New Jersey Innovation Institute
An NJIT Corporation

W.A.R.D.E.N.

Wireless Assessment Rover with Drone Extended Network

SUMMER INTERNSHIP 2024

THE OBJECTIVE

- DEVELOP A **CLOSED RECONNAISSANCE SYSTEM** CAPABLE OF OPERATING EFFECTIVELY IN **DENSE JUNGLE ENVIRONMENTS**. FOCUS ON INNOVATIVE SOLUTIONS FOR RELIABLE **NAVIGATION**, **COMMUNICATION**, AND **DATA TRANSMISSION.**

New Jersey Innovation Institute
An NJIT Corporation

OBSTACLES OF JUNGLE OPERATIONS

Climate

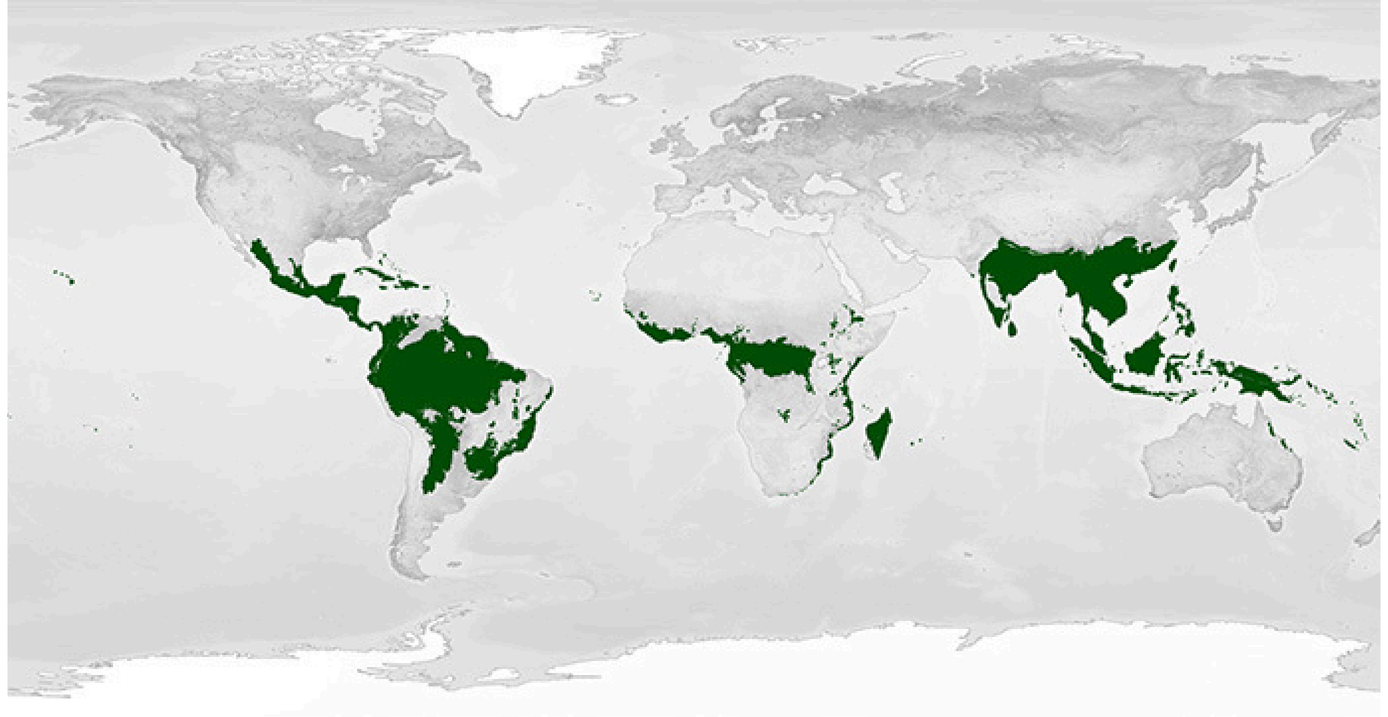
- Temperature
- Precipitation
- Seasons
- Humidity

Terrain

- Mountainous
- Bodies of water
- Rugged
- Swamps and marshes

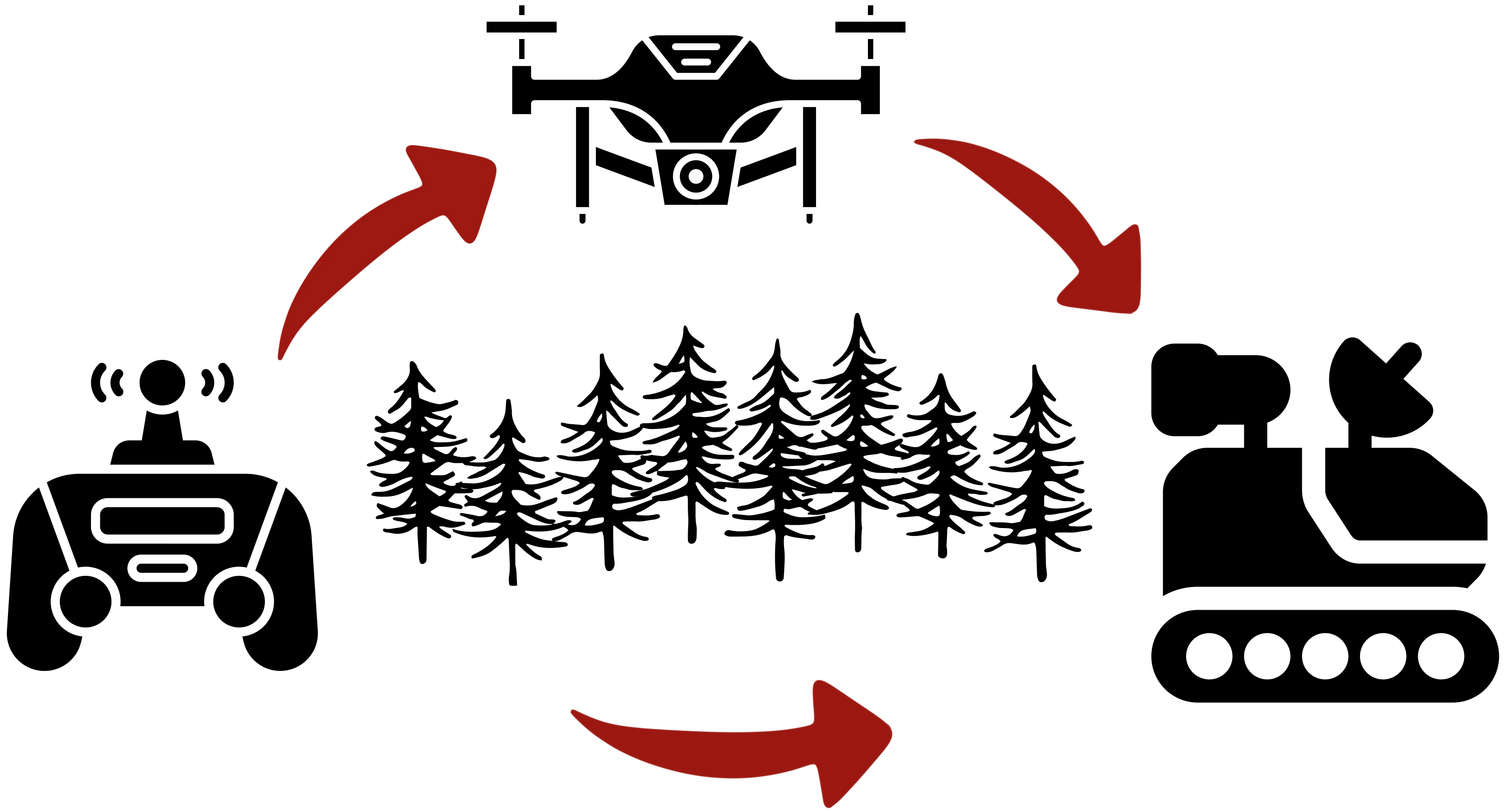
Vegetation

- Thick foliage
- Plant biodiversity
- Tree canopy
- Dense underbrush



THE SOLUTION

- DESIGN A **MESH NETWORK** OF AN **UNMANNED GROUND VEHICLE** (UGV) AND **AERIAL DRONE** TO CARRY OUT RECONNAISSANCE IN **DENSE** TERRAIN, USING THE DRONE TO **EXTEND** THE UGV'S COMMUNICATION RANGE.



AGENDA

System Overview

Network Integration

Ground Vehicle Overview

Aerial Drone Overview

User Interface

Future Goals

New Jersey Innovation Institute
An NJIT Corporation

POSSIBLE DESIGNS

New Jersey
Innovation Institute
An NJIT Corporation

DUAL USES

Uses

- Search and Rescue
- Disaster Relief
- Supply Delivery
- Law Enforcment
- Infrastructure Inspection
- Environmental Mapping

Environments

- GPS Deprived Zones
- Harsh Environments
- Disaster Zones
- Mining Operations
- Extreme Weather

CAPABILITIES

New Jersey Innovation Institute
An NJIT Corporation

The Team

19 interns from **7 universities** with diverse backgrounds in:

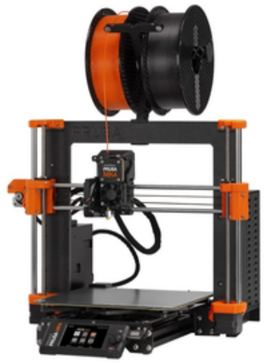
- Mechanical Engineering
- Industrial Design
- Electrical Engineering
- Software Engineering
- Computer Science/Engineering
- Chemical Engineering
- Human Computer Interaction

