Spring Final Review

Drone-Rover Integrated Fire Tracker

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Agenda

- Project Purpose and Objectives
- Design Description
- Test Overview and Results
  - Leveling Test
  - Slope Test
  - Maneuverability Test
  - Obstacle Test
  - Communication Test
  - Distance Test
- Systems Engineering
- Project Management

Project Purpose → **Test Overview and Results** → **Systems Engineering** → **Project Management** → **Design Description**

Project Purpose and Objectives

Project Overview: Fire Tracker System

- As a result of climate change, wildfire seasons are becoming hotter and longer
  - This allows for a wildfire to easily ignite and rapidly spread
  - United States Forest Service is consistently increasing its budget for wildfire mitigation, rising from 16 to 50% of the Forest Service Budget since 1995[1]
- A deployable **mother rover** and **autonomous drone** provide a low cost means of long-range reconnaissance for early detection of wildfires
- These systems can assist firefighters in investigating areas sometimes impassible by ground-based methods alone

[1]The Rising Cost of Wildfire Operations: Effects on the Forest Service's Non-Fire Work." United States Department of Agriculture: Forest Service, 4 Aug. 2015.

Mission Statement

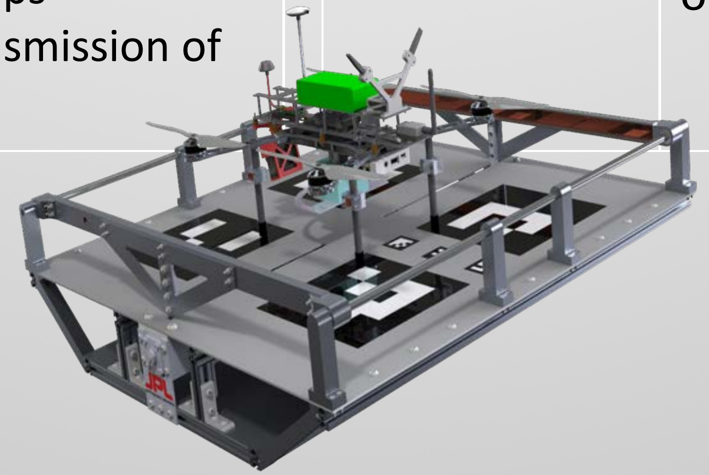
Drone-Rover Integrated Fire-Tracker (DRIFT) will develop a mother rover to secure, carry, and level an Unmanned Aerial Vehicle (UAV) for the purposes of gathering pertinent environmental data regarding locations at risk of or exposed to a wildfire.

Project Heritage

DRIFT will utilize both the **INFERNO** and **CHIMERA** hardware and software shown below:

Project Name	**INFERNO** **IN**tegrated **F**light **E**nabled **R**over for **N**atural disaster **O**bservation
Timeline	2015-2016
Overview	Semi-autonomous **Child Drone** capable of transporting and deploying a temperature sensor package to a location of interest
Capabilities	o Mission Duration: 13.5 min o Fully Autonomous Takeoff at inclinations < 3.5 degrees o 10 m/s Translational Flight o Video/Imaging: 720p at 30fps o Sensor Package: > 90% transmission of SPS data

Project Name	**CHIMERA** **CHI**ld drone deployment **ME**chanism and **R**etrieval **A**pparatus
Timeline	2016-2017
Overview	The landing, securing, and deployment system for the autonomous drone inherited from INFERNO (**Landing Platform**)
Capabilities	o Capable of securing CD up to 200m from GS o Drone recharging system can charge the CDS LiPo battery upon command o Autonomous landing functionality utilizing image recognition upon command from ground station



Levels of Success

Level 3

- MR can overcome slopes $\leq$ 20 degrees at speeds up to 0.5 m/s
- MR can maneuver around obstacle over 5 inches tall while the CD and LP remains securely fixed to the MR
- MR can level the platform to $\mathbf{0}° \pm \mathbf{3.5}°$ to take off and land on a 20 degrees slope
- MR can relay live video feed and location at least at 5Hz for a distance of 250 m to the GS
- MR can be powered to achieve a round trip mission of 500 m

Level 2

- MR can overcome slopes $\leq$ 10 degrees at speed up to 0.5 m/s
- MR can traverse a path that has obstacles less than or equal to 5 inch tall while the CD and LP remain securely fixed to MR
- MR can level the platform to $\mathbf{0}° \pm \mathbf{3.5}°$ for the CD to take off and land on a 10 slope
- MR can be driven by an operator at GS via live video feed to desired location
- MR can relay live video feed and location at least at 5 Hz for a distance of 150 m to the GS
- MR can be powered to achieve a round trip of 300 m

Level 1

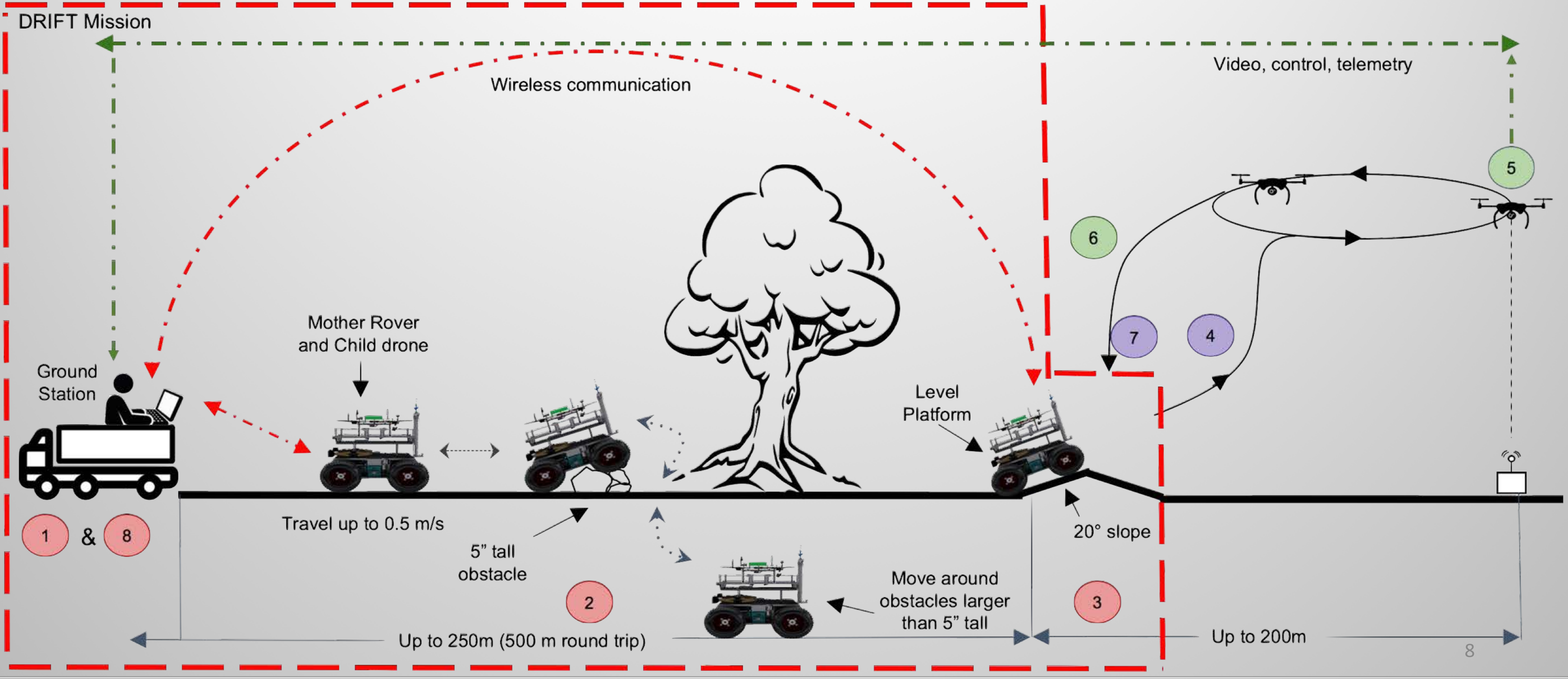
- MR can traverse over a flat dirt path while supporting the size and the weight of the attached LP and CD
- MR can be driven by operator to the desired location (and back) while operator walks alongside
- MR can relay location at least at 5 Hz at a distance of 100 m back to GS
- MR can be powered to achieve a round trip of 100 m

DRIFT CONOPS

CD - Child Drone
GS - Ground Station
MR - Mother Rover

DRIFT (2017 – 2018)
CHIMERA (2016 – 2017)
INFERNO (2015 – 2016)

MR path
MR Communications with GS
CD Communications with GS
DRIFT Mission



Design Description

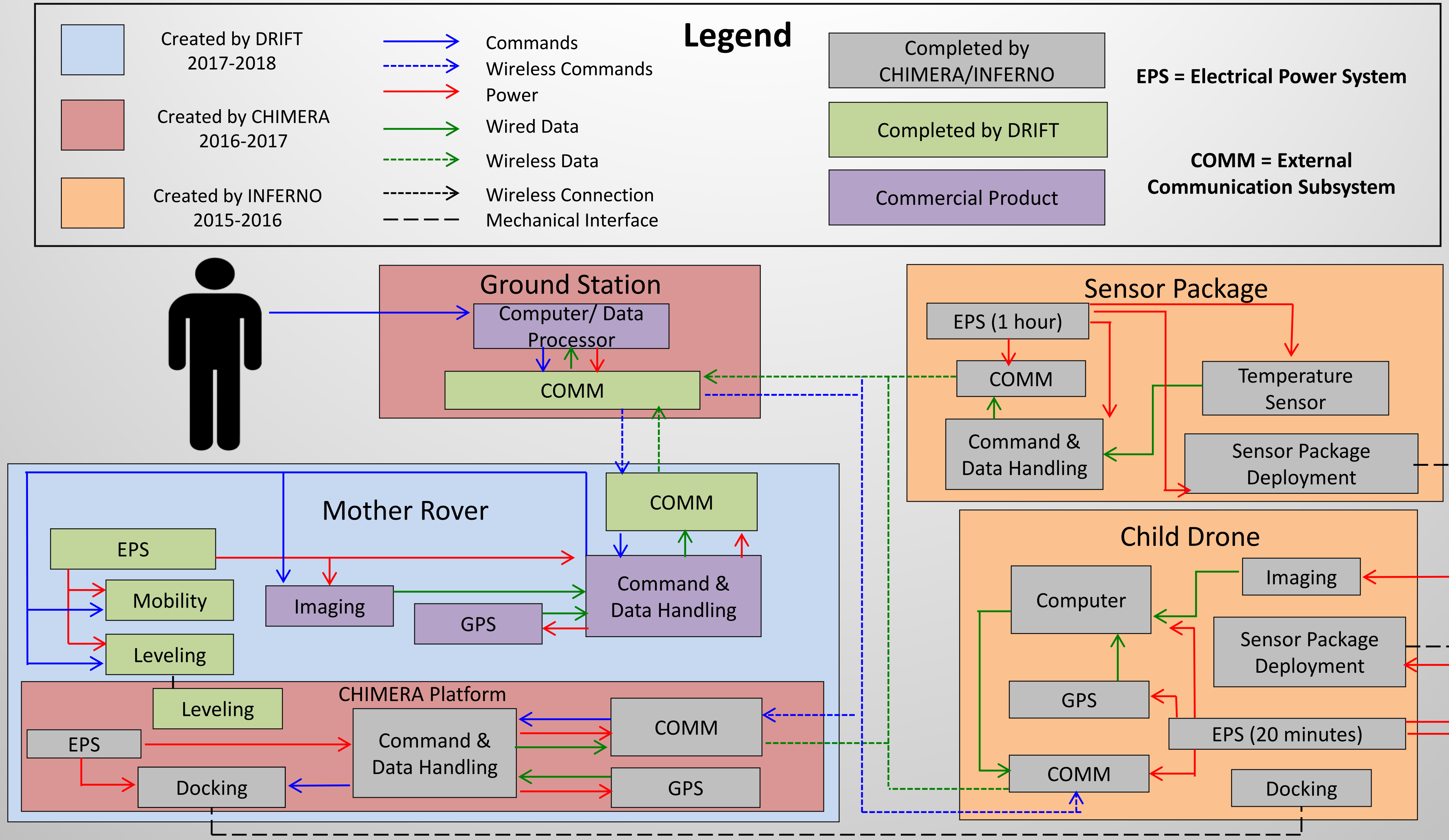
Project Purpose | **Design Description** | Test Overview and Results | Systems Engineering | Project Management

Design Solution: An Overview

1. CHIMERA Landing Platform
2. Landing Platform Securement Mechanism
3. Charging Bracket
4. Internal Leveling Jack System
5. Fixed-Chassis Body
6. 535 in-lb Motors
7. 18 in Diameter Wheels

Total Weight: 475 lbs

Functional Block Diagram



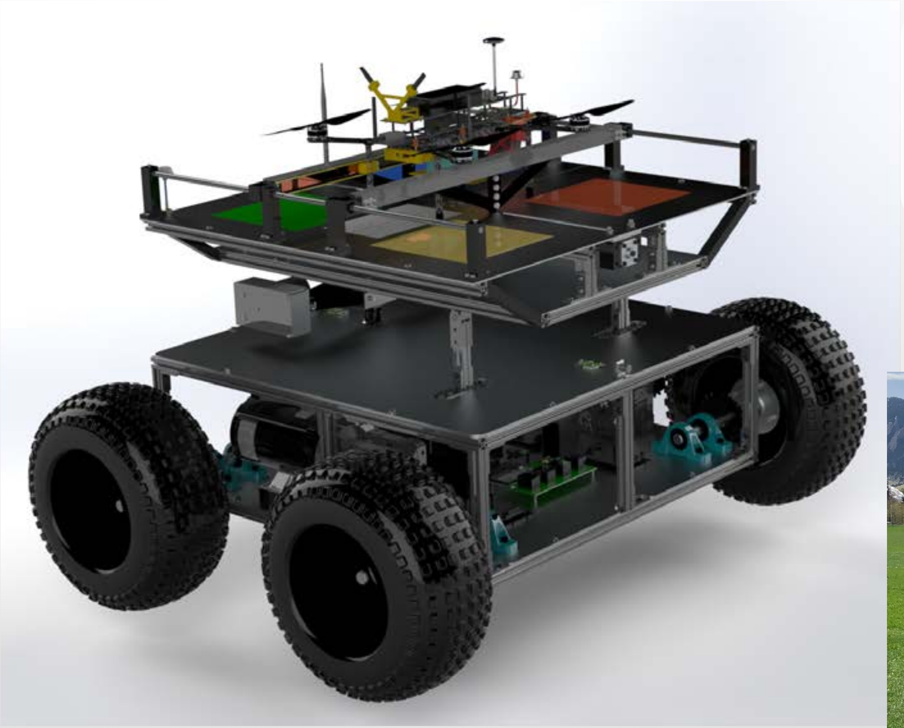
Critical Project Elements

- **Translational System**
  - **Fixed Chassis design** enables the mother rover to traverse rough terrain including fine dirt, small gravel, and lawn grass.
- **Leveling System**
  - Utilizes **internal leveling jack design** to level the landing platform to the required 0 ± 3.5^0 necessary for the child drone to deploy and autonomously land safely.
- **Electronics and Communication**
  - Necessary for communication between Ground Station and Mother Rover
    - Commands leveling system
    - Provides live video feed for operator
    - Commands Mother Rover for Translational motion

Translational System: An Overview

Translational System Objective

- MR must **traverse 250 meters** away from the GS to a specified GPS location
- MR must traverse over **rough terrain**
  - Loose gravel, fine dirt, and lawn grass
- MR must traverse up and down **slopes of 20º** or less.
- MR must traverse obstacles a maximum of **5 in tall**
- MR must traverse around obstacles greater than 5 in tall
- MR must travel at **speeds up to 0.5 m/s**



