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

Test Readiness Review

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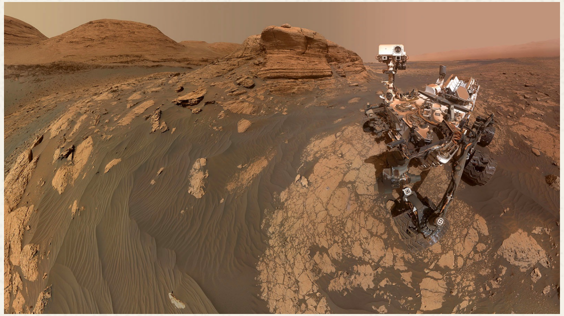
** **Emphasized names correspond to presenting members**

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

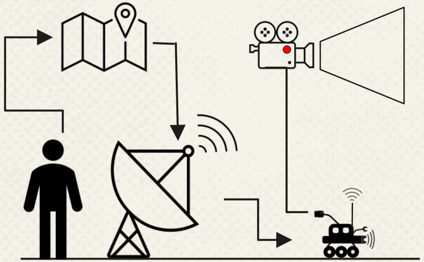
NIFTi Unmanned Ground Vehicle (UGV)
Image Source: Advanced Robotics

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

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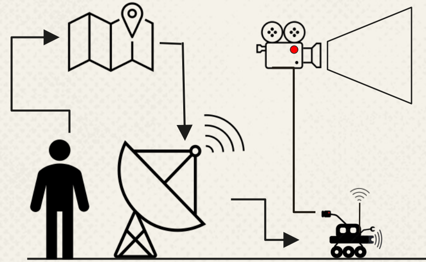

Initiate Rover

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

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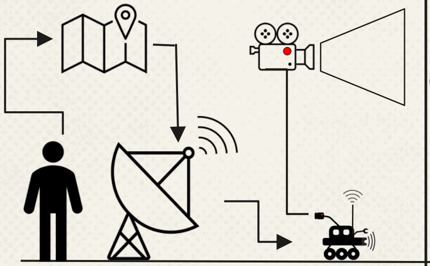

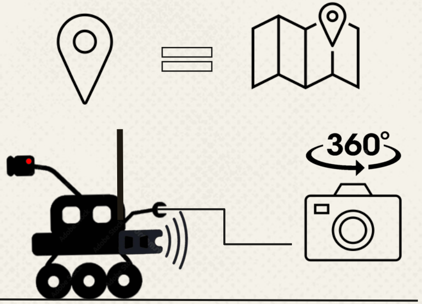

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Autonomous Navigation

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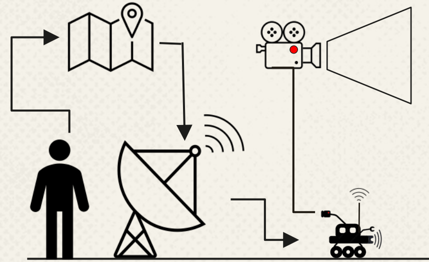
7. Rover transmits video to the ground station as it navigates

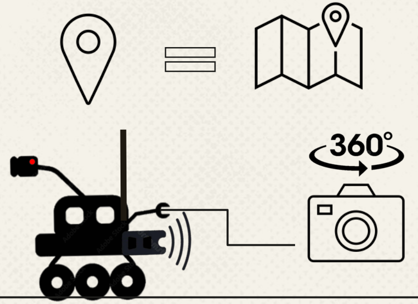
Reach Location of Interest

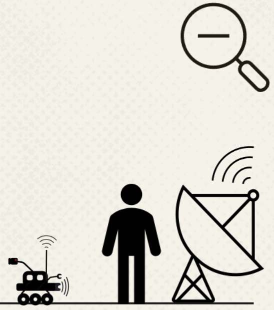
8. Rover reaches location of interest (up to 100m away from ground station)
9. Rover captures images of location of interest given user input
10. Rover transfers images to the ground station

High-Level Mission CONOPS

Rover Continuously Communicating & Sending Video Packets to Ground Station





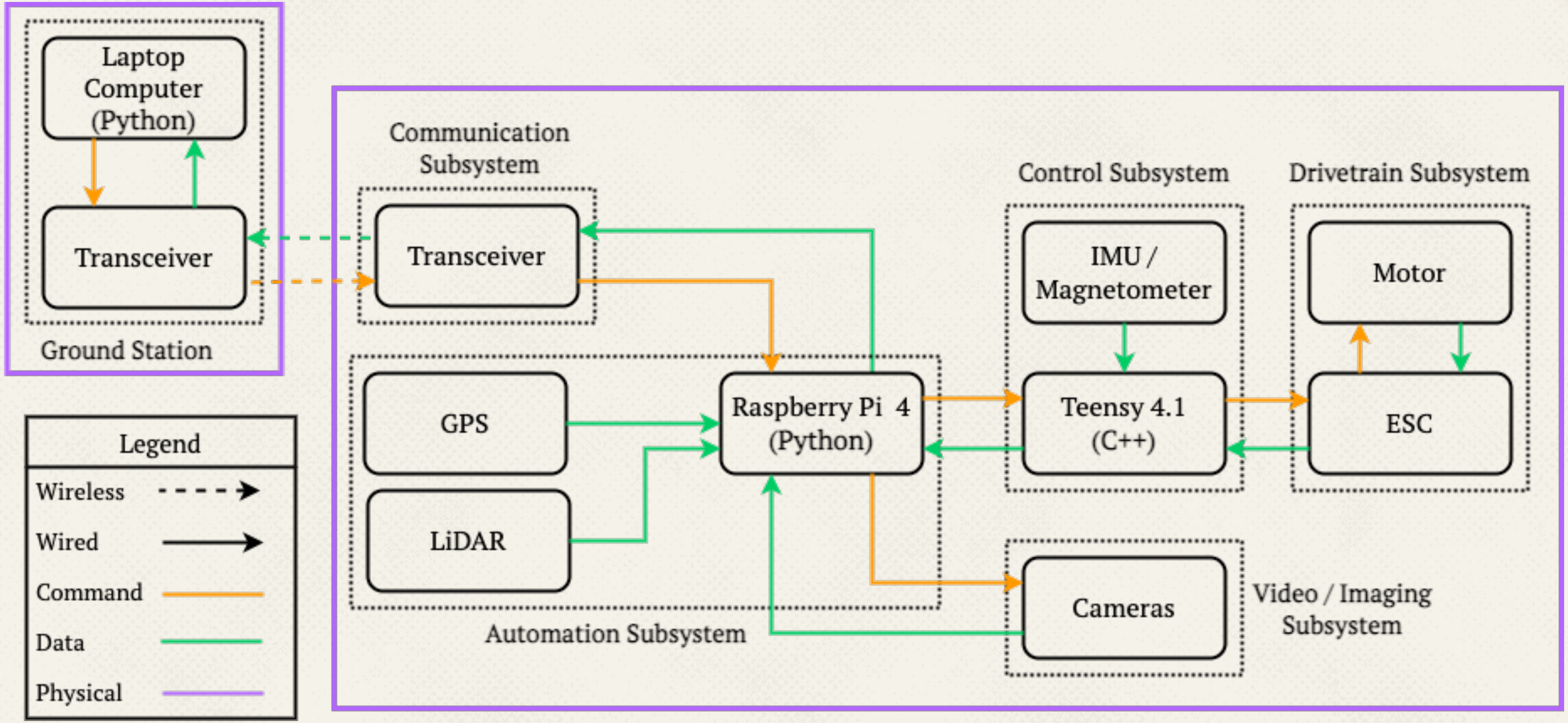


Initiate Rover	Autonomous Navigation	Reach Location of Interest	Return to Ground Station
1. Setup ground station **2.** Initialize rover and ground station communication **3.** User sends location of interest through ground station to rover **4.** Initiate rover video recording	**5.** Rover navigates over small sticks autonomously **6.** Rover navigates around obstacles autonomously **7.** Rover transmits video to the ground station as it navigates	**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	**11.** Rover autonomously navigates to ground station (steps 5,6,7) **12.** Rover is collected and prepared for next mission

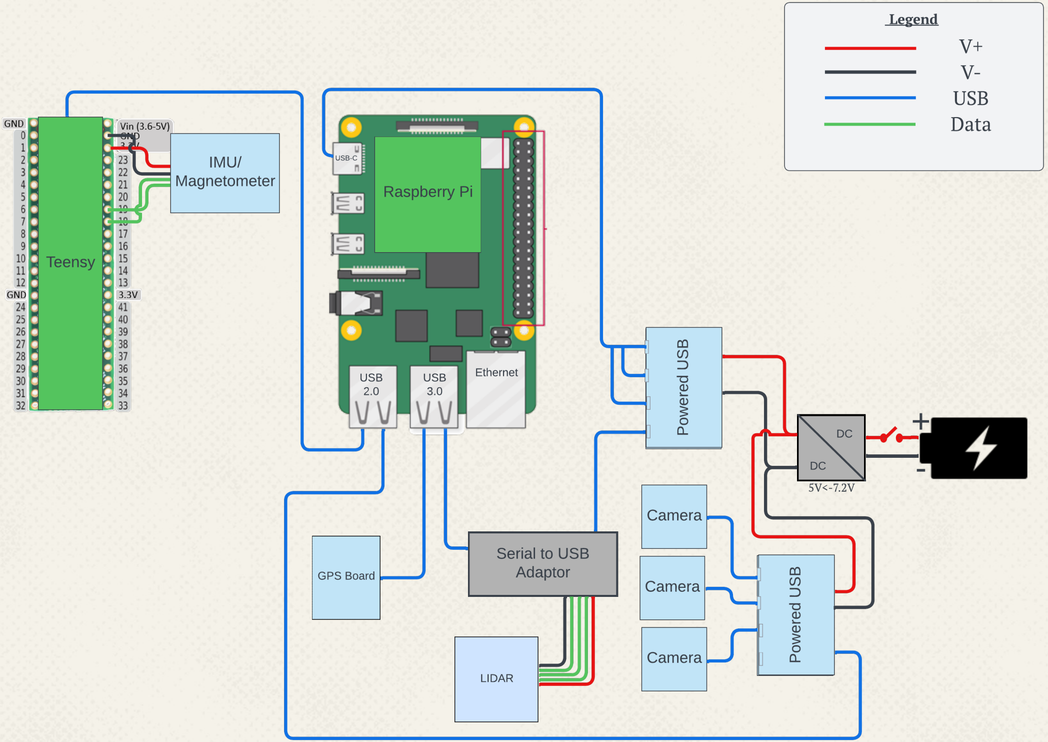
Design Solution Overview

Functional block diagram, circuit diagram, rover design overview, design changes

Functional Block Diagram



Circuit Diagram



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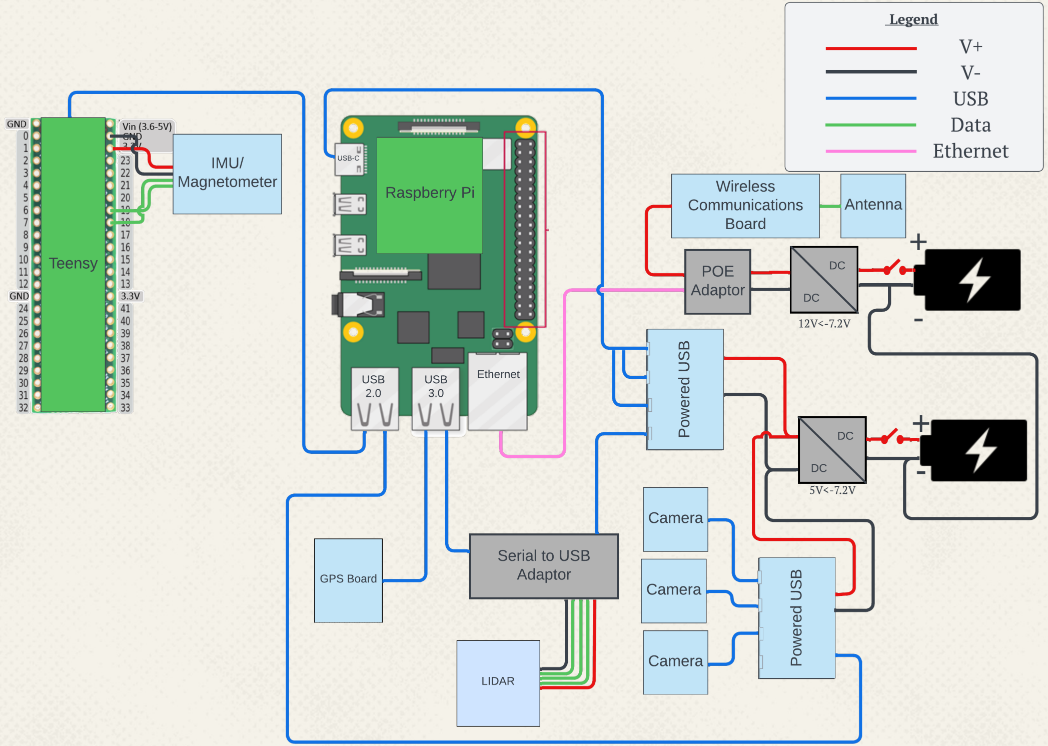

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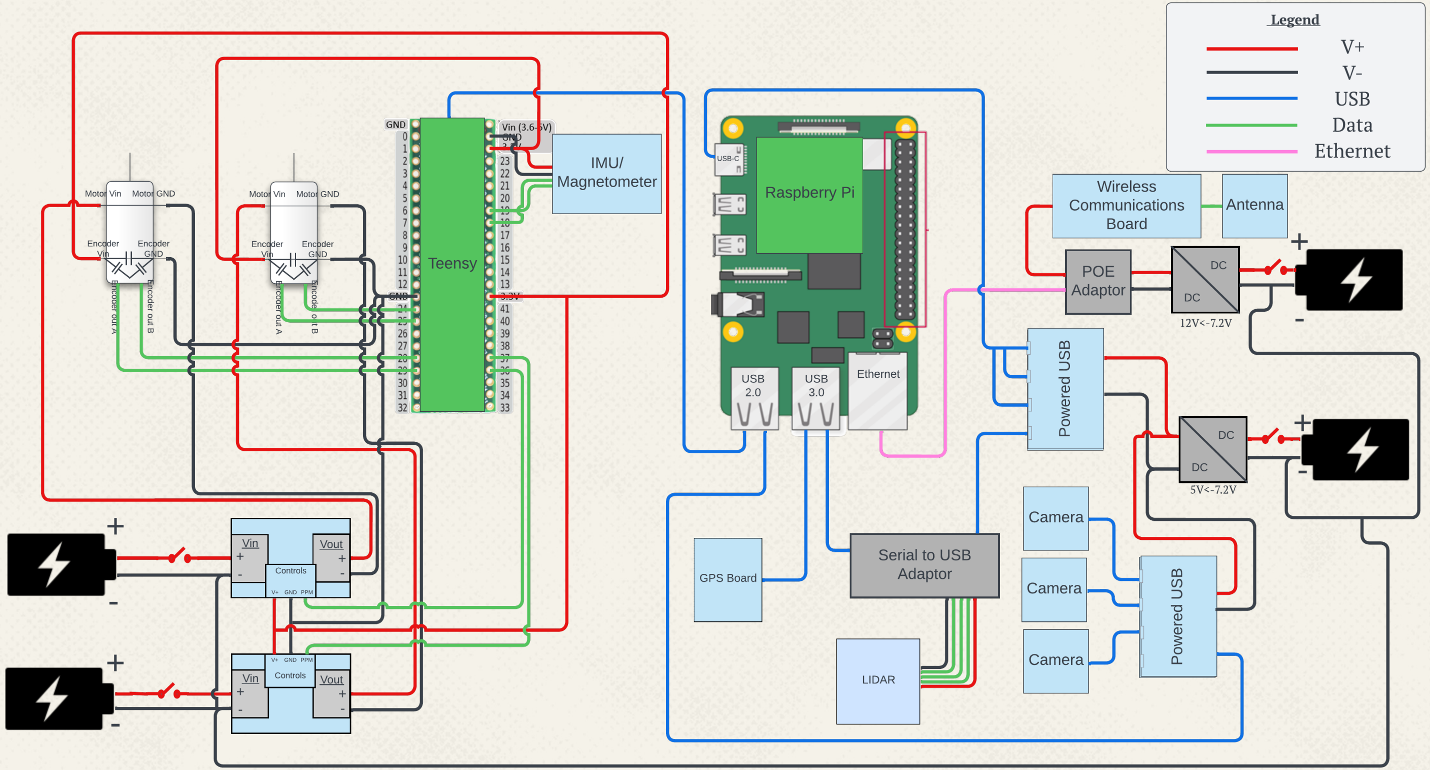
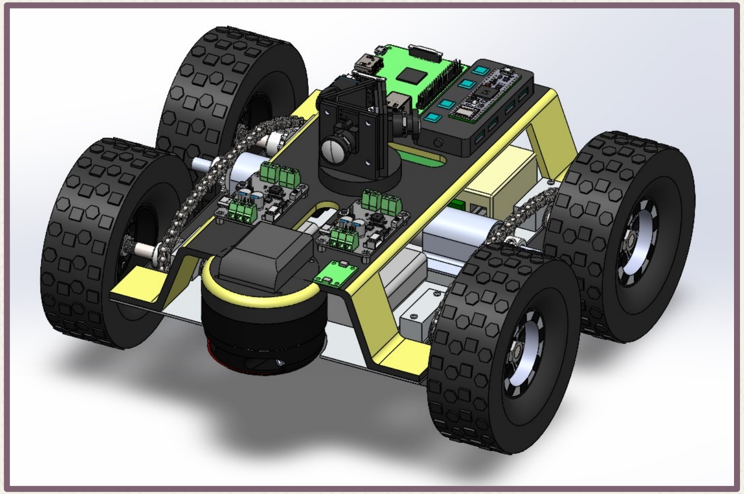
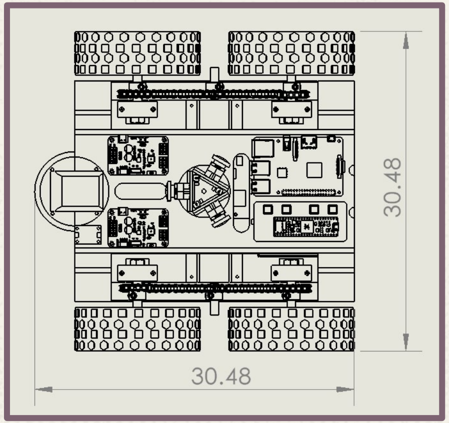
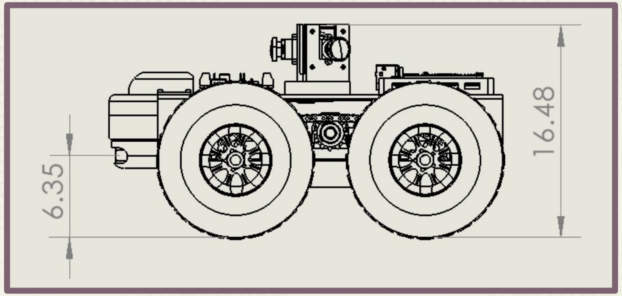