The Timeline

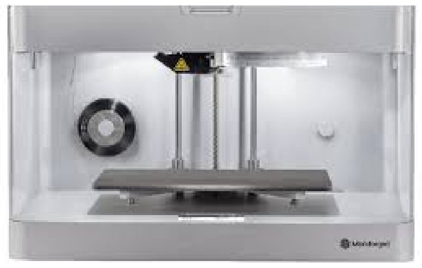
6 weeks for W.A.R.D.E.N. Project

- 2 weeks: Research
- 3 weeks: Designing and prototyping
- 1 week: Testing

In-House Manufacturing


Prusa MK4


Prusa XL


Markedforged Mark Two


XM200G


F900

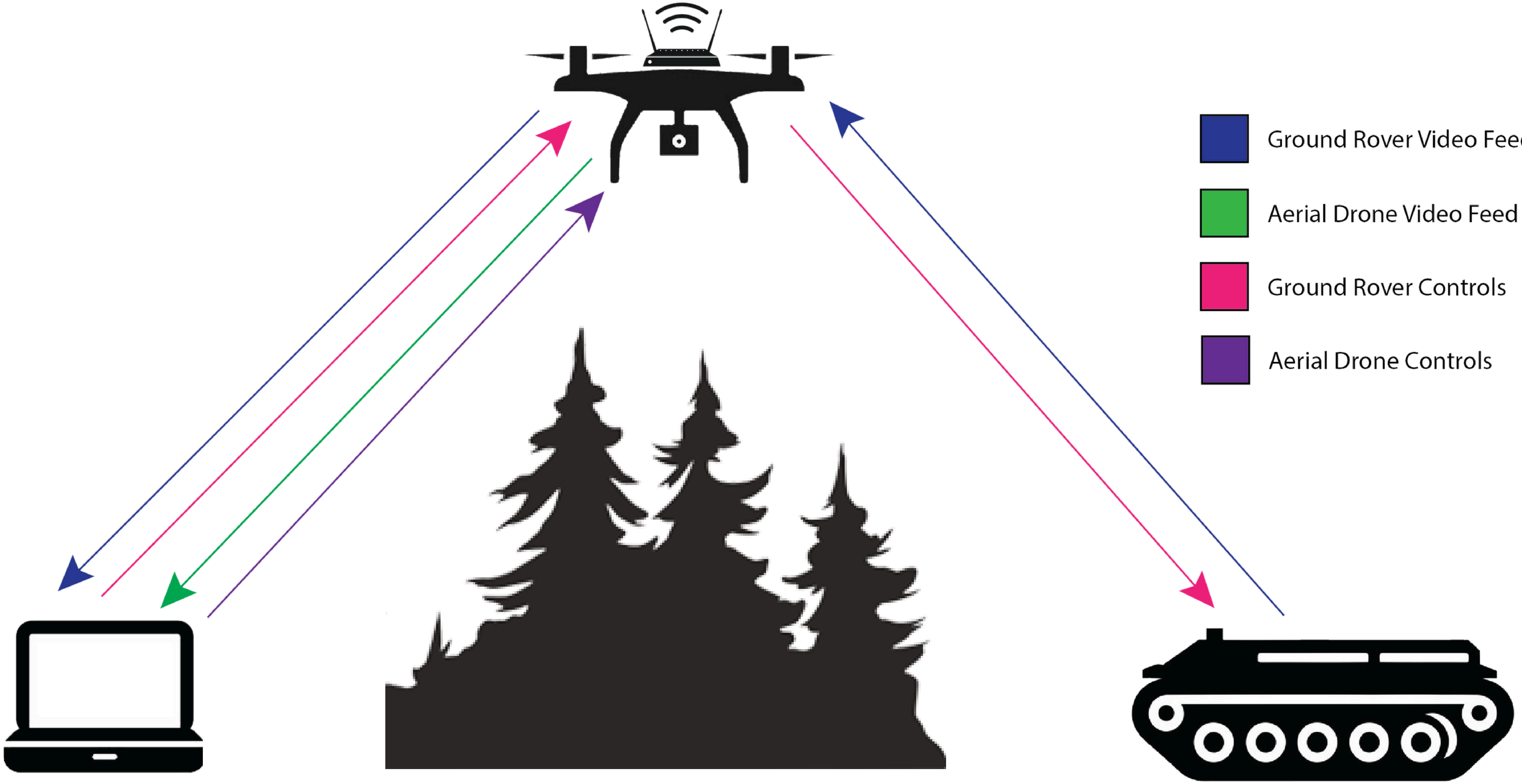

Fortus 450mc


LPKF ProtoLaser U4

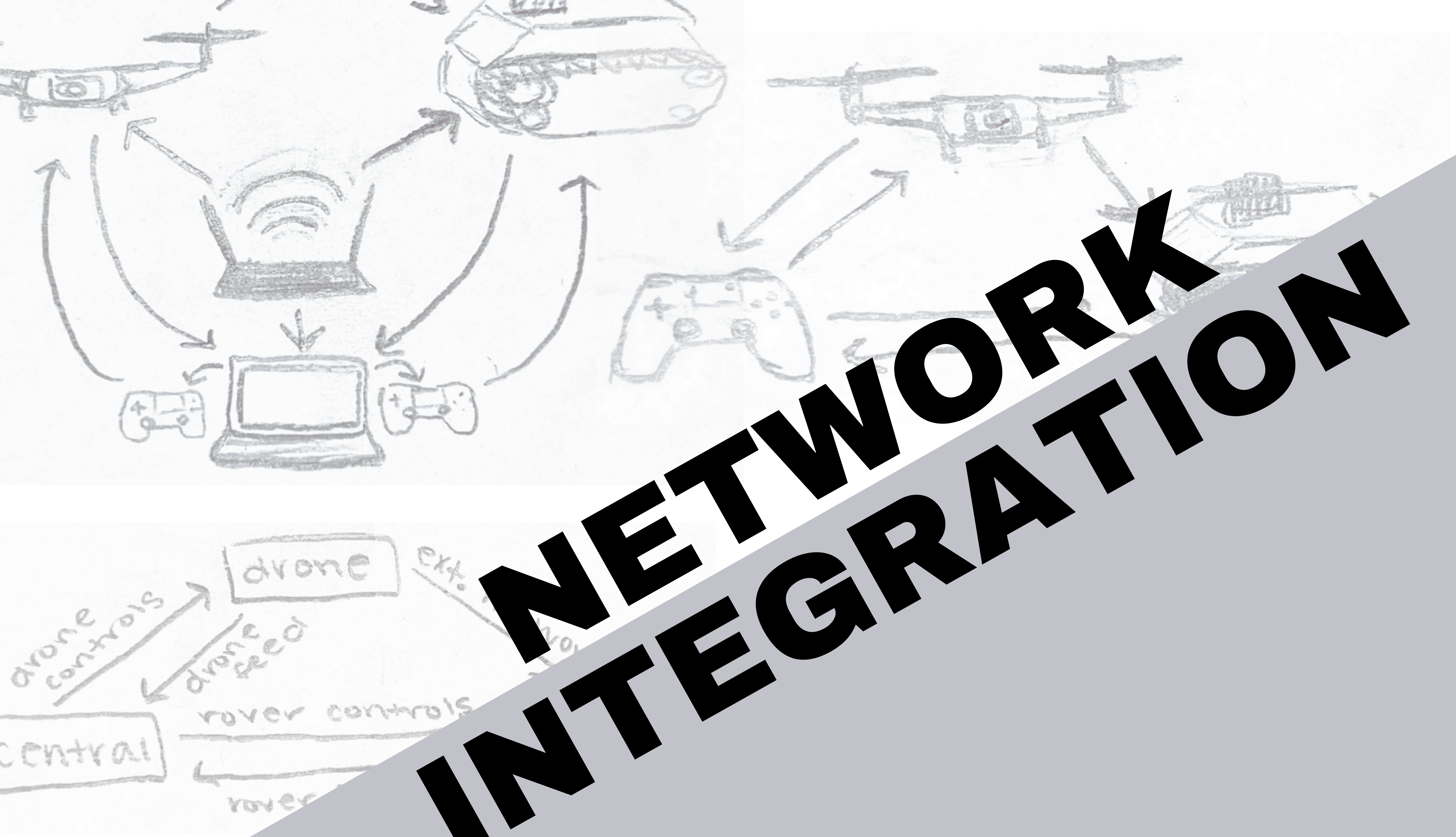

HP-2440 Laser Cutter

SYSTEM OVERVIEW

New Jersey Innovation Institute
An NJIT Corporation



Ground Rover Video Feed
Aerial Drone Video Feed
Ground Rover Controls
Aerial Drone Controls



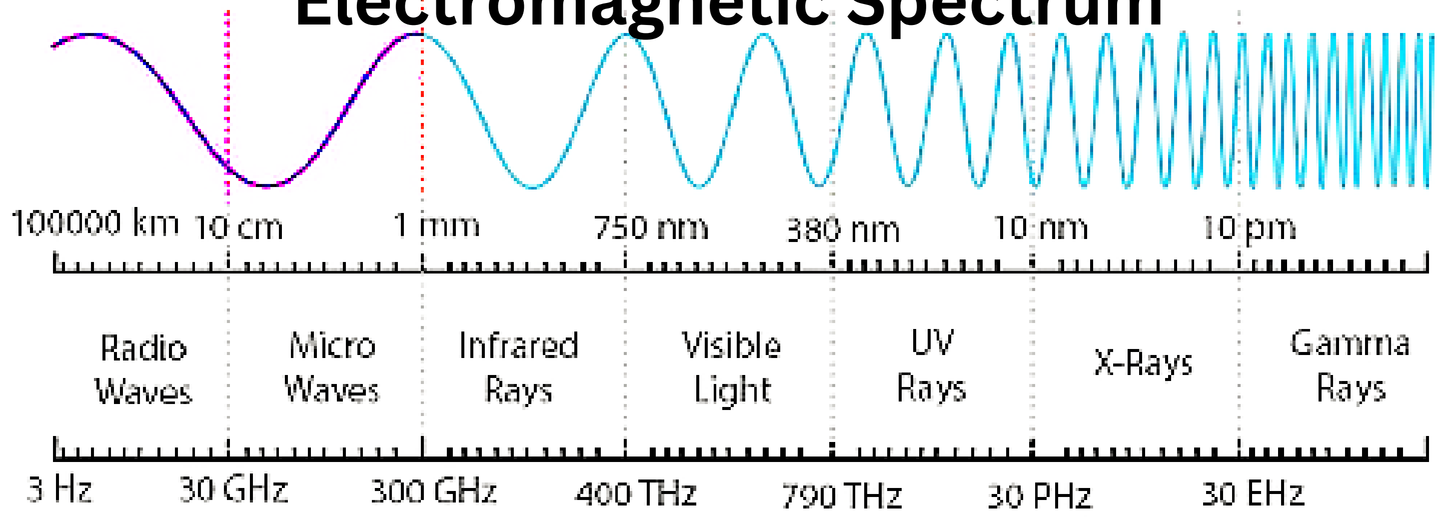
NETWORK INTEGRATION

COMMUNICATION

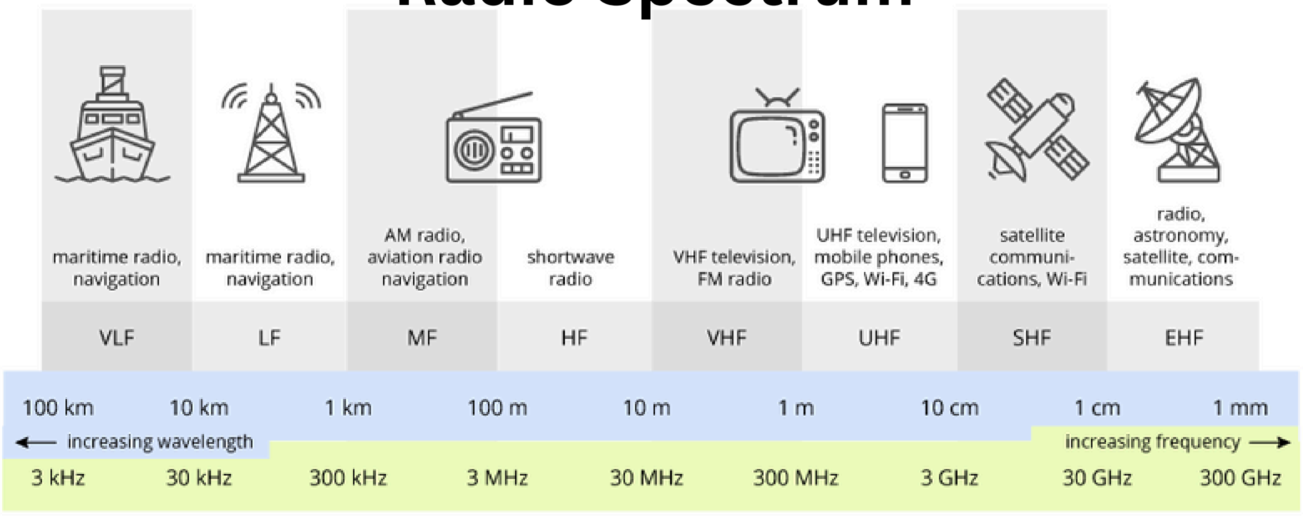
RADIO

3 kHz to 300 GHz

Electromagnetic Spectrum



Radio Spectrum



BLUETOOTH

2.4 GHz

- Short range (<30m)
- Not secure
- Slow data transfer
+ Low cost and power
+ Low complexity

WI-FI

2.4 GHz and 5 GHz

- Short range (<90m)
  - Can be extended
+ Supports higher/faster data rates (digital video)
+ Low cost

LoRa

915 MHz

+ Long range (>10km)
+ Low power
- Slower data transfer
- Complex

New Jersey Innovation Institute
An NJIT Corporation

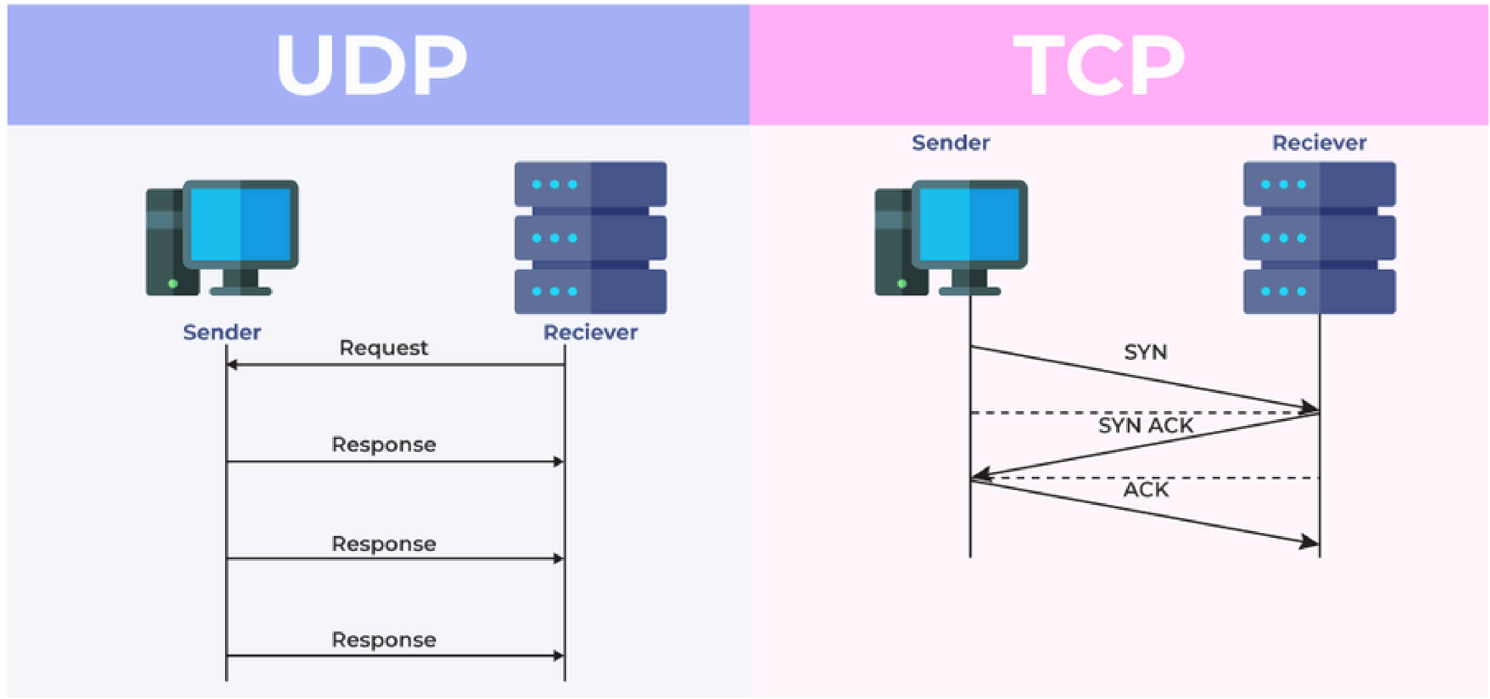
WI-FI PROTOCOLS

UDP

- Connection-less
  - Less secure
  - Possibility of lost packets
  + Longer range
  + Faster data transfer
- Seamless transition to drone extended network once connection is lost
  - Keeps listening for data after losing connection

TCP

- Requires handshake connection
  + More secure
  - Less range
  - Slower data transfer
  - Inefficient over long latencies
- Would need to reconnect entirely once connection is lost