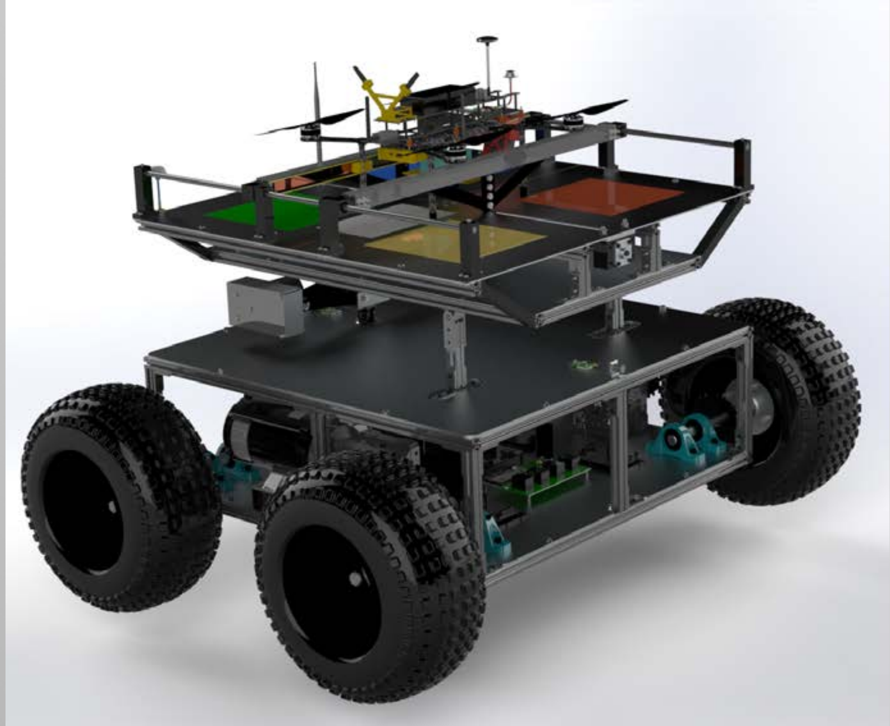
CAD Rendering of Mother Rover

Manufactured Translational System

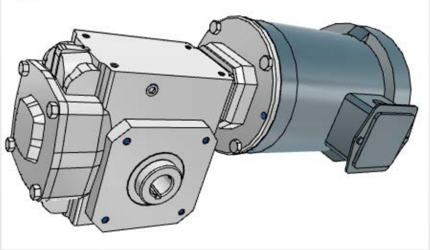
Translational System: Hardware

Roller Chains with Gear Sprockets

4-Wheeled
Fixed-Chassis Design



Two DC Gearmotors
Each provide 535
inlb Torque



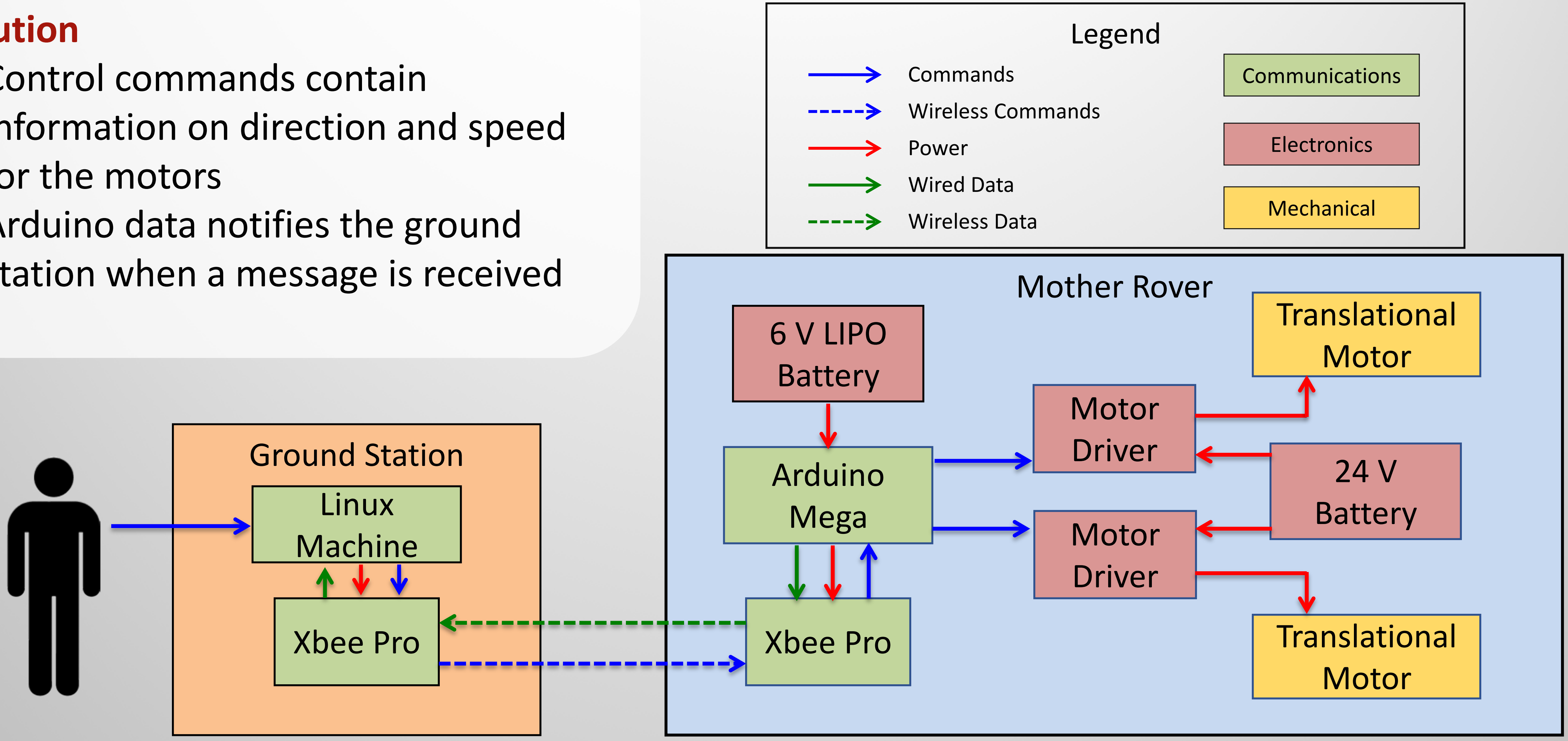
18 inch Diameter
ATV Off-Road Wheels

Chain Tensioners

Design Solution: Translational FBD

Solution

- Control commands contain information on direction and speed for the motors
- Arduino data notifies the ground station when a message is received

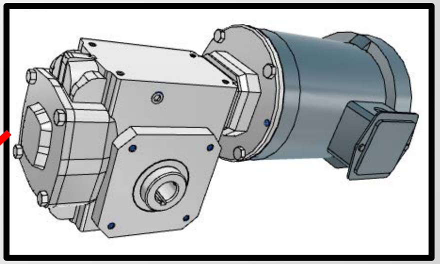


Translational System: Electronics

Solution

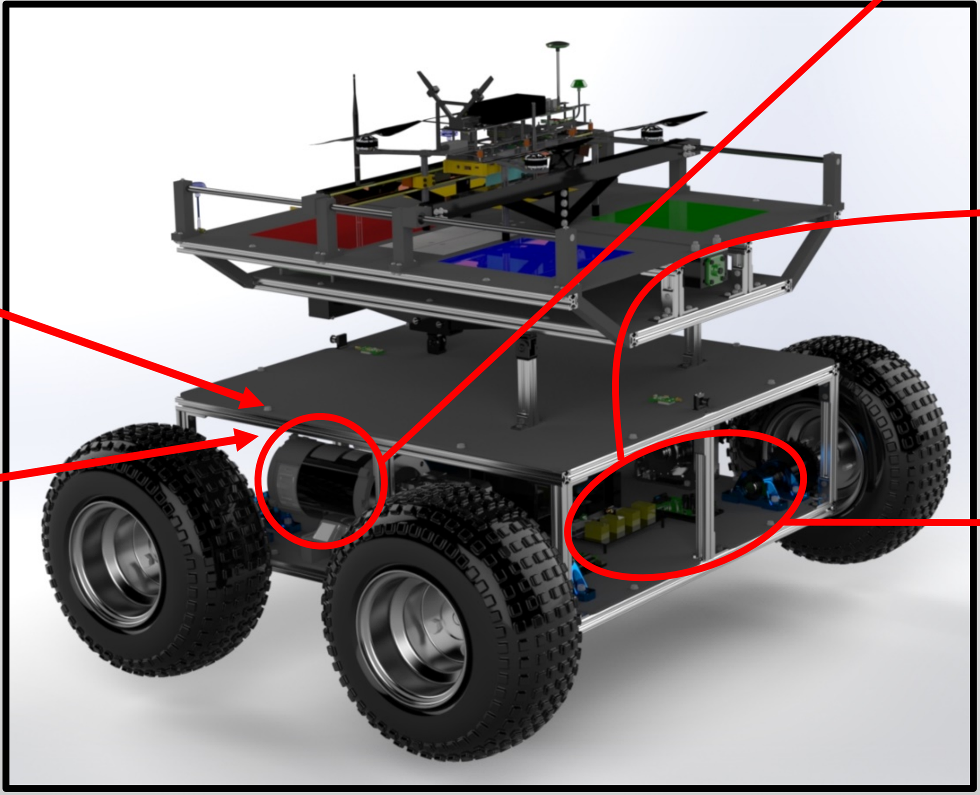
- Two DC60-4Q 24V 20A Motor Drivers – Motor Control
- Two MCP4131 Digital Potentiometers – Variable Speed Control
- Two Brushed DC Marathon Gear Motors with Reducer Producing 535 in-lb each
- Two 12V 100Ah Lead Acid Marine Batteries
- One 60A Time Delay Fuse – Current limiter for motor driver

2 x DC Brushed Motors

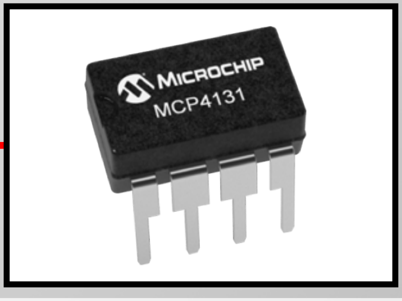


2 x 12V 100Ah Batteries

1 x 60A Time Delay Fuse



2 x 20A Motor Drivers



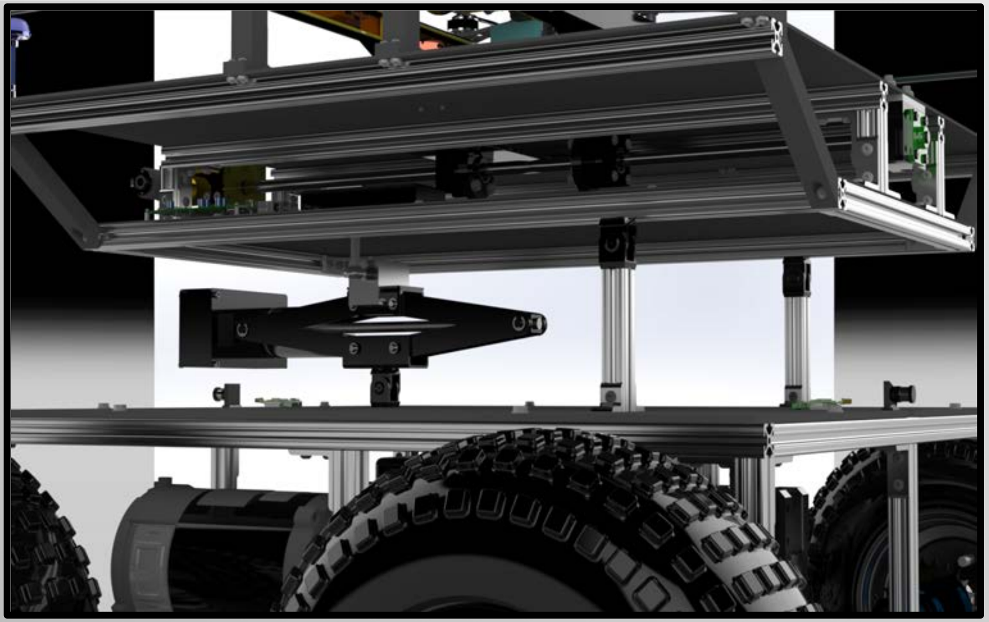
2 x Digital Potentiometers

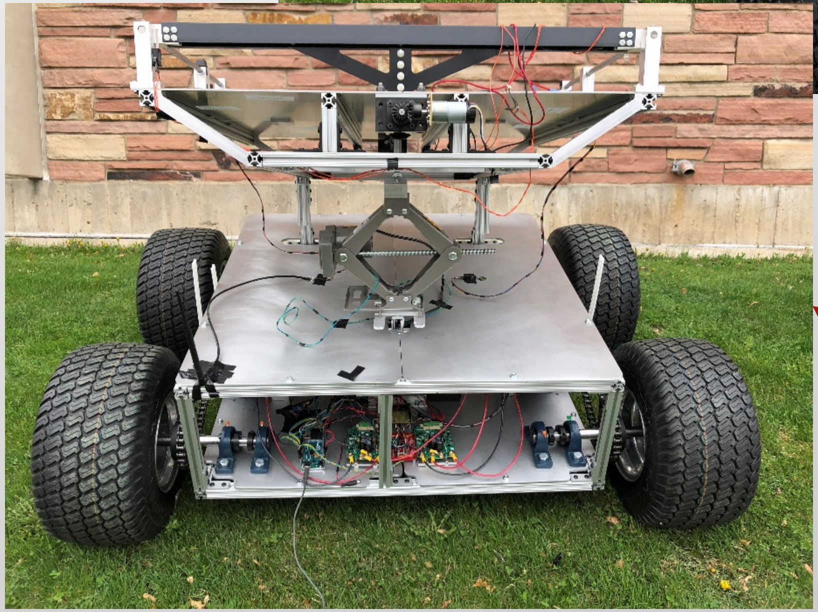
Leveling System: An Overview

Leveling System Objective:

- MR is required to **level the landing platform to 0 ± 3.5°** of the gravitational normal
  - Landing Platform must be level when on a **maximum 20° slope.**
- MR is required to be **stationary** when the Child Drone takes off and lands even on a slope of up to 20°

CAD Rendering of Leveling System





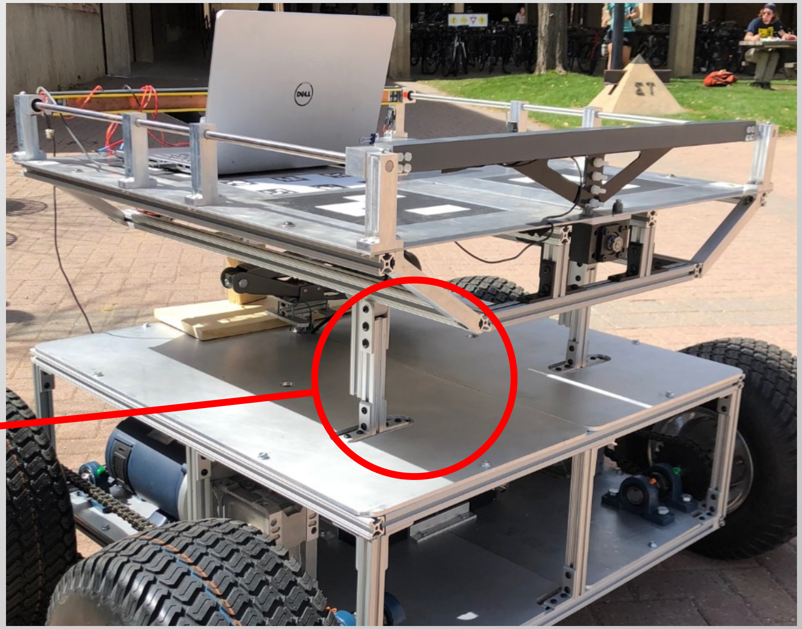
Manufactured and Integrated Leveling System

Leveling System: Hardware

EJ212 Electric Scissor Jack

7/16” Ball Joint

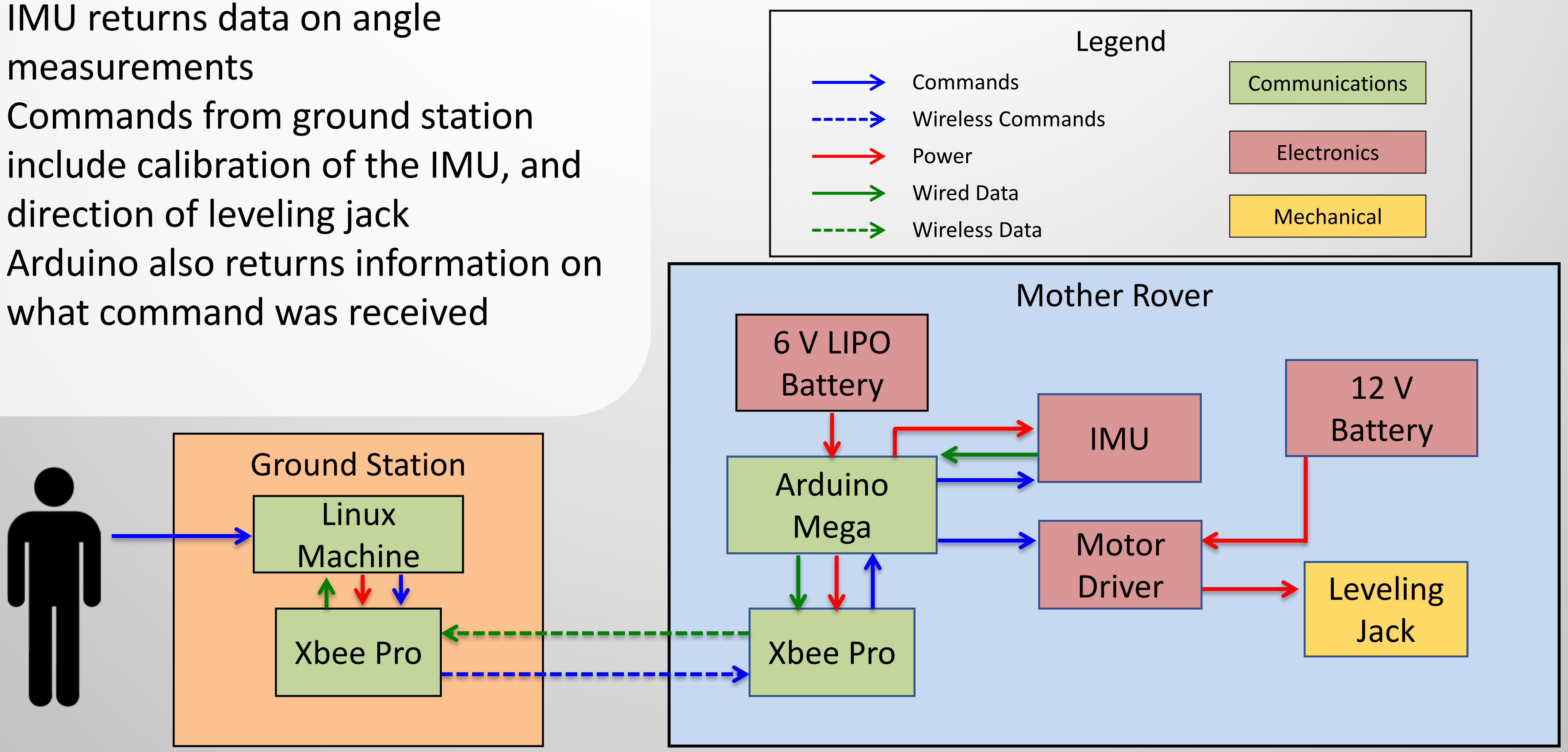
T-Slotted Pivot Joints



Design Solution: Leveling FBD

Solution

- IMU returns data on angle measurements
- Commands from ground station include calibration of the IMU, and direction of leveling jack
- Arduino also returns information on what command was received



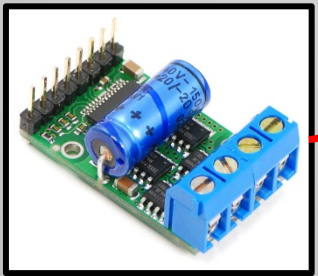
Design Solution: Leveling Electronics

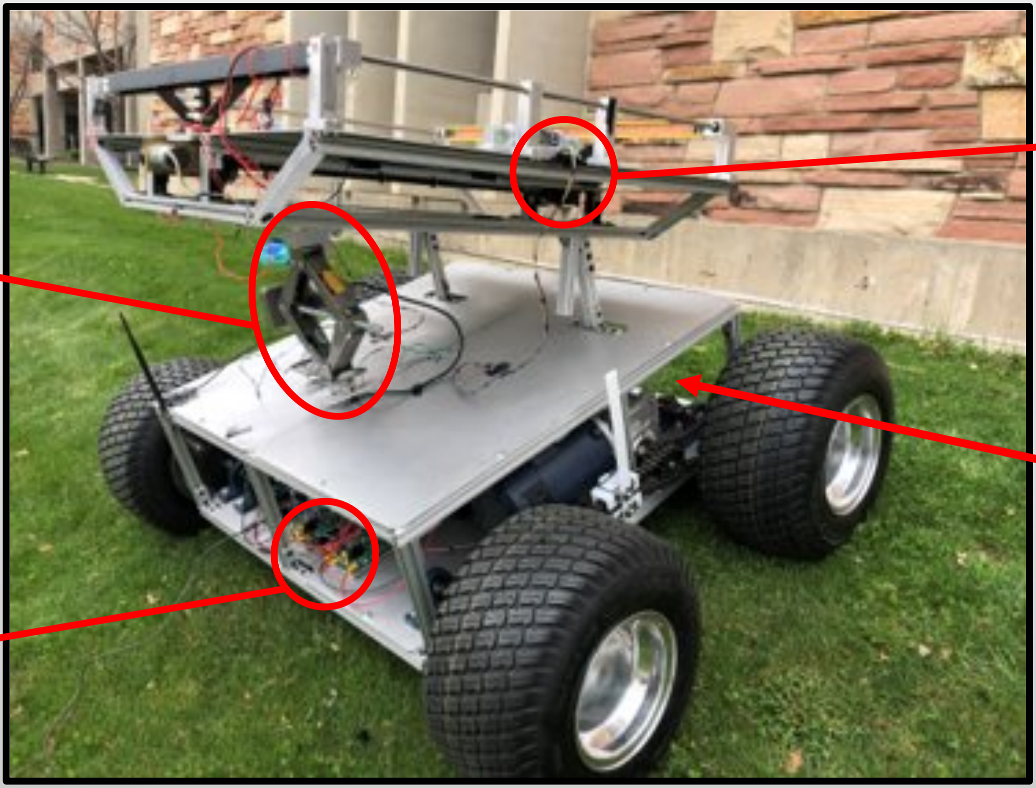
Solution

- One 15A Pololu Motor Driver – Motor Control
- One 12V Brushed DC Electric Scissor Jack Motor
- One 9-DOF Inertial Measurement Unit (IMU) – Inclination Sensing
- One 12V 100Ah Lead Acid Marine Battery

