values			Max Values	
Buck converter Effeciency	0.96		Buck converter Effeciency	0.96
Output power (W)	11.042		Output power (W)	14.21
Output Voltage (V)	5		Output Voltage (V)	5
Output Current (mA)	2.2084		Output Current (mA)	2.842
Input Power (W)	11.5941		Input Power (W)	14.9205
Input Voltage	7.2		Input Voltage	7.2
Avg. Input Current	1.610291667		Max Input Current	2.072291667

Communications Power Budget

Antenna Subsystem

boost converter calculations	RocketM2 Values (6.5W @ 24V, iv=p i=p/v=0.271)	POE Injector Values	Boost Converter
Effeciency	0.97	0.75	0.9
Power Needed Ideal (W)	6.5	6.53	8.1625
Power Needed Actual (W)	6.53	8.1625	8.97875
Current in (A)	0.272083333	0.680208333	1.247048611

Expected Current Draw (A)	1.247048611	
Max Current Draw	1.621163194	just added 30% margin
Loss	2.47875	loss=P_actual-P_expected=(8.97875)-(6.5)

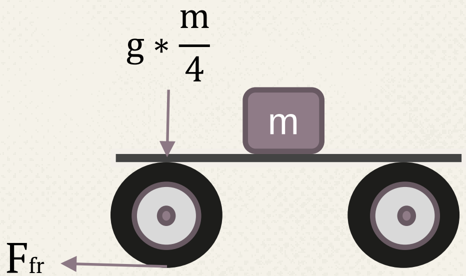
Battery Component Validation Testing

Component(s) Being Tested	Equipment Required	Test Description	Passing Metrics	Design Requirements
Motor Battery	1. Motor battery 2. Motors 3. Oscilloscope 4. Simulated load	1. Motors that will be set up with an equivalent load to the rover weight and powered with the respective battery 2. Battery terminal voltages will be measured using the oscilloscope	Recorded voltages will be compared to specification sheet voltage/capacity chart values to calculate actual discharge rate and capacity over time.	1.10.3, 1.10.4
Component/ RocketM2 Batteries	1. Component battery 2. Bread board equivalent circuit 3. Oscilloscope	1. A bread board circuit with expected equivalent current and voltage to the actual component circuit will be powered with the respective battery 2. Battery terminal voltages will be measured using the oscilloscope	Recorded voltages will be compared to specification sheet voltage/capacity chart values to calculate actual discharge rate and capacity over time.	1.10.1, 1.10.2, 1.10.5

Mechanical Backups

Torque Governing Equations

System Free Body Diagram:



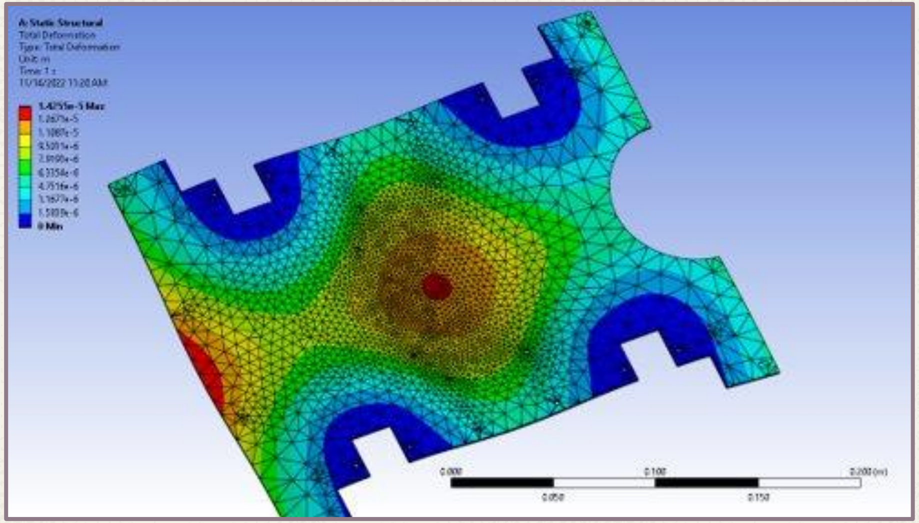
Governing Equations:

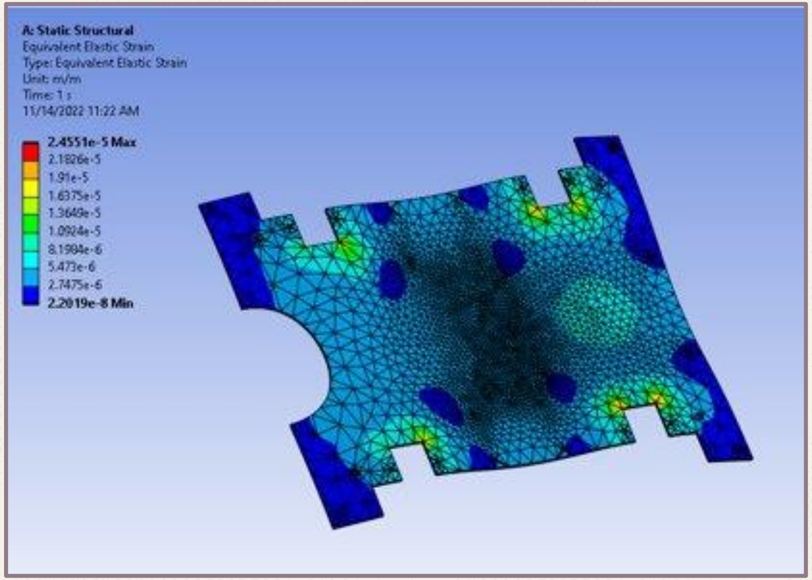
$$\tau = r \times F_{fr} \qquad F_{fr} = \mu * g * \frac{m}{4}$$

- **Nomenclature:**
  - m = mass of rover [kg]
  - r = radius of rover tire [m]
  - μ = static coefficient of friction; rubber on grass
  - F_{fr} = Frictional Force [N]
  - g = gravitational constant [m/s2]

Structural Analysis of Baseplate

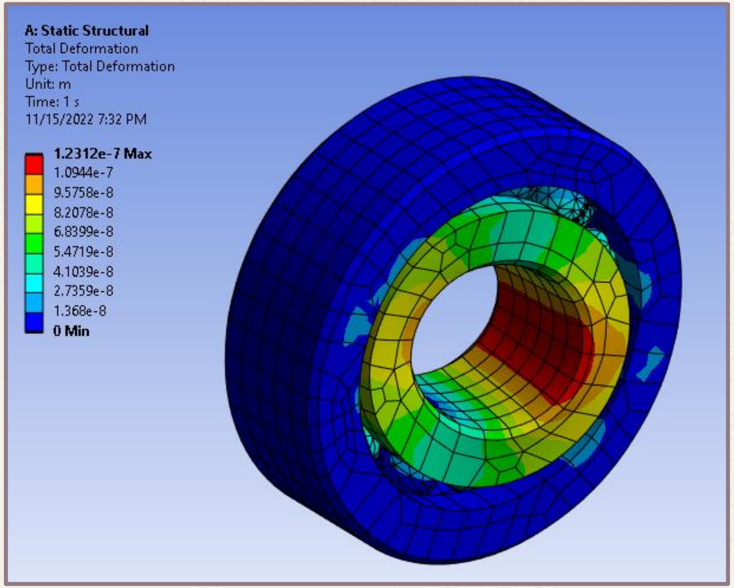
- Applied Load of 25 N (21 N is estimated weight Force Applied to Plate)