New Jersey Innovation Institute
An NJIT Corporation

NETWORK RANGE

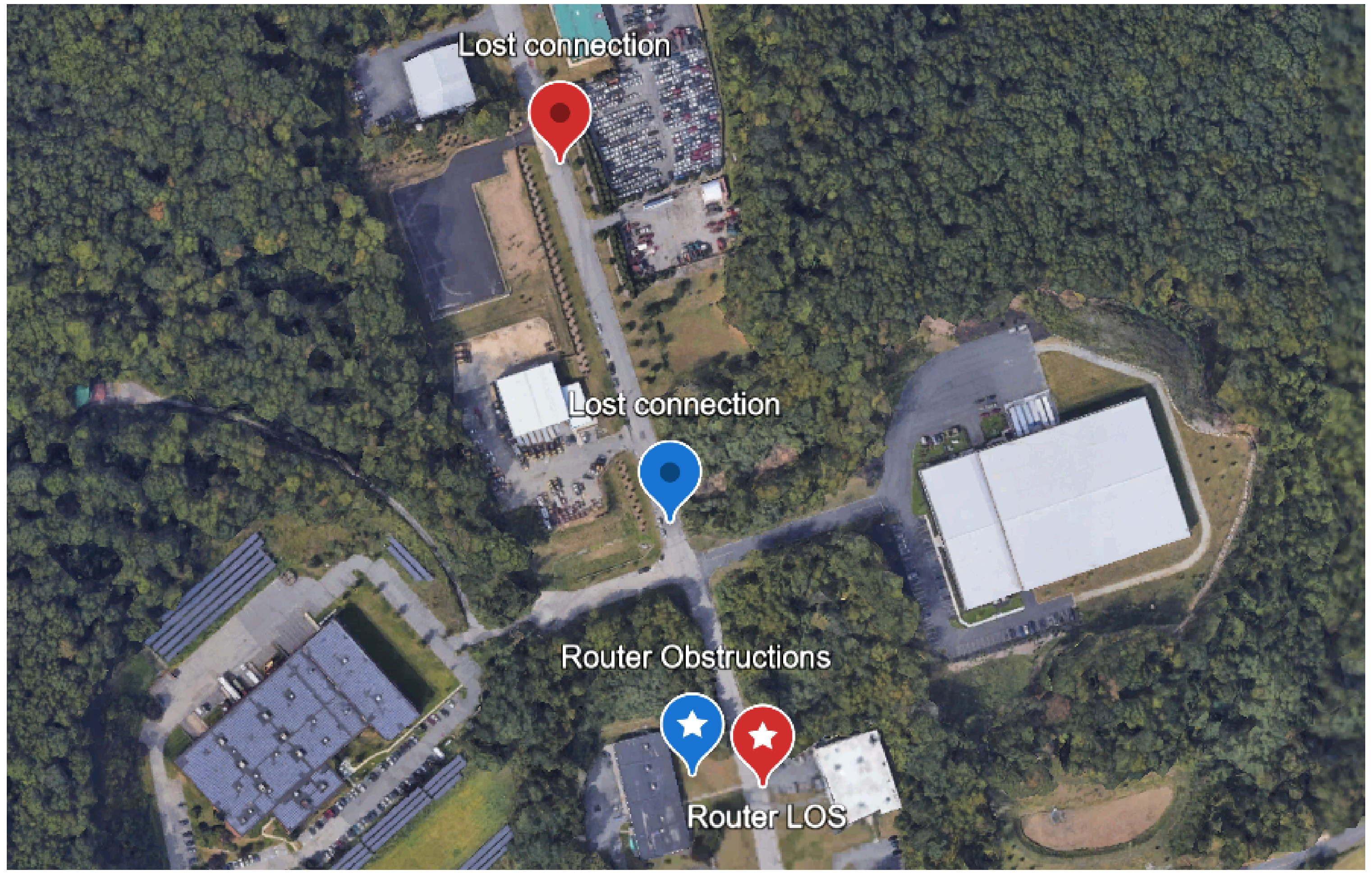
LAN

- Wi-Fi 6 router with extender
- **~150 ft** without extender
- With directional extender:
  - **~500 ft** with obstructions
  - **1000 ft +** line of sight

DRONE EXTENDER

- Portable router (acting as **Wi-Fi repeater)** with extender antenna
- Additional **~1000 ft** LOS of range

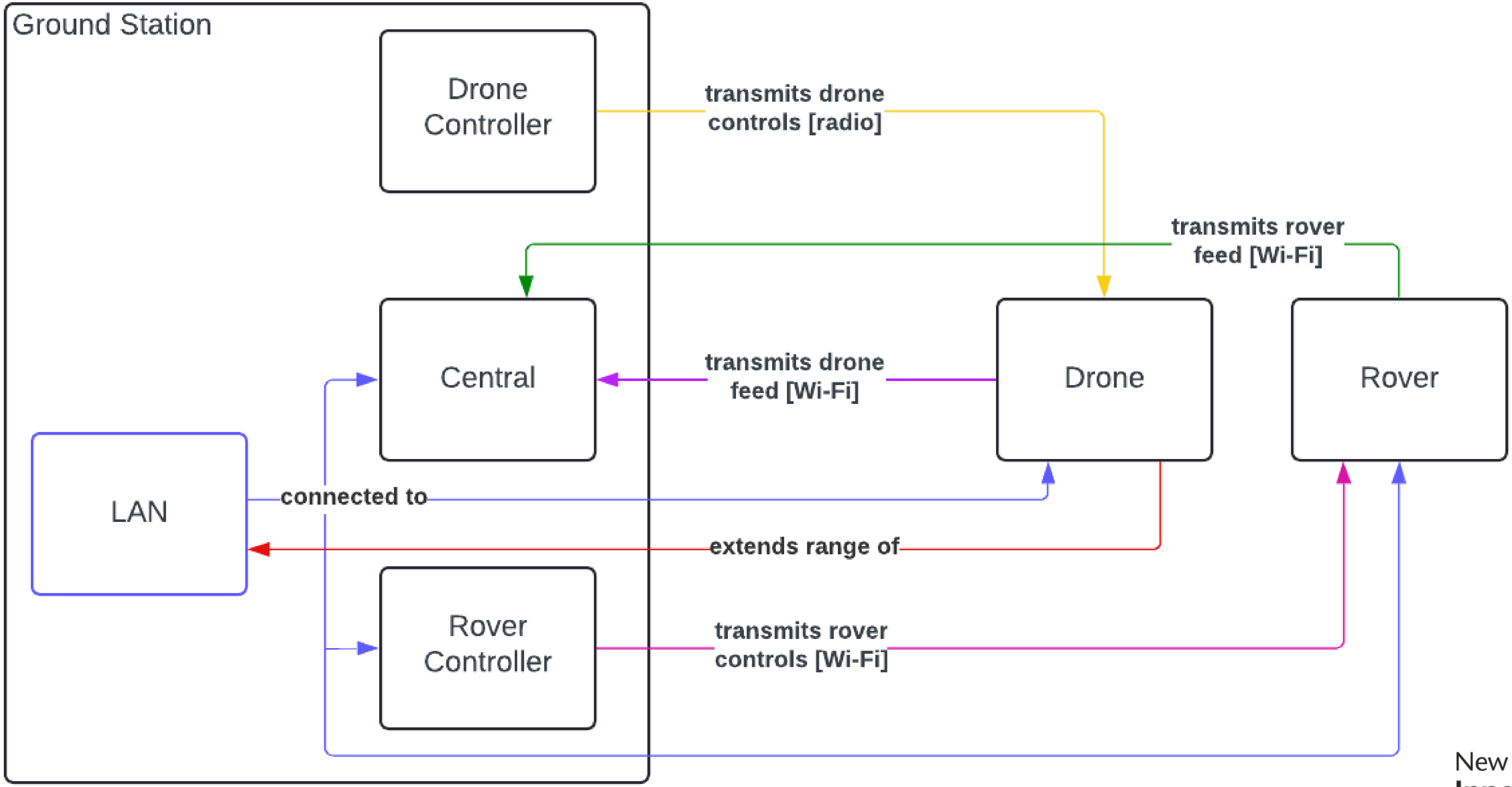
OVERALL, GROUND VEHICLE RANGE ~1000-2000 FT



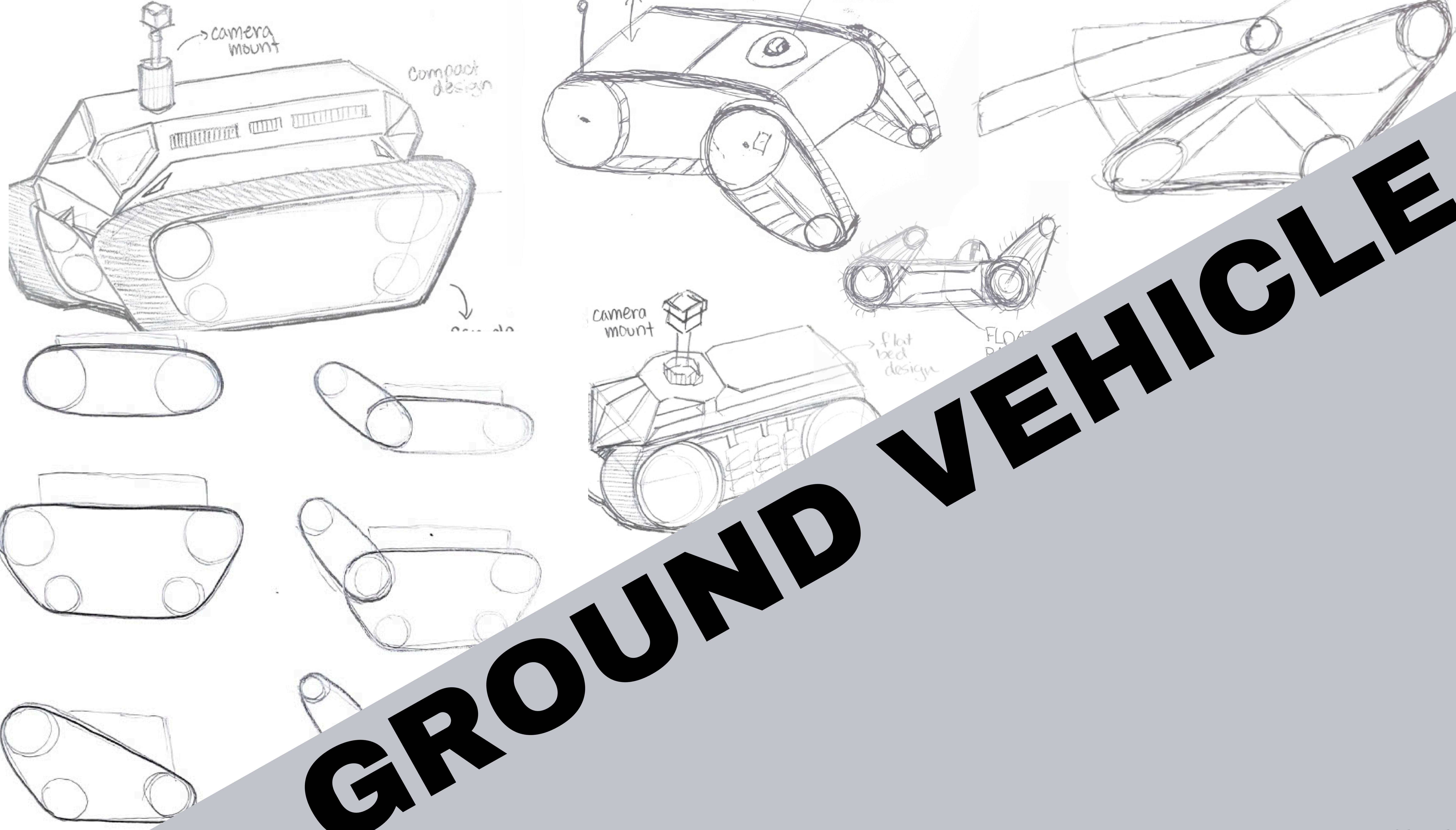
Signal strength test- LAN only (no drone)

New Jersey Innovation Institute
An NJIT Corporation

SYSTEM ARCHITECTURE



New Jersey Innovation Institute
An NJIT Corporation



GROUND VEHICLE

New Jersey Innovation Institute
An NJIT Corporation

GROUND VEHICLE GOALS

- Conduct recon
- Weather proof
- Terrain capable
- Long range
- Power efficient
- Rugged
- Carry a payload
- Stealthy

LOCOMOTION STRATEGIES

New Jersey Innovation Institute
An NJIT Corporation

Wheels

- Four-wheel
- Multi-wheel

\+ Simplicity and Serviceability
\+ Amphibious Potential
\- Increase Contact Patch with Additional Wheels