1 x DC Electric Scissor Jack

1 x 15A Motor Drivers





1 x 9-DOF IMU

1 x 12V 100Ah Batteries

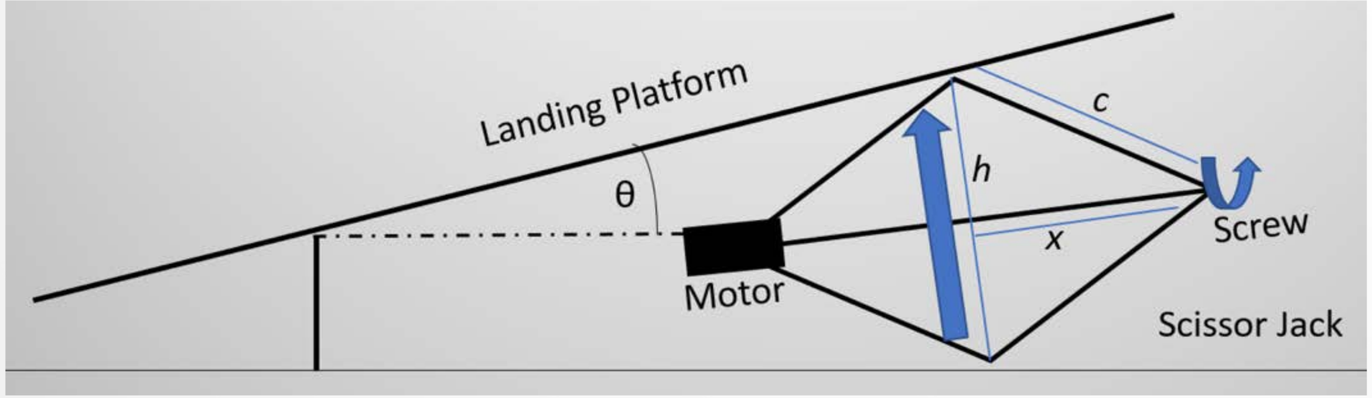
Test Overview and Result

Project Purpose | Design Description | **Test Overview and Results** | Systems Engineering | Project Management

Verification Testing Summary

Test	Simplified Requirements	Success	Explanation
Leveling	MR shall level on a 20° slope within 3.5° of the gravitational normal	Full Sucess	Successfully leveled on a 20° slope within 2.9° of the gravitational normal in all tests.
Slope	MR shall traverse up/down a 20° slope	Full Sucess	Successfully traversed up a 24° slope (highest tested)
Maneuverability	MR shall execute a 90° turn within a 10 ft. radius	Full Sucess	Successfully executed a 360° turn with 0 translational motion.
Obstacle	MR shall traverse 5 in. obstacles.	Full Sucess	Successfully traversed obstacles greater than 6 inches in height.
Communication	MR shall communicate with the rover over a 250 m. distance (188 m. free space + 62 m. trees)	Partial Success	Successfully transmitted commands when in the required amount of free space and the required amount of trees separately.
Distance	MR shall travel a distance of 500 m. on a full battery charge	Full Success	Successfully traversed over 600 m on flat surface while only depleting 7 % of total battery capacity.
GPS	MR GPS shall be accurate to within 5 m.	Partial Success	Successful GPS accuracy within 5 m 83.5% of times tested

Leveling Model



Fundamental Equations

$$x = x_0 - (turns)dx$$

$$h = \sqrt{c^2 - x^2}$$

$$\theta_{LP} = 2\arcsin(\frac{h}{2R})$$

Assumptions

- Jack starts horizontal
- Jack ends straight
- Screw can only perform full rotations

Constants

- *c*= 6.75 inch
- *R*= 19 inch

Input Parameters

- *h*= 0 inch
- *x*= 6.75 inch
- Θ= 0 degrees

Ending Parameters

- *h= 13.5* inch
- *x*= 0 inch
- Θ= 41.6 degrees

Threads per Inch	Accuracy per turn w/LP at 20º Slope
64	0.1683°
32	0.3348°
24	0.4449°
16	0.6627°
8	1.2990°
4	2.3224°

Green represents screw thread of jack used

- Model predicts the **change in LP inclination per turn of the screw of the scissor jack**
- Tabulated results show the rate of change in inclination when the LP is at 20°
- Jack used in leveling system has **8 threads per inch**

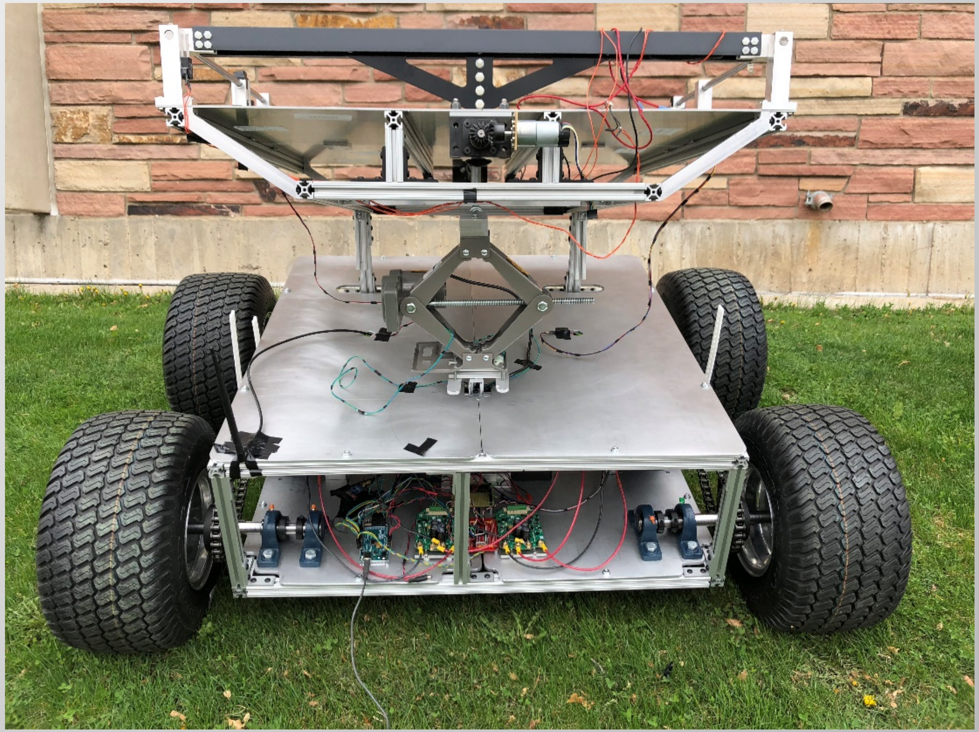
Leveling Test

- **Objective**: Demonstrate leveling capabilities of the rover as specified by the requirements
- **Requirements:**
  - MR shall level LP to 0 ± 3.5° from the gravitational normal when stopped on 20° slope
  - MR shall hold position while leveling on 20° slope
- **Procedure:**

  Indoor: Verify the accuracy of the leveling system to 0 ± 3.5° from the gravitational normal

  Outdoor: Verify ability to level while on a 20º slope.

Leveled on 20º Slope



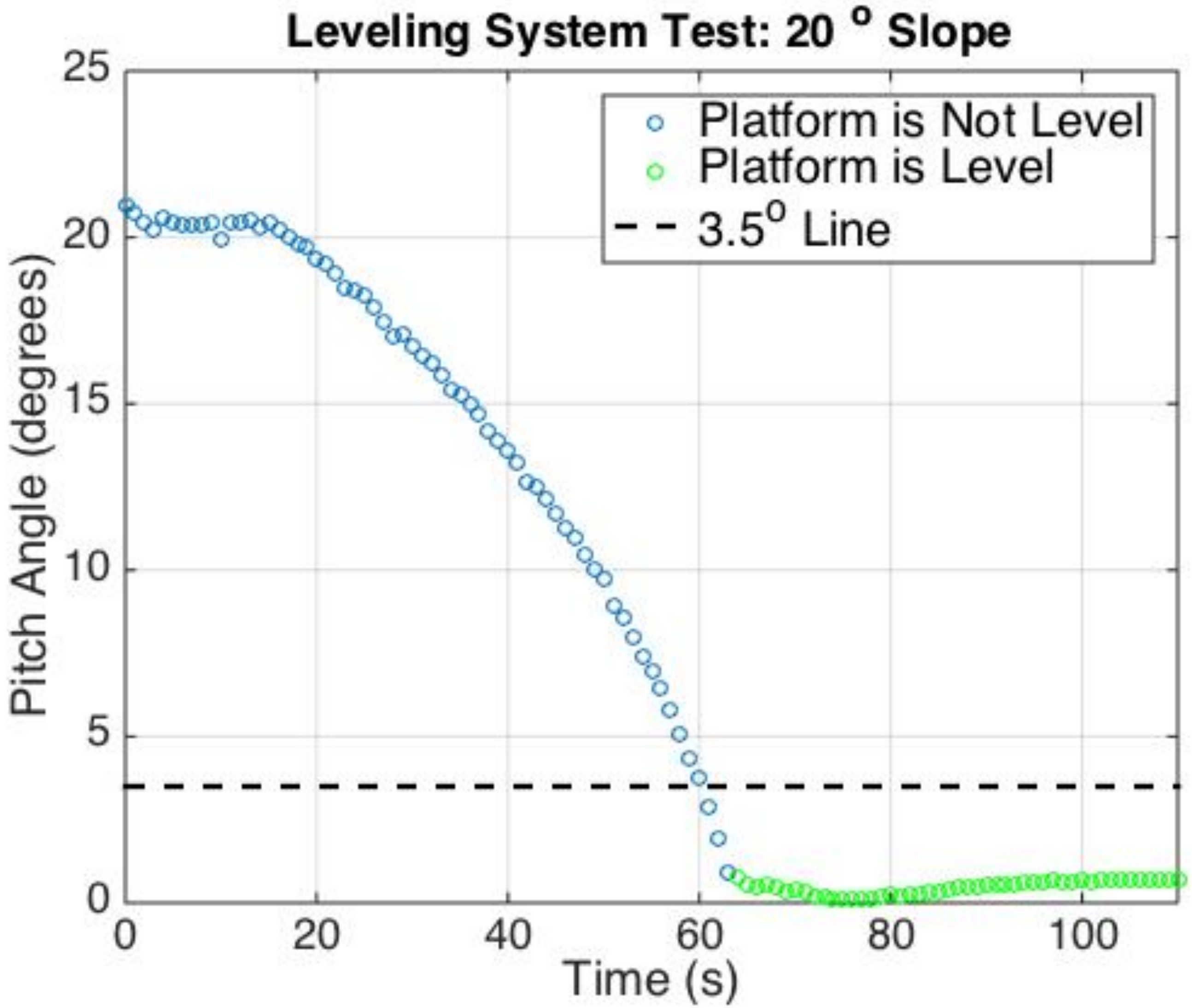
Leveling Test Results

- **Initial Result**
  - Rover leveled 7 times indoor with starting slope ranging from 9.0° - 10.4°.
    - Digital level utilized had marketed accuracy of +- 0.1 degrees for initial analysis
    - **Result:** mean pitch angle after level: 1.1°
  - Rover then placed on 19.6° slope outdoors
- **Complication:**
  - Problems with the "Stop Leveling" command during outdoor testing
    - Did not allow for accurate testing on 20° slope.
- **Solution**
  - Repeat 20° slope test inside with updated software
- **Validation**
  - Satisfies the requirement to level full 20° within 3.5° of the gravitational normal

Leveling Test Results

Model Validation

- Analyzed **final pitch angle** after leveling system considers platform to be less than 2° from level.
- **Mean Leveled Pitch Angle:** 0.477° from level.
- **Standard Deviation:** 0.212°
- **Conclusion**
  - Predicted accuracy of 1.299° per leveling jack screw turn
  - Achieved an accuracy of 0.477°
  - Model considered successful since predicted final pitch angle accuracy to be ≤ 1.299°



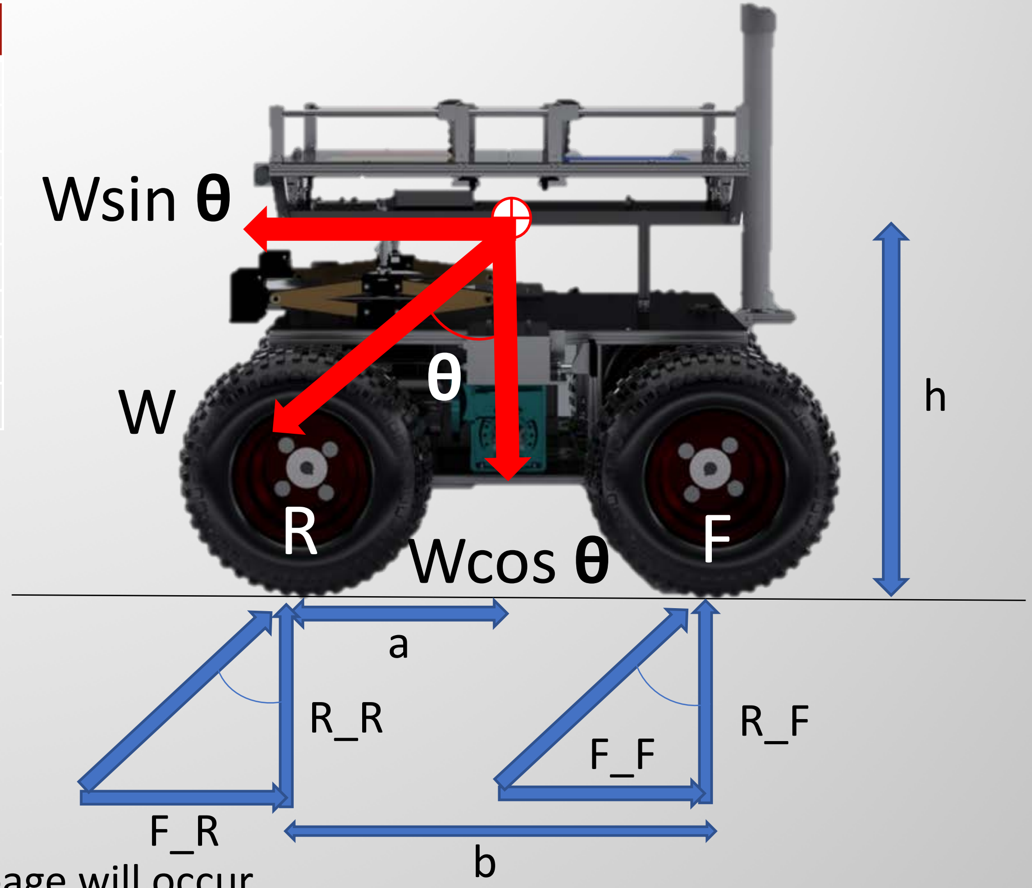
Result: All MR's Leveling Requirements Were Met ✓

Blue: Pitch Angle before LP considered level
Green: Pitch Angle after LP considered level

Slope Model: Traction Analysis

- Traction and Torque models primarily defined from grade resistance (GR), rolling resistance (RR), and inertial resistance (FA)
  - These forces summed to get Total Tractive Effort (TTE)

Input Parameters	
Weight, W	475 lb.
Incline Angle θ	20 degree
Velocity, V	0.5 m/s
Rolling resistance factor, C_{rr}	0.037
Frictional loss factor, FR	1.1
Wheel radius, R_w	9 in.
Acceleration time, t_a	3 seconds
Coefficient of friction on dry grass, μ	0.75



- $TTE[lb] = RR + GR + FA$
  - $RR = Reac_{wheel} \cdot C_{rr}$
  - $GR = Reac_{wheel} \cdot \sin(\theta)$
  - $FA = \frac{Reac_{wheel} \cdot V}{32.2\frac{ft}{s^2} \cdot t_a}$
- Wheel Torque Required: $T_w = TTE \cdot R_w \cdot RF$
- Max Tractive Torque: $MTT = Reac_{wheel} \cdot \mu \cdot R_w$
- Wheel Torque must be less than Max Tractive Torque, otherwise will slippage will occur.
- **Model Prediction Results using inputs:**
  - $T_{w,rear}$ = 565.94 in-lb. $T_{w,front}$ = 309.1 in-lb. $T_{w,motor}$ = $T_{w,rear}$ + $T_{w,front}$ = 874.95 in-lb
  - MTT_{rear}=974.40 in-lb. MTT_{front}=532.04 in-lb. MTT_{total}= MTT_{rear}+ MTT_{front} = 1506.44 in-lb.
  - No predicted slipping

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Slope Test

- **Objective:** Characterize capabilities of the rover traversing up and down slopes ≤ 20º slopes.
- **Requirements:**
  - MR shall traverse slopes ≤ 20° at speeds up to 0.5 m/s
- **Procedure:**
  - MR placed at the base of a hill with a slope varying from 19 ° to 24 °
  - MR then commanded to move forward up slope
  - Digital level (accuracy +- 0.1 degree) then used to find the max slope achieved