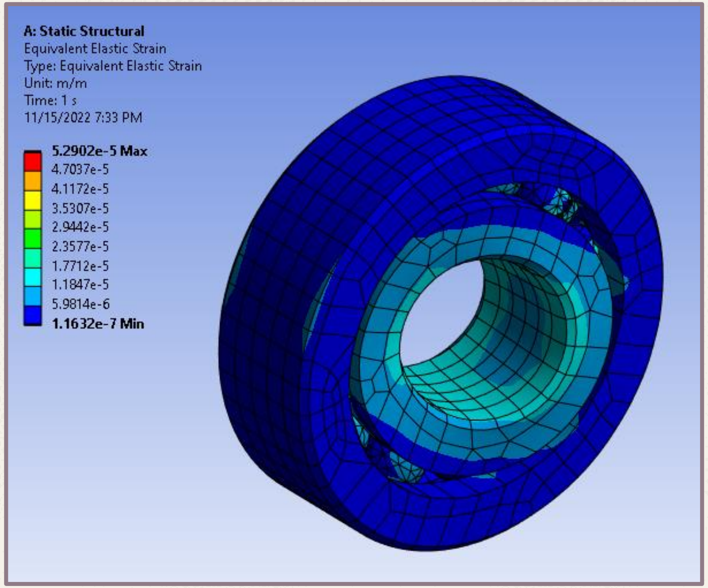




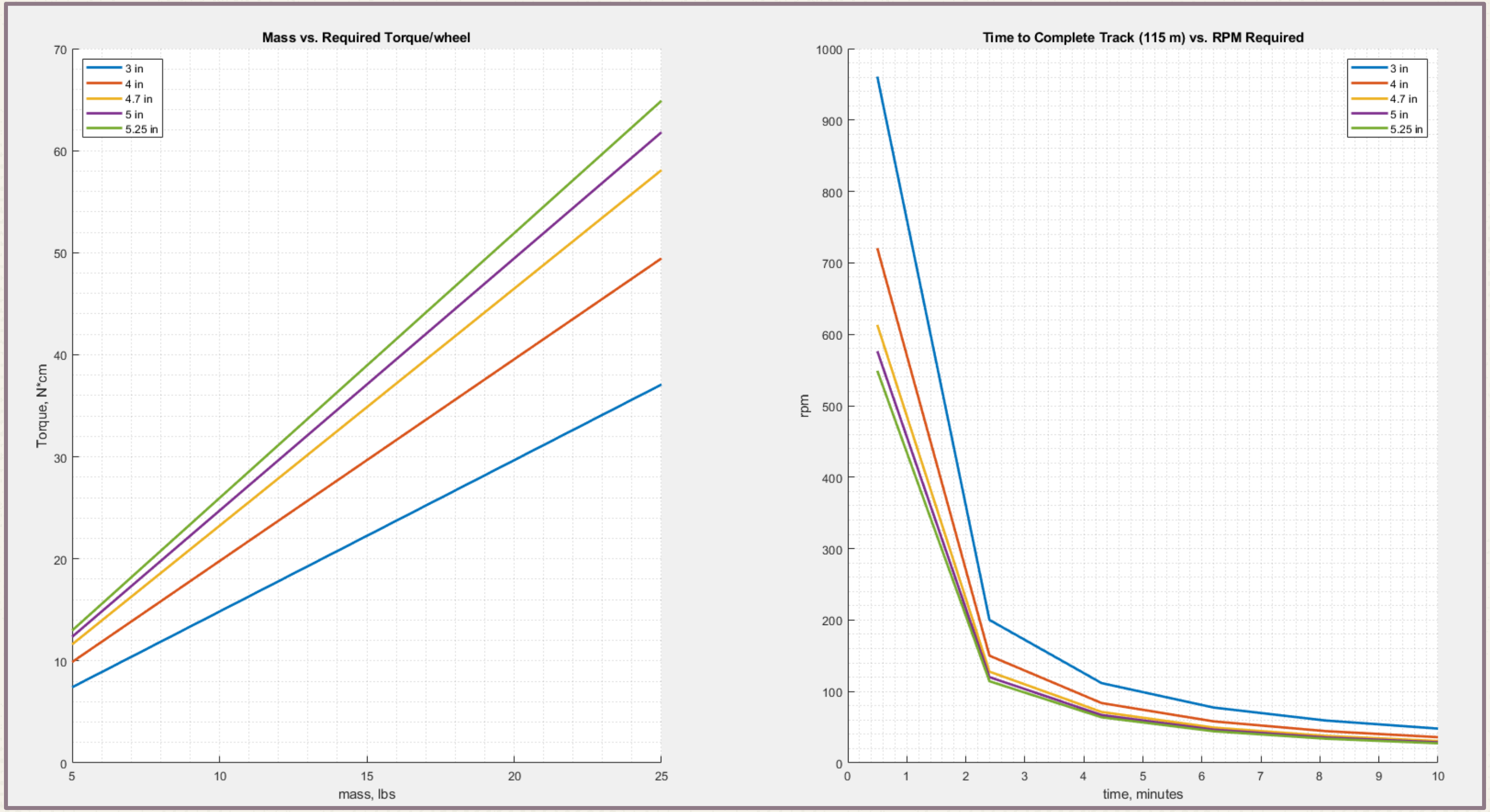
Structural Analysis of Bearing

- Moment of Chain force at Gear Distance + Weight Force of Rover at Wheel distance