Rover Design Overview



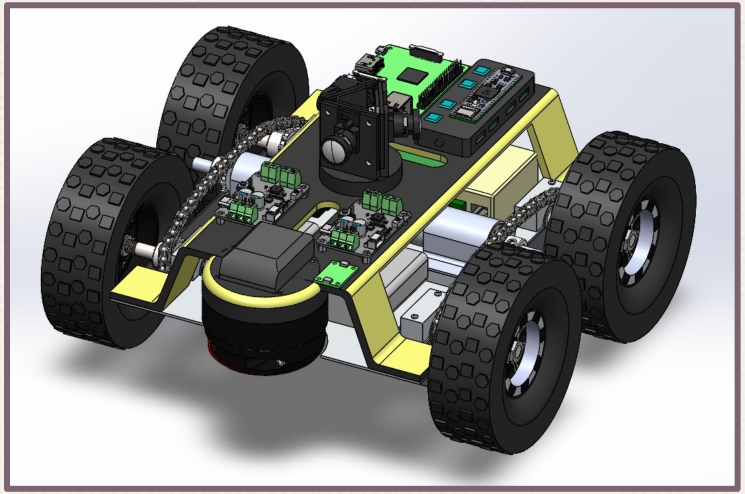


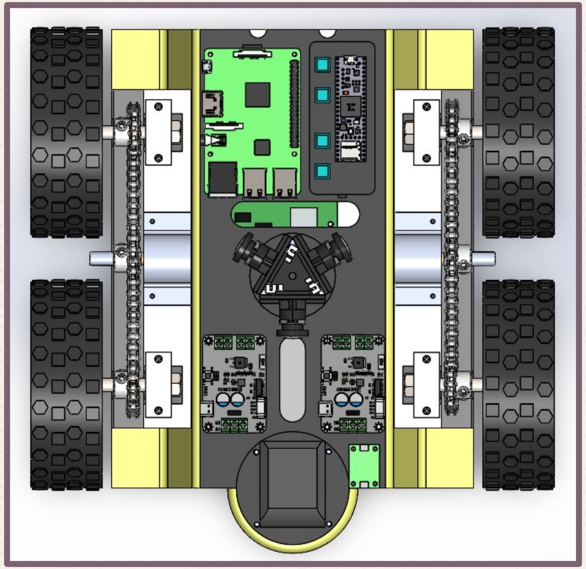


Predicted Rover Specs:

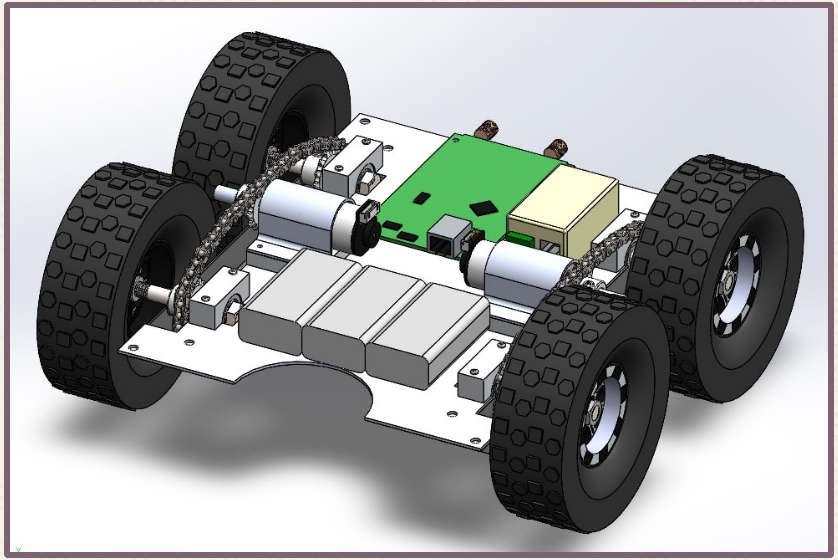
- Weight: 2.96 kg
- 30.48 x 30.48 x 16.5 cm (no antenna)

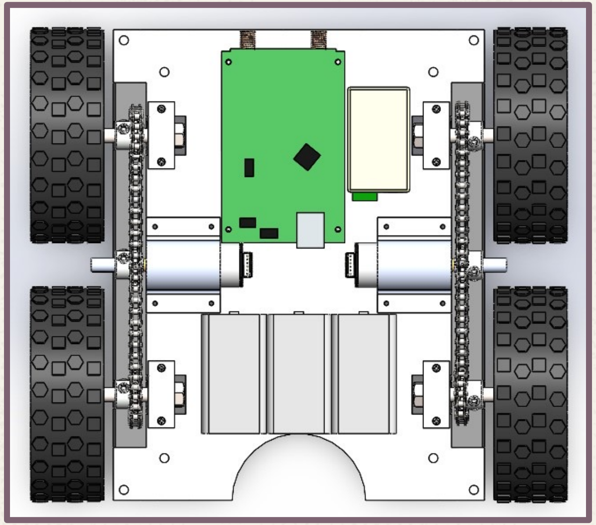
Notable Component Selection





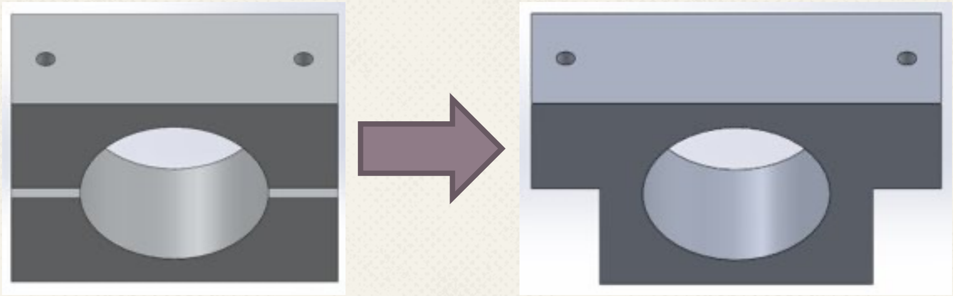
Notable Component Selection Continued





Design Changes

- **Hardware Changes**
  1. ESC: different hardware (old hardware didn't meet specifications)
  2. Onboard Batteries: 4 batteries instead of 3 to support extra current pulled by motors on startup
  3. Drivetrain: altered motor mounts, bearing mounts, drivetrain design



Old vs New Bearing Mount

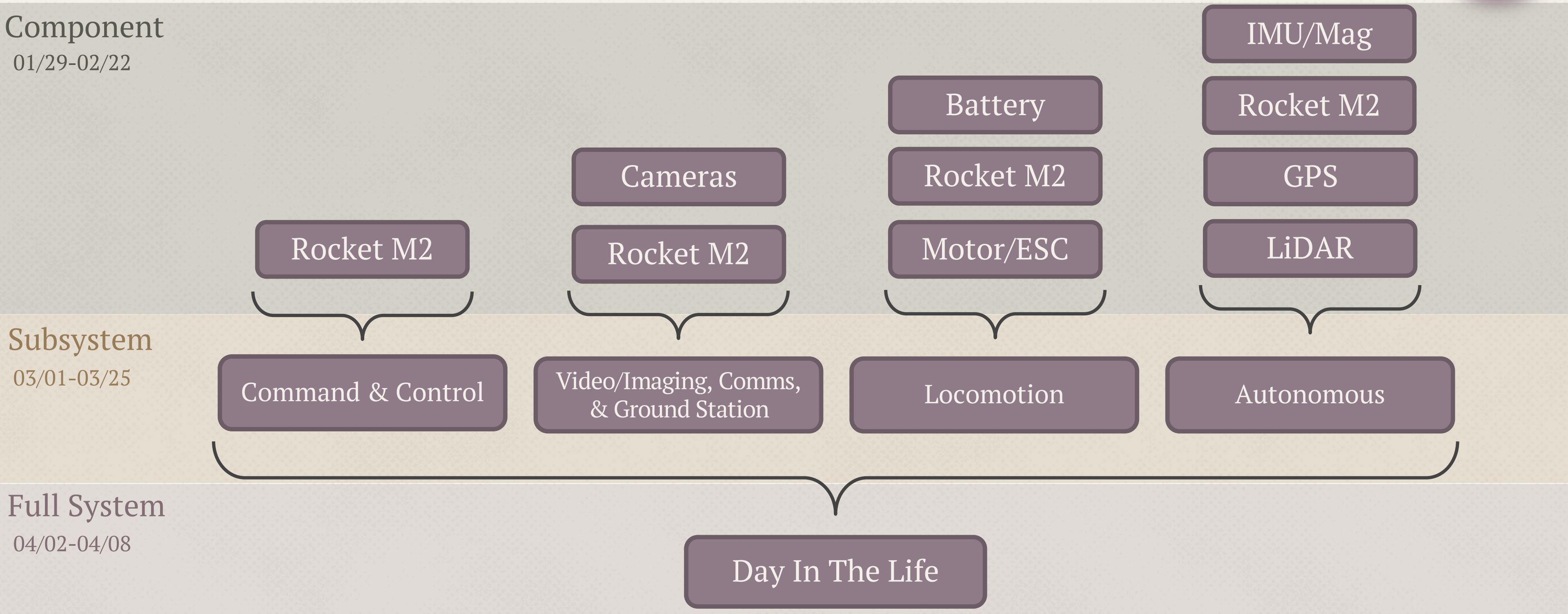
Critical Project Elements

CPE #	Relevant Area	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 autonomy 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

Schedule Overview

Test summary, GANTT chart development

Test Summary



Test Summary

Component
01/29-02/22

*Completed Tests

- Command & Control: Rocket M2
- Video/Imaging, Comms, & Ground Station: Cameras, Rocket M2
- Locomotion: Battery, Rocket M2, Motor/ESC
- Autonomous: IMU/Mag, Rocket M2, GPS, LiDAR

Subsystem
03/01-03/25

- Command & Control
- Video/Imaging, Comms, & Ground Station
- Locomotion
- Autonomous

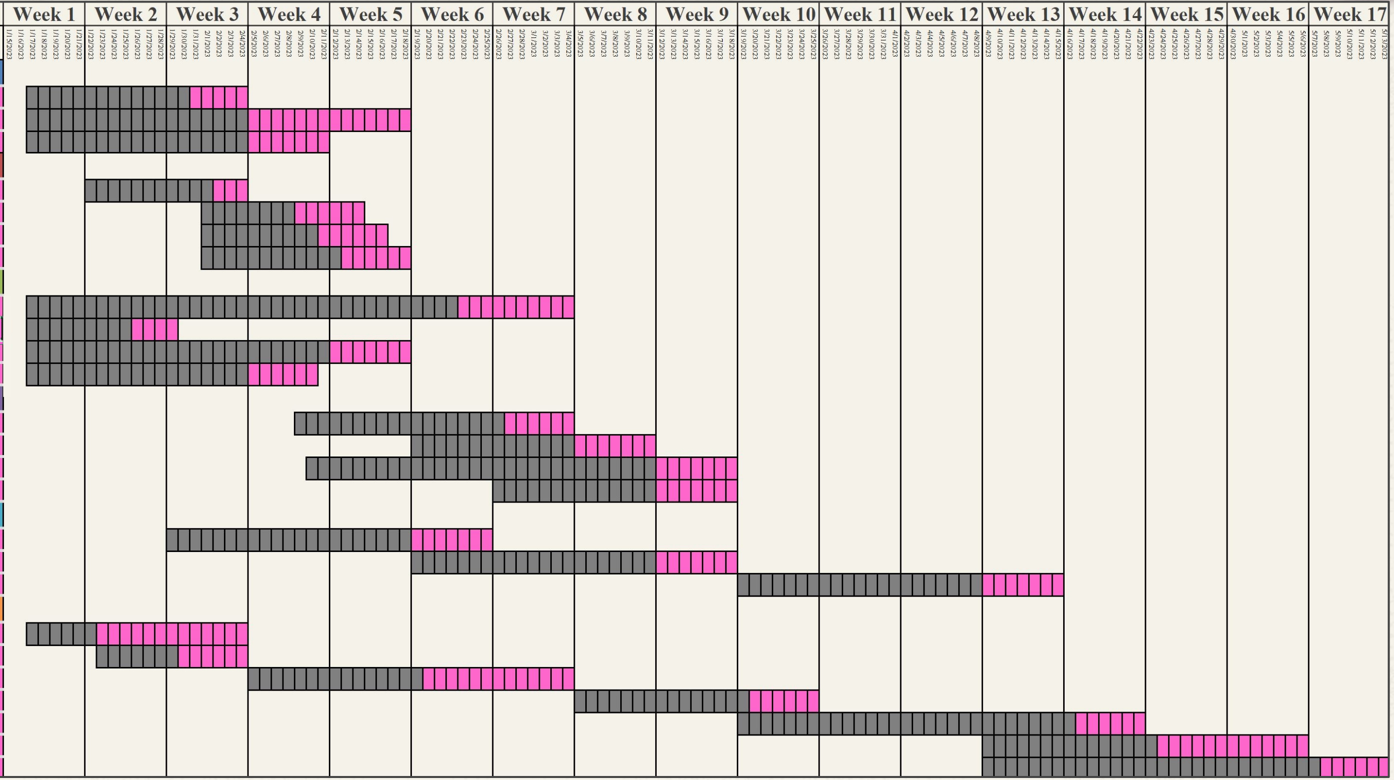
Full System
04/02-04/08

- Day In The Life

GANTT Chart

CDR version:

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



GANTT Chart

Schedule Changes:

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
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Fabrication			
Reviews / Setup	1/22/2023	2/1/2023	2/4/2023
Rover Structure	2/1/2023	2/8/2023	2/14/2023
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Integration			
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Electrical Integration	2/19/2023	3/4/2023	3/11/2023
Software Integration	2/10/2023	3/11/2023	3/18/2023
Final Integration	3/5/2023	3/18/2023	3/25/2023
Testing			
Component Testing	1/29/2023	2/18/2023	2/22/2023
Subsystem Testing	3/1/2023	3/21/2023	3/25/2023
"Day in the Life"	4/2/2023	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
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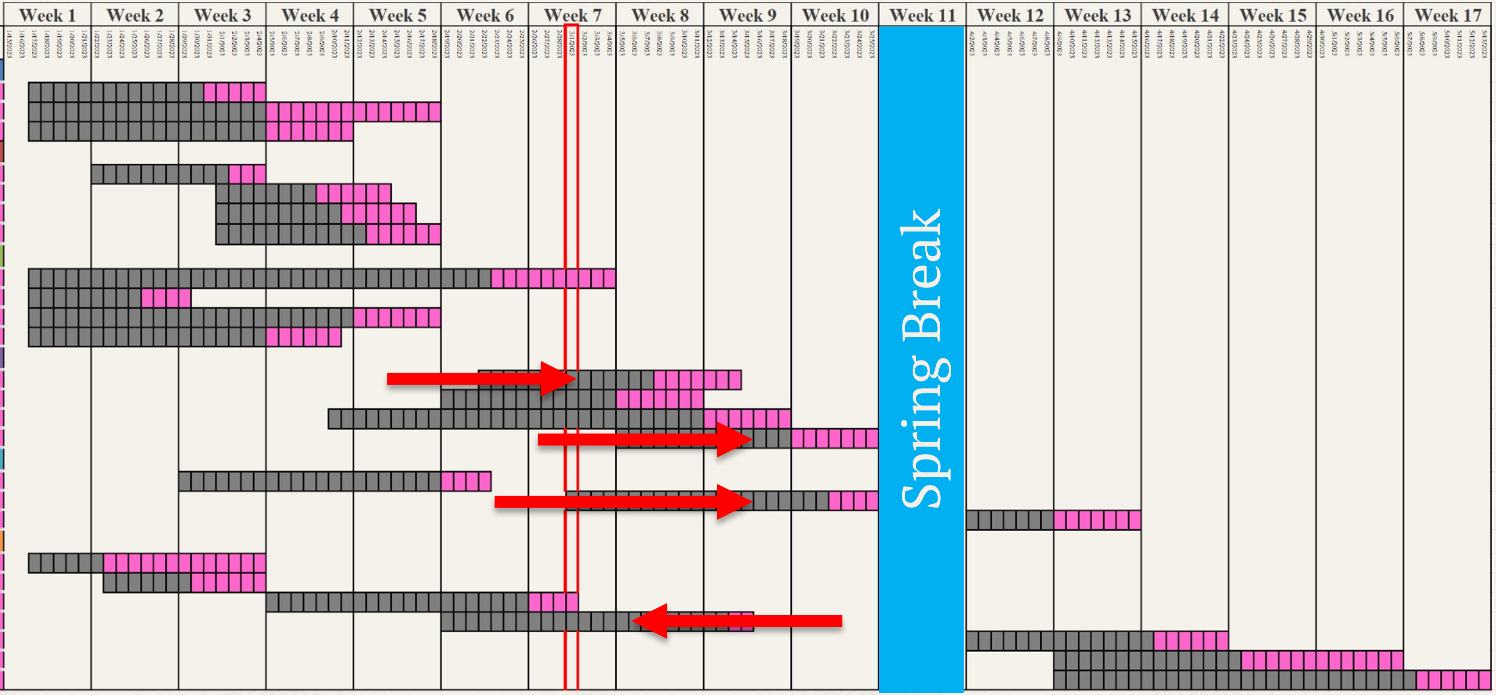
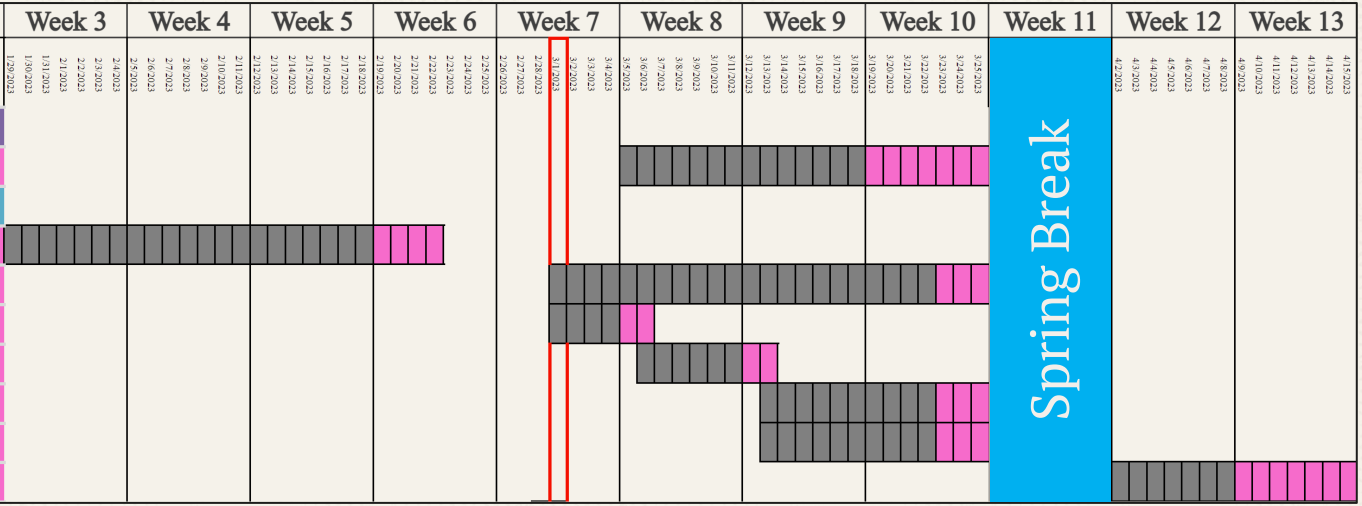


GANTT Chart

Testing Focus:

TASK	Start	End	Margin
Integration			
Final Integration	3/5/2023	3/18/2023	3/25/2023
Testing			
Component Testing	1/29/2023	2/18/2023	2/22/2023
Subsystem Testing	3/1/2023	3/22/2023	3/25/2023
Command and Control	3/1/2023	3/4/2023	3/6/2023
Video and Imaging	3/6/2023	3/11/2023	3/13/2023
Locomotion	3/13/2023	3/22/2023	3/25/2023
Automation	3/13/2023	3/22/2023	3/25/2023
"Day in the Life"	4/2/2023	4/8/2023	4/15/2023



GANTT Chart

Critical Path:

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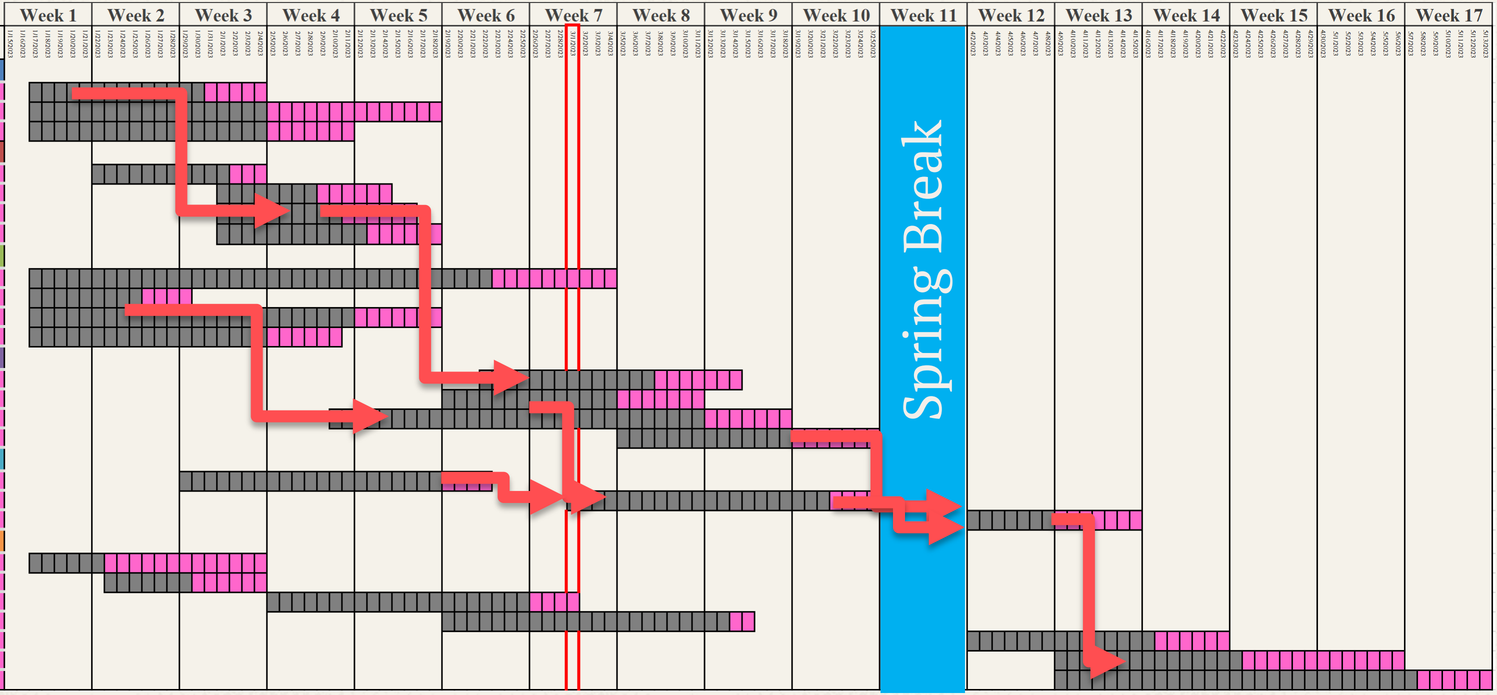


Test Readiness

Autonomous subsystem test, "Day in The Life" test

Autonomous Validation

Test Introduction :

- **Test Purpose:**
  - To verify the autonomy procedures and functions used to reach location of interest without any user input

Design Requirements Being Verified:

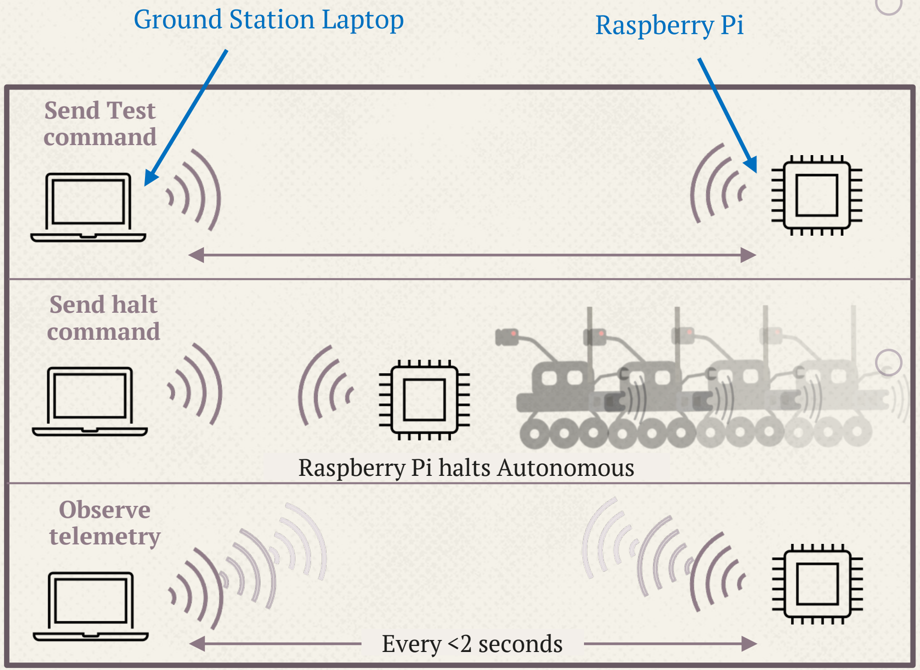
DR. 1.5, 1.8, 2.2, 3.2, 3.3, 3.5, 3.8, 3.9, 6.1, 6.5

Preliminary Testing Required

Test Type	Test	Test Description	Status
Component	LiDAR Sensor	Utilize the Raspberry Pi to record and process data received by the LiDAR sensor pertaining to obstacles in view. Must ensure objects of defined obstacle size are capable of detection by the selected component.	Complete
Component	GPS	Analyze navigation accuracy of GPS receiver and processing board using known US Geological Survey locations for optimal mission LOI determination.	Complete
Component	IMU / Magnetometer	Confirm acceleration and magnetic field data produced by IMU/Magnetometer sensor is in accordance with predefined sensor orientations.	Complete
Component	Rocket M2	Transmit data through the ground station and rover Rocket M2 devices verifying receival of complete data package.	Complete

Autonomous Verification

Autonomous Subsystem Test Overview:



* Safety plan for autonomy testing detailed in Back Ups

Test Setup:

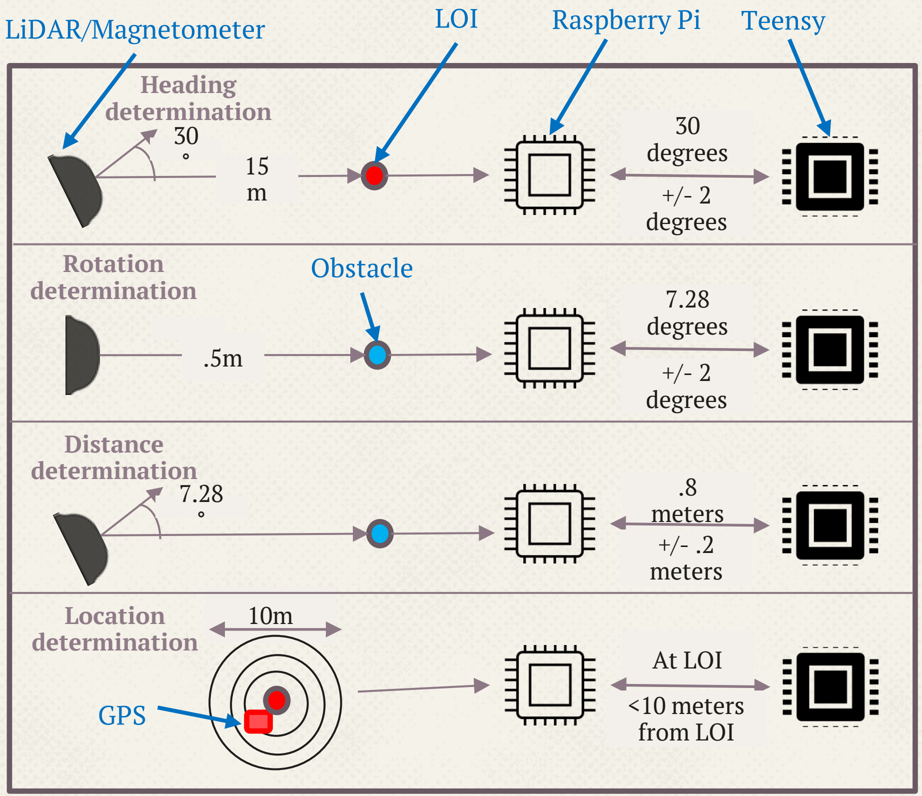
- Test materials needed: 6.4cm wide Obstacle, Protractor, Raspberry Pi, GPS, Teensy, LiDAR, Magnetometer, Ground Station, Timer, Meter stick
- Place GPS/Raspberry Pi/Teensy/Ground Station
- Define LOI 15 m away due North
- Place and connect LiDAR/Magnetometer to Pi

Ground Station Test Procedure:

1) Start timer
2) Send a test command
3) Note the time between sending the command and receiving a ping back to the ground station (DR. 6.1, 6.5)
4) Send a halt manual command and note response (DR. 1.8)
5) Start timer
6) Observe telemetry for 10 seconds and note the time between each location update (DR. 3.9)

Autonomous Verification

Autonomous Subsystem Test Overview :



Autonomy Test Procedure:

1) Use a protractor to place LiDAR/Magnetometer at a 30 degree offset from pointing at LOI
2) Start heading determination function and save the value passed to the Teensy (DR. 3.2, 3.3, 3.8,1.5)
3) Use a protractor to rotate LiDAR/Magnetometer 30 degrees
4) Use a meter stick to place an obstacle .5m away from LiDAR centered obstructing the view of the LOI
5) Start rotation determination function and save value passed to the Teensy. (DR. 3.2, 3.3, 3.8,1.5)
6) Rotate LiDAR/Magnetometer 7.28 degrees
7) Start distance determination function and save the value passed to the Teensy (DR. 3.2, 3.3, 3.8,1.5)
8) Place GPS/Raspberry Pi at LOI.
9) Start location determination function and save the value passed to the Teensy (DR. 3.2, 3.5, 6.1)

Autonomous Verification

Autonomous Subsystem Test Success Criteria :

Design Requirements Being Verified:

DR. 1.5, 1.8, 2.2, 3.2, 3.3, 3.5, 3.8, 3.9, 6.1, 6.5

Pass Criteria and Expected Performance				
Req. #	**Requirement / Specification**	**Pass Criteria**	**Expected Result**	**Verification Method**
DR 1.5	Rover control subsystem shall receive commands from autonomous subsystem	Teensy receives commands from Pi	Teensy outputs a response that a command is received	Demonstration
DR 1.8	Rover control system shall override autonomous commands with manual control commands when manual control commands are received.	Autonomous procedures halted with manual command	Pi will receive a command and stop autonomous function	Demonstration/ Testing
DR 2.2	The communication subsystem shall send telemetry data to ground station	Ground station receives telemetry data from Pi	Ground station receives data from Pi as demonstrated in component test	Demonstration

Autonomous Verification

Autonomous Subsystem Test Success Criteria :

Design Requirements Being Verified:
DR. 1.5, 1.8, 2.2, 3.2, 3.3, 3.5, 3.8, 3.9, 6.1, 6.5

Pass Criteria and Expected Performance				
Req. #	**Requirement / Specification**	**Pass Criteria**	**Expected Result**	**Verification Method**
DR 3.2	The autonomous subsystem shall receive data from the remote sensing subsystem	Pi receives telemetry from Teensy and data from LiDar	Pi receives telemetry and LiDar data as shown in component testing	Testing
DR 3.3	The autonomous subsystem shall send commands to the control subsystem	Pi sends commands to Teensy	Teensy outputs a response that command received	Demonstration/ Testing
DR 3.5	The autonomous subsystem shall determine when the rover has reached the location of interest	Rover detects it is within 10m of LOI	Rover detects it is within 2.5m of LOI	Testing
DR 3.8	The remote sensing subsystem shall send data to the autonomous subsystem	LiDAR/GPS will send data to Pi	LiDAR/GPS will send data to Pi	Testing

Autonomous Verification

Autonomous Subsystem Test Success Criteria :

Design Requirements Being Verified:
DR. 1.5, 1.8, 2.2, 3.2, 3.3, 3.5, 3.8, 3.9, 6.1, 6.5

Pass Criteria and Expected Performance				
Req. #	**Requirement / Specification**	**Pass Criteria**	**Expected Result**	**Verification Method**
DR 3.9	Rover shall communicate its location to the ground station at least once every 2 seconds	Telemetry is received at least once every 2 seconds	Telemetry is received every second	Demonstration
DR 6.1	Ground station shall receive rover telemetry data from the rover	Ground station receives telemetry data from Pi	Ground station receives data from Pi as demonstrated in component test	Demonstration
DR 6.5	Ground station shall display rover telemetry within 2 seconds of receiving it	Telemetry is displayed in <2 seconds	Telemetry is displayed in less than 1 second	Demonstration/ Testing

Day in the Life

Test Introduction :

- **Test Purpose:**
  - To execute the mission CONOPS and satisfy all functional requirements
  - To cover all design requirements for the integrated system

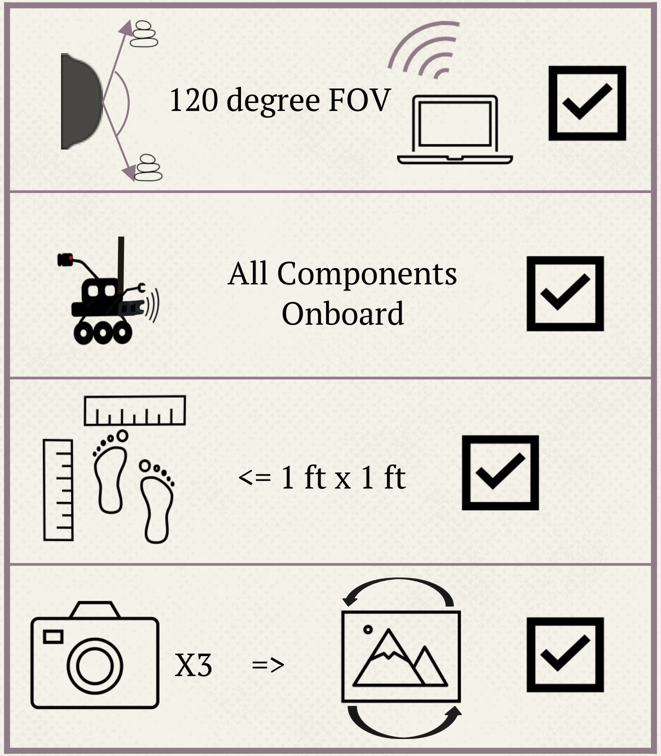
Functional and Design Requirements Being Verified:

DR. 2.10, 2.11, 2.12, 3.1, 3.4, 3.7, 4.1, 4.2, 4.3, 4.4, 4.5, 5.1
FR. 1, 2, 3, 4, 5, 6, 7

Preliminary Testing Required			
Test Type	**Test**	**Test Description**	**Status**
Subsystem	Command and Control	Capability of the ground station to send location of interest coordinates and manual commands and capability of the rover to receive these commands	In Progress
Subsystem	Locomotion	Motion of the rover to move forward backward and turn 360 degrees, as well as the range requirement of the rover	Not Complete
Subsystem	Autonomous	Capability of the autonomous subsystem to detect obstacles and gather telemetry data to define the appropriate movement commands	Not Complete
Subsystem	Video and Imaging	Demonstrate capability to take, send, and receive the required video and image files	Not Complete

Day in the Life

Test Overview:

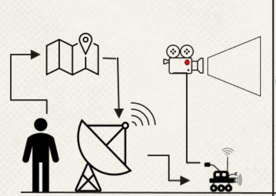


- **Test Setup:**
  - Hardware:
    - Fully integrated rover
    - Fully integrated ground station
    - Fire extinguisher
  - Location: Pleasant View Sports Complex
- **Component Integration Test:**
  1. Power on fully integrated rover
  2. Inspect rover ensuring all components are onboard rover (DR 5.1)
  3. Measure rover footprint (FR.5)
  4. Place objects at different angles around LiDar sensor, and gather relevant data (DR 3.7)
  5. Enable camera and take panoramic image (DR 2.10, 2.11)
  6. Power down rover
  7. Inspect relevant data to determine satisfaction of relevant requirements

* Safety plan for "Day in the Life" testing detailed in Back-Ups

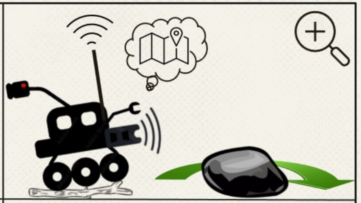
Day in the Life

Test Overview:



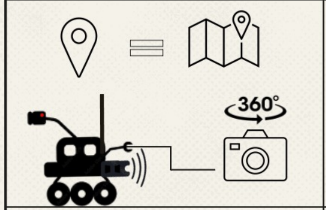
Initiate Rover

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



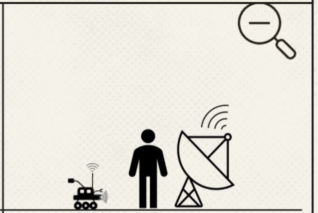
Autonomous Navigation

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



Return to Ground Station

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

- **Day in the Life Test:**
  1. Initialize ground station and rover
  2. Send location of interest to rover (FR.2)
  3. Observe autonomous navigation to location of interest (observing video and telemetry data at ground station) (DR 3.1, FR.1, FR.2, FR.3, FR.6)
  4. Verify panoramic image received at ground station (once reaching LOI) (DR 2.12, FR.2, FR.6)
  5. Observe autonomous navigation back to ground station (DR 3.4)
  6. At ground station conduct final inspections including verifying powered components, and demonstrating manual commands (DR 4.1, 4.2 4.3, 4.4, 4.5, FR.1, FR.4, FR.7)
- **Safety:**
  - Fire extinguisher
  - Manual On/Off switch on board rover

Day in the Life

Test Success Criteria:

Functional and Design Requirements Being Verified:

DR. 2.10, 2.11, 2.12, 3.1, 3.4, 3.7, 4.1, 4.2, 4.3, 4.4, 4.5, 5.1
FR. 1, 2, 3, 4, 5, 6, 7

Pass Criteria and Expected Performance				
Req. #	**Requirement / Specification**	**Pass Criteria**	**Expected Result**	**Verification Method**
DR 2.10	Rover imaging subsystem shall have a 360 degree field of view	Stitched panoramic image covers at least 360 degree field of view	3 camera FOV covers more than 360 degrees and design allows for 360 degree FOV from tallest point on rover	Inspection
DR 2.11	Rover imaging subsystem shall take image at a minimum resolution of 1920 x 360	Stitched image resolution greater than 1920 x 360	Individual image resolution greater than that required to achieve 1920 x 360 stitched	Inspection
DR 2.12	Rover video subsystem shall take a panoramic image when it reaches the location of interest	Verify reception of panoramic image on ground station when rover reaches LOI	Rover will have previously demonstrated panoramic image and reaching location of interest	Demonstration