Rover Successfully Traverses Up 20º Slope

Rover Successfully Traverses Down 20º Slope

Slope Test Results

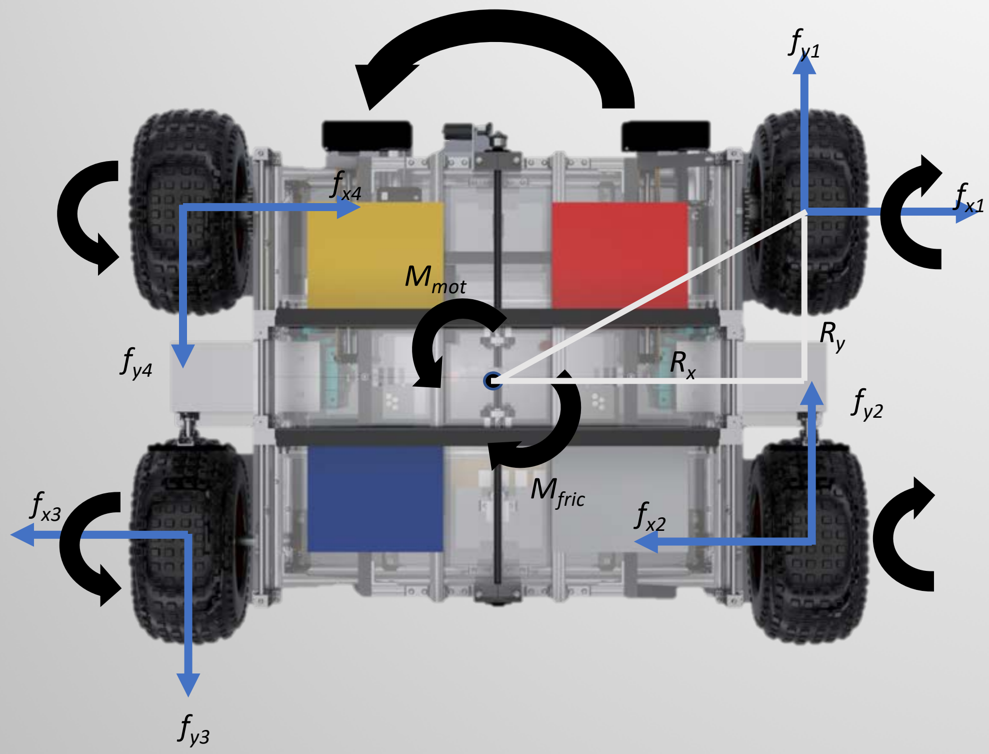
- **Initial Result**
  - MR traversed all slopes ≤ 24°
- **Complication**
  - Chain fell off
    - No power to wheels
- **Solution**
  - Chain tensioners were added to ensure power transfer to the wheels
- **Validation**
  - Satisfies the requirement as rover was able to exceed the required slope by 4°
  - MR did not slip on any slope therefore traction model has been validated
  - Visual Inspection Test Methodology indicated Traction Analysis is Correct

Result: All MR's Slope Requirements Were Met ✓

Rover Successfully Traverses Down 20º Slope (before chain tensioners added)

Rover Successfully Traverses Up 20º Slope

Maneuverability Model



Assumptions:

Rover turns in place

Acceleration is constant, $a = \frac{V_f - V_o}{\Delta t}$

Parameters:

$R_x = 2.11 \text{ ft} \quad R_y = 1.23 \text{ ft} \quad m = 475 \text{lbm} \quad V_f = 1.64 \frac{ft}{s}$

$\Delta t = 1s \quad V_o = 0$

Axial force at each Wheel:

$$f_x = \frac{R_x}{R_y}\frac{ma}{4}$$

Axial Force on Each Wheel from Parameters:

$f_x = 334.08 \frac{lbf\ ft}{s^2} = 10.38\ lbf$

Selected Bearings have axial load rating of 6.65 kN, or 1495 lbf

Maneuverability Test

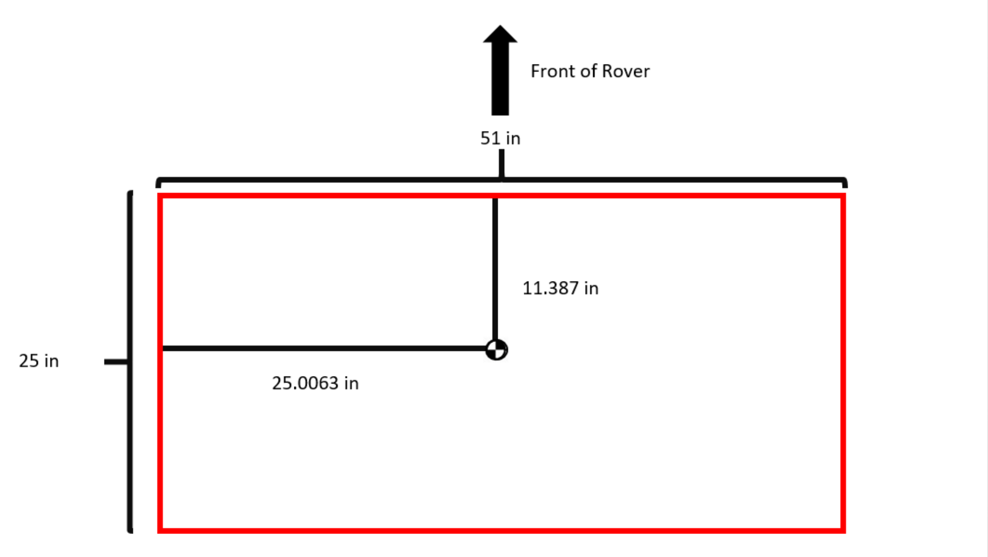
- **Objective:** Demonstrate MR's Skid Steering capability
- **Requirements:**
  - MR shall execute a 90° turn in a 10 foot radius
- **Initial Result**
  - MR executed 360° turn
  - Center of rover experienced only a 2 inch offset after complete turn
- **Complication**
  - None
- **Solution**
  - N/A
- **Result**
  - Bearings remained intact after experiencing skid steering axial loads
  - Using the Visual Inspection Test Methodology it was verified the maneuverability of the MR within requirement specification

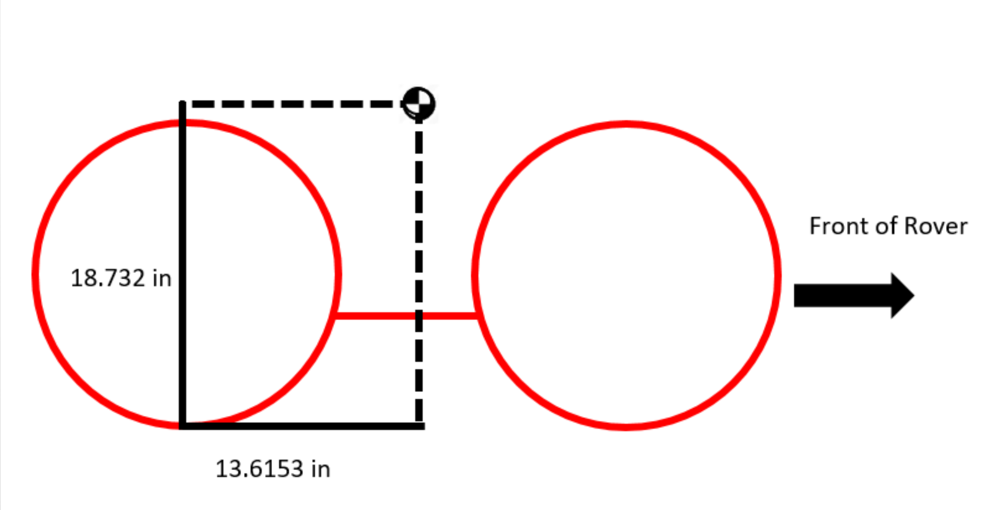
Result: All MR's Maneuverability Requirements Were Met ✓

Obstacle Model

Tipping Analysis

- **CAD Model Center of Gravity Prediction (COG)**
  - 14 in. from contact point of left wheel to right side
  - 26.06 in. forward from back contact point of the MR
  - 14.22 in. above the ground
- **Maximum Slope allowed CAD Model**
  - 44.55°
- **Actual COG from Testing**
  - 11.39 in. from contact point of left wheel to right side
  - 25.01 in. forward from back contact point of the MR
  - 18.732 in. from the ground
- **Maximum Slope Allowed Actual**
  - 36.01°
- **Causes for Difference in CAD COG and Actual COG:**
  - Weights of each component were taken from manufacturer and used for initial model
  - Some components could have had weight approximated differently than actual
  - Different dimensions of final constructed design





Obstacle Test

- **Objective:** Demonstrate MR's ability to traverse obstacles ≤ 5 inches in height.
- **Requirements:**
  - MR shall traverse obstacles up to ≤ 5 in. in height.
- **Initial Result**
  - Traversed up & down curbs over 6 inches in height.
- **Complication**
  - None
- **Solution**
  - N/A
- **Validation**
  - Satisfies the requirement as the rover was able to overcome obstacles ≤ 6 in tall
  - Rover tested on slope < 36.01^{o} (calculated max slope allowed) and did not tip
  - Visual Inspection, Demonstration and Test to verify the tipping analysis was correct

Result: All MR's Obstacle Requirements Were Met ✓

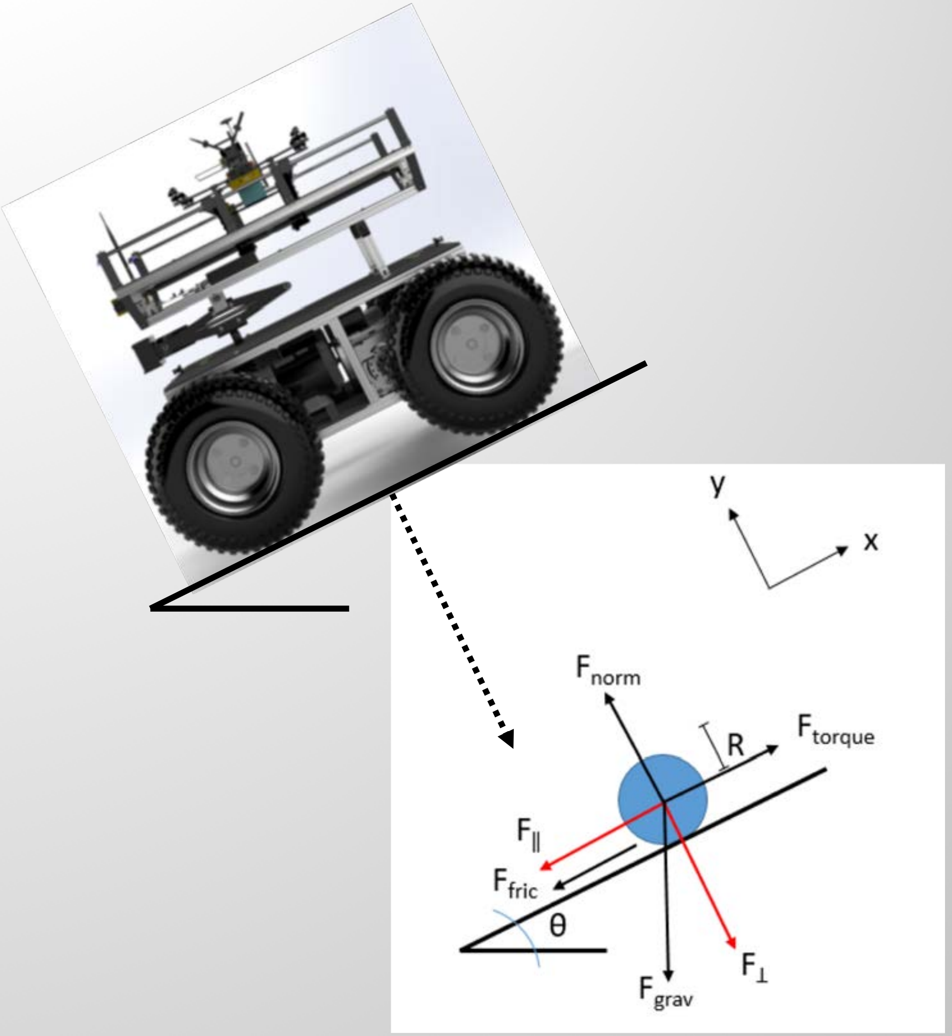
Traverse Up 6in Curb

Traverse Down 6in Curb

Distance Model

Assumptions for Analysis:
- Motor efficiency is 65%
- Air resistance is negligible
- Inclination of the surface is greater than or equal to zero
- Friction is not negligible
- MR is treated as a point mass

Constants:
- $g_0 = 32\ ft/s^2$
- $m = 475\ lb$
- $e = 0.65$
- $R = 9\ in$
- $V = 0.5\ m/s$
- $t = 60\ min$



Using the same torque equation from the slope model:
- $TTE[lb] = RR + GR + FA$
  - $RR = Reac_{wheel} \cdot C_{rr}$
  - $GR = Reac_{wheel} \cdot \sin(\theta)$
  - $FA = \frac{Reac_{wheel} \cdot V}{32.2\frac{ft}{s^2} \cdot t_a}$
- $T_w = TTE \cdot R_w \cdot RF$

Model Results for Total Torque Applied to One Motor

Incline Angle θ	Wheel Torque Applied, T_w
0°	126.92 in-lb
5°	330.59 in-lb
10°	527.08 in-lb
15°	710.41 in-lb
20°	874.95 in-lb

Distance Model

Speed – Torque – Current Curve Results:

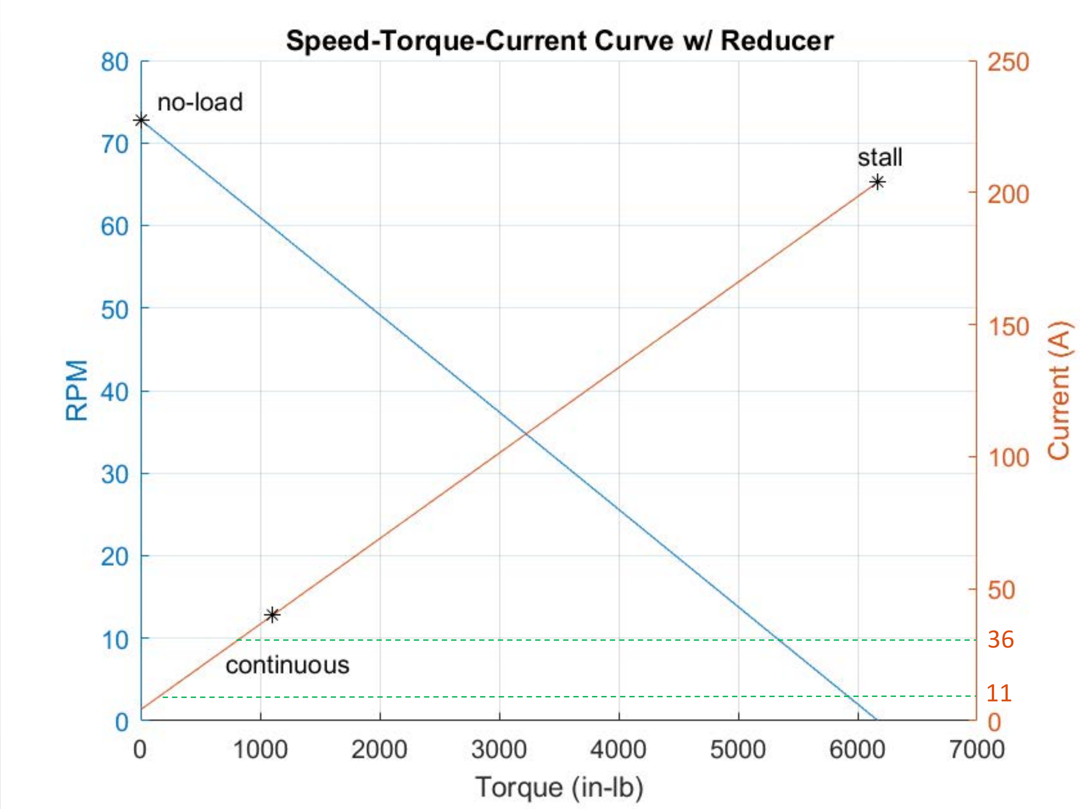
- 475 lbs → 0° → 126.92 in-lb → 11 A/h
- 475 lbs → 20° → 874.95 in-lb → 36 A/h

Distance Predictions:

- 600 m for 40 min on 0° slope ≈ 7.33 A/h
- Estimated 7.33 A/h of 100Ah battery

Conclusions:

- 500 m for 0.5 hr on 20° slope → 18 A/h
- 500 m for 1 hr on 20° slope → 36 A/h



The three data points labeled on the plot were provided by Marathon Motors

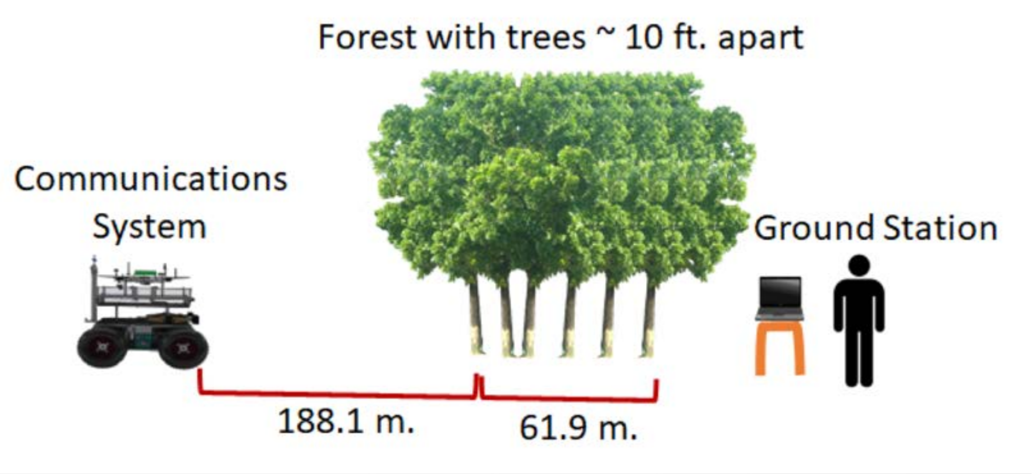
Distance Test

- **Objective:** Find the distance the rover can travel on a full battery charge.
- **Requirements:**
  - Rover must travel 250 m away from the ground station and return.
- **Initial Result (on a flat surface)**
  - 600 m for 40 min on 2°
  - 7% battery capacity utilized according to battery charger
  - Model predicted close to measured value
- **Complication**
  - None
- **Solution**
  - N/A
- **Validation**
  - Satisfies requirements by traveling up to 500m on one charge
  - Test Methodology determined Distance Model to be accurate