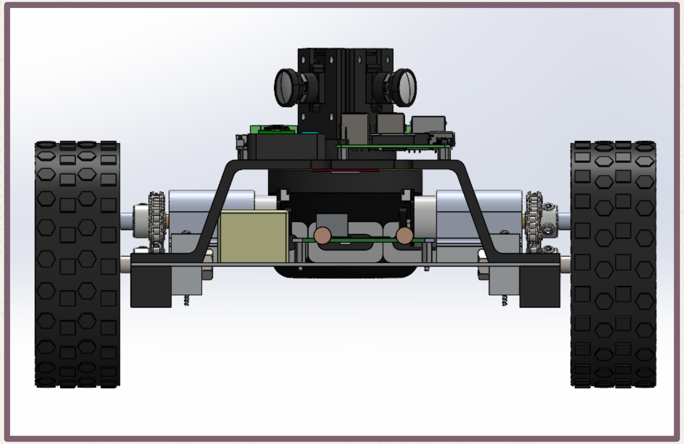


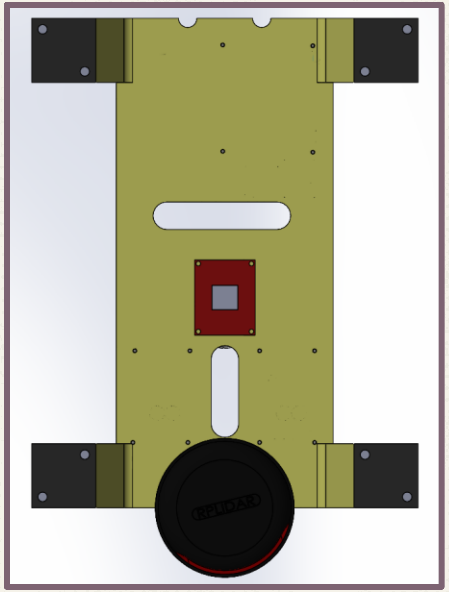


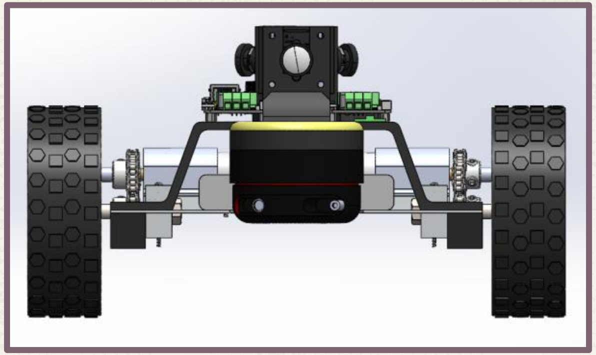
Torque Requirements and Speed Estimates

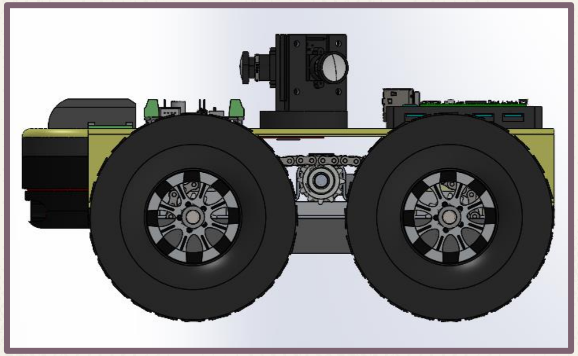


Additional CAD Views of Rover





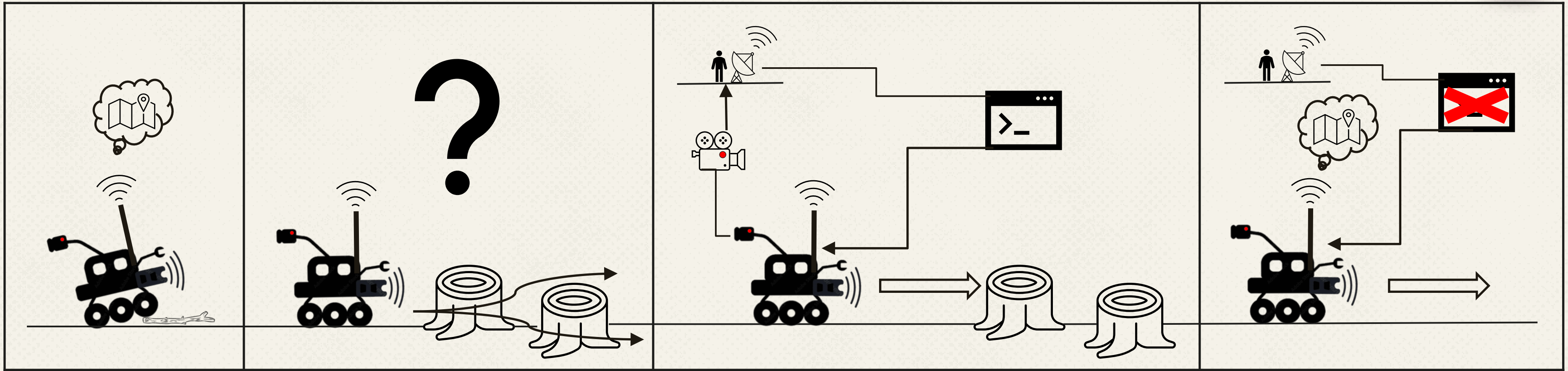




General Backups

Additional CONOPS, mission environment, assumptions, cost breakdown, resources

Manual Control CONOPS



Rover Autonomously Navigates

1. Rover is autonomously navigating to location of interest

Rover Automation Fails

2. Rover encounters an obstacle
3. Rover automation fails and cannot determine a path around the obstacle OR user desires manual control

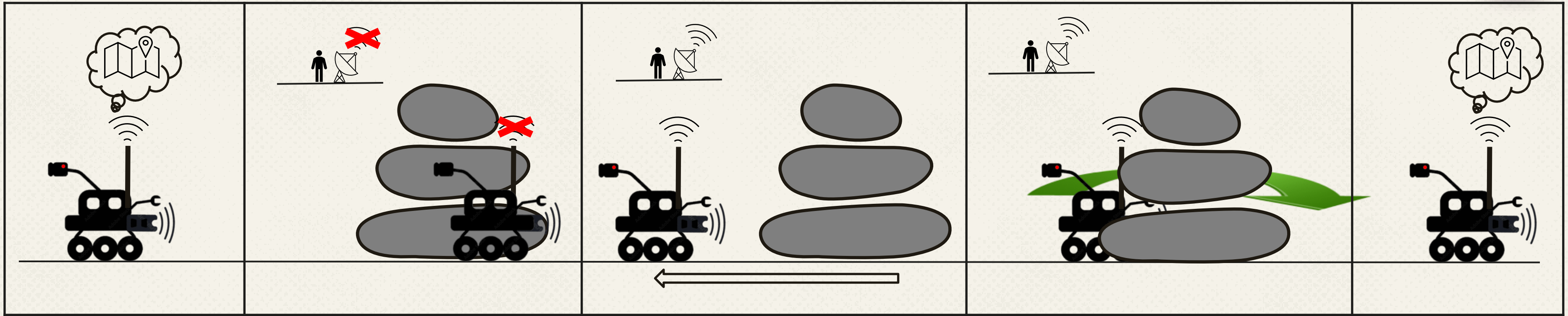
Manual Control

4. User sends command through ground station disabling automation control and enabling manual control
5. User views rover video to determine manual commands
5. User sends commands through ground station instructing rover motion
6. User repeats until obstacle is passed OR user no longer desires automation commands

Re-engage Automation and Continue Mission

7. User sends commands through ground station enabling automation commands and disabling manual commands
8. Rover continues to autonomously navigate to location of interest

Loss of Signal CONOPS



Rover Autonomously Navigates	Rover Moves out of Communication	Rover Navigates into Communication	Rover Sets new Path	Continue Mission
1. Rover is autonomously navigating to location of interest	2. Rover loses communication to the ground station due to an obstacle or due to being out of range of the ground station 3. Communication check detects that is no longer in communication with the ground station	4. The rover automation shall control the rover to move backward following the same path it had just taken 5. The rover will continue to move backward until the communication check detects that communication has been re-established	6. Rover manual control shall be enabled by the automation code after the rover moves back into communication 7. The rover will move past the obstacle continuing to check communication with the ground station 8. If communication is lost under manual command return to step 2	9. The rover shall pass the object and continue autonomously navigating towards the location of interest

Mission Environment Elements

***Images not to scale*

<u>Ideal Shrub:</u>

- Height greater than 2.5 inches
- Diameter greater than 2.5 inches
- High leaf density to prevent visibility through the shrub