Day in the Life

Test Success Criteria :

Functional and Design Requirements Being Verified:

DR. 2.10, 2.11, 2.12, 3.1, 3.4, 3.7, 4.1, 4.2, 4.3, 4.4, 4.5, 5.1
FR. 1, 2, 3, 4, 5, 6, 7

Pass Criteria and Expected Performance

Req. #	Requirement / Specification	Pass Criteria	Expected Result	Verification Method
DR 3.7	The remote sensing subsystem shall have a horizontal FOV of at least 120 degrees	LiDar effective FOV of equal to or greater than 120 degrees	Total FOV is 360 degrees, and design aims for 180 degree FOV	Test
DR 3.1	The autonomous subsystem shall determine a path to location of interest	Rover navigates from ground station to location of interest under autonomous control	Algorithm designed to minimize failure in autonomy	Demonstration
DR 3.4	The autonomous subsystem shall determine a path back to the ground station after taking a panoramic image at the location of interest	Rover navigates from the location of interest to the ground station under autonomous control	Algorithm designed to minimize failure in autonomy and begin autonomous navigation after photo	Demonstration
DR 5.1	Rover structure shall physically contain all subsystems (excluding ground station) on the rover	All components other than ground station computer and antenna must be onboard rover platform	CAD model demonstrates all components onboard rover	Inspection

Day in the Life

Test Success Criteria :

Functional and Design Requirements Being Verified:

DR. 2.10, 2.11, 2.12, 3.1, 3.4, 3.7, 4.1, 4.2, 4.3, 4.4, 4.5, 5.1
FR. 1, 2, 3, 4, 5, 6, 7

Pass Criteria and Expected Performance				
Req. #	**Requirement / Specification**	**Pass Criteria**	**Expected Result**	**Verification Method**
DR 4.1	The electrical subsystem shall provide sufficient power for the autonomous subsystem specifications	Subsystem powered throughout mission	Analysis demonstrates margin	Demonstration
DR 4.2	The electrical subsystem shall provide sufficient power for the communication subsystem specifications	Subsystem powered throughout mission	Analysis demonstrates margin	Demonstration
DR 4.3	The electrical subsystem shall provide sufficient power for the control subsystem specifications	Subsystem powered throughout mission	Analysis demonstrates margin	Demonstration
DR 4.4	The electrical subsystem shall provide sufficient power for the mechanical subsystem specifications	Subsystem powered throughout mission	Analysis demonstrates margin	Demonstration
DR 4.5	The electrical subsystem shall provide sufficient power for the video/imaging subsystem specifications	Subsystem powered throughout mission	Analysis demonstrates margin	Demonstration

Day in the Life

Test Success Criteria :

Functional and Design Requirements Being Verified:

DR. 2.10, 2.11, 2.12, 3.1, 3.4, 3.7, 4.1, 4.2, 4.3, 4.4, 4.5, 5.1
FR. 1, 2, 3, 4, 5, 6, 7

Pass Criteria and Expected Performance				
Req. #	**Requirement / Specification**	**Pass Criteria**	**Expected Result**	**Verification Method**
FR.1	The rover shall move forwards, backwards and turn in any direction	Demonstrates required motion	Subsystem test demonstrates this motion	Demonstration
FR.2	The rover shall transmit and receive data between the on-board computer and the ground station	Communicates telemetry, LOI coordinates, photo, video, and manual commands	Subsystem test demonstrates this capability	Demonstration
FR.3	The rover shall utilize remote sensing subsystems to autonomously determine a path to a location of interest	Rover successfully avoids obstacles and reaches location of interest under autonomous control	Combine remote sensing and autonomy logic	Demonstration

Day in the Life

Test Success Criteria :

Functional and Design Requirements Being Verified:

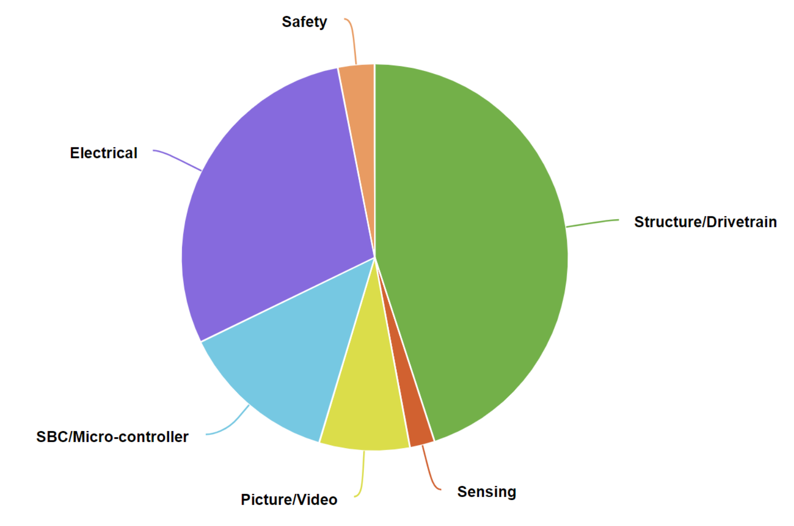
DR. 2.10, 2.11, 2.12, 3.1, 3.4, 3.7, 4.1, 4.2, 4.3, 4.4, 4.5, 5.1
FR. 1, 2, 3, 4, 5, 6, 7

Pass Criteria and Expected Performance				
Req. #	**Requirement / Specification**	**Pass Criteria**	**Expected Result**	**Verification Method**
FR.4	The power delivery subsystem shall be able to sustain the rover / ground station for the duration of the mission	At end of mission, ensure all components powered (either through power lights or demonstrated capability)	Analysis shows heavy margin for powering components	Demonstration
FR.5	Rover shall have a footprint no larger than 1’ x 1’	Measured footprint of rover at largest point is less than 1' x 1'	CAD model shows dimensions less than 1' x 1'	Inspection
FR.6	The ground station shall display video, images, and location of rover	During mission, verify video, image, and telemetry display at ground station	Previously demonstrated capability	Demonstration
FR. 7	The ground station shall provide an interface to allow for input of manual commands from user	Demonstrate capability for user to input manual commands	Capability demonstrated in multiple subsystem tests	Demonstration

Budget

Cost Plan

Subsystem(s)	Cost
Structure/ Drivetrain	$892.40
Sensing	$41.53
Picture/Video	$149.97
SBC/Micro-controller	$260.84
Electrical	$577.70
Safety	$60.78
Pilot Tools Deposit	$200
Total Spent	$2189.55



- **Remaining funds:** $1810.45
- Projected expenses as of CDR: $899.39
- Discrepancy mainly caused by pilot tools deposit, shipping + handling, and duplicate orders

Questions?

Back Ups

Test Descriptions

Component Test Descriptions and Status			
Test Type	**Test**	**Test Description**	**Status**
Component	LiDAR Sensor	Utilize the Raspberry Pi to record and process data received by the LiDAR sensor pertaining to obstacles in view. Must ensure objects of defined obstacle size are capable of detection by the selected component.	Complete
Component	GPS	Analyze navigation accuracy of GPS receiver and processing board using known US Geological Survey locations for optimal mission LOI determination.	Complete
Component	IMU / Magnetometer	Confirm acceleration and magnetic field data produced by IMU/Magnetometer sensor is in accordance with predefined sensor orientations.	Complete
Component	Rocket M2	Transmit data through the ground station and rover Rocket M2 devices verifying receival of complete data package.	Complete
Component	Cameras	Power selected cameras and analyze the field of view capable for video and imaging. Upon capture of video ensure recorded frame rate and resolution conforms with commanded values.	Complete
Component	Motor / ESC	Run power through motors and ESCs ensuring appropriate output RPM for motor, with expected input voltage and current for motor, and commands from ESC.	Complete
Component	Battery	Power an equivalent circuit for expected rover voltage and current for fifteen minutes verifying voltage and current is sustained at optimal values for entire duration of power provided.	Complete

Subsystem Tests

Locomotion

Test Introduction :

- **Test Purpose:**
  - To ensure rover can achieve desired motion throughout mission

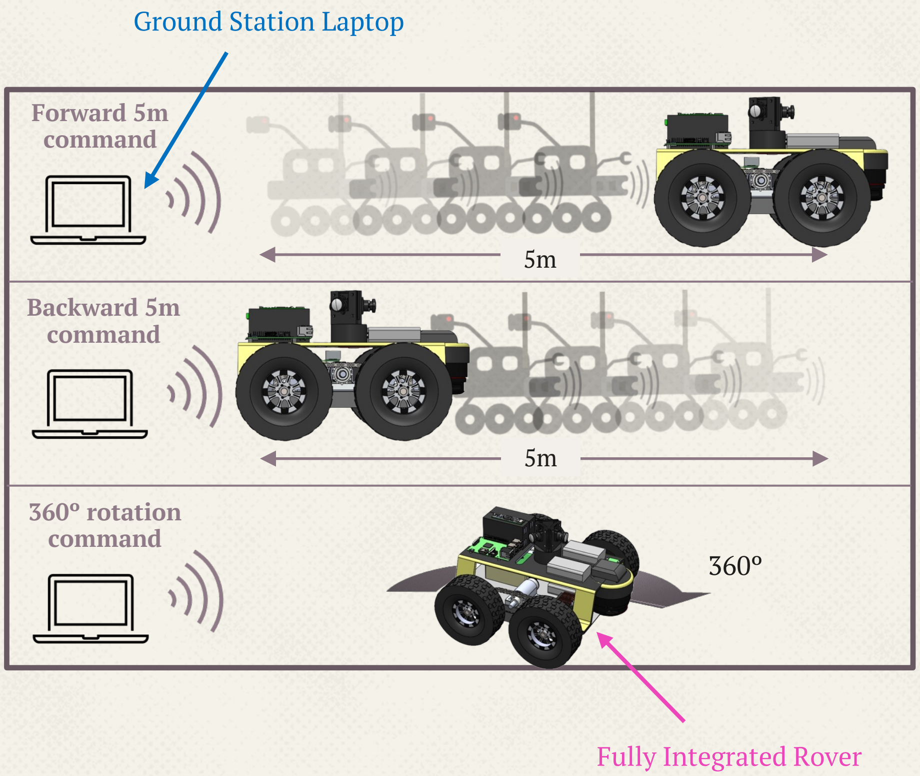
Design Requirements Being Verified:

DR. 1.1, 1.2, 1.3, 1.4, 1.7

Preliminary Testing Required			
Test Type	**Test**	**Test Description**	**Status**
Component	Motors / ESC	Run power through motors and ESCs ensuring appropriate output RPM for motor, with expected input voltage and current for motor, and commands from ESC.	Complete
Component	Battery	Power an equivalent circuit for expected rover voltage and current for fifteen minutes verifying voltage and current is sustained at optimal values for entire duration of power provided.	Complete
Component	Rocket M2	Transmit data through the ground station and rover Rocket M2 devices verifying receival of complete data package.	Complete

Locomotion

Test Overview:



- **Test Setup:**
  - Controls and mechanical team members shall convene to test functionality of rover locomotion. The rover shall be tested at Pleasant View Sports Complex. The test results shall be recorded with a measuring tape and video.
- **Test Procedure:**
  - Initialize communication systems
  - Power motors and ESCs
  - Command rover to move as desired through manual commands from the ground station
- **Safety:**
  - Chain guard, moving components painted yellow, power on / off switch on rover
- **Risk Mitigation**
  - Lower potential of drivetrain failure

Locomotion

Test Success Criteria :

Design Requirements Being Verified:

DR. 1.1, 1.2, 1.3, 1.4, 1.7

Pass Criteria and Expected Performance				
Req. #	**Requirement / Specification**	**Pass Criteria**	**Expected Result**	**Verification Method**
DR 1.1	Rover shall be able to move within 100m radius from ground station	Rover was able to move up to 100 m of ground station	Rover will be able to travel distance greater than 100m as not limited by battery or communication	Test
DR 1.2	Rover shall be able to move forward	Rover moves forwards	Rover will be able to drive forwards	Demonstration
DR 1.3	Rover shall be able to move backward	Rover moves backwards	Rover will move be able to reverse	Demonstration

Locomotion

Test Success Criteria :

Design Requirements Being Verified:

DR. 1.1, 1.2, 1.3, 1.4, 1.7

Pass Criteria and Expected Performance				
Req. #	**Requirement / Specification**	**Pass Criteria**	**Expected Result**	**Verification Method**
DR 1.4	Rover shall be able to turn 360°	Rover turns 360°	Rover can turn at any angle	Demonstration
DR 1.7	Rover control subsystem shall control the rover motors	Rover control successfully induces the above motion	Rover will move in all the above manners	Demonstration

C&C Subsystem Test

Command & Controls Verification

Test Introduction :

- **Test Purpose:**
  - To verify that commands and controls input by the user at the ground station are properly passed to be utilized by the rover

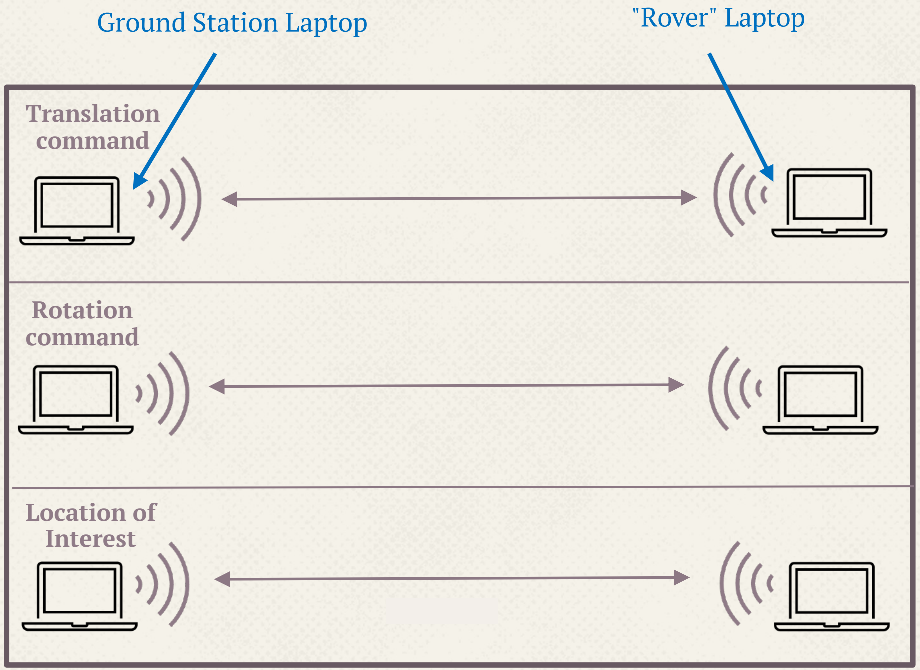
Functional and Design Requirements being Verified:

DR. 1.6, 2.1, 2.5, 7.1, 7.2, 7.3

Preliminary Testing Required			
Test Type	**Test**	**Test Description**	**Status**
Component	Rocket M2	Transmit data through the ground station and rover Rocket M2 devices verifying receival of complete data package.	Complete

Command and Control Verification

Test Overview :



- **Test Setup:**
  - Test will be conducted by ground station and communications specialist
  - Components for testing are in possession of team SAILR and ready for use
  - Completed in senior projects room using two laptops, two Rocket M2 radios, and necessary batteries and antennas
- **Test Procedure:**
  - Connect Rocket M2s to PoE adapters and antennas
  - On web browser connect to airOS interface
    - Verify connection status and details
  - Start ground station GUI with terminal command
  - Enter test commands into GUI
    - Manual commands for movement and translation, location of interest command
  - Verify reception of output control file at on board computer
- **Safety Concerns and Mitigation**
  - There are no relevant safety concerns

Command and Control Verification

Test Success Criteria :

Design Requirements being Verified:

DR. 1.6, 2.1, 2.5, 7.1, 7.2, 7.3

Pass Criteria and Expected Performance				
Req. #	**Requirement / Specification**	**Pass Criteria**	**Expected Result**	**Verification Method**
DR 1.6	Rover control subsystem shall receive manual control commands from the ground station	Manual commands received by Teensy	Teensy outputs a response that a command is received	Demonstration
DR 2.1	The communication subsystem shall receive location of interest coordinates from ground station	LOI coordinates received in text file	Text file at rover end updated with LOI input at ground station	Demonstration
DR 2.5	The communication subsystem shall receive manual control commands from the ground station	Manual commands received in text file	Text file at rover end updated with manual command input at ground station	Demonstration

Command and Control Verification

Test Success Criteria :

Design Requirements being Verified:

DR. 1.6, 2.1, 2.5, 7.1, 7.2, 7.3

Pass Criteria and Expected Performance				
Req. #	**Requirement / Specification**	**Pass Criteria**	**Expected Result**	**Verification Method**
DR 7.1	Ground station shall send coordinates of location of interest to the rover	GS GUI writes LOI coordinates to text file	Text file at rover end updated with LOI input by user	Demonstration
DR 7.2	Ground station shall receive manual control commands inputs from user	GS GUI writes manual commands to text file	Text file at ground station end updated with manual command input by user	Demonstration
DR 7.3	Ground station shall transmit manual control commands to the rover	GS sends manual commands in text file to rover	Text file at ground station end will be seen on the rover end	Demonstration

Video/Imaging/Ground Station Subsystem Test

Video/Imaging, Comms, Ground Station Validation

Test Introduction:

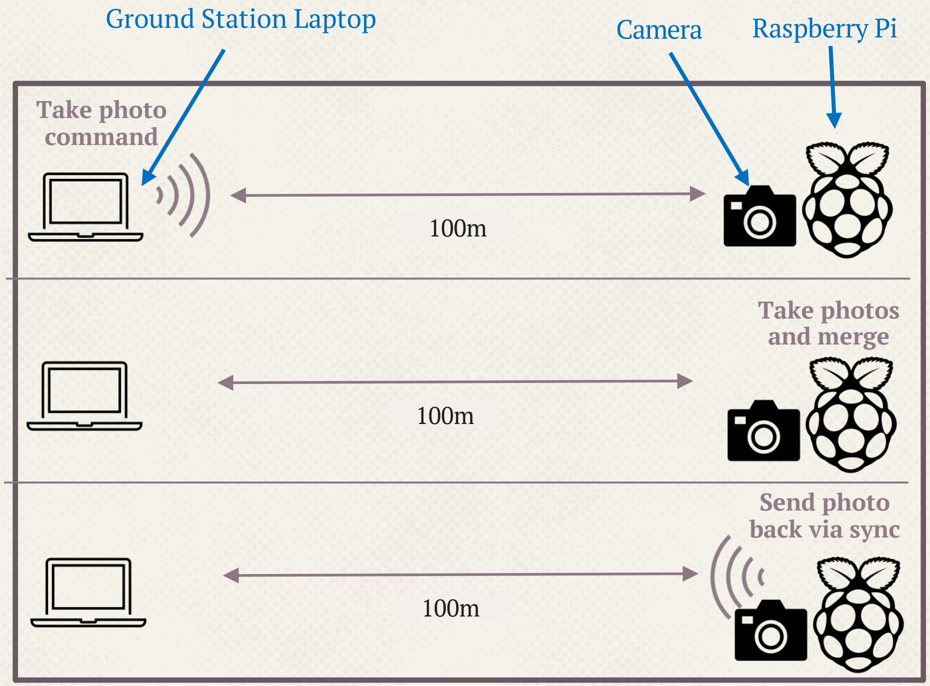
- **Test Purpose:**
  - To verify end to end functionality between the Ground Station, communications subsystem, and camera/video subsystem