Treads

- Mechanical Treads
- Rubber Treads

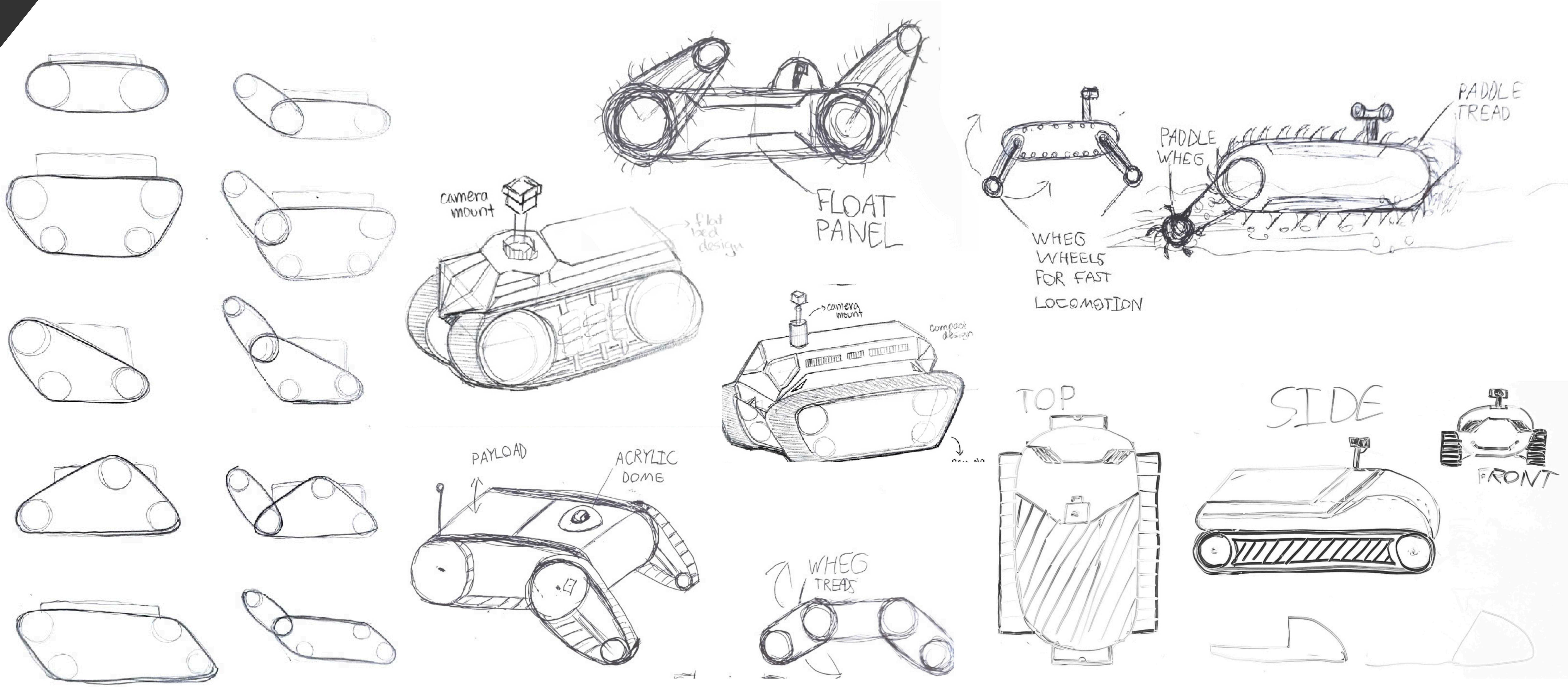
\+ Maximize Contact Patch
\+ Durability
\- Noise Vibration & Harshness (NVH)

Alternatives

- Legged
- Wheel Leg Hybrid (WHEG)
- Omni-wheels

\+ Potential to Surmount Larger Obstacles up to 40% larger Obstacles then similar sized wheels
\- Additional Weight & Complexity

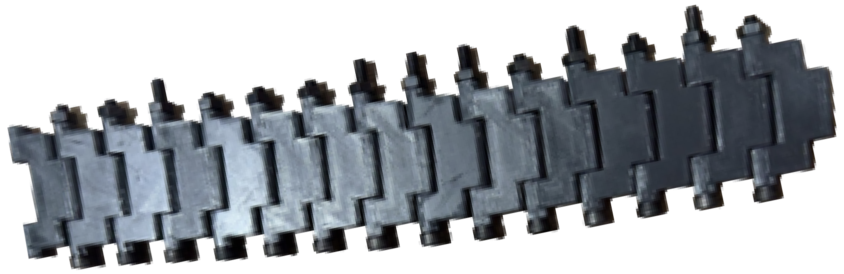
GROUND IDEATION



TREAD RESEARCH AND DESIGN

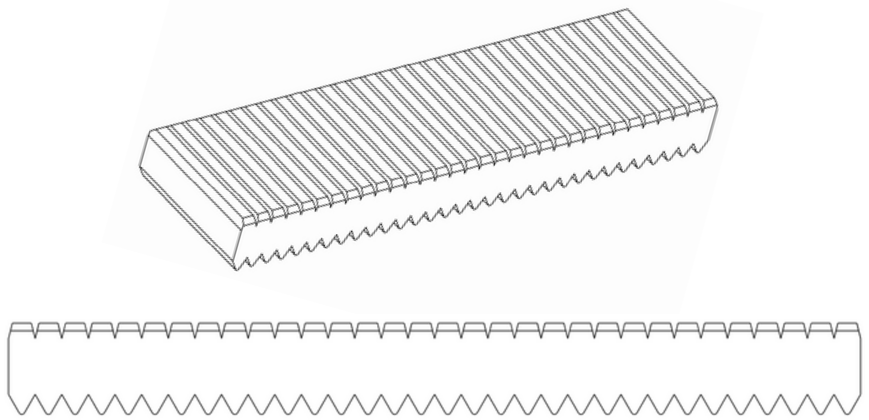
(PRUSA MK4)

Iteration 1



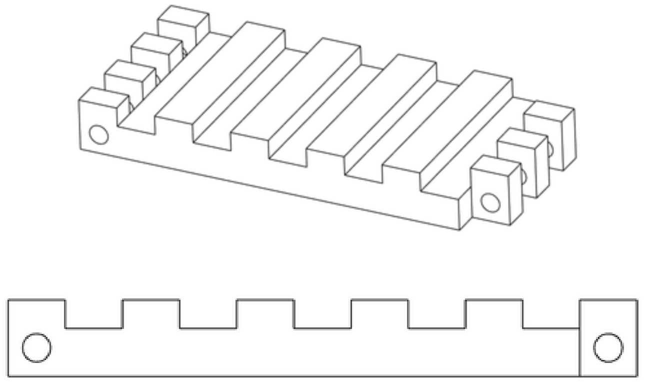
PLA mechanical treads

Iteration 2



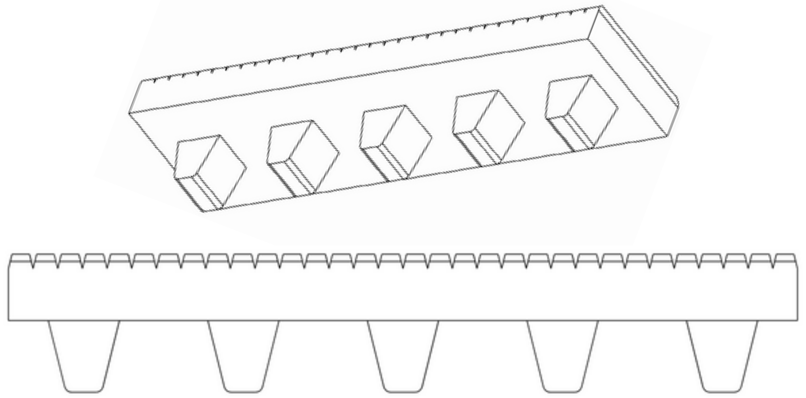
Continuous TPE belt with small teeth

Iteration 3



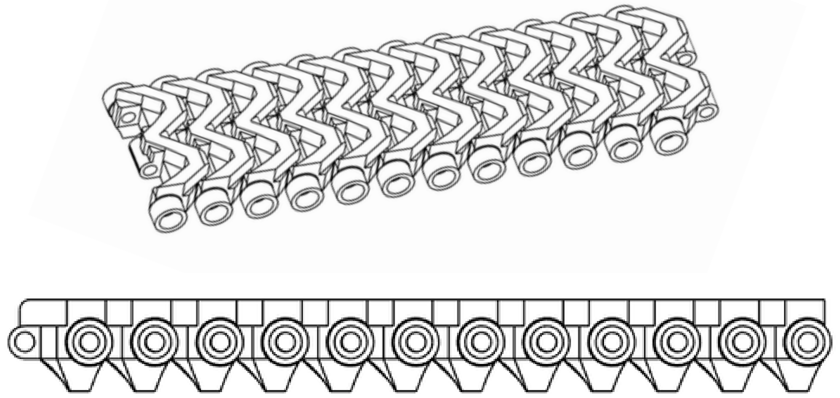
Continuous flat TPU belt with screw connectors

Iteration 4



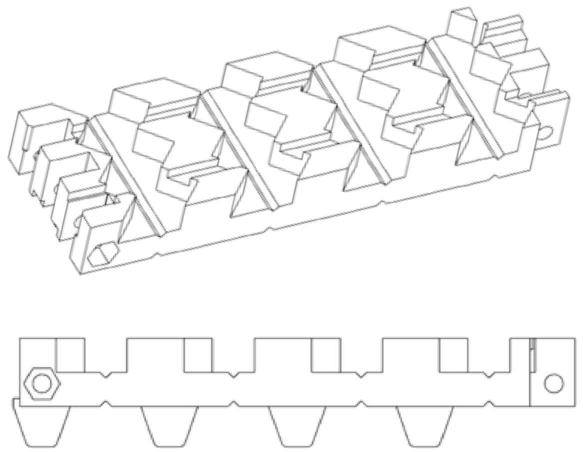
Continuous TPE belt with large teeth

Iteration 5

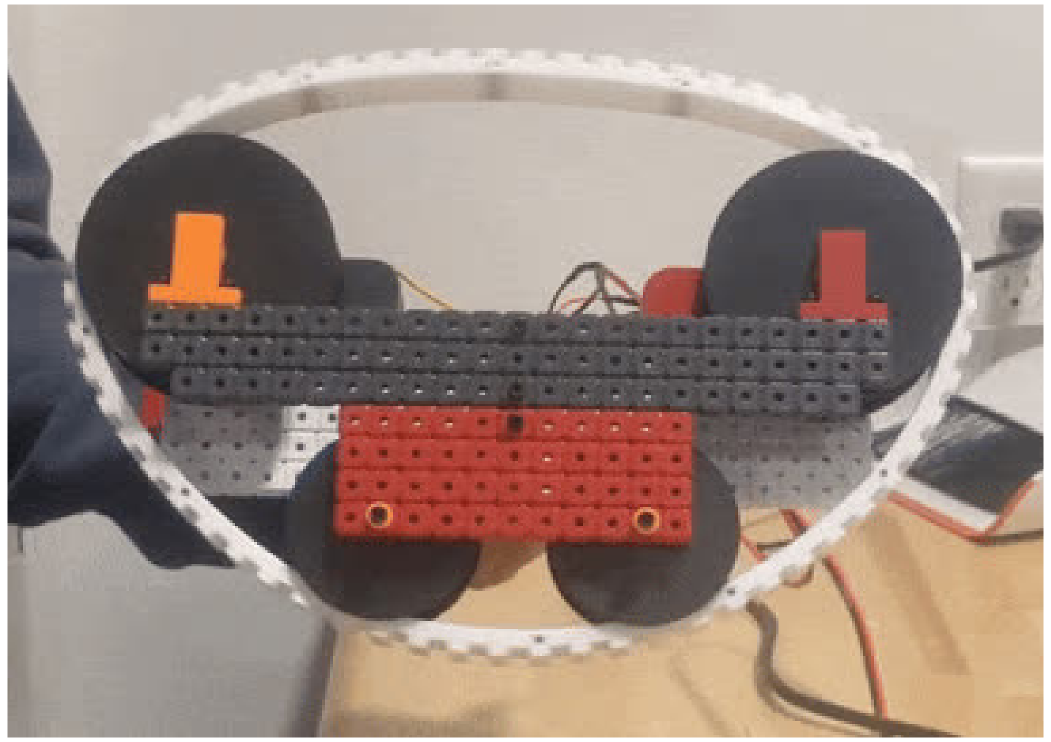


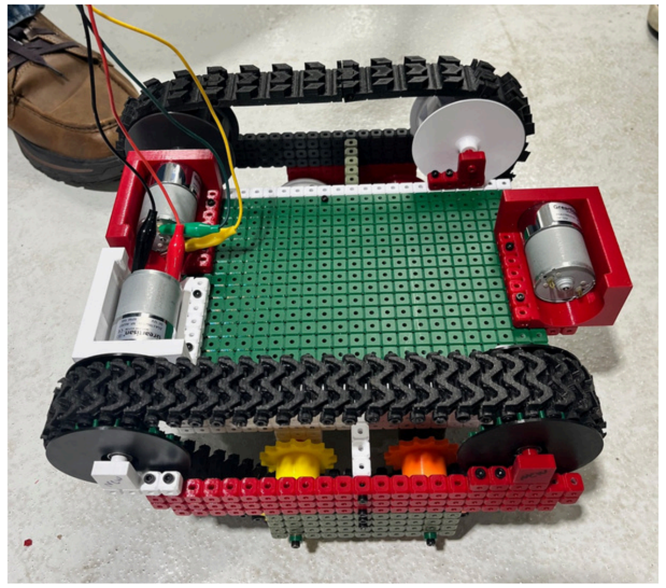
Mechanical Rubber TPE treads

Iteration 6



More aggressive TPE tread pattern





PLA Test Rig made on Prusa MK4

TREAD RESEARCH AND DESIGN

	ROCK	DIRT	MUD	SLOPED	CLAY	SAND	CONCRETE	DEMOLITION	TURF	SNOW
PREMIUM C PATTERN	Best	Best	Best	Better	Better	Better	Best	Best	Better	Good
STANDARD C PATTERN	Better	Best	Best	Better	Better	Better	Better	Better	Better	Good
ZIG ZAG PATTERN	Best	Best	Best	Best	Best	Best	Better	Better	Good	Best
MULTI-BAR LUG	Better	Best	Better	Good	Better	Best	Better	Good	Better	Better
HEX PATTERN	Good	Better	Good	Good	Good	Better	Good	Good	Best	Good
H PATTERN	Better	Good	Better	Better	Better	Better	Better	Better	Good	Good