<u>Ideal Rock:</u>

- Height greater than 2.5 inches
- Diameter greater than 2.5 inches

<u>Ideal Twigs:</u>

- No more than 0.5 inches in diameter

Assumptions

- Uniformity of the environment – the grass height will be approximately constant throughout the entire mission environment
- Obstacles will be fixed in place, meaning they will not move relative to the ground
- To test our rover’s ability to navigate around obstacles we will test the rover's ability to navigate around the smallest obstacles. It is assumed that if our rover can sense and navigate around the smallest obstacles it will be able to sense and navigate around larger obstacles (given sufficient battery life and a possible path)

Assumptions

- The terrain will be hard enough that the rover does not sink into the ground more than 0.5 inches when initially placed in the environment.
- There will not be an obstacle located within the 10m radius around the location of interest or the ground station
- The LOI coordinates will be determined using the GPS sensor onboard the rover

Cost Breakdown

Item	Quantity	Cost	Purpose	Obtained? Y/N	Total
Motor	2	$19.90	Drivetrain	No	$39.80
Wheels	1	$52.99	Drivetrain	No	$52.99
Chain	2	$17.64	Drivetrain	No	$35.28
Structure Material	1	$0.00	Structure	Yes	$0.00
Sprocket	4	$13.25	Drivetrain	No	$53.00
Axle	4	$10.28	Drivetrain	No	$41.12
Nut	1	$11.00	Drivetrain	No	$11.00
Bearing	8	$4.82	Drivetrain	No	$38.56
GPS Chip	1	$0.00	GPS	Yes	$0.00
GPS Antenna	1	$0.00	GPS	Yes	$0.00
Lidar	1	$0.00	Sensing	Yes	$0.00
Camera	3	$50.00	Pictures / Video	No	$150.00
Rocket M2	1	$0.00	Comms	Yes	$0.00
Magnetometer	1	$19.95	Control	No	$19.95
ESC	2	$8.90	Drivetrain	No	$17.80
Teensy	1	$31.50	Control	No	$31.50
Raspberry Pi	1	$118.99	OBC	No	$118.99
8mm x 1' shaft	1	$5.35	Drivetrain	No	$5.35
Bearing Mount Screws	1	$12.45	Drivetrain	No	$12.45
Aluminum Sheet	1	$7.97	Motor Bracket	No	$7.97
Neodymium Magnets	8	$0.50	Structure	No	$4.00
Boost Converter	1	$0.00	Electrical	Yes	$0.00
USB Hub	2	$16.95	Electrical	No	$33.90
DC-DC Poe Adapter	1	$0	Electrical	Yes	$0.00
Buck Converter	1	$14.88	Electrical	No	$14.88
Batteries	3	$50	Electrical	No	$150.00
Standoffs	12	$1.88	Structure	No	$22.56
Standoffs	4	$1.99	RocketM2	No	$7.96
Standoff Screws	1	15.08	Structure	No	$15.08
Bearing Mount Material	1	15.25	Structure	No	$15.25

Resources

- IMU/Magnetometer Selection: https://www.adafruit.com/product/5543
- Lidar Selection: RPLidar A2M8 Photo, https://www.slamtec.com/en/Lidar/A2Spec
- Lidar Selection: Datasheet A2M8, https://www.slamtec.com/en/Support#rplidar-a-series
- GPS Selection: https://www.sparkfun.com/products/15005
- GPS Survey Point Map: https://geodesy.noaa.gov/NGSDataExplorer/
- Land Moves: https://www.weather.gov/jetstream/plates_max
- Ground Station Antenna Selection: https://www.tupavco.com/products/panel-antenna-24ghz-wifi-20dbi-wireless-outdoor-18-directional-n-f
- Ground Station/Rover Radio Selection: https://store.ui.com/collections/operator-airmax-devices/products/rocket-m2
- Camera Selection/Spec Sheet: https://www.arducam.com/product/arducam-1080p-low-light-wdr-ultra-wide-angle-usb-camera-module-for-computer-2mp-cmos-imx291-160-degree-fisheye-mini-uvc-usb2-0-spy-webcam-board-with-microphone-3-3ft-cable-for-windows-linux-mac-os/
- Coefficient of Friction: https://www.engineeringtoolbox.com/friction-coefficients-d_778.html