Design Requirements being Verified:

DR 6.2, 6.3, 6.4, 6.6, 6.7, 2.3, 2.4, 2.6

Preliminary Testing Required			
Test Type	**Test**	**Test Description**	**Status**
Component	Cameras	Power selected cameras and analyze the field of view capable for video and imaging. Upon capture of video ensure recorded frame rate and resolution conforms with commanded values.	Complete
Component	Rocket M2	Transmit data through the ground station and rover Rocket M2 devices verifying receival of complete data package.	Complete

Video/Imaging/Comms/Ground Station Validation
Test Overview:



- **Test Setup:**
  - Test will be conducted by ground station and communications specialists
  - Test requires Rocket M2s, laptop, PoE adapters, antennas, Raspberry Pi, and Arducam cameras with USB cables
  - Connect Rocket M2s to PoE adapters and antennas
  - Connect Raspberry Pi and cameras
- **Test Procedure:**
  - Start ground station GUI with terminal command
  - Enter take photo command into GUI and verify reception on OBC side
  - Verify image taken
  - Verify sync reception of video and image from OBC to GS via rsync
  - View video and image ground station
    - Confirm successful image merging

Video/Imaging/Comms/Ground Station Validation: Test Success Criteria

Design Requirements being Verified:

DR 2.3, 2.4, 2.6, 6.2, 6.3, 6.4, 6.6, 6.7

Pass Criteria and Expected Performance				
Req. #	**Requirement / Specification**	**Pass Criteria**	**Expected Result**	**Verification Method**
DR 2.3	The communication subsystem shall send video to the ground station	Communication subsystem transmits video to ground station communication device	Confirmation of video file transmission from rover communication subsystem	Demonstration
DR 2.4	The communication subsystem shall send images to the ground station	Communication subsystem transmits image to ground station communication device	Confirmation of image file transmission from rover communication subsystem	Demonstration
DR 2.6	Rover shall send video to ground station at least every 15 seconds	Communication subsystem capable of transmitting video every 15 seconds	Confirmation of video transmission at least once every 15 seconds	Demonstration

Video/Imaging/Comms/Ground Station Validation: Test Success Criteria

Design Requirements being Verified:

DR 2.3, 2.4, 2.6, 6.2, 6.3, 6.4, 6.6, 6.7

Pass Criteria and Expected Performance				
Req. #	**Requirement / Specification**	**Pass Criteria**	**Expected Result**	**Verification Method**
DR 6.2	Ground station shall receive images from the rover at a minimum resolution of 1920 x 360	Image synced to ground station file system with resolution greater than 1920 x 360	Image located in the file system with appropriate resolution	Inspection
DR 6.3	Ground station shall receive video from the rover at a minimum resolution of 640 x 360	Video synced to ground station file system with resolution greater than 640 x 360	Video located in the file system with appropriate resolution	Inspection
DR 6.4	Ground station shall display images and video within 10 seconds of receiving them	Ground station displays image and video in the GUI no more than 10 seconds after receiving the files	GUI will display video and images within desired timeframe	Demonstration

Video/Imaging/Comms/Ground Station Validation: Test Success Criteria

Design Requirements being Verified:

DR 2.3, 2.4, 2.6, 6.2, 6.3, 6.4, 6.6, 6.7

Pass Criteria and Expected Performance				
Req. #	**Requirement / Specification**	**Pass Criteria**	**Expected Result**	**Verification Method**
DR 6.6	Ground station shall display images at a minimum resolution of 1920 x 360	Image displayed on GUI possesses a resolution greater than 1920 x 360	Image will be displayed on GUI with appropriate resolution	Inspection
DR 6.7	Ground station shall display video at a minimum resolution of 640 x 360	Video displayed on GUI possesses a resolution greater than 640 x 360	Video will be displayed on GUI with appropriate resolution	Inspection

Component Tests

GPS Component Test

GPS Component Validation

Test Introduction :

- **Test Purpose:**
  - To verify that the GPS can output accurate Earth coordinates with acceptable delay between each reading

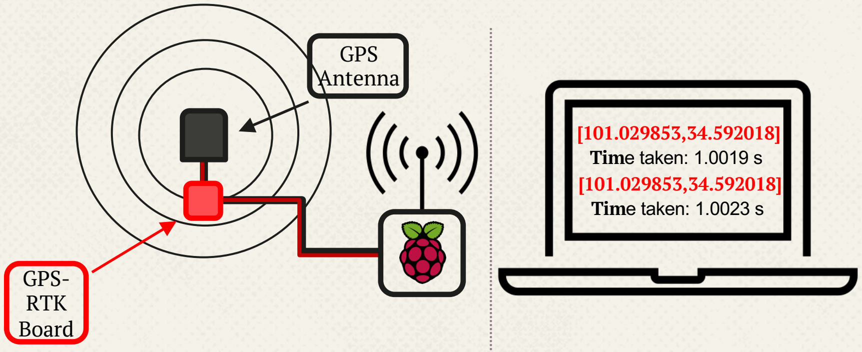
Design Requirements Being Verified:

DR. 3.10

Preliminary Testing Required			
Test Type (Inspection, Analysis, Demonstration, or Test)	**Test**	**Test Description**	**Status**
N/A	N/A	N/A	N/A

GPS Component Validation

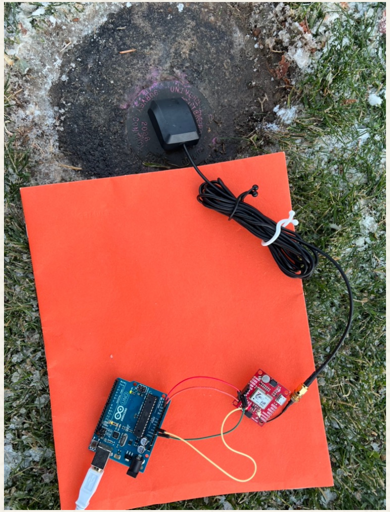
GPS Test Overview:



- **Test Setup:**
  - Connect GPS, keyboard, monitor, and power source to Raspberry Pi.
  - Ensure GPS is transmitting data
- **Test Procedure:**
  - At known coordinates, place GPS antenna right on top of the marker
  - Record GPS coordinates for 100 points and time between each reading

GPS Component Validation

GPS Test Overview :



- **Test Setup:**
  - Connect GPS, keyboard, monitor, and power source to Raspberry Pi.
  - Ensure GPS is transmitting data
- **Test Procedure:**
  - At known coordinates, place GPS antenna right on top of the marker
  - Record GPS coordinates for 100 points and time between each reading

GPS Component Validation

GPS Test Success Criteria :

Design Requirements Being Verified:

DR. 3.10

Pass Criteria and Expected Performance				
Req. #	**Requirement / Specification**	**Pass Criteria**	**Expected Result**	**Risk Reduction**
SPEC	Rover shall communicate its location to the ground station at least once every 2 seconds	Output delay no more than 2 seconds	Output delay of 0.1 second	N/A
DR 3.10	Rover shall determine its location to an accuracy of 10m or less	Telemetry data more accurate than 10m	Telemetry data accurate to 2.5m	N/A

GPS Component Validation

Test Results:

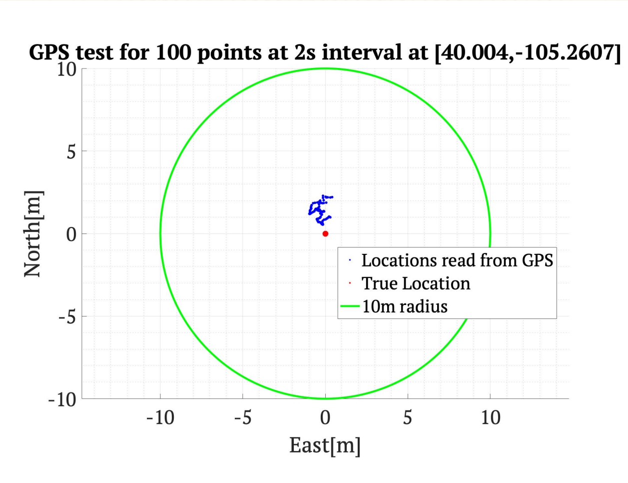
Design Requirements Being Verified:

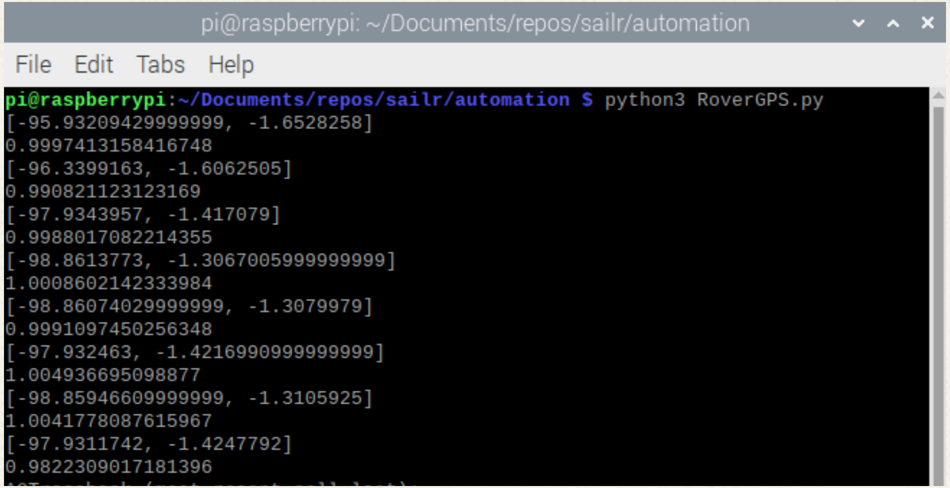
DR. 3.10

Test Performance & Results				
Req. #	**Requirement / Specification**	**Verification Method**	**Performance Metrics**	**Performance**
SPEC	Rover shall communicate its location to the ground station at least once every 2 seconds	Test	Output delay is 1 second	**Pass with Margin**
DR 3.10	Rover shall determine its location to an accuracy of 10m or less	Test	Telemetry data is accurate to 2.29 m	**Pass with Margin**

GPS Component Validation

Test Results:





Maximum distance error is **2.29 meters,**
Exceeding the 10-meter requirement (DR.3.10)

Output delay is **1 second,**
Fulfills communication requirement (DR.3.9)

Precision is +/- 1.15 meter

LiDAR Component Test

LiDAR Component Test:

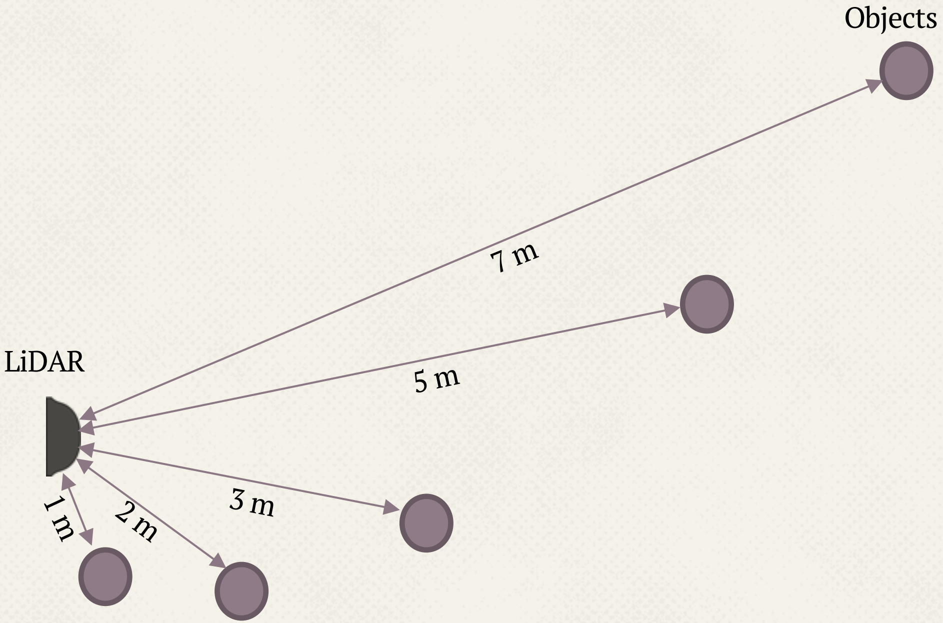
Test Introduction :

- **Test Purpose:**
  - To verify the LiDAR can detect obstacles as defined by our environmental definitions

Preliminary Testing Required			
Test Type (Inspection, Analysis, Demonstration, or Test)	**Test**	**Test Description**	**Status**
N/A	N/A	N/A	N/A

LiDAR Component Test

Test Setup:



- **Test Setup:**
  - Set 6.4 cm diameter obstacles in a radial pattern at various distances of 1, 2, 3, 5, and 7 m away from the LiDAR sensor with enough separation such that the sensor can see the full width of each obstacle.
  - Connect Raspberry Pi to LiDAR and connect to external power.
- **Test Procedure:**
  - Run SAILR's RoverMove library with testing script 10 times to collect measurements and create maps of environment.
  - Inspect the generated maps to ensure that obstacles within 3 m are detected on each run.
- **Risk Mitigation:**
  - Verify that the rover can detect and then navigate around obstacles.

LiDAR Component Test

Test Success Criteria :

Pass Criteria and Expected Performance			
Req. #	**Requirement / Specification**	**Pass Criteria**	**Expected Result**
Component Specification	Detects obstacles of 6.4cm diameter and greater at distances of ⩽ 3m*	One "hit" on objects ⩽ 3m away in a 1 second duration test	Objects ⩽3 m away are detected.

* The spec being tested is the angle between measurements. From 1° angle between measurements reported in the spec sheet, the distance at which 6.4cm (2.5in) diameter objects should be detected with every pass was calculated to be 3.5 meters distance from the LiDAR sensor.

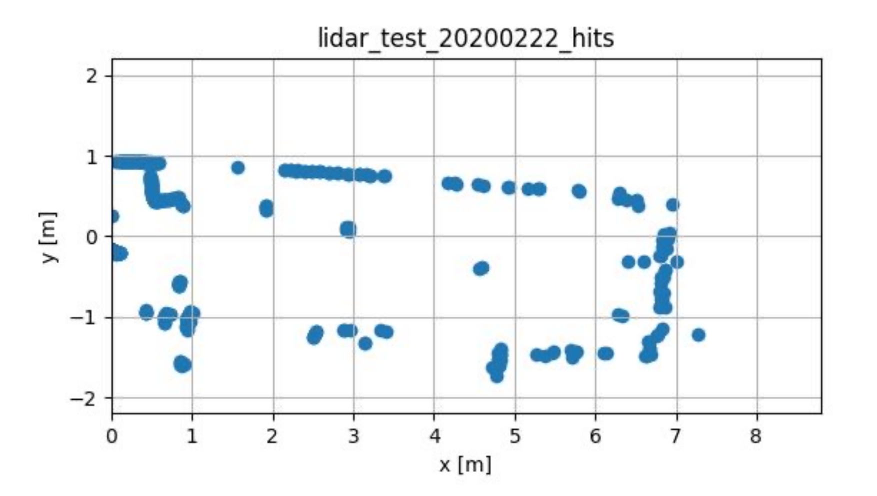
LiDAR Component Test

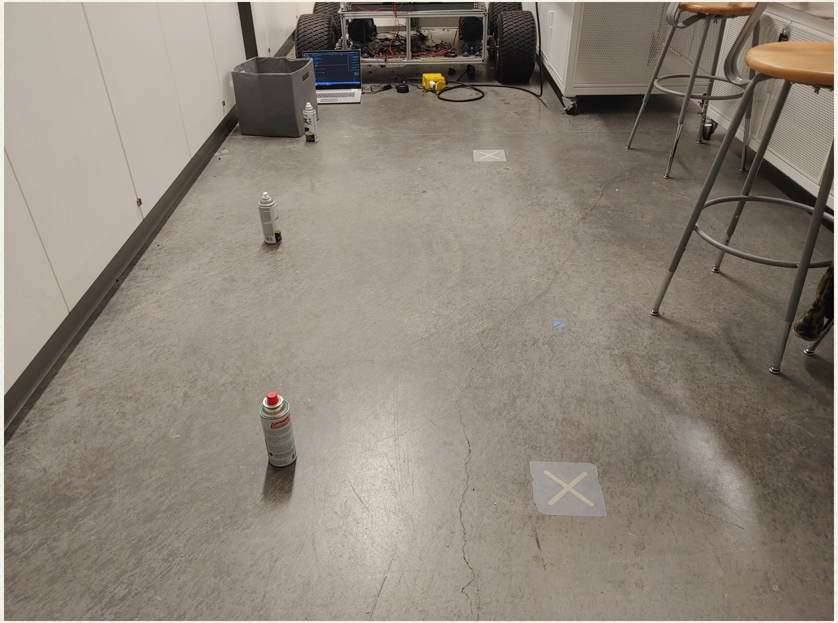
Test Results

Test Performance & Results				
Req. #	**Requirement / Specification**	**Verification Method**	**Performance Metrics**	**Performance**
Spec	Detects obstacles of 6.4cm diameter and greater at distances of ⩽ 3m	Test	6.4cm diameter obstacles were detected at ⩽ 3m. Obstacle at 5 meters were intermittently detected.	**Pass with Margin**

LiDAR Component Test

Test Results:





- Objects of 6.4 cm diameter as defined by our environment definitions were detected at 1, 2, and 3 meters.
- The precision of the distance measured decreases as the magnitude of the distance increases.