Result: All MR's Distance Requirements Were Met ✓

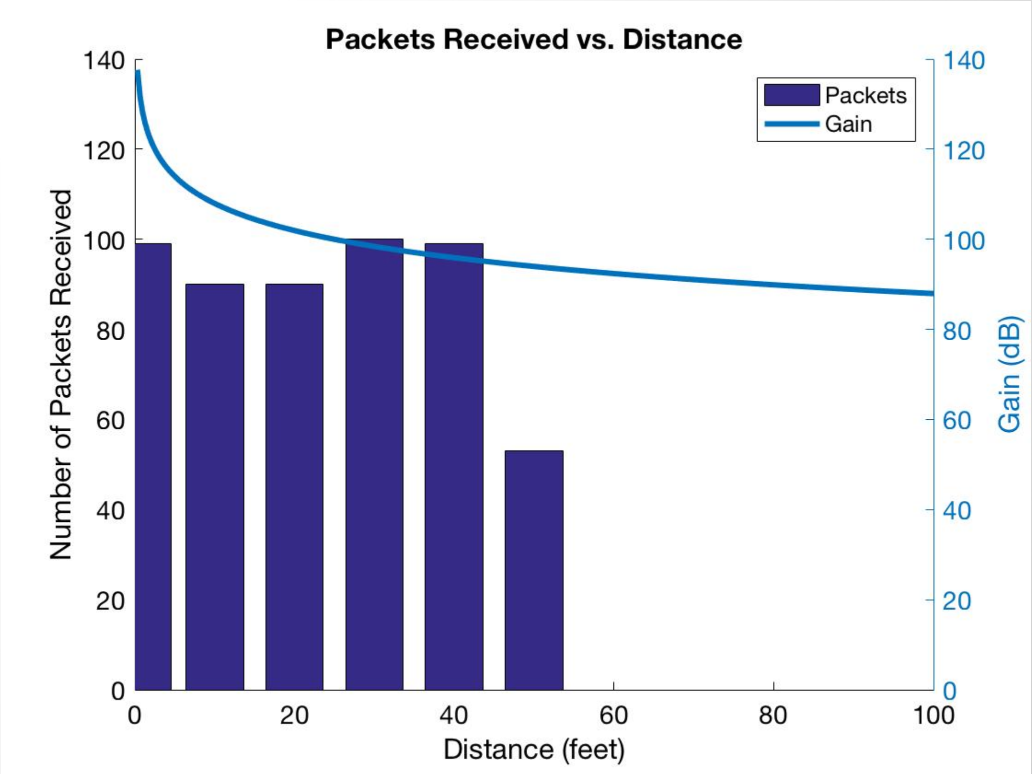
Communications Test

- **Objective:** Demonstrate the Rover's ability to communicate as specified in the terrain through trees and open space.
- **Requirements:**
    - The MR shall ***receive commands from the GS at 5 Hz***.
    - The MR shall receive signals with a ***signal to noise ratio of at least 6 dB-Hz***
    - The MR shall receive commands at a ***distance of 250 meters***.
    - The MR shall ***transmit specified data to the GS at 30 Hz.***
    - The MR shall transmit its ***current GPS location*** to the GS with an ***accuracy of 5 m***
- **Procedure:**
    - Comms system consisted of Xbees and a ground station.
    - Tested in free space with the defined free space (188 m)
    - Tested in defined woods terrain (trees ~ 10 ft apart) at a distance of (62 m)



Communications Test

- **Initial Result**
  - Transmitters able to receive and send commands for specified free space and forest depth separately
  - The wireless communication works for 250m of free space
- **Complication**
  - Signal loss will cause the operator to lose control of the rover
  - Xbees performance considerably degraded from 1st to 2nd test
  - Could not pull the RSSI (Received Signal Strength Indicator)
- **Solution**
  - Upgrade to more reliable equipment
  - Run more tests with same setup to verify the issue lies in the components themselves
  - Used XCTU software's range text mechanism to view RSSI values, and count number of packets received
- **Validation**
  - Only partially satisfied communications requirement



Location	Send	Received	Loss	% Success Rate
1. Full Distance	63	27	36	43%
2. Forest Edge	71	60	11	85%
3. Inside Forest	8	3	5	38%

Systems Engineering

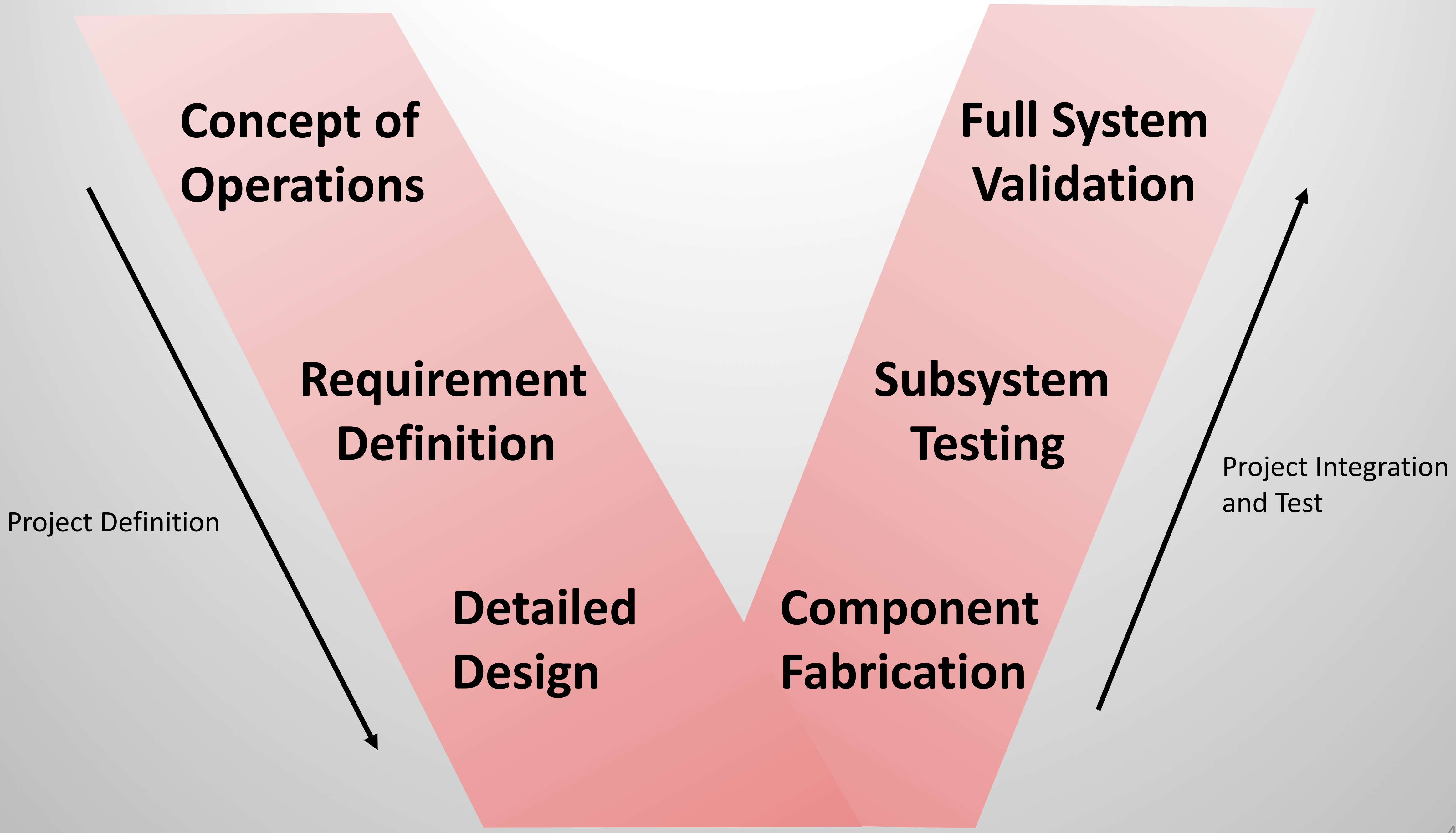
Project Purpose

Design Description

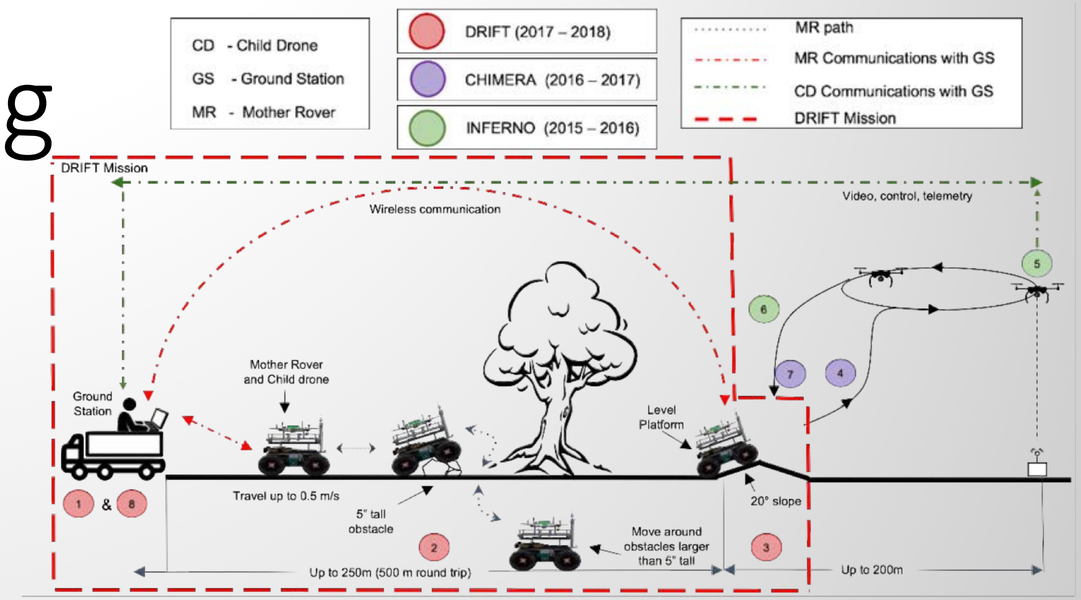
Test Overview and Results

Systems Engineering

Project Management


Concept of Operations
Requirement Definition
Detailed Design
Component Fabrication
Subsystem Testing
Full System Validation
Project Definition
Project Integration and Test

Fall Semester : Project Planning



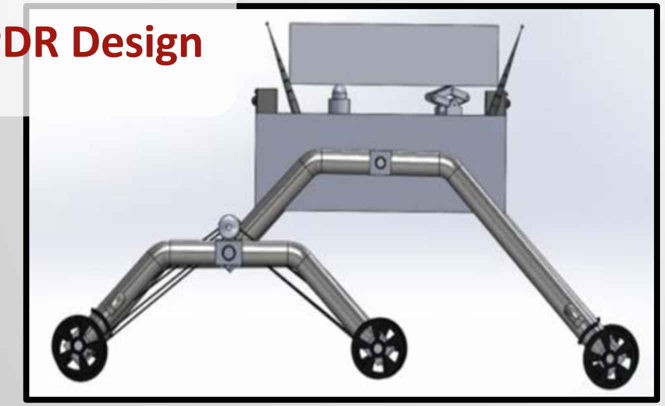
- CONOPS
  - Defined rough terrain to meet customers requirement
- Requirement Definition
  - Specified design requirements to validate and verify the functional requirements
  - The changes in requirements are driven by project's BUDGET and negotiated with customers

Functional Requirement	Description
FR1.0	The MR shall ***integrate with the attached landing platform*** such that it is permanently fixed and ***securely carries*** the CD without tipping while traversing the defined rough terrain.
FR2.0	The MR shall receive commands from the GS at a rate of 5 Hz.
FR3.0	The MR shall transmit data to the GS at a rate of 30 HZ.
FR4.0	The MR shall ***traverse 250 meters*** away from the GS to a specified GPS location over ***rough terrain*** defined by varying slopes and obstacles which require the MR to ***navigate over and around them***. The MR shall ***return to the GS*** after the mission is complete.
FR5.0	The MR shall position itself for the CD to take-off and land safely such that it is able to be secured by the MR's securement mechanism.

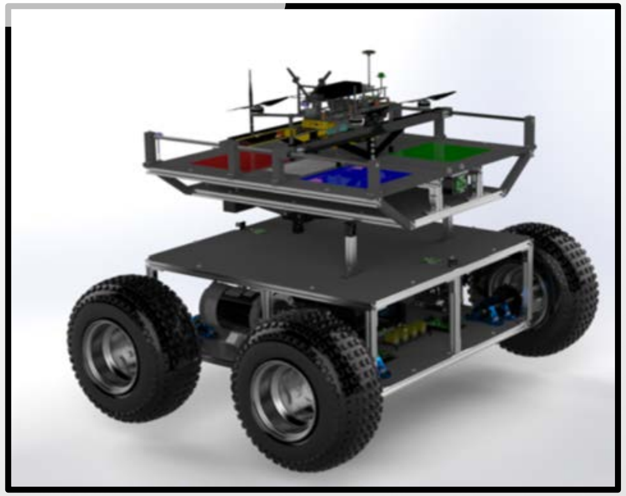
o Detailed Design and Design Evolution

Translational System Design

PDR Design



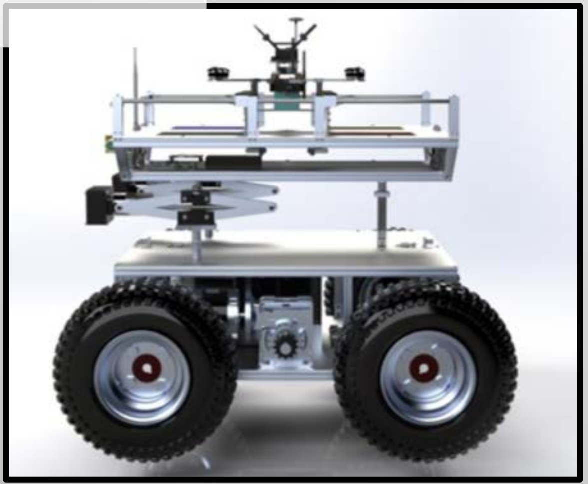
Final Design



- Trade design to accommodate the requirements better within the budget
- Simple design and geometry

Leveling System Design

PDR Design



Final Design

- Degree of freedom and time constraint plays an important role for the changes

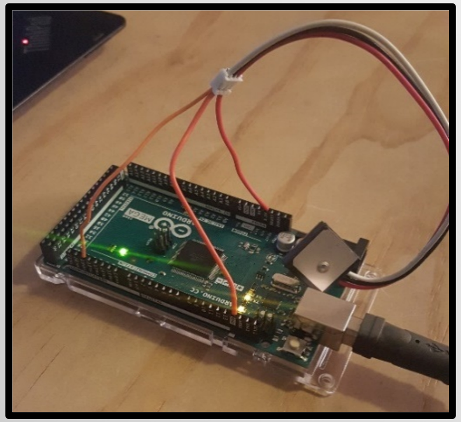
Spring Semester : Project Integration

- **Final Manufacturing Status**
  - Manufacturing was completed as scheduled
    - Some leveling components required additional margin which was allocated in the schedule due to changes made in the design
  - All components were fabricated and fully integrated to the frame by **March 28th**

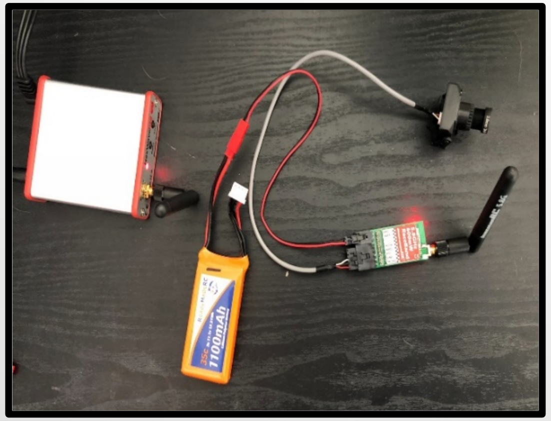
o Testing

o TRR Status Update

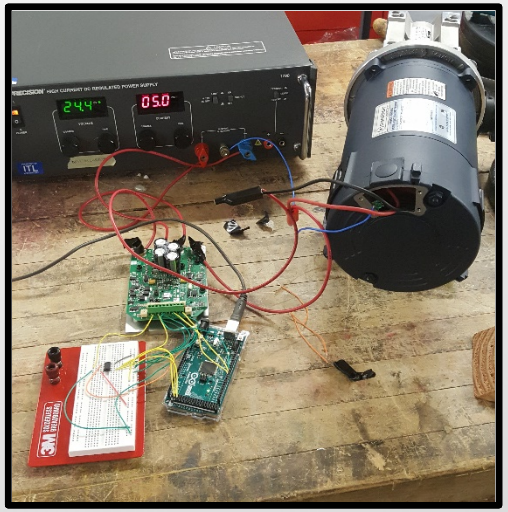
- o Unit testing for electronics has been in progress since January 16.



GPS

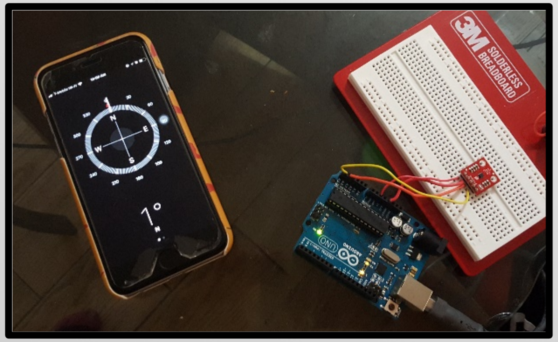


Hazard Camera System



Translational Motors System

Electric Scissor Jack Leveling System& IMU



Compass

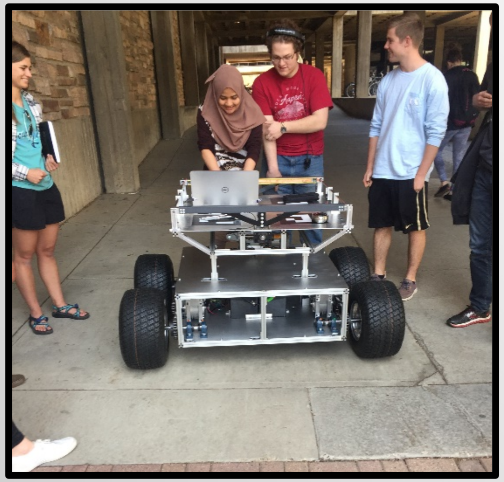
Debugging has been executed thoroughly before each component was integrated with others.