Resources

- Curiosity Image: https://www.nasa.gov/image-feature/jpl/curiosity-s-selfie-at-mont-mercou
- NIFTi Image: Kruijff, G. J. M., Kruijff-Korbayová, I., Keshavdas, S., Larochelle, B., Janíček, M., Colas, F., Liu, M., Pomerleau, F., Siegwart, R., Neerincx, M. A., Looije, R., Smets, N. J. J. M., Mioch, T., van Diggelen, J., Pirri, F., Gianni, M., Ferri, F., Menna, M., Worst, R., … Hlaváč, V. (2014). Designing, developing, and deploying systems to support human–robot teams in disaster response. Advanced Robotics, 28(23), 1547–1570. https://doi.org/10.1080/01691864.2014.985335
- Pleasant View Sports Complex Image: https://sportsfieldmanagementonline.com/2015/12/21/championship-field-pleasant-view-sports-complex-boulder-co/7729/
- Shrub Image: https://www.collinsdictionary.com/us/dictionary/english/bush
- Rock Image: https://www.pngwing.com/en/free-png-zaziy
- Twig Image: https://daily.wordreference.com/2021/07/05/intermediate-word-of-the-day-twig-2/

Resources

- All Components

Motor	https://www.mouser.com/ProductDetail/DFRobot/FIT0521?qs=0lQeLiL1qyZe5LlZGe9xQg%3D%3D
Wheels	https://www.amazon.com/INJORA-Beadlock-Wheels-Crawler-Traxxas/dp/B07CWQ7BS7
Chain	https://www.mcmaster.com/6261K171/
Chain Sprocket	https://www.mcmaster.com/2737T102/
Fastener (Hex Screw)	https://www.mcmaster.com/91280A284/
Fastener (Nut)	https://www.mcmaster.com/91423A511/
Ball Bearing	https://www.mcmaster.com/5972K91/
GPS RTK Board	https://www.sparkfun.com/products/15005
GPS/GNSS Antenna	https://www.sparkfun.com/products/14986
LiDAR Sensor	https://www.slamtec.com/en/Lidar/A2Spec
Camera	https://www.amazon.com/Arducam-Computer-Fisheye-Microphone-Windows/dp/B07ZS75KZR?th=1
IMU	https://www.adafruit.com/product/5543?gclid=Cj0KCQjwteOaBhDuARIsADBqRejB6XwzW9MWYGnD6Z1rjf-sMFtspATbbgo9m5cIFM6jJ76kiW9WyzEaAl36EALw_wcB
ESC- Motor Driver	https://www.dfrobot.com/product-2429.html
Teensy 4.1	https://www.pjrc.com/store/teensy41.html
Raspberry Pi 4 Model B	https://www.raspberrypi.com/products/raspberry-pi-4-model-b/

Resources

- All Components

Steel Rod	https://www.mcmaster.com/8920K26-8920K261/
Fastener (Screw)	https://www.mcmaster.com/91772A508/
Aluminum Sheet	https://www.mcmaster.com/89015K171/
DC-DC Converter	https://www.amazon.com/dp/B09ZXT6J7S?ref_=cm_sw_r_cp_ud_dp_MSED5QYZBHRZ4P14AVBR
USB Hub	https://www.amazon.com/Sabrent-4-Port-Individual-Switches-HB-UM43/dp/B00JX1ZS5O?th=1
DC to DC Converter & PoE Injector	https://www.tyconsystems.com/tp-dcdc-1224g
Voltage Regulator	https://www.amazon.com/dp/B099YQDGCH?_encoding=UTF8&psc=1&ref_=cm_sw_r_cp_ud_dp_GP1JMZDDT5M5T11FRJJM
Battery	https://www.digikey.com/en/products/detail/rose-batteries/LI-2S1P-2200/15283295?utm_adgroup=Battery%20Products&utm_source=google&utm_medium=cpc&utm_campaign=Dynamic%20Search_EN_Product&utm_term=&utm_content=Battery%20Products&gclid=Cj0KCQiA4OybBhCzARIsAIcfn9k3V3ybhwnEMUH8EVHfyMmRkzJJIdbGGh4rBpF5R22EuIMkg1x87iQaAkadEALw_wcB
Fastener (Standoff)	https://www.mcmaster.com/98952A101/
Fastener (Standoff)	https://www.mcmaster.com/98952A107/
Fastener (Screw)	https://www.mcmaster.com/91290A013/
Aluminum Bar	https://www.mcmaster.com/9008K87-9008K871/