Battery Component Test

Battery Component Test:

Test Introduction :

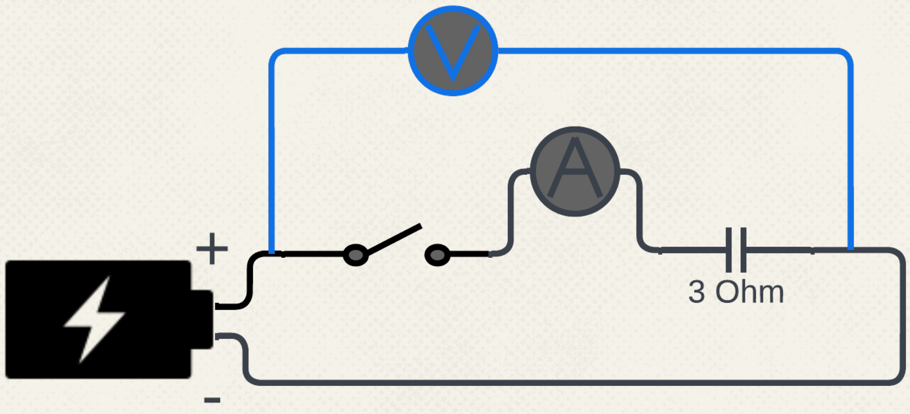
Test Purpose:

- To verify the battery can provide the current and voltage as specific by the spec sheet

Preliminary Testing Required			
Test Type (Inspection, Analysis, Demonstration, or Test)	**Test**	**Test Description**	**Status**
N/A	N/A	N/A	N/A

Battery Component Test

Test Overview:



- **Test Setup:**
  - Required Equipment: Battery pack, switch, 3-Ohm power resistor, timer, voltmeter, ammeter.
  - Setup: Ensure switch is set to OFF and battery pack is fully charged (8.4V). Connect switch, power resistor, and ammeter in series. Complete circuit by connecting battery back to either end (shown on left).
- **Test Procedure:**
  - Simultaneously set switch to the ON position and start the timer. Monitor current of circuit and voltage of battery for 15 minutes. Set switch back to OFF after 15 minutes.
- **Risk Mitigation**
  - Increases certainty in battery discharge calculations and confidence in powering components for entire mission duration

Battery Component Test

Test Success Criteria:

Pass Criteria and Expected Performance			
Req. #	**Requirement / Specification**	**Pass Criteria**	**Expected Result**
Component Specification	Outputs at 7.2 nominal volts	Battery starts charged (>8.3V) and remains above 6.5V after 15 minutes	Battery voltage will start around 8.35V and end above 7.2V
Component Specification	Can output 2.4A continuous current	Battery outputs above 2.3A continuously for 15 minutes	Battery current will start around 3A and end around 2.4A

Battery Component Test

Test Results:

Results				
Req. #	**Requirement / Specification**	**Verification Method**	**Performance Metrics**	**Performance**
Spec	Outputs at 7.2 nominal volts	Test	From full charge, outputted 8.4V, and after 15-minute test, was still at 7.78V	Passed with Margin
Spec	Can output 2.4A continuous current	Test	Outputted above 2.3A for 15-minute test duration	Passed with Margin

IMU/MAG Component Test

IMU/Mag Verification

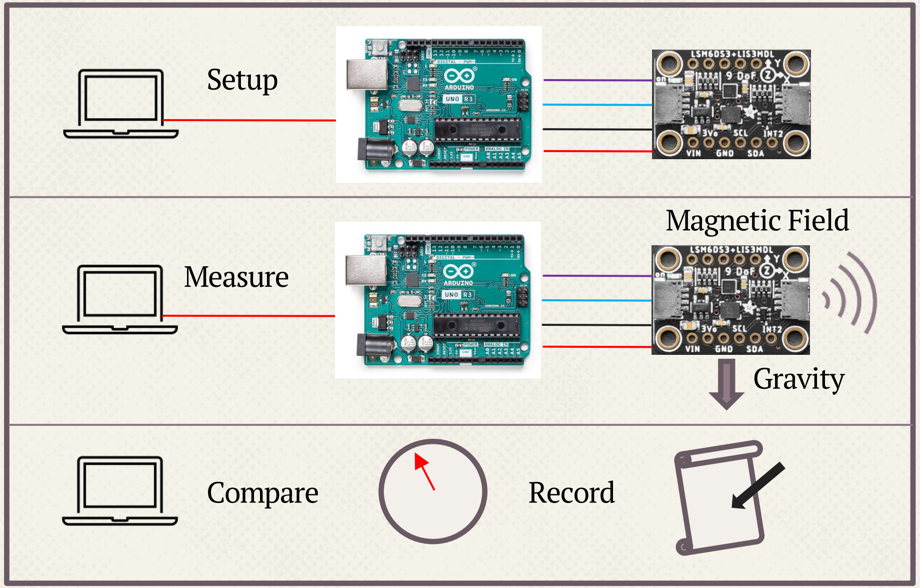
Test Introduction :

- **Test Purpose:**
  - To verify the IMU measures accelerations to the precision specified in the datasheet.
  - To verify the Magnetometer measures magnetic fields to the precision specified in the datasheet.

Preliminary Testing Required			
Test Type (Inspection, Analysis, Demonstration, or Test)	**Test**	**Test Description**	**Status**
N/A	N/A	N/A	N/A

IMU/Mag Verification

Test Overview:



- **Test Setup:**
  - One member of the team will connect an Arduino analog to a laptop, and the IMU/Magnetometer breakout board to the Arduino analog. An LED on the IMU/Mag should light up. Testing code will be uploaded to the Arduino analog.
- **Test Procedure:**
  - The IMU will be oriented with different axes pointing down.
    - Acceleration readings are recorded.
  - The magnetometer will be oriented with different axes pointing towards magnetic North.
    - Magnetometer readings are recorded.
- **Risk Mitigation**
  - Ensures appropriate resolution required for feedback control

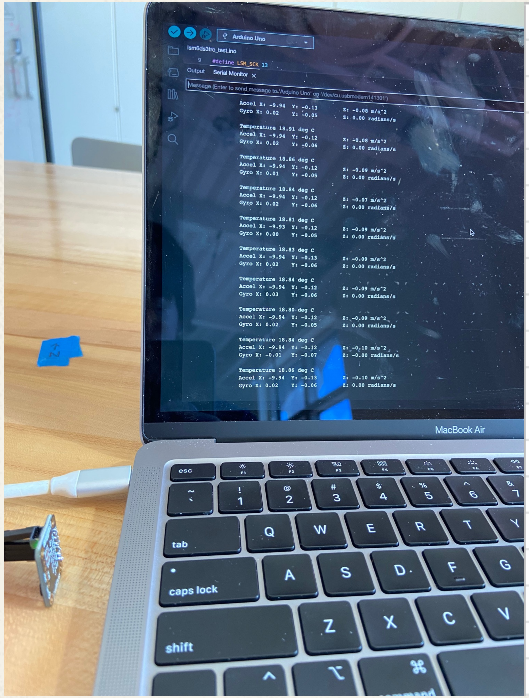
IMU/Mag Verification

Test Success Criteria :

Pass Criteria and Expected Performance			
Req. #	**Requirement / Specification**	**Pass Criteria**	**Expected Result**
SPEC	The IMU measures Earth's gravity at 9.81 m/s^2 (1 g)	Acceleration should be measured within 0.01 m/s^2 of 9.81 m/s^2	The IMU measured gravity between 9.91 and 9.96 m/s^2
SPEC	The Magnetometer measures Earth's magnetic field at 0.25 - 0.65 gauss	Magnetic fields should be measured within 0.01 gauss of 0.25-0.65 gauss	The Magnetometer measured Earth's magnetic field between 0.34 and 0.53 gauss

IMU/Mag Verification

Test Results :



Up (North)	x (uTesla)	y (uTesla)	z (uTesla)	x (m/s^2)	y (m/s^2)	z (m/s^2)
Z (y)	-61.82	50.07	-110.49			
Z (x)	-53.01	56.5	-113.49			
Z (-y)	-50.73	51.71	-117.36			
Z (-x)	-55.06	37.27	-115.74			
Y (z)	-47.44	-28.63	-34.96			
Y (x)	-47.98	-25.23	-41.22			
Y (-z)	-63.55	-20.59	-47.25			
Y (-x)	-54.82	-24.51	-36.6			
X (y)	-125.01	52.41	-38.35			
X (z)	-128.02	47.11	-35.95			
X (-y)	-126.63	49.78	-46.26			
X (-z)	-125.88	61.11	-47.14			
X				9.74	0.32	0.22
-X				-9.77	1.19	-0.36
Y				0.46	9.63	0.81
-Y				-0.69	-9.79	-1.64
Z				-0.45	1.31	9.98
-Z				0.04	0.94	-9.5

IMU/Mag Verification

Test Results :

Pass Criteria and Expected Performance				
Req. #	**Requirement / Specification**	**Verification Method**	**Performance Metrics**	**Performance**
SPEC	The IMU measures Earth's gravity at 9.81 m/s^2	Test	The IMU measured gravity at 9.94 +- 0.01 m/s^2	Pass
SPEC	The Magnetometer measures Earth's magnetic field at 0.25 - 0.65 gauss	Test	The Magnetometer measured Earth's magnetic field between 0.34 and 0.53 gauss	Pass

Rocket M2 Component Test

Rocket M2 Verification

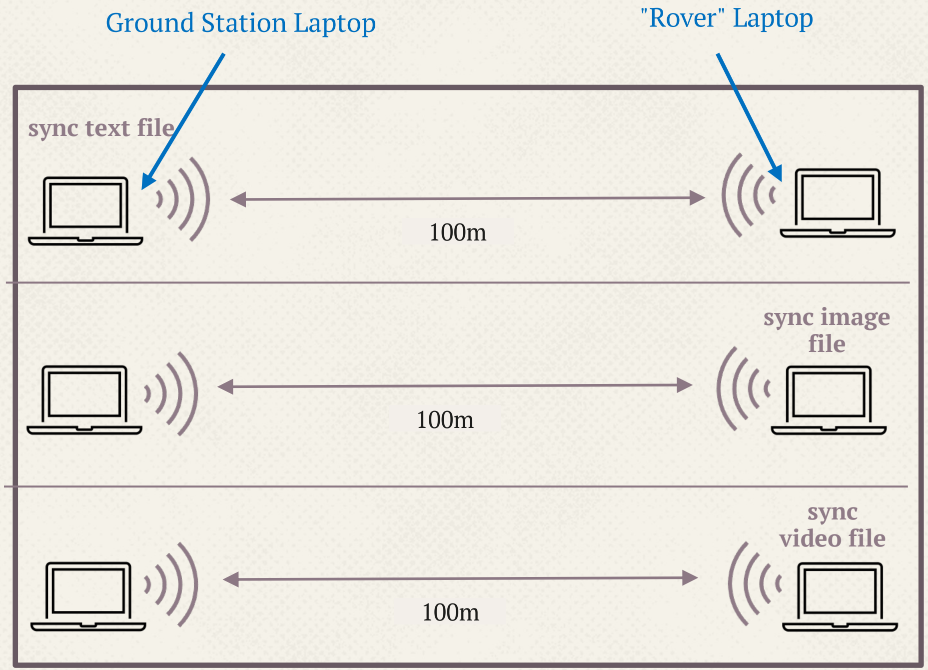
Test Introduction :

- **Test Purpose:**
  - To verify that the Rocket M2 radio can send and receive data to provide for communication between the rover and ground station

Preliminary Testing Required			
Test Type (Inspection, Analysis, Demonstration, or Test)	**Test**	**Test Description**	**Status**
N/A	N/A	N/A	N/A

Rocket M2 Verification

Test Overview:



- **Test Setup:**
  - Test will be conducted by ground station and communications specialists
  - Components for testing are in possession of team SAILR and ready for use
  - Connect Rocket M2s to PoE adapters and antennas
- **Test Procedure:**
  - On web browser connect to airOS interface
    - Verify connection status and details
  - Start ground station GUI with terminal command
  - Enter test commands into GUI and verify reception on OBC side
  - Manually sync video and image from OBS to GS via rsync and verify reception on GS side
- **Risk Mitigation**
  - Ensure all necessary file types can be sent

Rocket M2 Verification

Test Success Criteria :

Pass Criteria and Expected Performance				
Req. #	**Requirement / Specification**	**Pass Criteria**	**Expected Result**	**Verification method**
SPEC	The rocket m2 shall communicate text files wirelessly to another rocket m2	Text file communicated at 100 meters	Text file appears on rover rocket m2	Demonstration
SPEC	The rocket m2 shall communicate image files wirelessly to another rocket m2	Test image from cameras communicated at 100 meters	Image file appears at ground station rocket m2	Demonstration
SPEC	The rocket m2 shall communicate video files wirelessly to another rocket m2	Test video from cameras communicated at 100 meters	Video file appears at ground station rocket m2	Demonstration

Rocket M2 Verification

Test Results

Pass Criteria and Expected Performance				
Req. #	**Requirement / Specification**	**Verification Method**	**Performance Metrics**	**Performance**
SPEC	The rocket m2 shall communicate text files wirelessly to another rocket m2	Demonstration	Text file in ground station file system updated	Pass
SPEC	The rocket m2 shall communicate image files wirelessly to another rocket m2	Demonstration	Image file in ground station file system received	Pass
SPEC	The rocket m2 shall communicate video files wirelessly to another rocket m2	Demonstration	Video file in ground station file system received	Pass

Arducam Component Test

Arducam

Test Introduction :

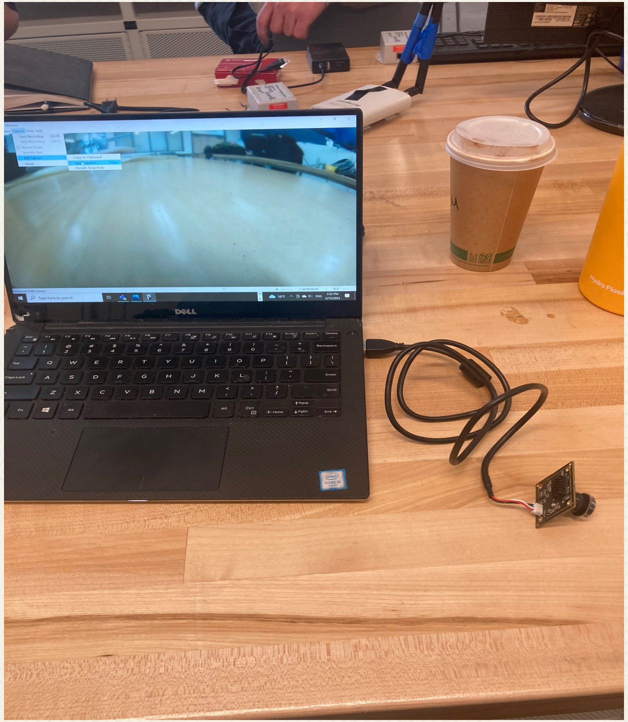
- **Test Purpose:**
  - To verify camera can record video with resolution of at least 640 x 360p with a minimum frame rate of 15fps
  - To verify camera horizontal FOV is at least 100 degrees

Design Requirements Being Verified:
DR. 2.7, 2.8, 2.9

Preliminary Testing Required			
Test Type (Inspection, Analysis, Demonstration, or Test)	**Test**	**Test Description**	**Status**
N/A	N/A	N/A	N/A

Arducam

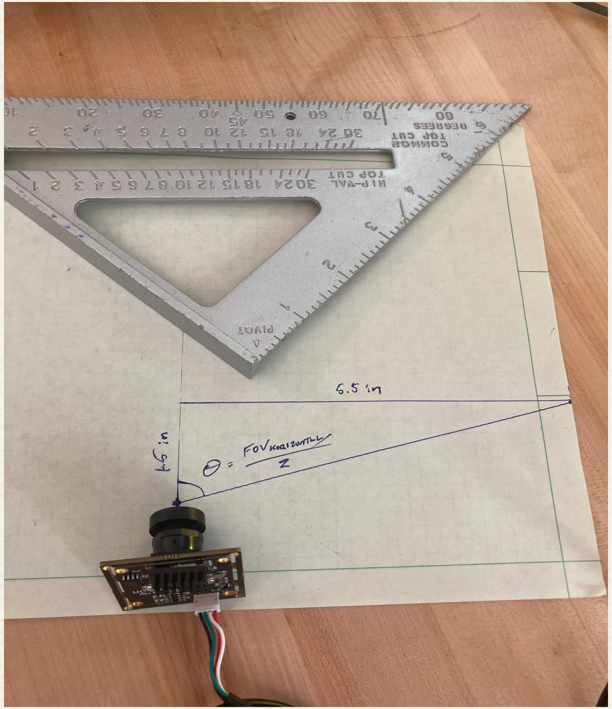
Test Overview:



- **Test Setup:**
  - One individual needed to run test
  - Test requires Arducam with USB cable, laptop or computer with USB port, AMCap software, paper, pen or pencil, and a measuring device
  - Connect Arducam to laptop via USB cable
- **Test Procedure 1:**
  - Run AMCap software and select Arducam from devices menu
  - Set an appropriate file output directory
  - Set video frame rate to 15 fps and set video resolution to 640x360p
  - Start recording, then after 15 seconds stop recording

Arducam

Test Overview:



- **Test Procedure 2:**
  1. Connect Arducam to laptop via USB cable
  2. Run AMCap software and select Arducam from devices menu
  3. Ensure video aspect ratio is 16:9
  4. Hold Arducam on piece of grid paper so that video orientation is vertical and mark the front of camera lens on paper
  5. Observe the video and mark on the paper where the side of the video ends
  6. Draw right triangle by connecting marks and calculate the angle by measuring sides
- **Risk Mitigation**
  - Ensure camera resolution and FOV is appropriate for requirements

Arducam

Test Success Criteria :

Design Requirements Being Verified:
DR. 2.7, 2.8, 2.9

Pass Criteria and Expected Performance				
Req. #	**Requirement / Specification**	**Pass Criteria**	**Expected Result**	**Method Verification**
DR 2.7	Rover video subsystem shall have at least a 100 degree field of view	Horizontal FOV is at least 100 degrees	Horizontal FOV = 157.1 degrees	Demonstration
DR 2.8	Rover video subsystem shall take video at minimum 15 frames per second	Video frame rate is at least 15 fps	Video frame rate = 15 fps	Demonstration
DR 2.9	Rover video subsystem shall take video at a minimum resolution of 640 x 360p	Video resolution is at least 640 x 360p	Video resolution = 640 x 360 p	Demonstration

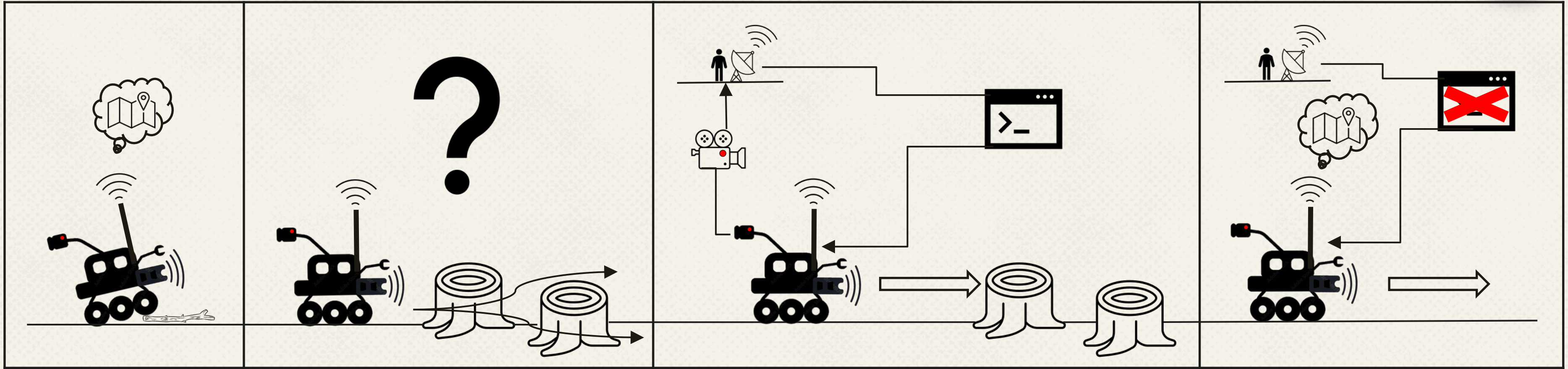
Arducam

Test Results

Design Requirements Being Verified:
DR. 2.7, 2.8, 2.9

Pass Criteria and Expected Performance				
Req. #	**Requirement / Specification**	**Verification Method**	**Performance**	**Performance**
DR 2.7	Rover video subsystem shall have at least a 100 degree field of view	Inspection	Horizontal FOV = 149 degrees	**Pass with Margin**
DR 2.8	Rover video subsystem shall take video at minimum 15 frames per second	Inspection	Video frame rate = 30 fps	**Pass with Margin**
DR 2.9	Rover video subsystem shall take video at a minimum resolution of 640 x 360p	Inspection	Video resolution is 1920 x 1080p	**Pass with Margin**