Adapted from graphic by Bobcat Company. (n.d.). How to choose compact track loader tracks. Retrieved July 6, 2024, from https://www.bobcat.com/na/en/buying-resources/loaders/how-to-choose-compact-track-loader-tracks

Best Better Good

Tread Pattern Research

Zig zag pattern shown to be most effective in relevant environments for our jungle application

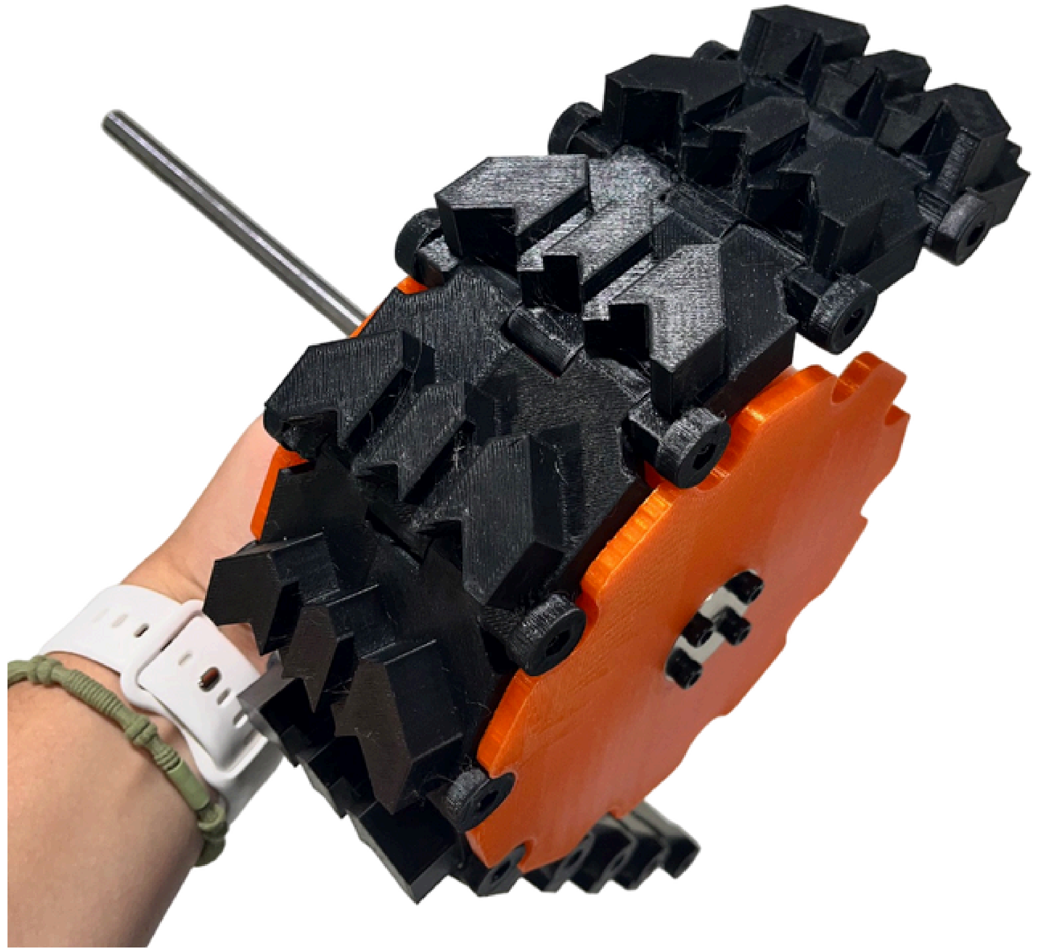
New Jersey Innovation Institute
An NJIT Corporation

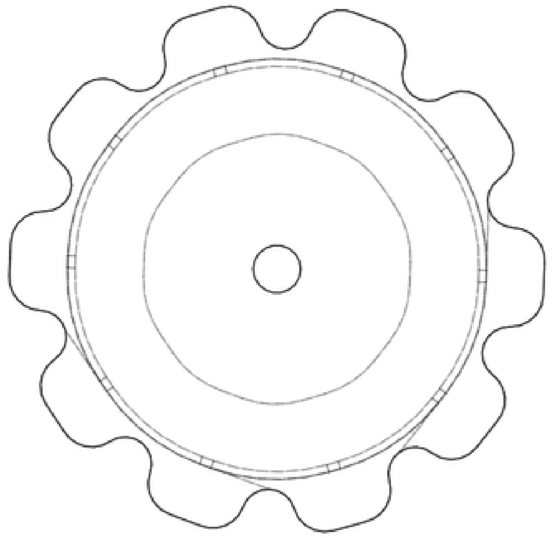
TREAD RESEARCH AND DESIGN

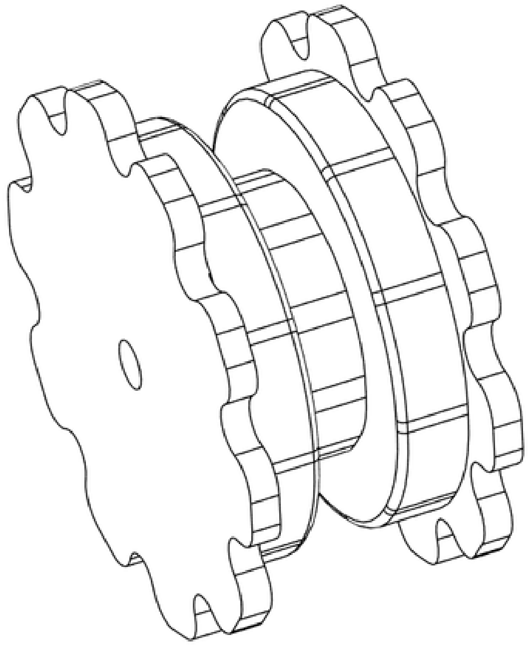
(PRUSA MK4)

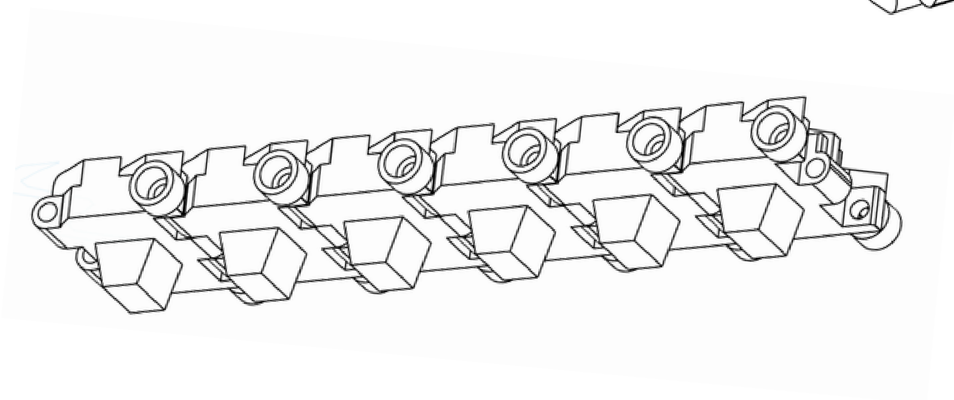
Final Design

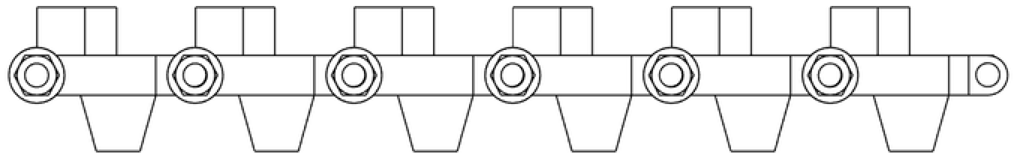
- TPE Mechanical Rubber Hybrid Treads
- Large teeth for alignment
- Quieter than existing mechanical treads
- Enhanced repair-ability and flexibility