Identified issues :

- o The Foxeer camera can tolerate 12V but prefers 6V
- o Electric scissor jack relay system replaced with Pololu motor driver

o Full System Validation

- Full integration test and validation started on 1st April



Driving

Slope

Obstacle

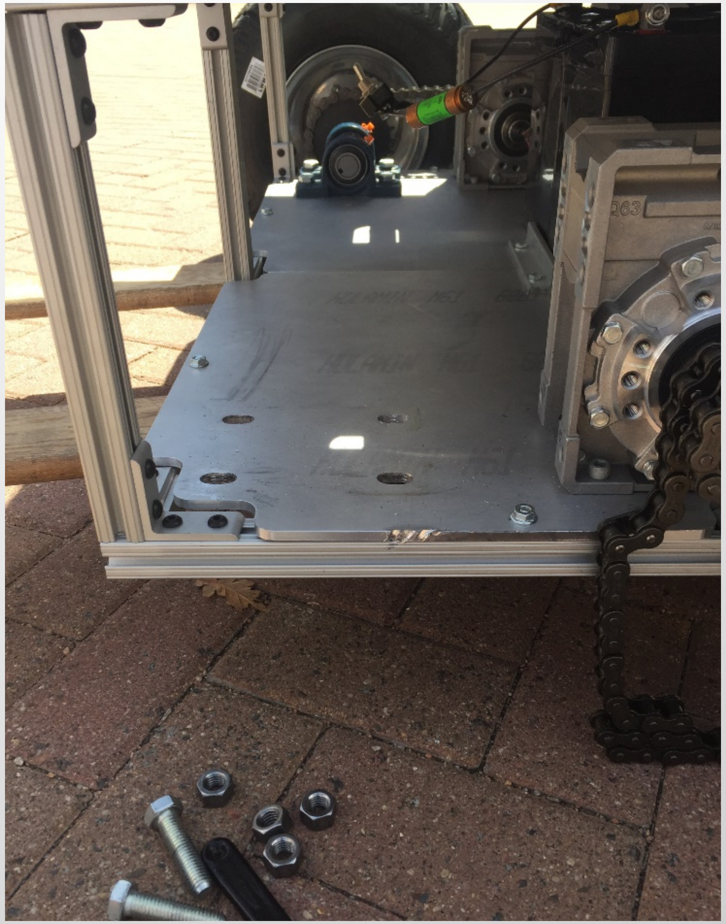
Integrated test of the subsystem is used to validate the requirements

Identified issues :

- Missing wire in digital potentiometer circuit and wire connection correction for proper control of the motor drivers
- IMU wiring requires some changes

Risk Trades

	Risks
R1	Structural Deformation/Breakage of Drive Shaft
R2	Wheel Slippage
R3	Shearing/Shifting of connections to LP
R4	Leveling system control failure
R5	Instability of the leveling connections to MR
R6	Instability of the leveling connections to LP
R7	Communication signal loss
R8	Overheating of the Motor
R9	Motor Overloads
R10	Back Drive
R11	Short Circuit
R12	Battery dies during mission
R13	Overheated components

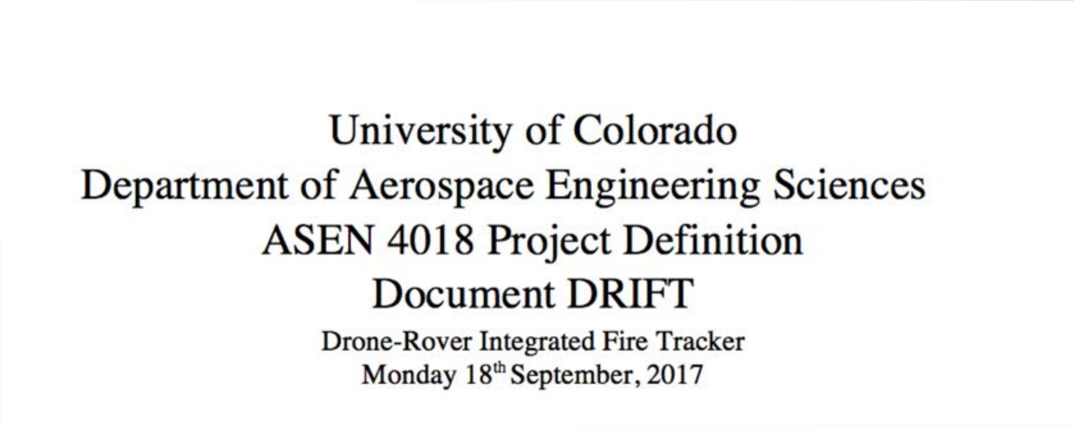


Only R1 and R2 occurred but no major impact.

Lessons Learned

- **Well-defined requirements are necessary to the success of the project**
  - Helps in designing the project and avoid confusion during validation and verification
- **Need better communication methods for tracking design changes of subsystems**
  - Miscommunication occurred during design changes that can be avoided if the team is well informed

From PDD…


University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018 Project Definition
Document DRIFT
Drone-Rover Integrated Fire Tracker
Monday 18th September, 2017

To Full System Integration and Test

Project Management

Project Purpose

Design Description

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Lessons Learned

- **Testing**
  - Allow more than one day of margin for repeat testing
    - Adverse Weather
    - Logistics of Moving 475 lb Rover
    - Software Glitches
  - Organize testing schedule such that everyone is able to contribute to test
    - Would make testing more efficient
- **Deliverables**
  - Ask PAB and customer to review material before presentation date

Final Budget Comparison

Category:	CDR Budget:	Actual Budget:	Difference:
Administrative	$150.00	$250.00	+$100.00
Communications	$225.94	$144.12	-$81.82
Electronics	$438.00	$594.26	+$156.26
Leveling	$256.48	$249.00	-$7.48
Shipping	$241.95	$337.74	+$95.79
Testing	$100.00	$249.41	+$149.41
Translational	$3,104.46	$3,161.17	+$56.71
Total Expenses	$4,516.83	$4,985.70	+$468.87

Totals:	CDR Budget:	Actual Budget:
Expenses	$4,516.83	$4,985.70
Funding	$5,000.00	$5,675.00
Margin	$483.17 (9.66%)	$689.30 (12.15%)

Major Changes

- Budget increased by $675 from EEF
  - Allowed for more money to be allocated to subsystems
- Purchased 100Ah batteries versus original 55Ah
- Leveling changed from 2DOF to 1DOF

Industry Cost

Assumptions

- Entry-Level Aerospace Engineer Salary of $65,000 for 2080 hours work
- 200% Overhead Rate

Fall Semester Hours	2590
Spring Semester Hours (as of 4/17/18)	2295.5
Total Project Hours	4885.5
Entry-Level Hourly Salary	$31.25
Total Personnel Cost	$152,671.88
Total Overhead Cost	$305,343.75
Total Material Cost	$4,985.70
Total Industry Cost (as of 4/17/18)	**$463,001.33**

Acknowledgements

Project Customer: Barbara Streiffert

Project Advisor: Dr. Jelliffe Jackson

Project Coordinator: Dr. Dale Lawerence

Aerospace Instrumentation: Trudy Schwartz and Robert Hodgkinson

Aerospace Machinist: Matt Rhode and Adrian Stang

Additional Funding: Engineering Excellence Fund

Questions?

Backup slides

Requirements Flow down

Functional Requirement	**Description**
FR1.0	The MR shall integrate with the attached landing platform
Design Requirement	Definition
DR1.1	The MR shall have sufficient structural integrity capable of supporting the size (1.1m X 1.1m) and weight (55lbs) of the LP and CD without deformation to the structure.
DR1.2	The MR shall incorporate the preexisting software/hardware of the LP to operate through one communication system.
DR1.3	The LP shall be fixed permanently to the MR.

Functional Requirement	Description
FR2.0	The MR shall receive commands from the GS at 5 Hz.
Design Requirement	Definition
DR2.1	The MR shall record a log of received commands from the GS detailed in DR2.4.
DR2.2	The MR shall receive signals with a signal to noise ratio of at least 6 dB-Hz (industry standard).
DR2.3	The MR shall receive commands at a distance of 500 meters.
DR2.4	The commands to be received by the MR from the GS include: forward/backward translational motion, turning motion, to turn on/off the MR video feed, opening/closing the CD securement mechanism, and to level the LP.

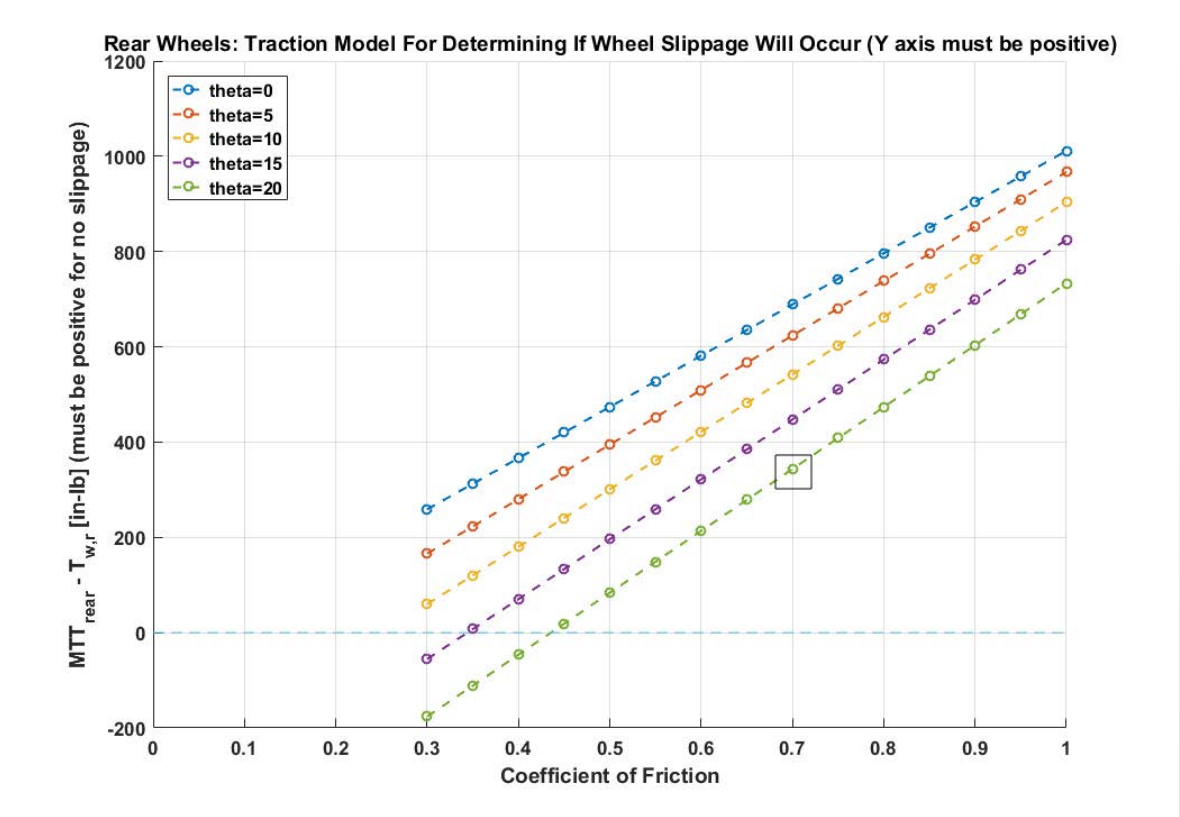
Functional Requirement	Description
FR3.0	The MR shall transmit specified data to the GS at 30 Hz.
Design Requirement	Definition
DR3.1	The MR shall transmit its current GPS location to the GS with an accuracy of 5 m.
DR3.2	The MR shall transmit live video feed at 1080p at 30 fps to the GS

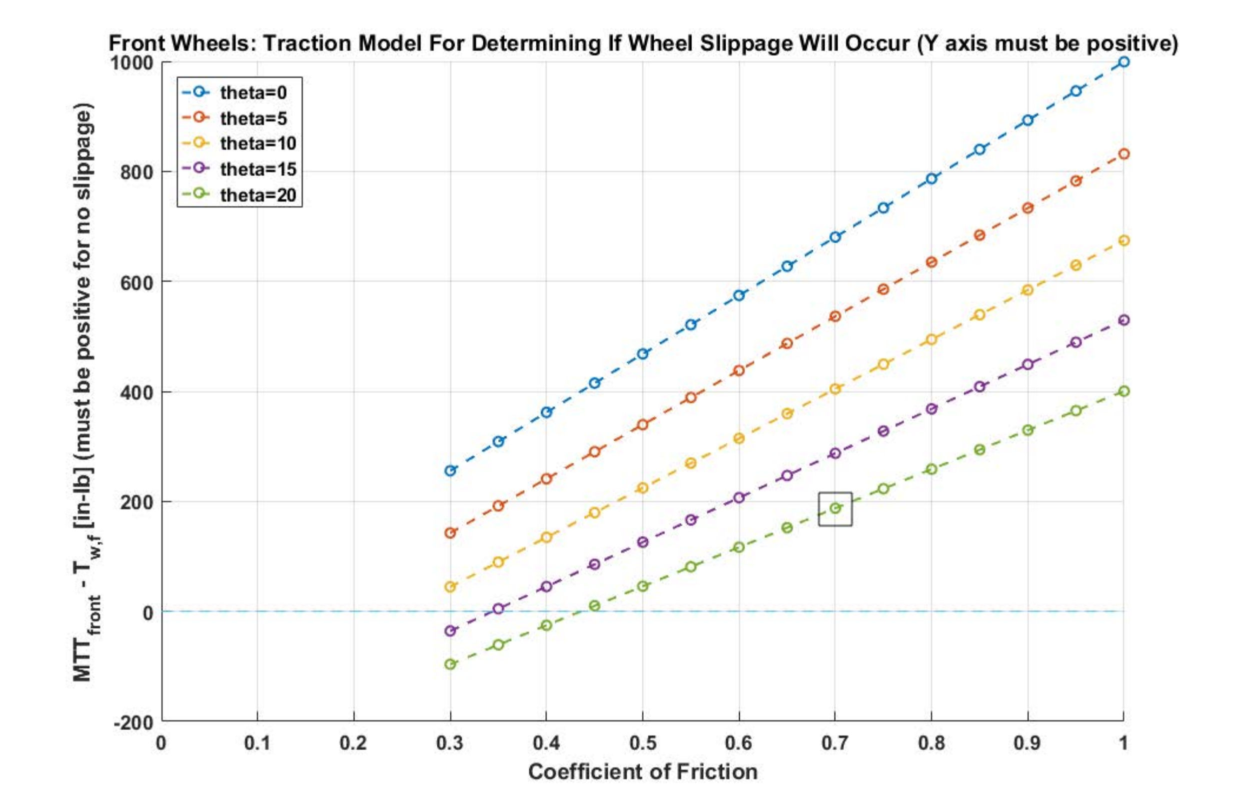
Functional Requirement	Description
FR4.0	The MR shall traverse 500 meters away from the GS to a specified GPS location over rough terrain defined by varying slopes and obstacles which require the MR to navigate over and around them. The MR shall return to the GS after the mission is complete.
Design Requirement	Definition
DR4.1	The MR shall travel at a speed within the range of 0 to 0.5m/s in forward and reverse.
DR4.3	The MR shall turn 90 degrees in a 10 ft. radius
DR4.4	The MR shall execute received commands including moving forwards, backwards, turning, speed variation, and coming to a complete stop.
DR4.5	The MR shall traverse up and down a slope of 20 degrees.
DR4.6	The MR shall traverse 5 in. tall obstacles.

Functional Requirement	Description
FR5.0	The MR shall position itself for the CD to take-off and land safely such that it is able to be secured by the MR's securement mechanism
Design Requirement	Definition
DR5.1	The MR shall level itself within 3.5 degrees after coming to a complete stop.
DR5.2	The MR shall hold a completely stopped position on a slope of 20 degrees by using a mechanism.

Modeling and Software

Driving Directly Uphill (Per Motor):





20 Degrees, Rear: $T_{wr} = 565.9\ inlb$
$MTT_r = 974.4\ inlb$

20 Degrees, Front: $T_{wf} = 309.0\ inlb$
$MTT_f = 532.0\ inlb$

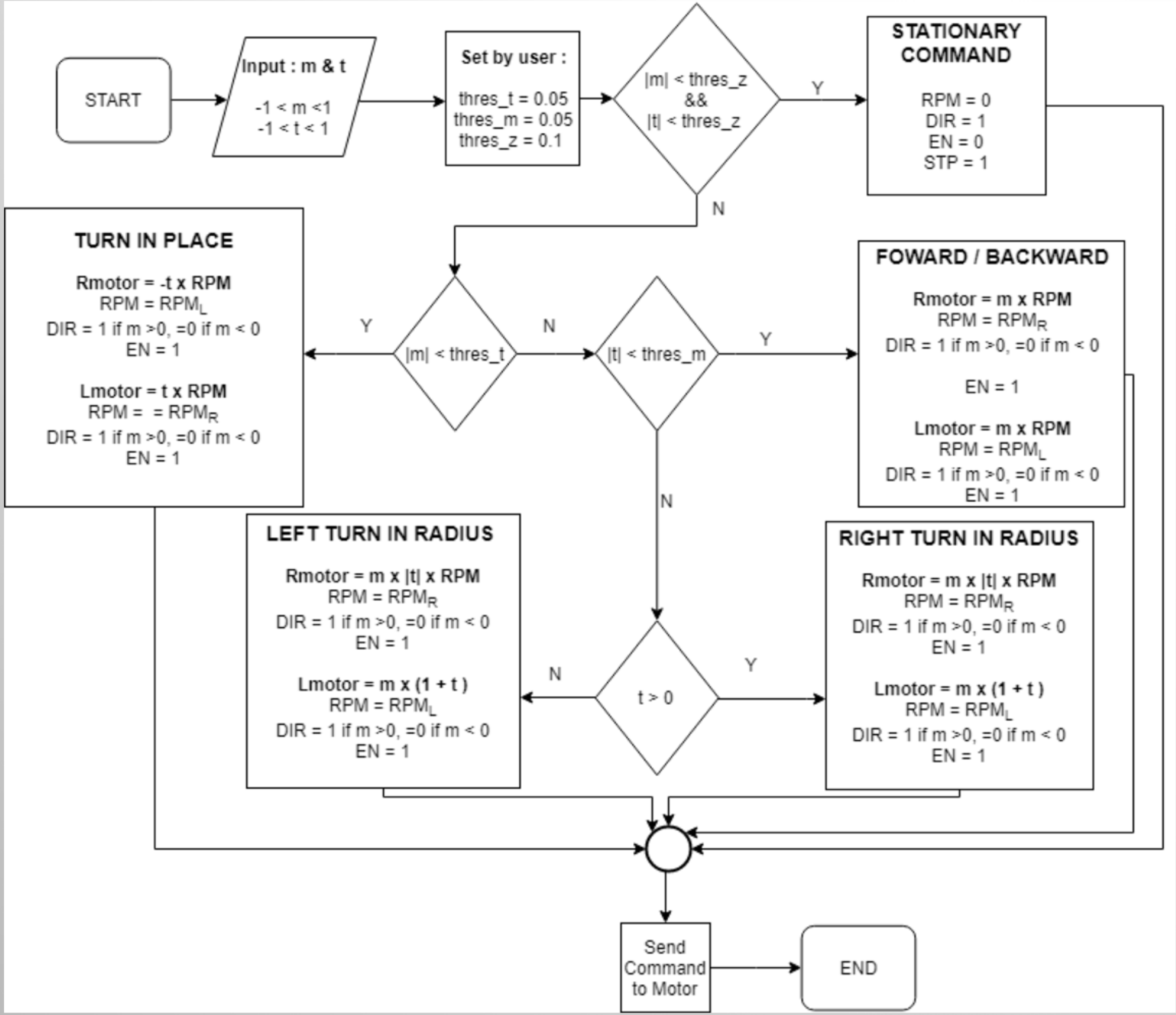
<u>Driving directly sideways along a 20 degree slope:</u>