Manual Control CONOPS



Rover Autonomously Navigates

1. Rover is autonomously navigating to location of interest

Rover Autonomy Fails

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

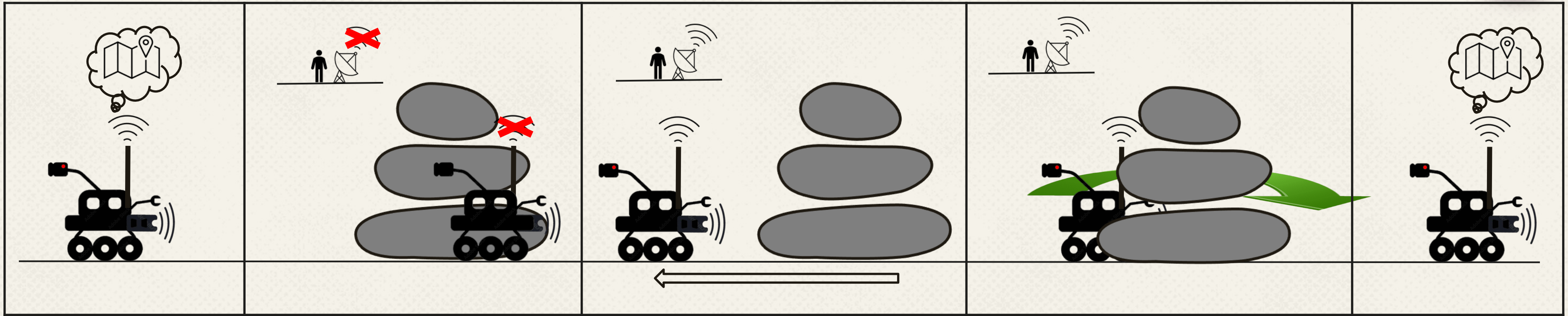
Manual Control

4. User sends command through ground station disabling autonomy 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 autonomy commands

Re-engage Autonomy and Continue Mission

7. User sends commands through ground station enabling autonomy 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 autonomy 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 autonomy 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

Safety IDR

Slides from Safety IDR presentation

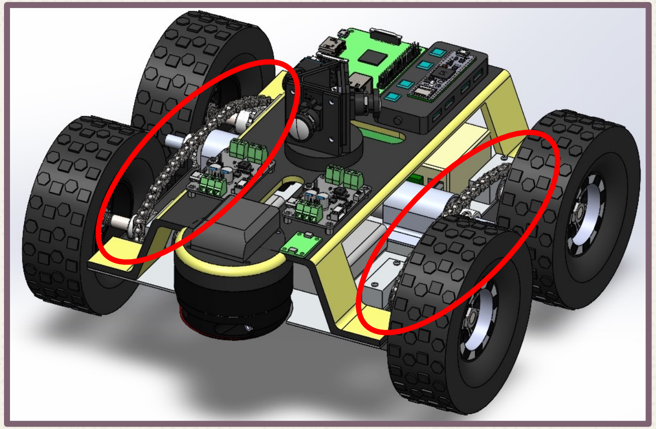
Risks

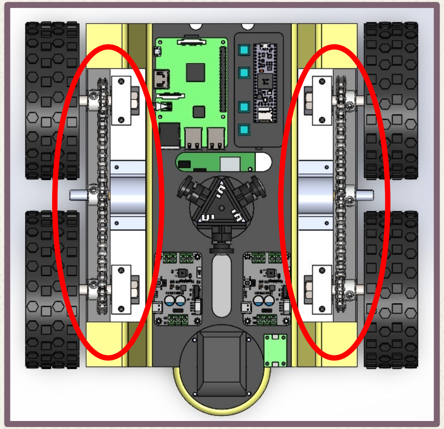
Safety risks in fabrication, integration, and test

Safety IDR

Risk #1: Drivetrain

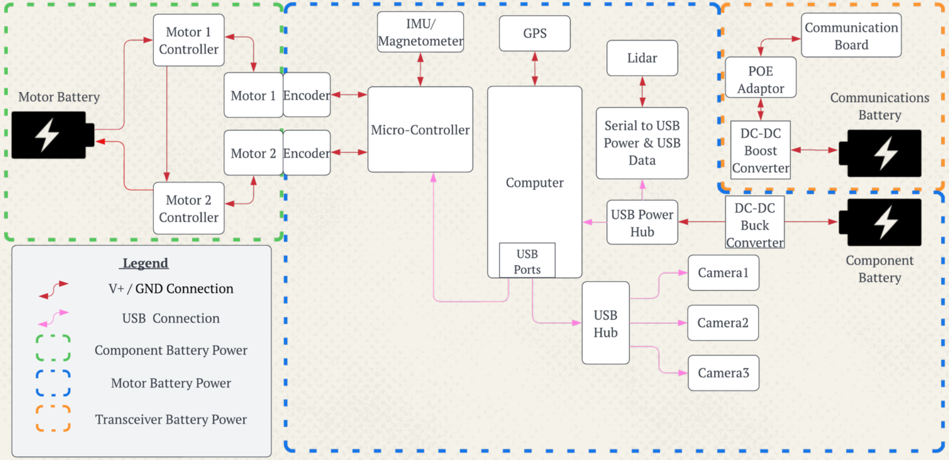
- Drivetrain (I&T) - **High Likelihood**
  - Moving components (i.e. chain and sprocket) introduce numerous pinch points and opportunity for loose items to get caught and pulled into the system that could result in personnel injury.
  - Drivetrain is necessary to satisfy the locomotion CPE and relevant functional requirements.
  - **Restriction**: structure / integration required before testing to ensure safe handling of moving parts





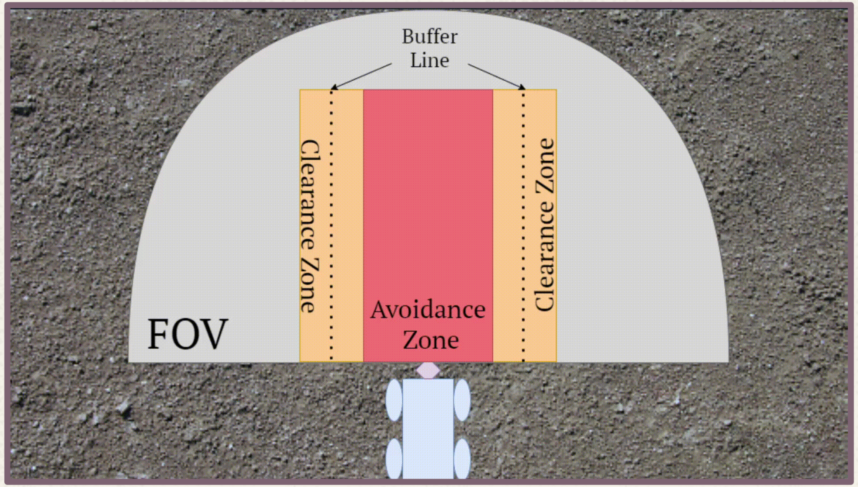
Risk #2: Power Delivery

- Battery and Electronics (I&T) - **High Likelihood**
  - Improper use of lithium-ion batteries introduces risk of electrical shock, short circuiting, and fire.
  - Battery and corresponding electronics are necessary to satisfy the power/endurance CPE and relevant functional requirements.
  - **Restriction**: Require fire extinguisher and proper ESD for necessary electrical testing and integration



Risk #3: Autonomy

- Autonomous Operation (T) - **High Likelihood**
  - Rover operates independently of user during autonomous operations which may result in loss of control posing risk for personnel (although motion occurs at a low speed).
  - The autonomous operations are required for the rover to satisfy the autonomous command and control CPE and functional requirements.
  - **Restriction**: Requirement for onboard and remote kill switch & manual control to test



Risk #4: Off-Site Testing

- "Day in the Life" (T) - **High Likelihood**
  - Team will be required to test at an off-site location introducing the risks mentioned previously to the public.
  - Off-site testing is required for verification of customer requirements to operate within a 100m radius of ground station.
  - **Restriction**: Day in the life testing will only be conducted if the mission environment is in accordance with the specifications currently defined (i.e. not tested in snow or in the presence of unspecified obstacles, no other people in the environment).

Procedures and Mitigation

Reason for risk and appropriate mitigation strategies

Safety IDR

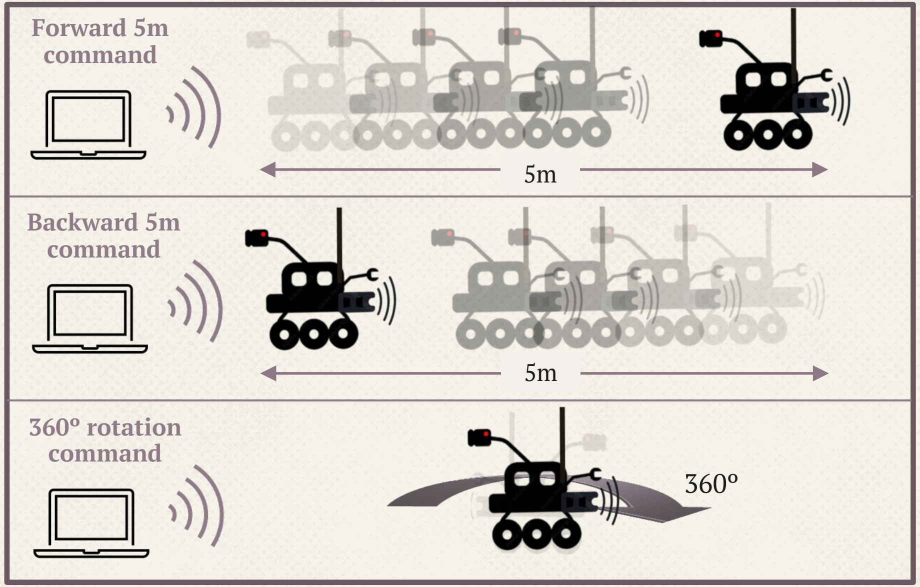
Risk #1: Drivetrain

Facilities	Equipment	Personnel
• Environment in line with typical mission environment • Ann and H.J. Smead Aerospace Building	• Rover Structure • Rover Drivetrain • Ground Station	• Structure / Drivetrain Lead Luca Barton • Systems / PM

- Schedule
  - Begin Week 6 (Start Subsystem Testing)
  - End Week 12 (Finish Day in the Life testing)
- Mitigation Strategies:
  - Warning symbols for moving parts on the rover
    - Spray-paint all pinch points yellow
  - Auditory announcement and confirmation of rover power on and off

Risk #1: Drivetrain

- Summarized Procedure:
  1. Identify First Aid equipment
  2. Setup Rover and Ground Station
  3. Command rover to move forward backward and turn 360 degrees
  4. Power off rover and ground station
  5. Clean up rover and ground station



- Emergency Plans:
  1. Have first aid kit handy for emergencies
  2. Call 911 for severe injuries
  3. Notify safety coordinator of any incidents

Risk #2: Power Delivery

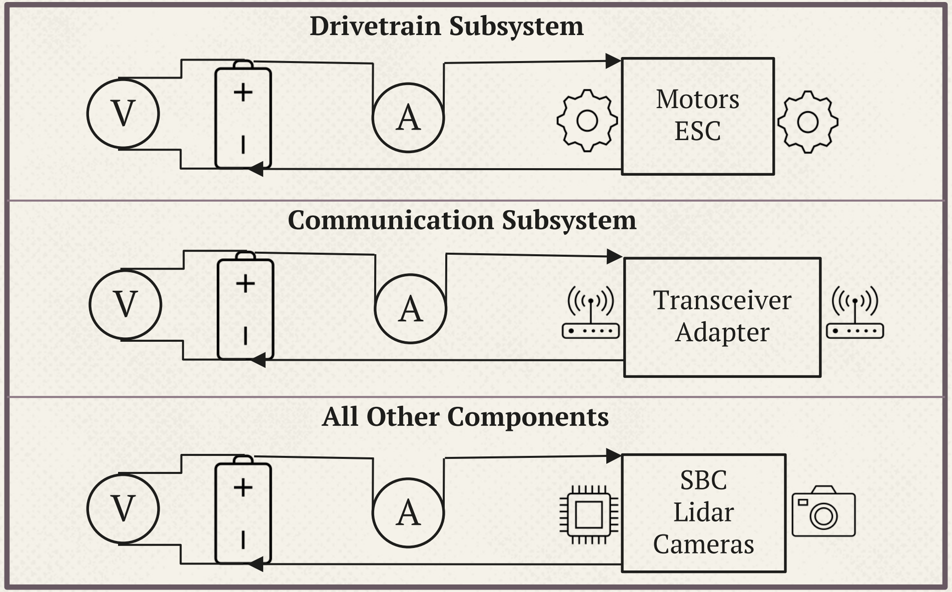
Safety IDR

Facilities	Equipment	Personnel
• Ann and H.J. Smead Aerospace Building • Electronics lab and pilot lab	• ESD Equipment • Fire Extinguisher • Digital Multimeter • Power Supply • Hardware	• Electrical Lead Skyler Schull • Systems / PM

- Schedule
  - Begin Week 3 (Start Component Testing)
  - End Week 12 (Finish Day in the Life testing)
- Mitigation Strategies:
  - Constant surveillance during charge and discharge
  - Storage in battery bags provided by CU Electronics Lab
  - Large rover termination switch for all powered systems

Risk #2: Power Delivery

- Summarized Procedure:
  1. Setup test environment in AERO Pilot lab
  2. Connect voltmeter, ammeter, and components to respective battery
  3. Observe and measure discharge of battery and verify component functionality for each respective battery system
  4. Break down test setup and clean up all components



- Emergency Plans:
  1. Have fire extinguisher and first aid kit handy for emergencies
  2. Call 911 for severe injuries
  3. Notify safety coordinator of any incidents

Risk #3: Autonomy

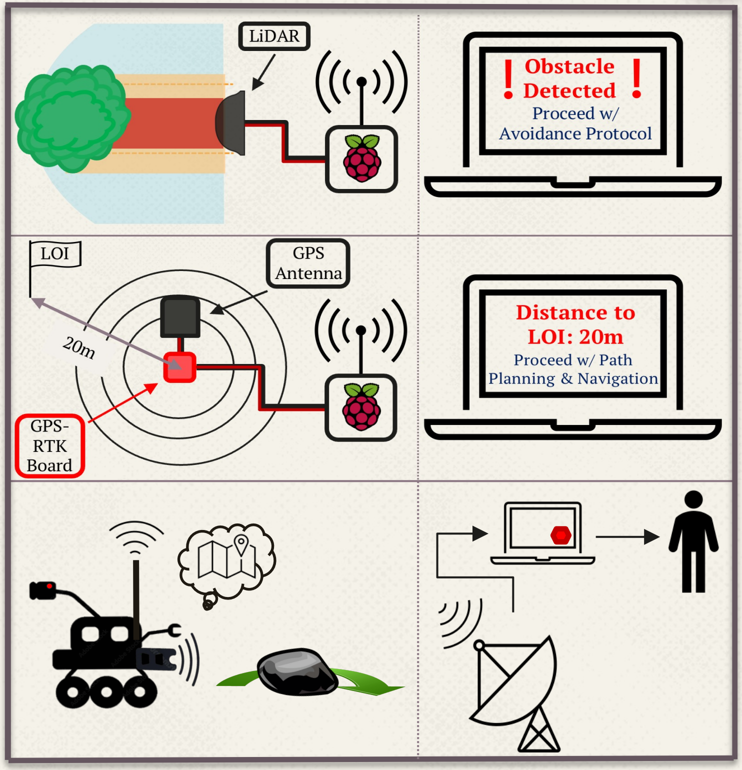
Facilities	Equipment	Personnel
• Environment in line with typical mission environment • Ann and H.J. Smead Aerospace Building	• Completed Rover • Kill Switch • Manual Control System	• Autonomous Subsystem Team Trevor Reed, Luke Roberson, Suphakan Sukwong • Systems / PM

- Schedule
  - Begin Week 6 (Start Subsystem Testing)
  - End Week 12 (Finish Day in the Life testing)
- Mitigation Strategies:
  - Kill Switch
  - Manual Control Override
  - Closed Toed Shoes
  - Completed component/algorithm testing

Risk #3: Autonomy

- Procedure:
  1. Set up mock environment for LiDAR and GPS
  2. Initiate autonomous mode and verify function of physical and remote kill switch
  3. Sense appropriately defined objects using LiDAR, and execute resulting command
  4. Capture GPS coordinates relative to location of interest coordinates and observe resulting command
  5. Terminate
  6. Clean up rover and ground station

- Emergency Plans:
  1. Have fire extinguisher and first aid kit handy for emergencies
  2. Call 911 for severe injuries
  3. Notify safety coordinator of any incidents



Risk #4: Off-Site Testing

Facilities	Equipment	Personnel
• Environment in line with typical mission environment (Pleasant View Sports Complex)	• All equipment required for other risks • Completed rover • Completed ground station	• Entire team

- Schedule
  - Begin Week 10 (Start Day in the Life Testing)
  - End Week 12 (Finish Day in the Life testing)
- Mitigation Strategies:
  - Maintain situational awareness during testing to avoid injury of personnel and/or property

Risk #4: Off-Site Testing

Safety IDR

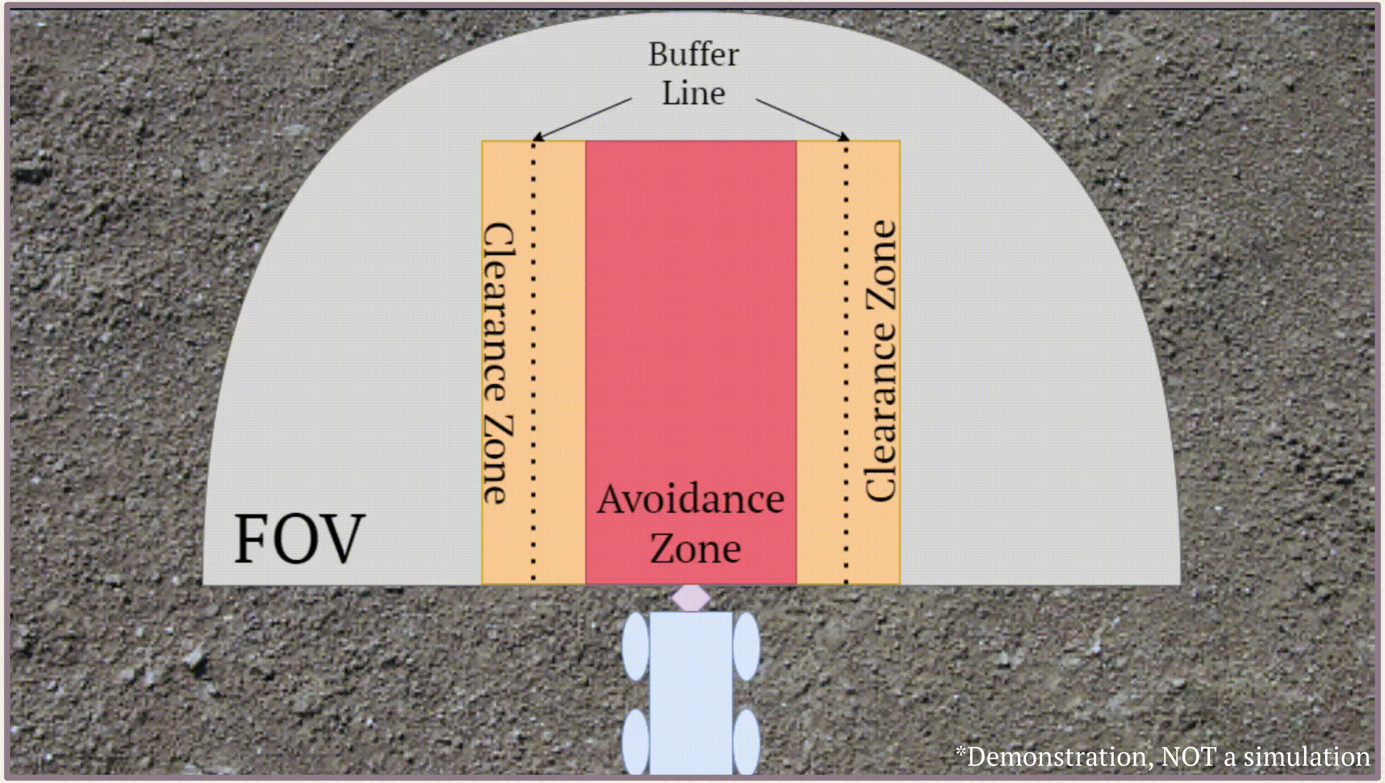
S.A.I.L.R

- Procedure:
  1. Team will travel to offsite location
  2. Verify environment is inline with defined typical mission environment
  3. Setup ground station and rover
  4. Execute total mission CONOPS
     1. Rover navigates to and from location of interest 100 meters away from ground station
  5. Collect and clean up rover and ground station