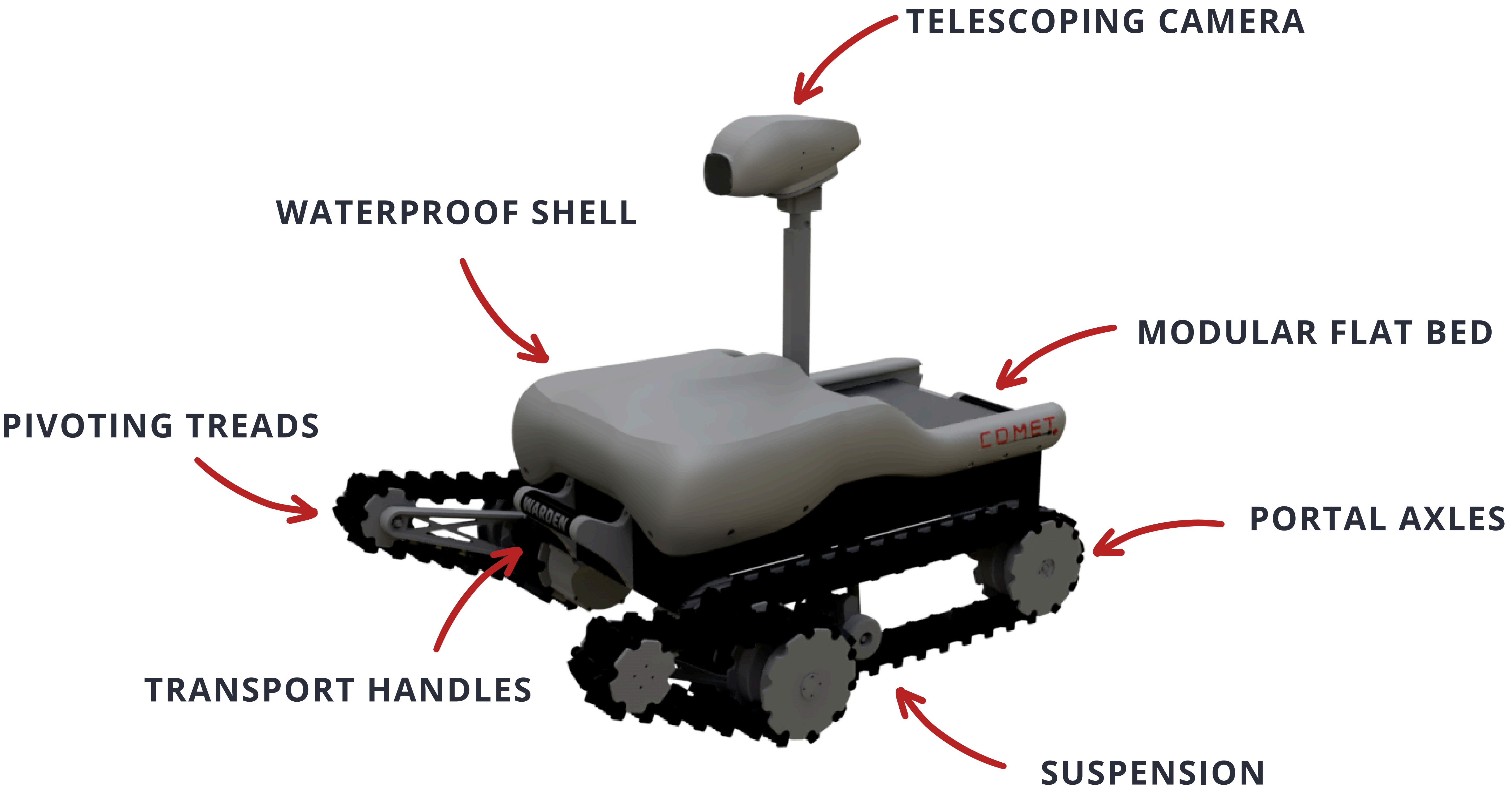


New Jersey Innovation Institute
An NJIT Corporation

GROUND VEHICLE OVERVIEW

New Jersey Innovation Institute
An NJIT Corporation

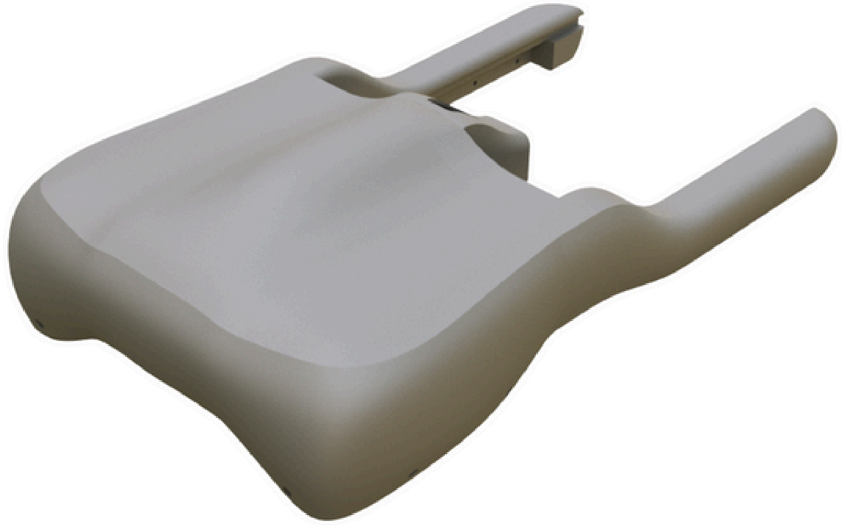
GROUND VEHICLE FEATURES

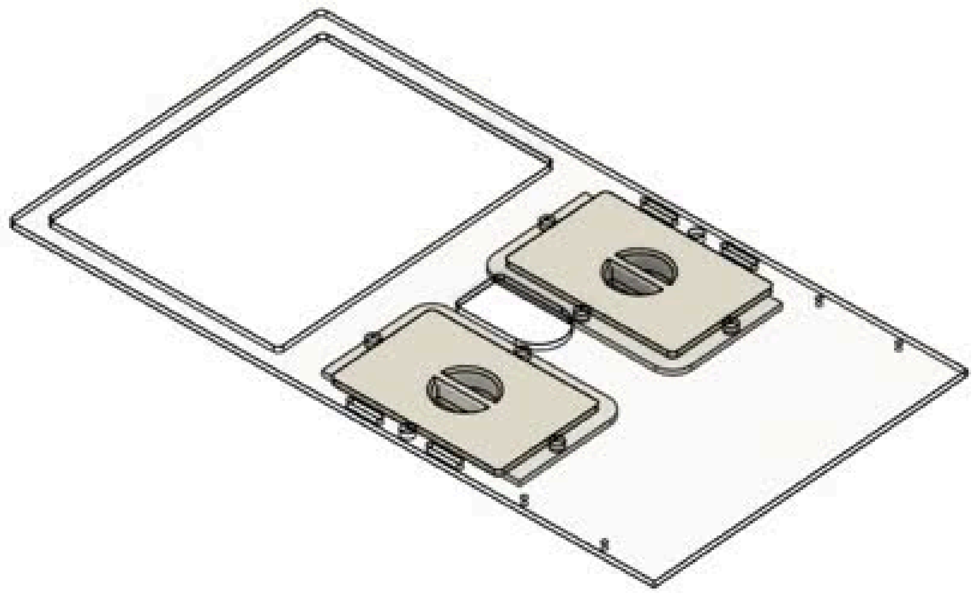


PROTECTIVE OUTER SHELL

Waterproof Shell

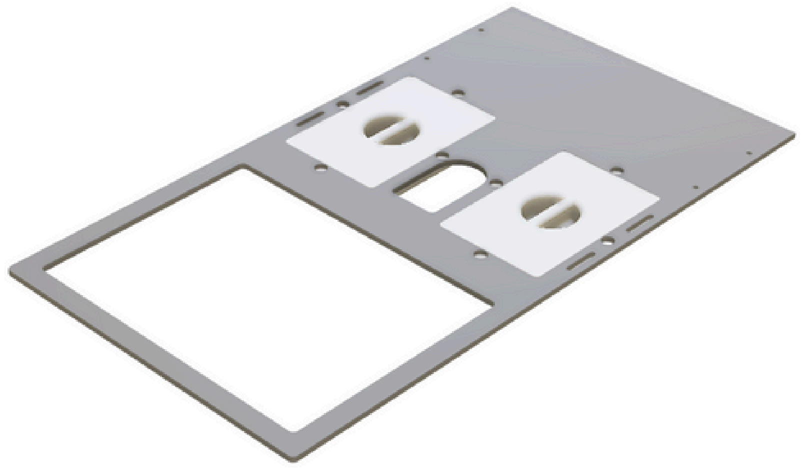
- High strength ASA Shell printed on the Stratasys F900
- Secures the flatbed and electronics box in place and protects the electronics from water.
- The left and right fenders act as rails to secure a payload.

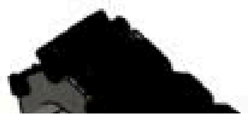




Flatbed

- Laser cut flatbed.
- Removable magnetic panels that give access to the batteries.
- Easy to use attachment system.



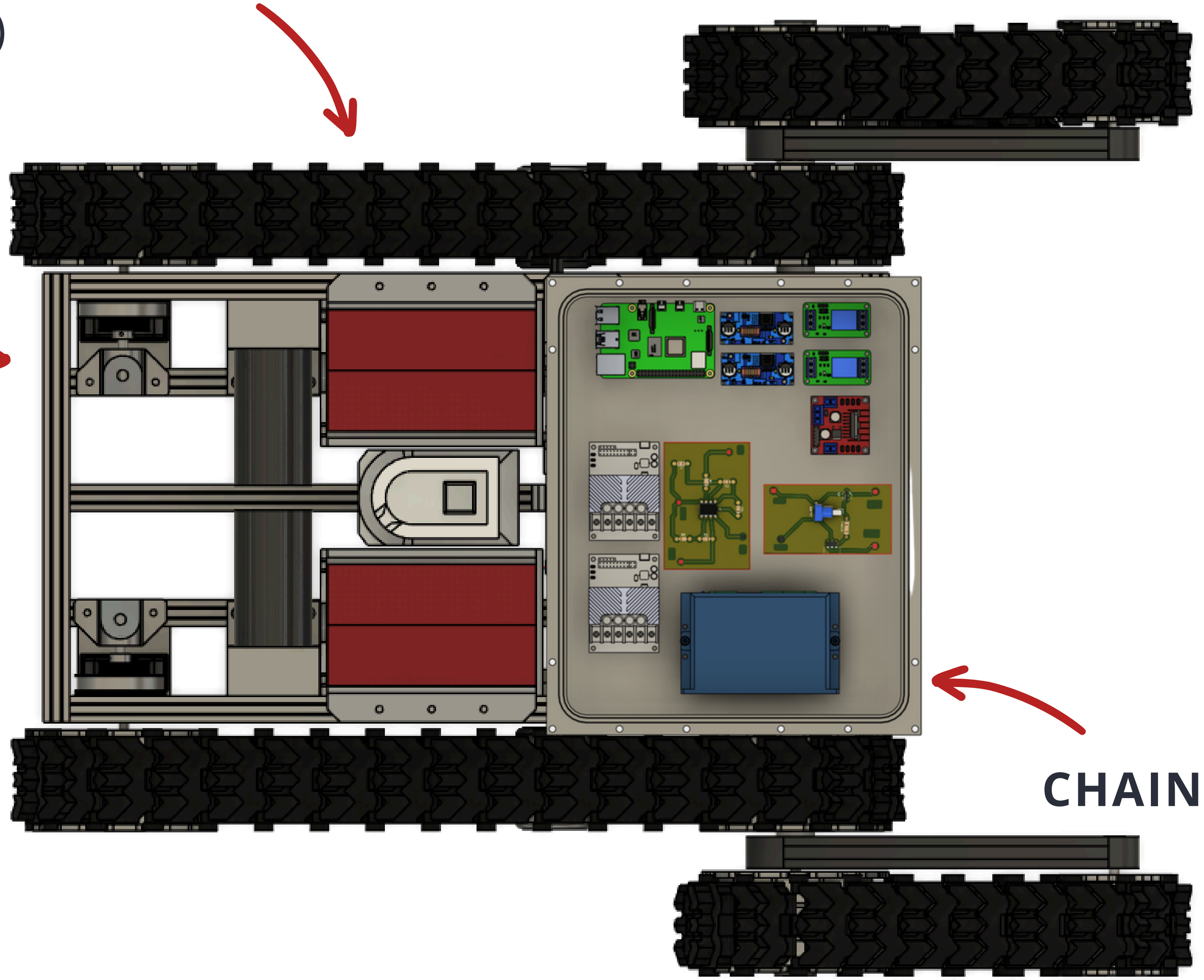


GROUND VEHICLE PACKAGING

BATTERY COMPARTMENTS
(PRUSA MK4)

ELECTRONICS BOX WITH CUSTOM PCBS
(LPKF PROTOLASER U4)

EXTRUDED ALUMINUM FRAME

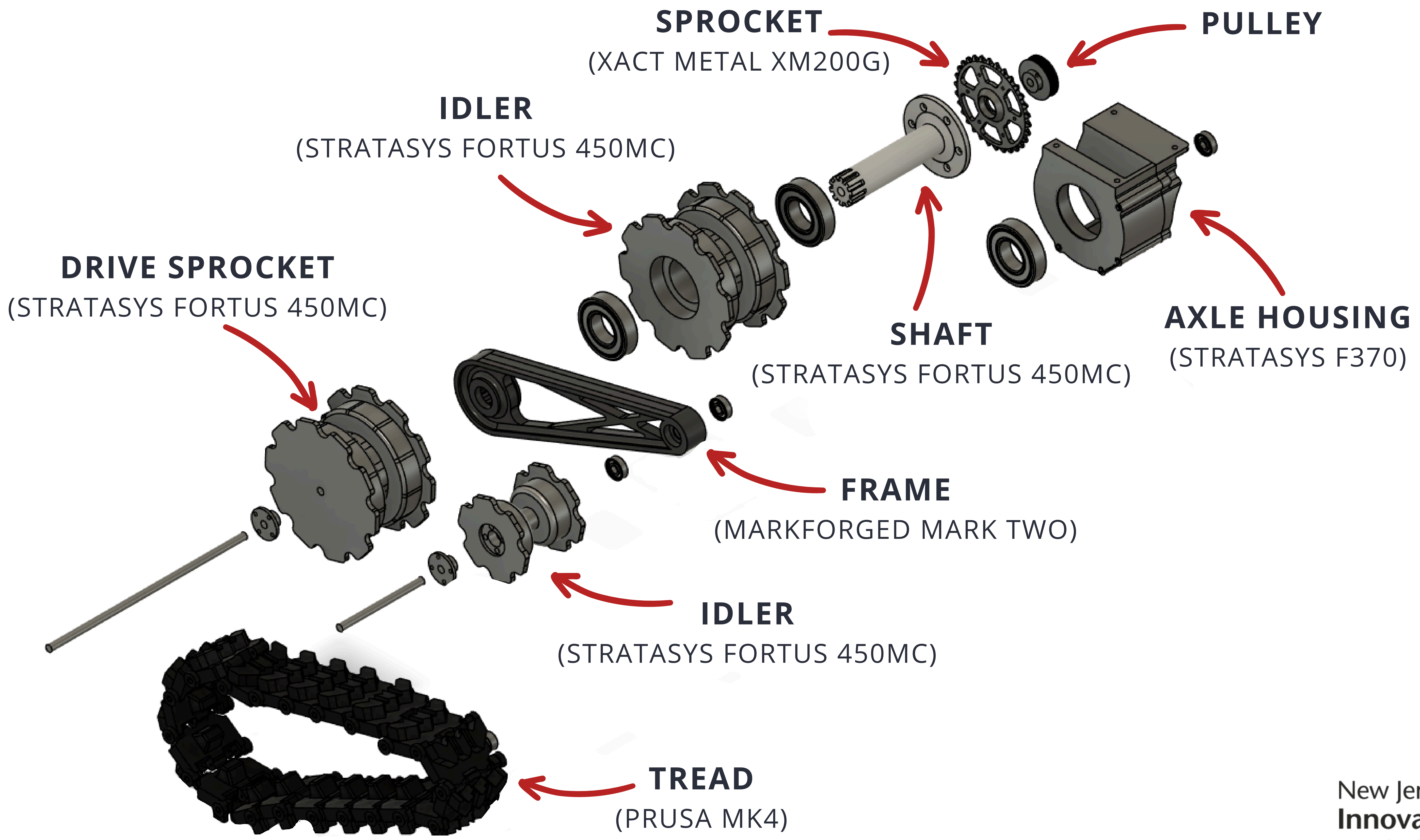


BELT DRIVE SYSTEM

CHAIN DRIVEN ARTICULATION

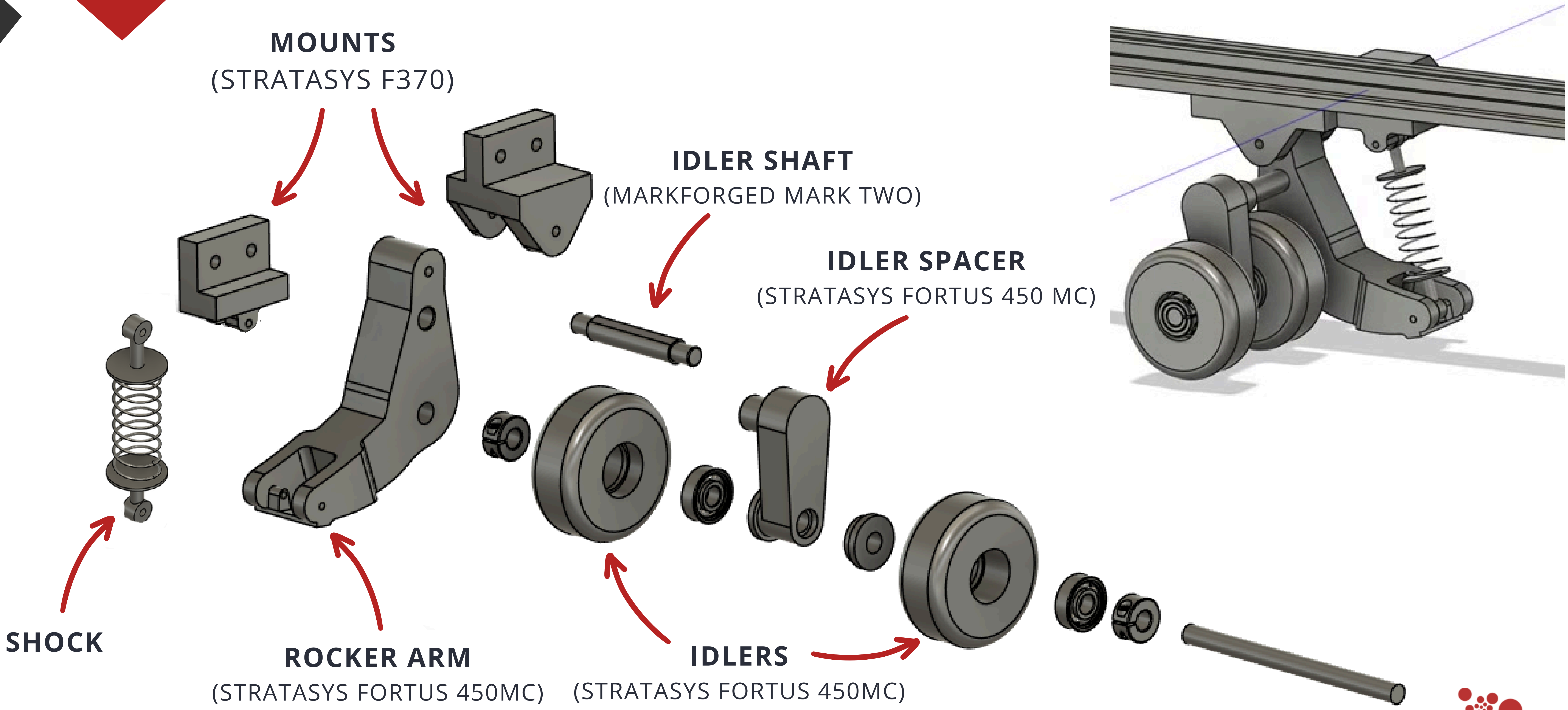
New Jersey Innovation Institute
An NJIT Corporation