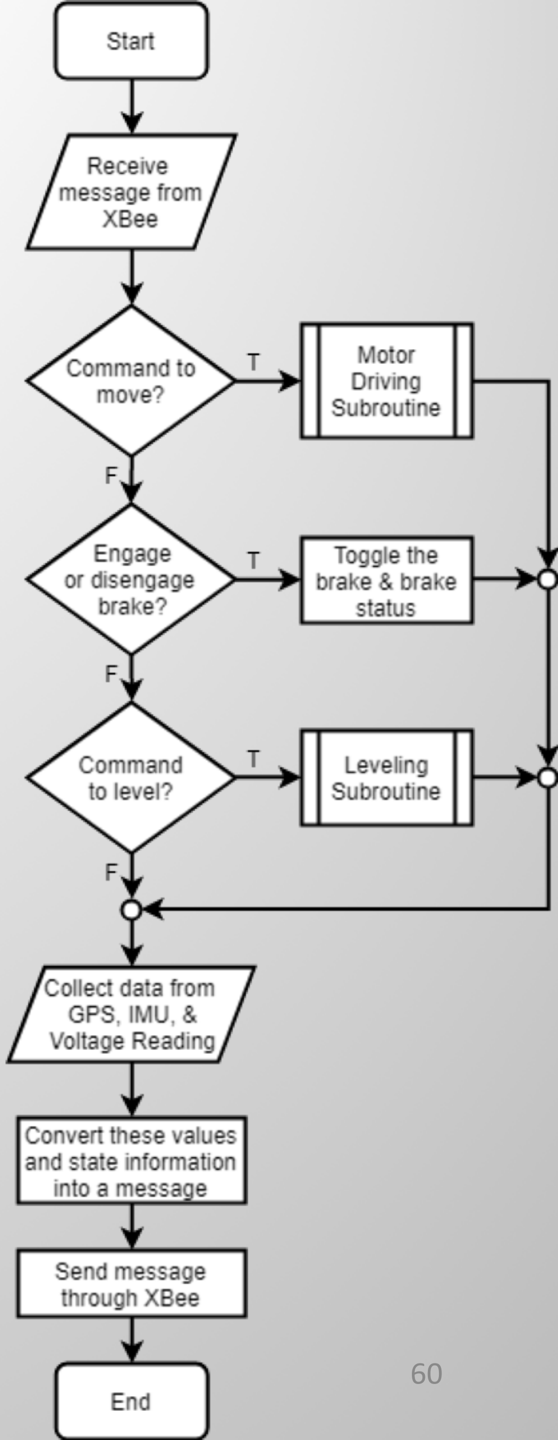
Left: $T_{w,left} = 153.5\ inlb$
$MTT_{left} = 969.8\ inlb$

Right: $T_{w,right} = 84.9\ inlb$
$MTT_{right} = 536.6\ inlb$

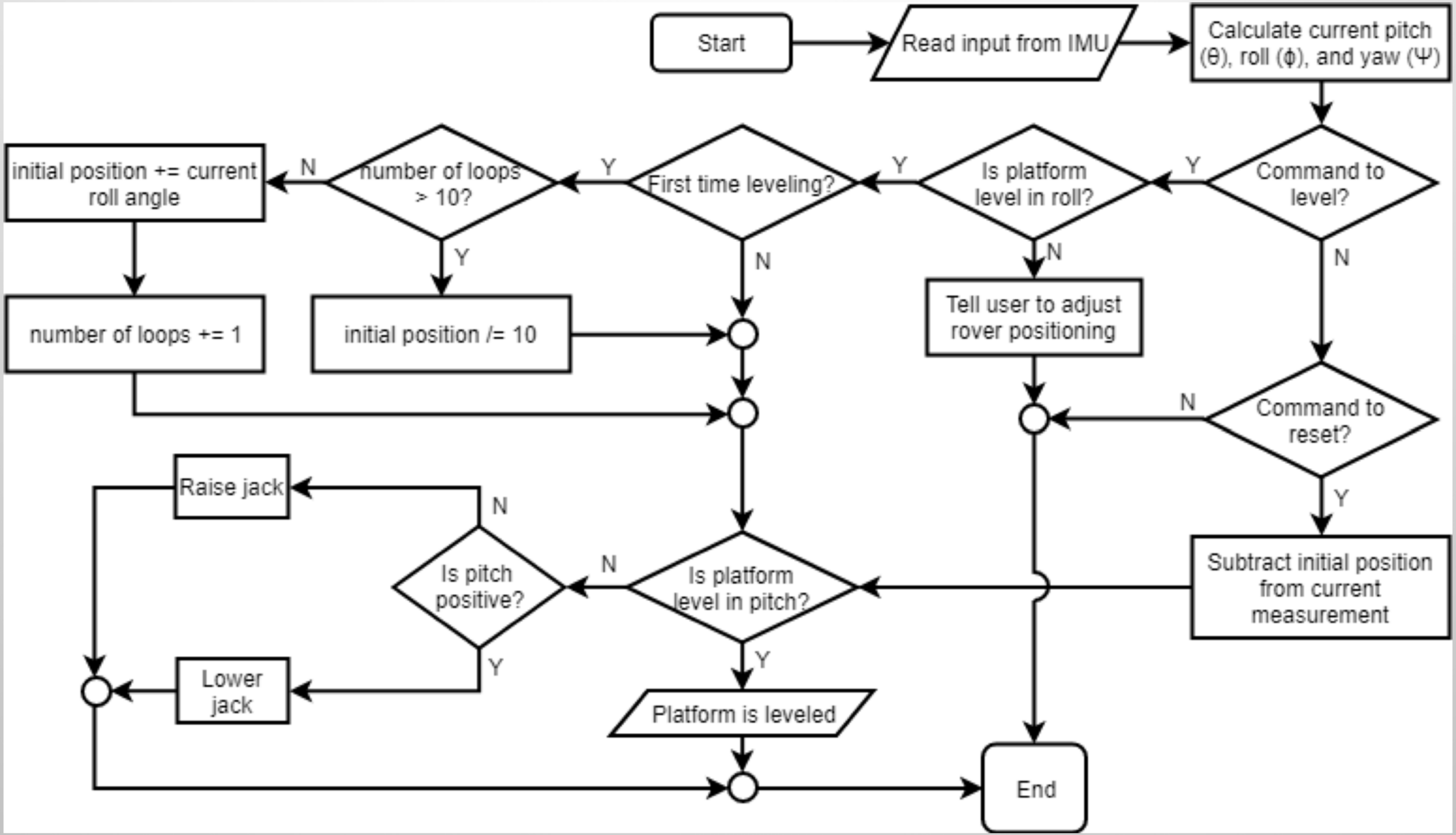
No slipping predicted for a dry grass slope

Translational System & Main Flowchart





Leveling System Flowchart



Test Results

GPS Testing

Integrated Testing

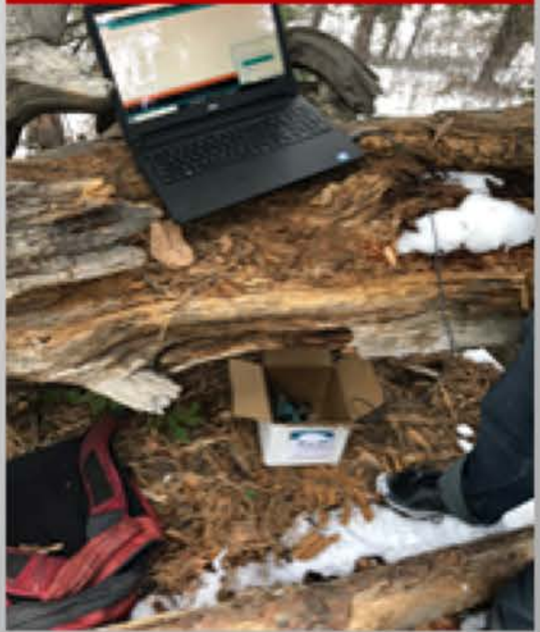
- Conducted on February 28th 2018
- Collected 4 sets of 5-10 minute data sets
  - Known GPS location (40°00'00.3"N 105°15'41.0"W)
  - Open Space
  - Approximately Mission Defined (Trees 10 ft apart)
  - Greater Interference than Mission Defined. Denser forest and under a log.
- Find Accuracy with known GPS then find how forest environment effected GPS readings.
- Attempt to Verify DR 3.1 (GPS accuracy of 5 m. in mission environment)