- Emergency Plans:
  1. Have fire extinguisher and first aid kit handy for emergencies
  2. Call 911 for severe injuries
  3. Document any safety violations and notify safety coordinator

*Mission CONOPS located on slide 3

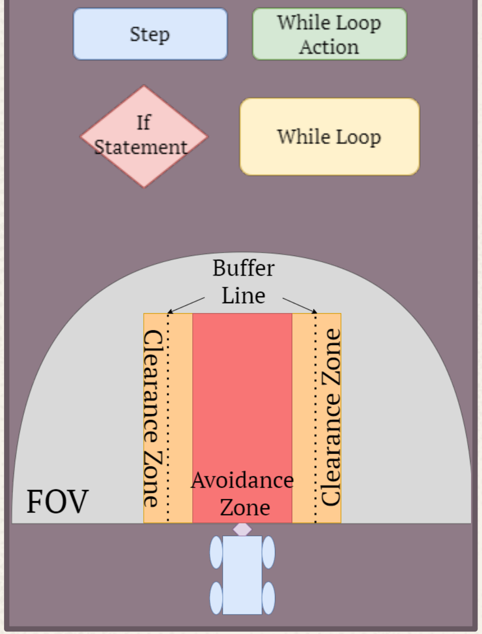
Autonomy Animation

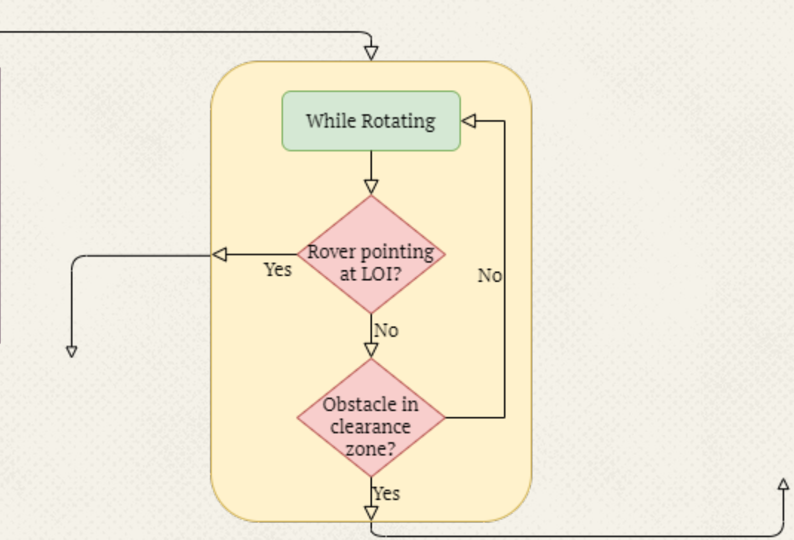


Autonomy Algorithm Flow Chart

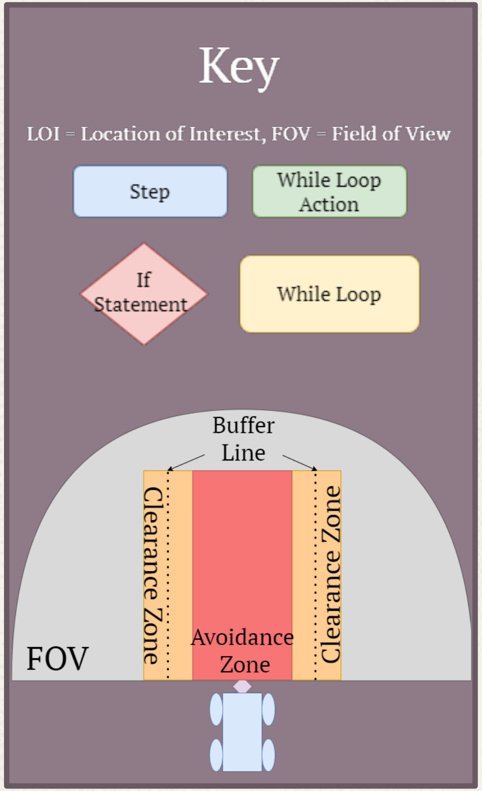
Key

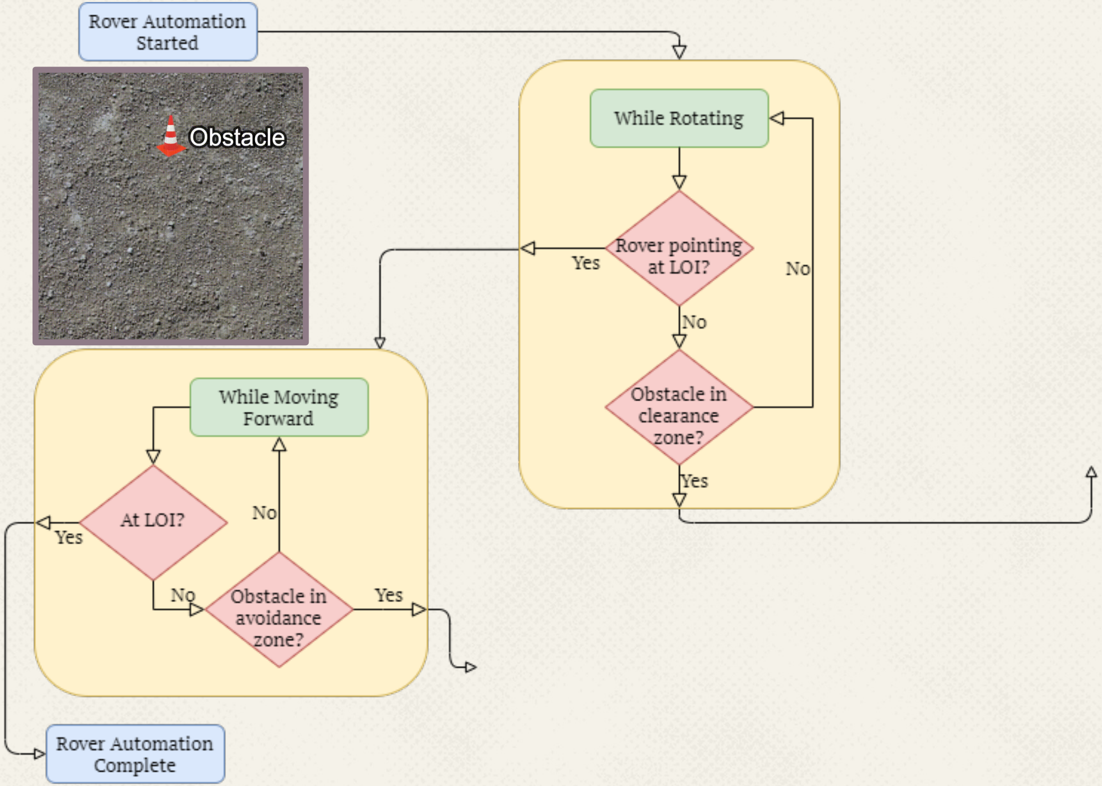
LOI = Location of Interest, FOV = Field of View



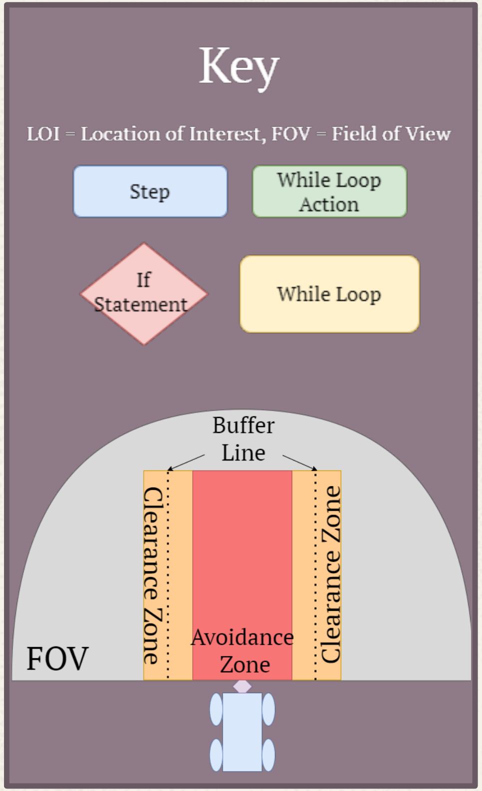


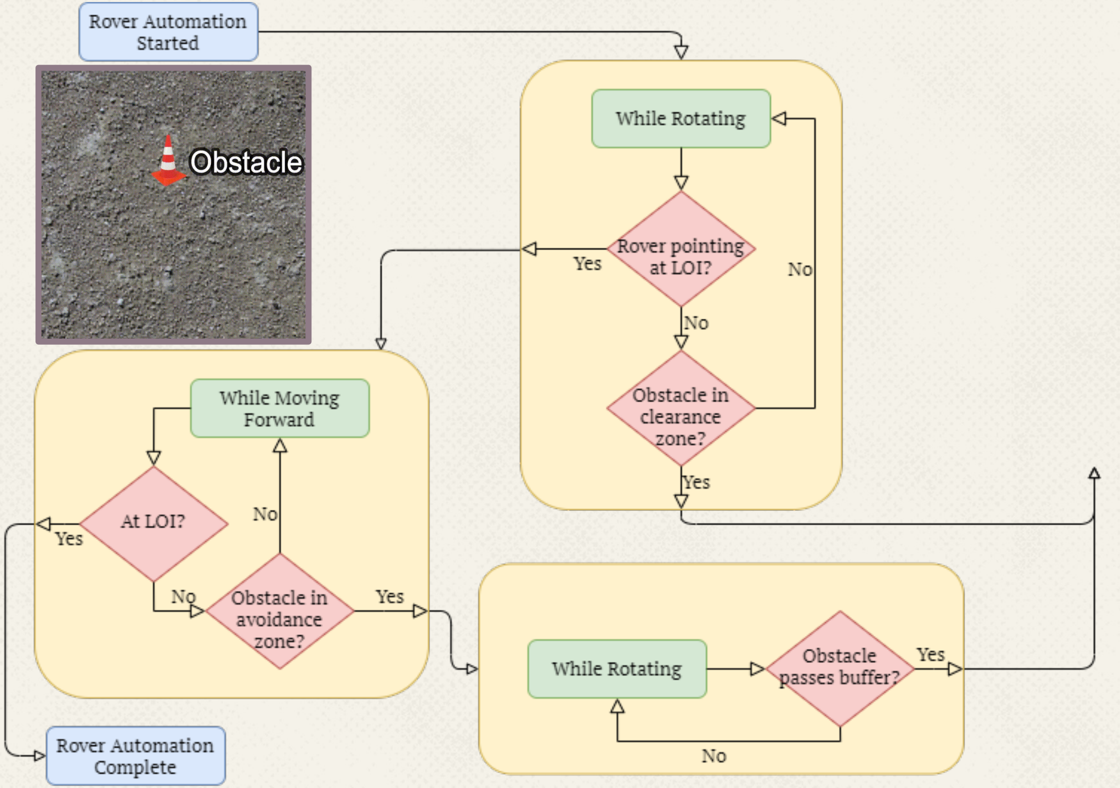
Autonomy Algorithm Flow Chart



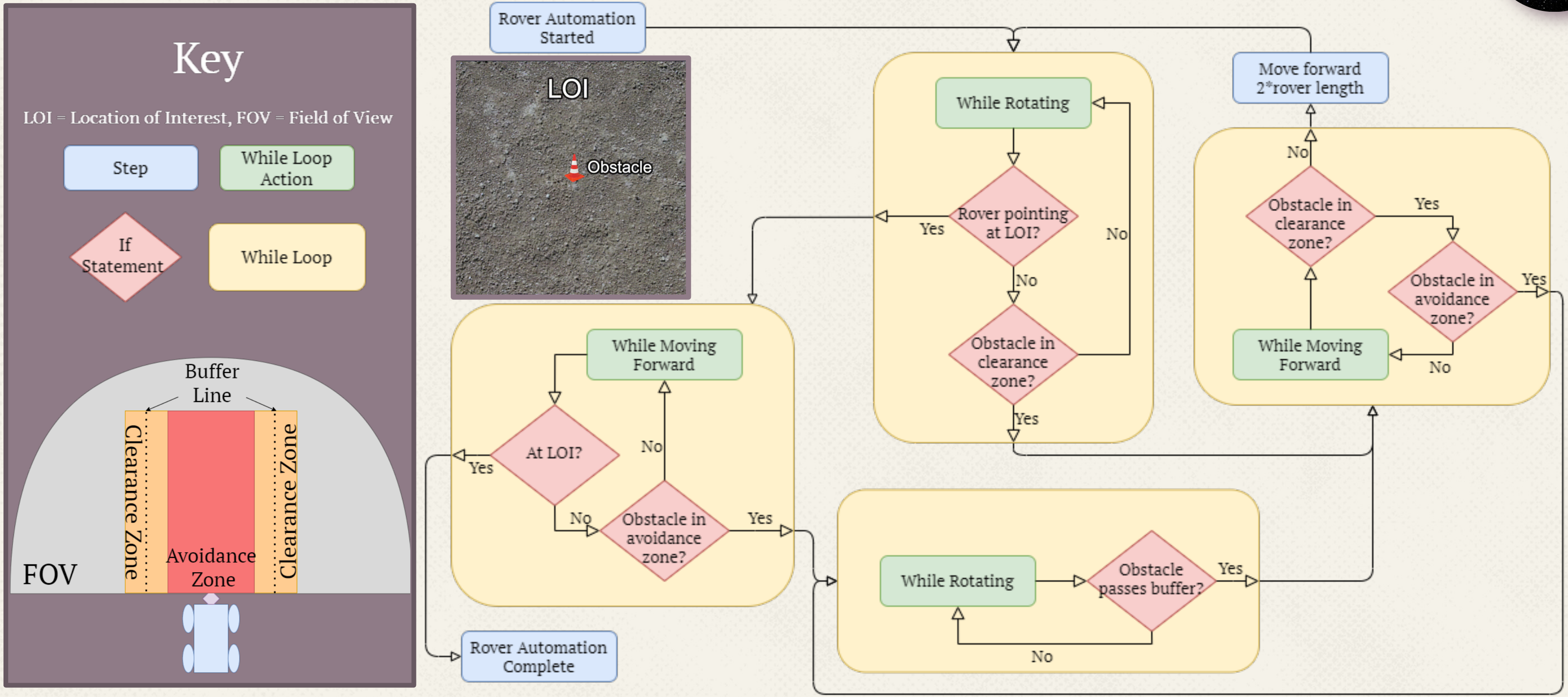


Autonomy Algorithm Flow Chart





Autonomy Algorithm Flow Chart



Component List

All components purchased as of TRR

Structure and Drivetrain

Item	Quantity	Cost	Obtained?	Total
Wheels	1 pack of 4	$52.99	Yes	$52.99
Chain Tool	1	$14.99	Yes	$14.99
Sprocket	6	$13.25	Yes	$79.50
Chain	1	$35.28	Yes	$35.28
8.8 Hexthread Screws	1 pack of 25	$10.28	Yes	$10.28
M8 Hex Head Nut	1 pack of 25	$10.34	Yes	$10.34
Ball Bearing	8	$4.82	Yes	$38.56
Steel Rod	1	$5.35	Yes	$5.35
Routing Clamp	2	$2.83	Yes	$5.66
Aluminum Bar	1	$23.97	Yes	$23.97
Master Chain Link	4	$2.32	Yes	$9.28
Motors	2	$19.90	Yes	$39.80
Locknuts	1 pack of 100	$5.09	Yes	$5.09
M8 Locknuts	1 pack of 10	$10.80	Yes	$10.80
Retaining Ring	1 pack of 100	$10.00	Yes	$10.00
Head Screws	1 pack of 25	$12.55	Yes	$12.55
Aluminum Bar	1	$36.38	Yes	$36.38
Standoffs	14	$1.61	Yes	$22.54
Head Screws	1 pack of 50	$11.52	Yes	$11.52
Washers	4 packs of 5	$9.62	Yes	$38.48
Spacers	1 pack of 100	$6.61	Yes	$6.61
Locknuts	1 pack of 100	$9.29	Yes	$9.29
Electronic Speed Controllers	2	$44	Yes	$88

Sensing + Photo/Video + SBC/Microcontroller

Item	Quantity	Price	Obtained	Total
IMU/Magnetometer	1	$19.95	Yes	$19.95
USB C to A Adapter	1	$5.88	Yes	$5.88

Item	Quantity	Price	Obtained	Total
Cameras	3	$49.99	Yes	$149.97

Item	Quantity	Price	Obtained	Total
Raspberry Pi 4 Model B	1	$165.09	Yes	$165.09
Teensy 4.1	1	$35.36	Yes	$35.36
MicroSD Card	1	$19.49	Yes	$19.49
Micro HDMI to HDMI Adapter	1	$9.69	Yes	$9.69
SD Card Reader	1	$12.59	Yes	$12.59
Raspberry Pi 4 Power Supply	1	$9.99	Yes	$10.00
USB A to Micro B Adapter	1 pack of 2	$8.63	Yes	$8.63

Electrical + Safety

Item	Quantity	Price	Obtained	Total
DC DC Converters	1 pack of 3	$8.99	Yes	$8.99
Switches	1 pack of 5	$9.89	Yes	$9.89
Buck Converters	1 pack of 4	$14.99	Yes	$14.99
Jumper Wires	1 pack of 120	$6.86	Yes	$6.86
Capacitors	1 pack of 300	$9.89	Yes	$9.89
USB Splitter	1	$7.99	Yes	$7.99
Wire Kit	1	$16.95	Yes	$19.95
Velcro	1	$7.25	Yes	$7.25
Electrical Tape	1	$2.99	Yes	$2.99
Digital Multimeter	1	$23.51	Yes	$23.51
Batteries	4	$41.00	Yes	$164.00
Chargers	2	$22.95	Yes	$45.90
USB Power Hub	2	$69.99	Yes	$139.98
Wire Splicers	1 pack of 10	$25.55	Yes	$25.55

Item	Quantity	Price	Obtained	Total
Fire Extinguisher	1	$49.99	Yes	$49.99
Markers	1 pack of 8	$10.79	Yes	$10.79

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/

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/