ARTICULATING TREAD ASSEMBLY



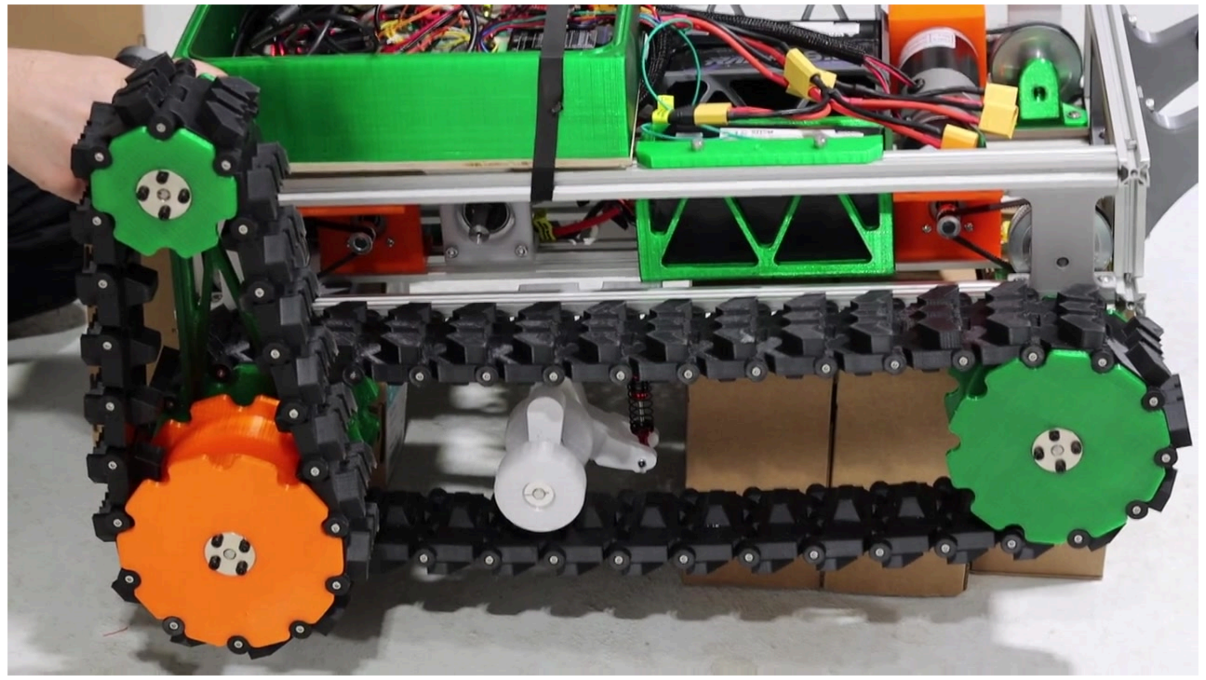
New Jersey Innovation Institute
An NJIT Corporation