Known Location

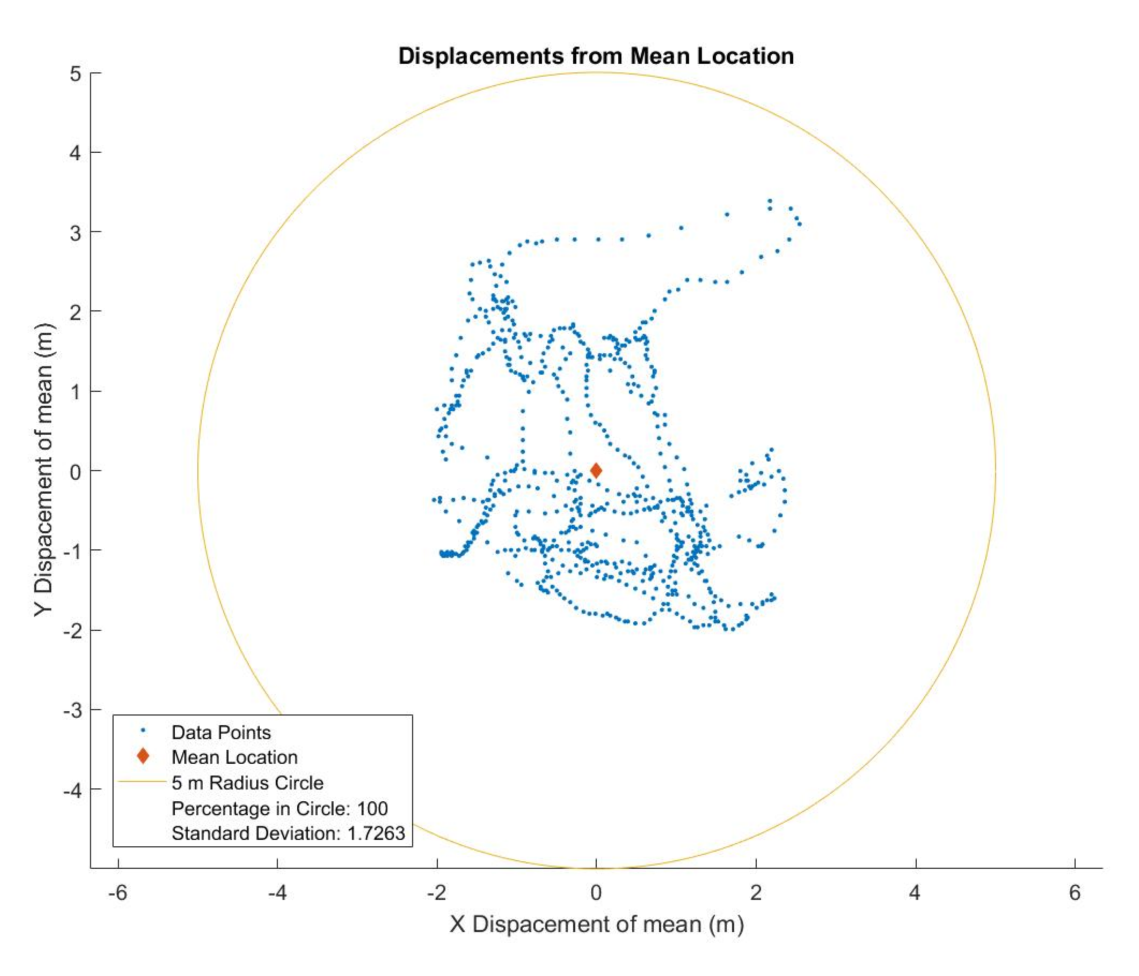
Open Space

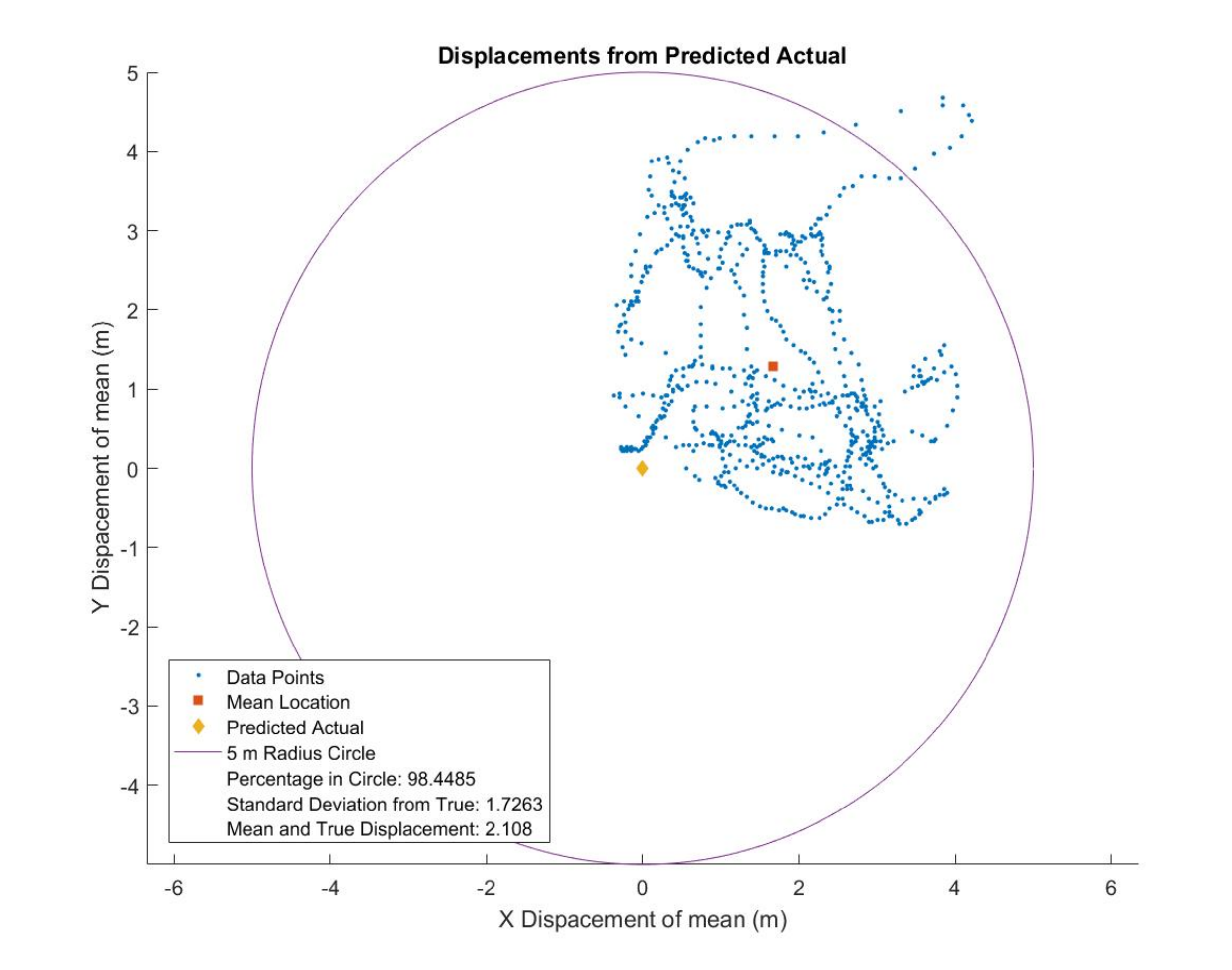
Mission Analog

Greater Interference

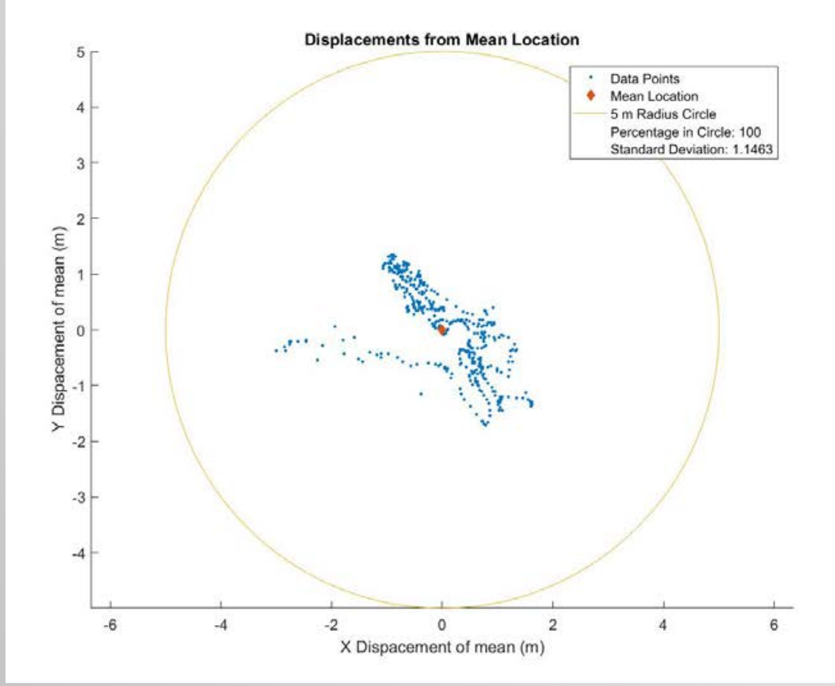


Baseline Data Analysis

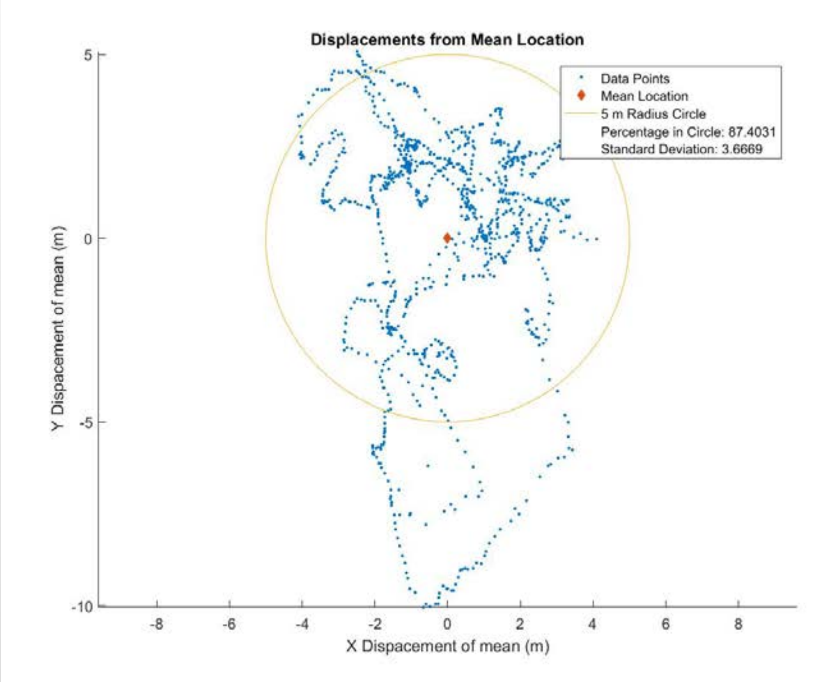




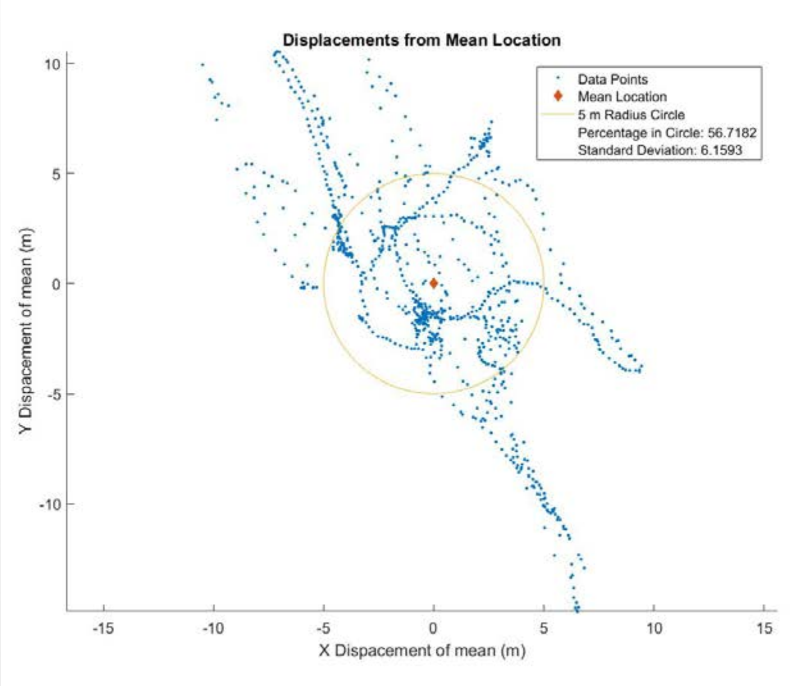
Various Tree Densities



Open Space



Mission Simulation

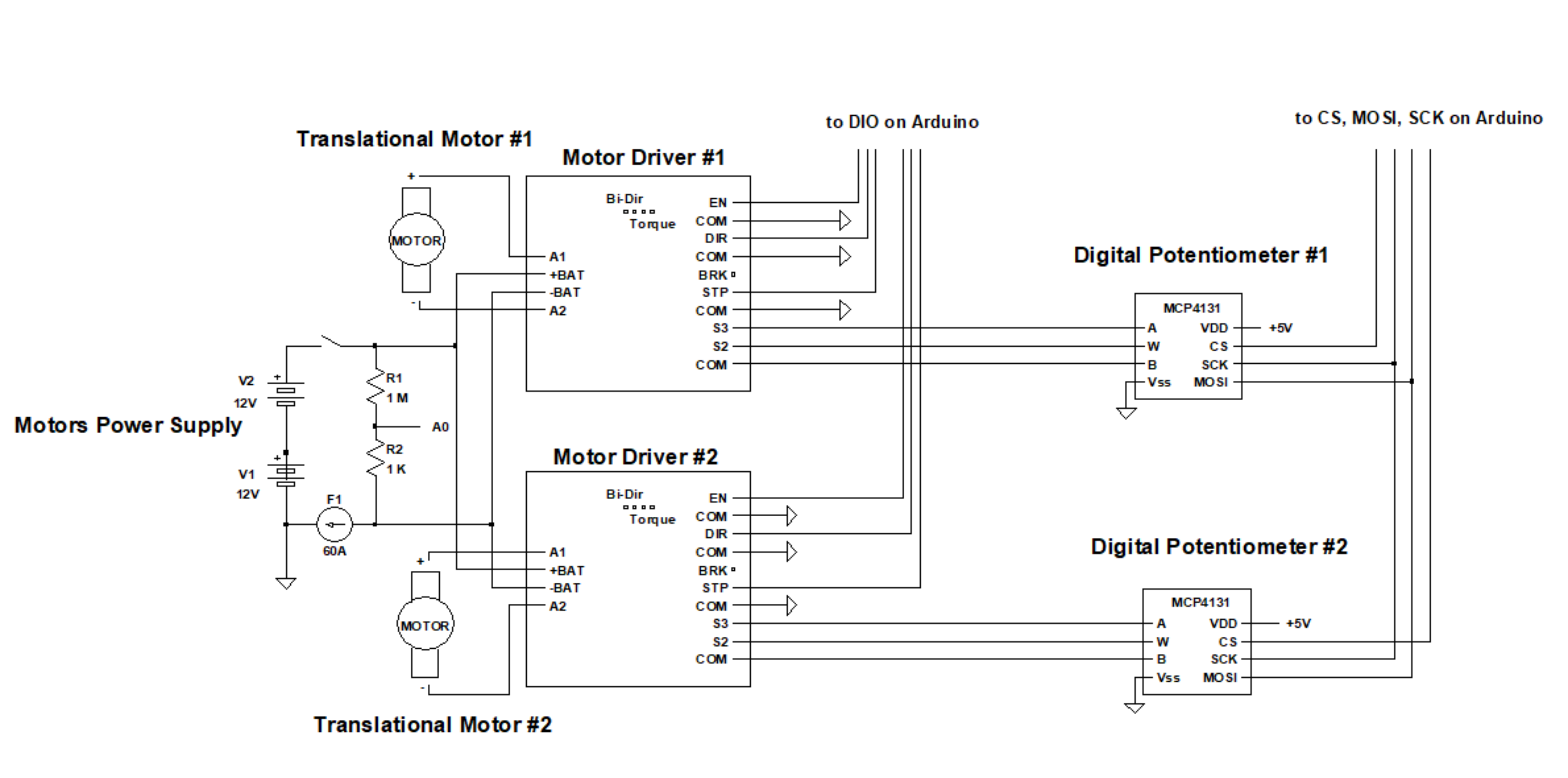


High Density.

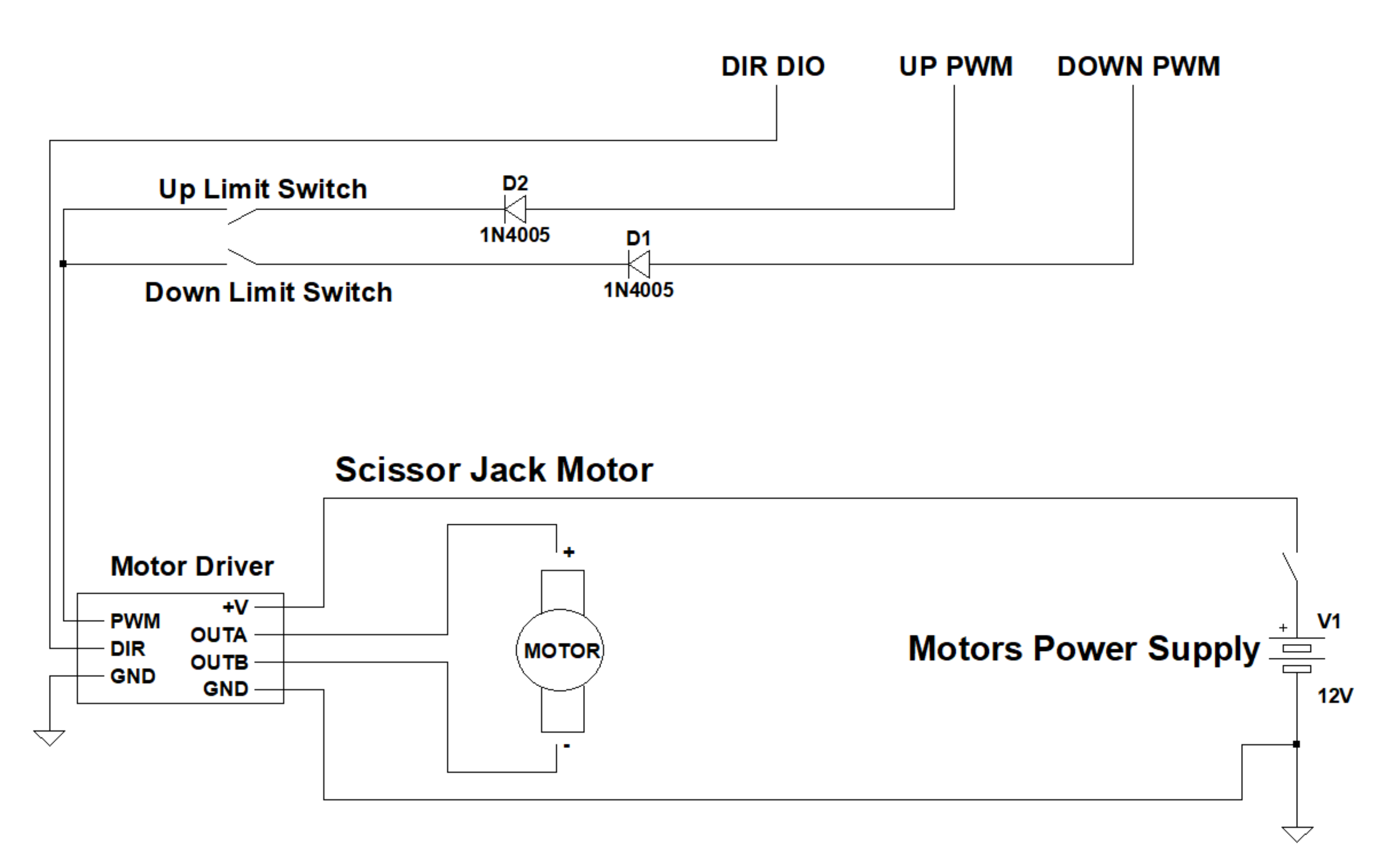
- Baseline Test had 96 % within requirements to the actual location
- Mission mean is with an 87% within requirements
- GPS accuracy predicted to be 83.5 % confidence that any given point is within the requirements.

Electronics

Design Solution: Translational Electronics



Design Solution: Leveling Electronics

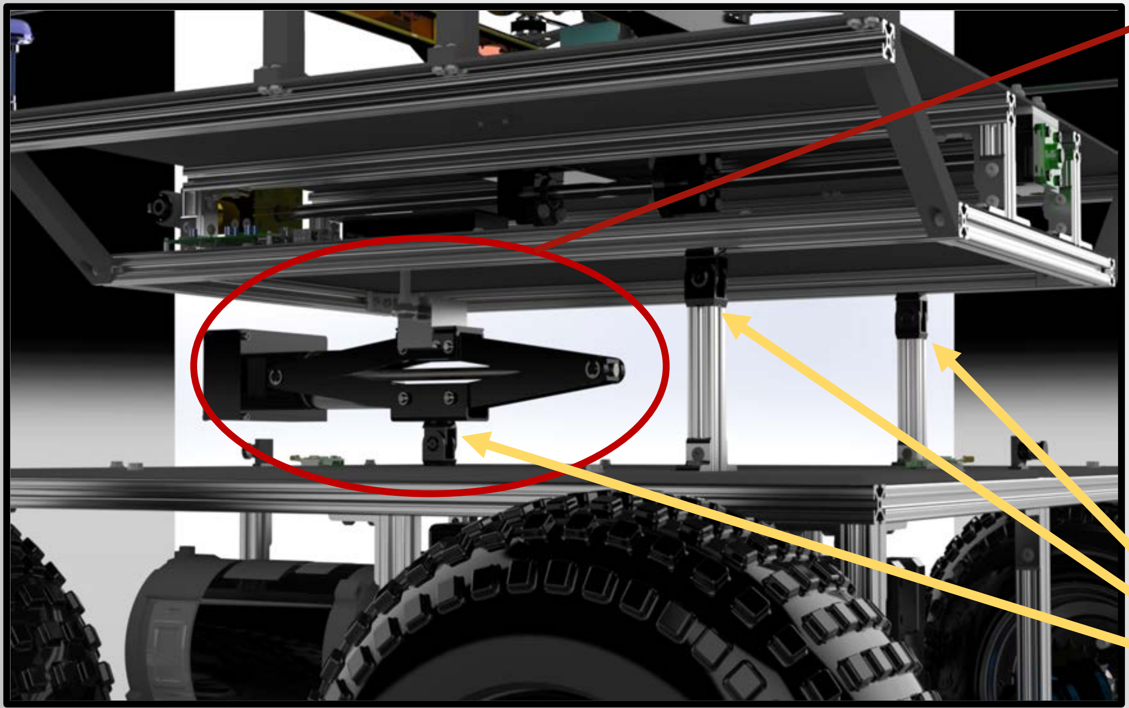


Hardware

Design Solution: Leveling

Solution
- Electric Scissor Jack
- T-slotted Pivot Joints

Scissor Jack

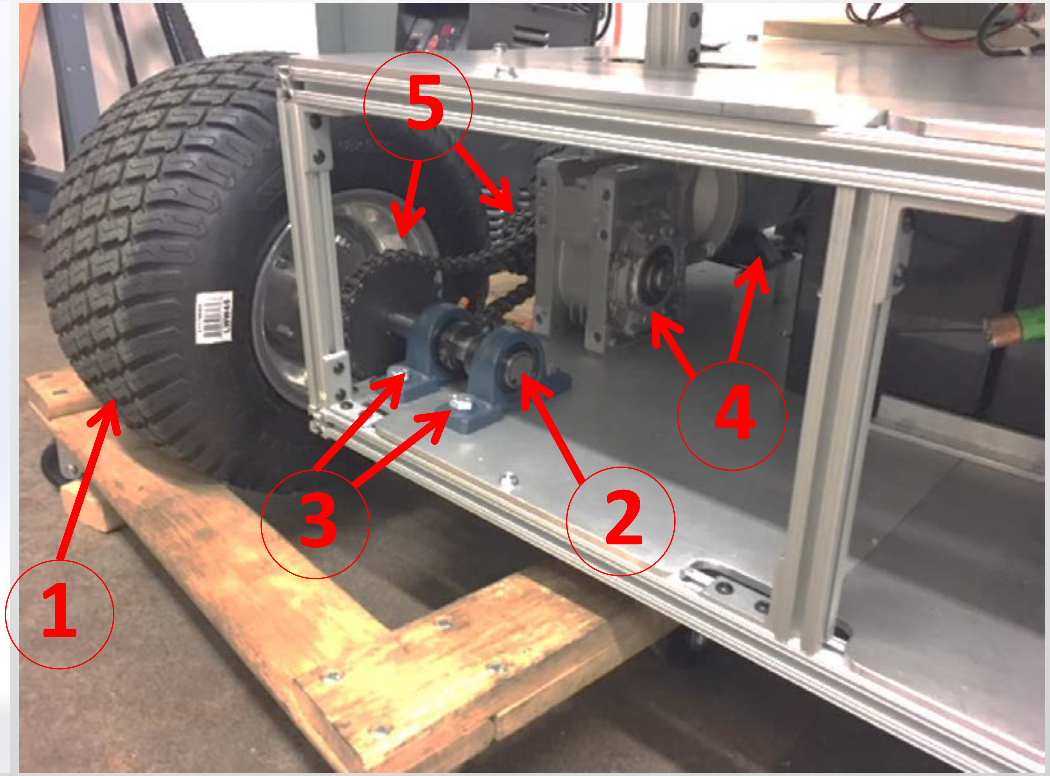


CAD Rendering of System

Pivot Joints

Actual Leveling System

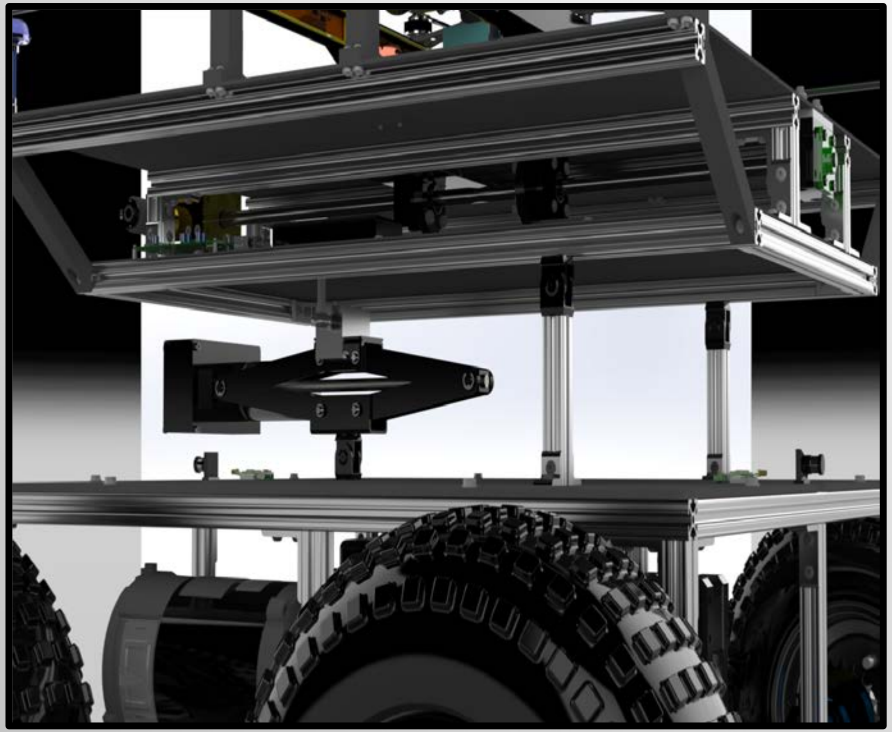
Translational System

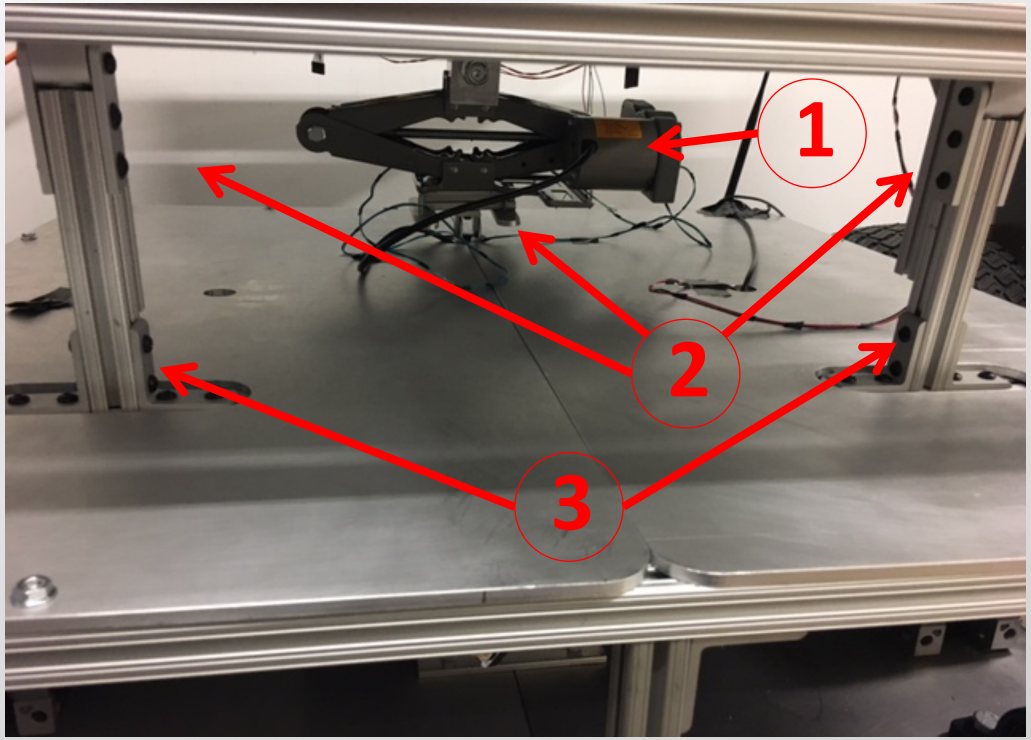


Main Components

1. 18 in. diameter wheels
2. 1 in. diameter 1045 carbon steel rotary shaft
3. 1 in. 2-bolt pillow block bearings
4. 12V DC motor and reducer
5. 2:1 gear ratio sprockets with ANSI 50 roller chain

Leveling System





Main Components

1. Automatic scissor jack
2. 2 hole pivot joint
3. 80/20 forward pivots