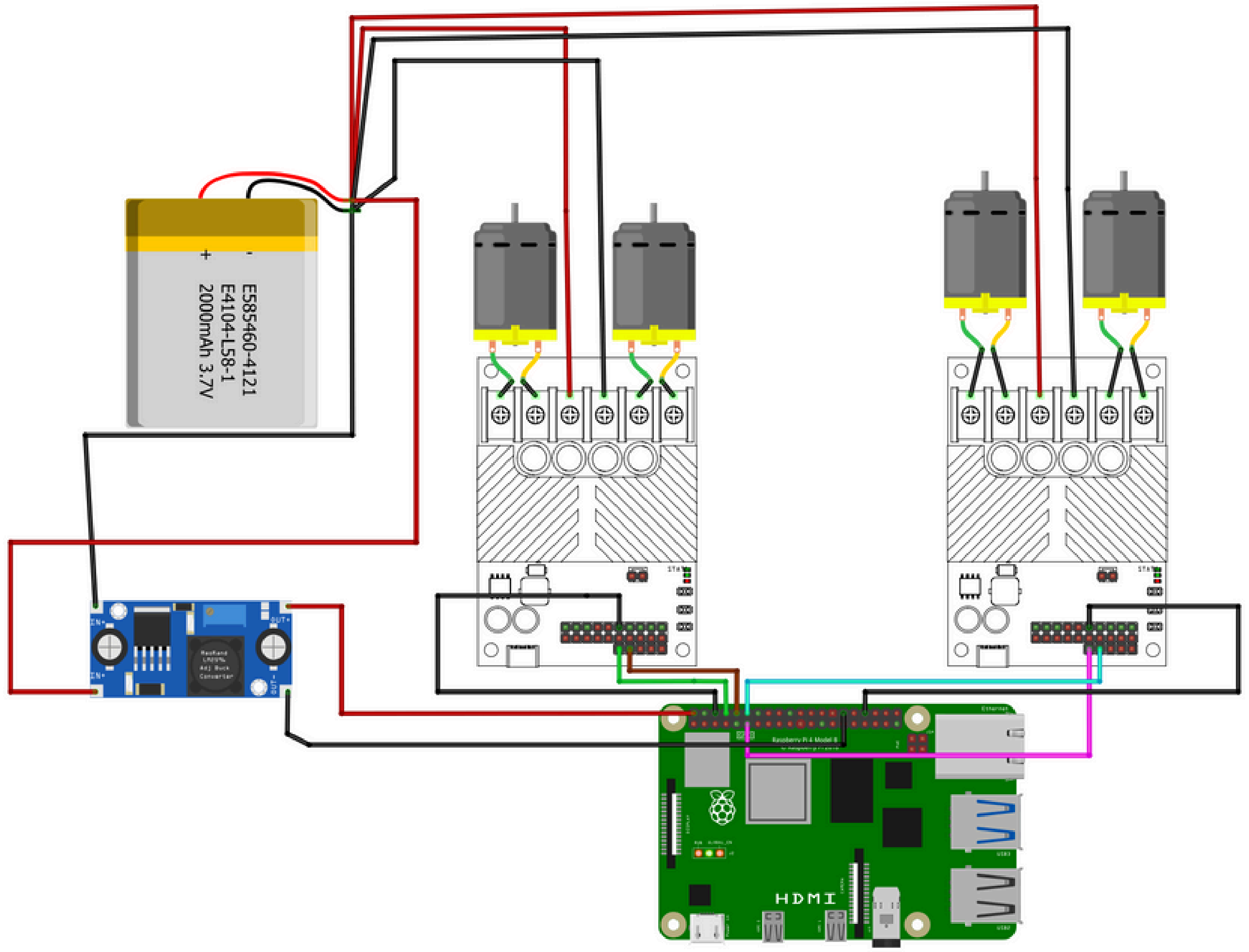
SUSPENSION ASSEMBLY

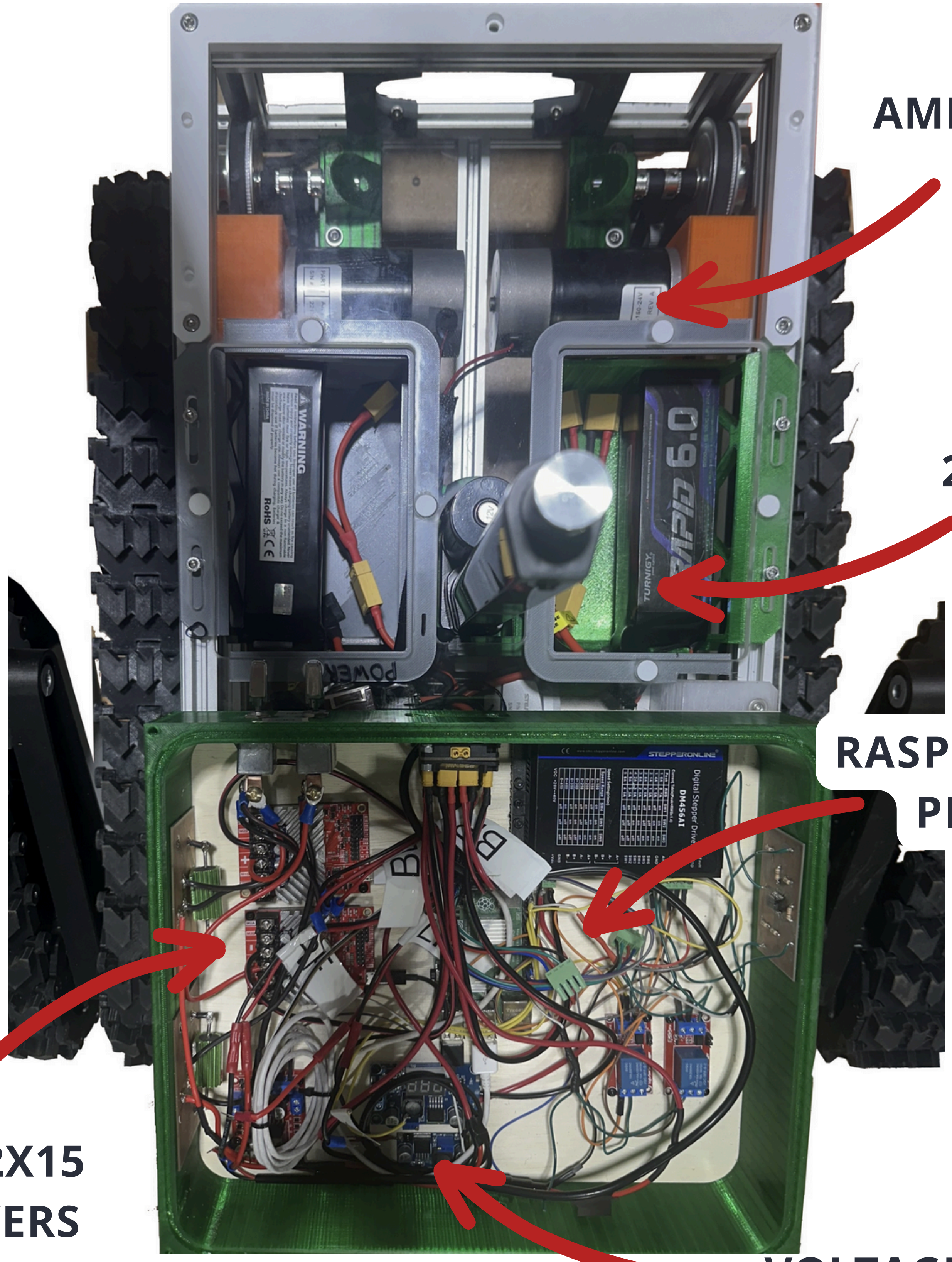


New Jersey
Innovation Institute
An NJIT Corporation

DRIVE SYSTEM SCHEMATIC

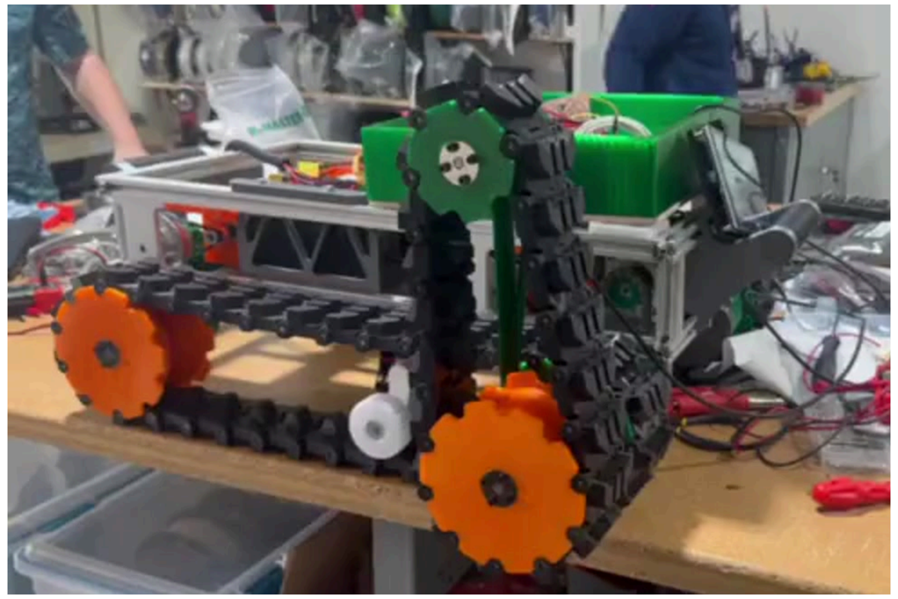


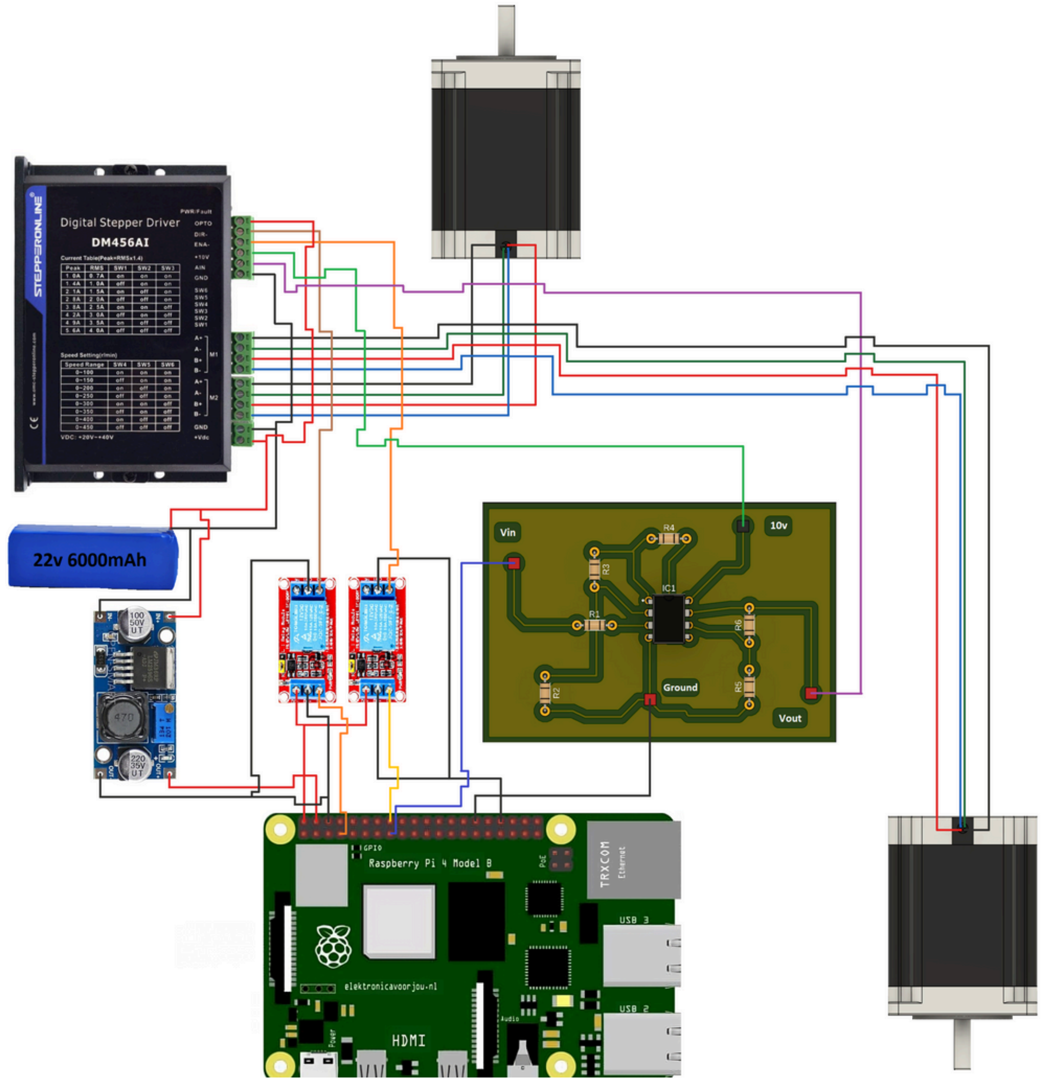


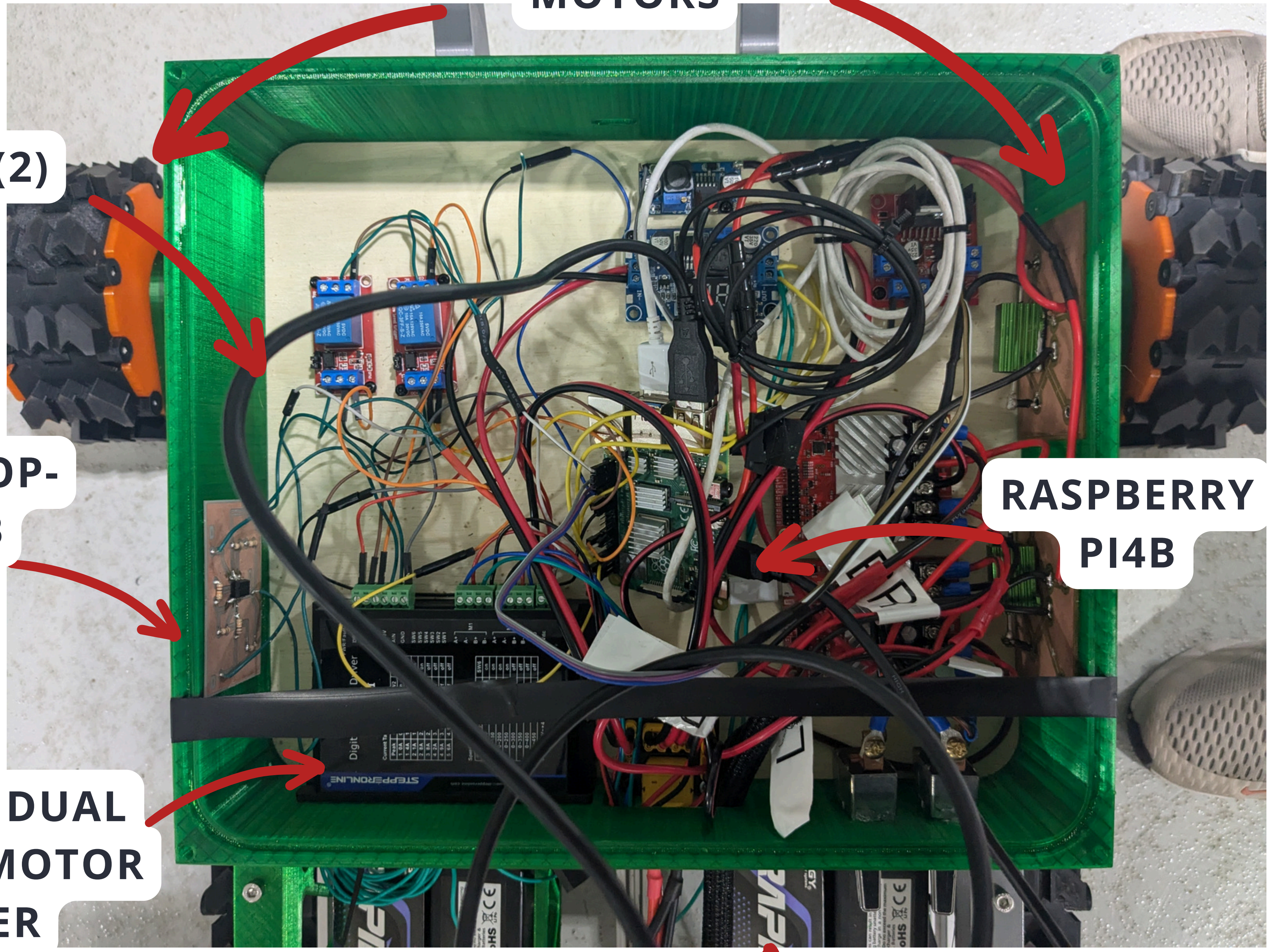


New Jersey Innovation Institute
An NJIT Corporation

STEPPER MOTOR SCHEMATIC





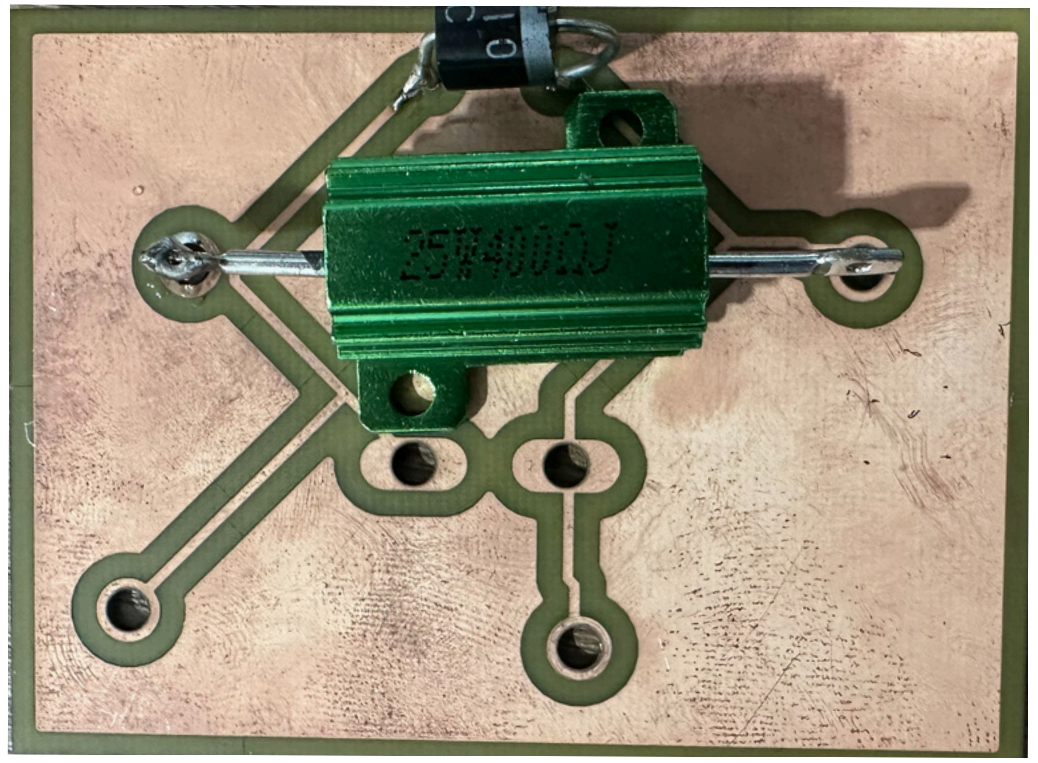


New Jersey Innovation Institute
An NJIT Corporation

IN-HOUSE BOARDS ITERATIONS

Manufactured with LPKF ProtoLaser U4

New Jersey Innovation Institute
An NJIT Corporation



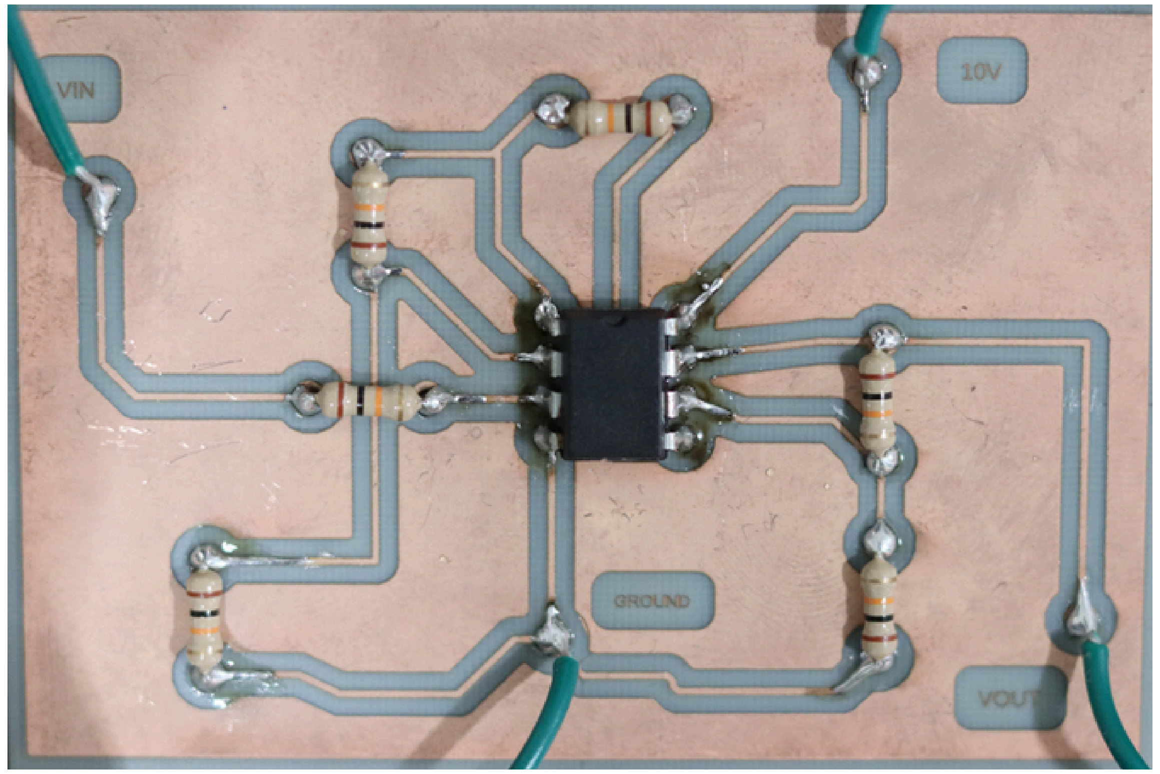
Fuse Safety Circuit v1

FUSE CIRCUIT

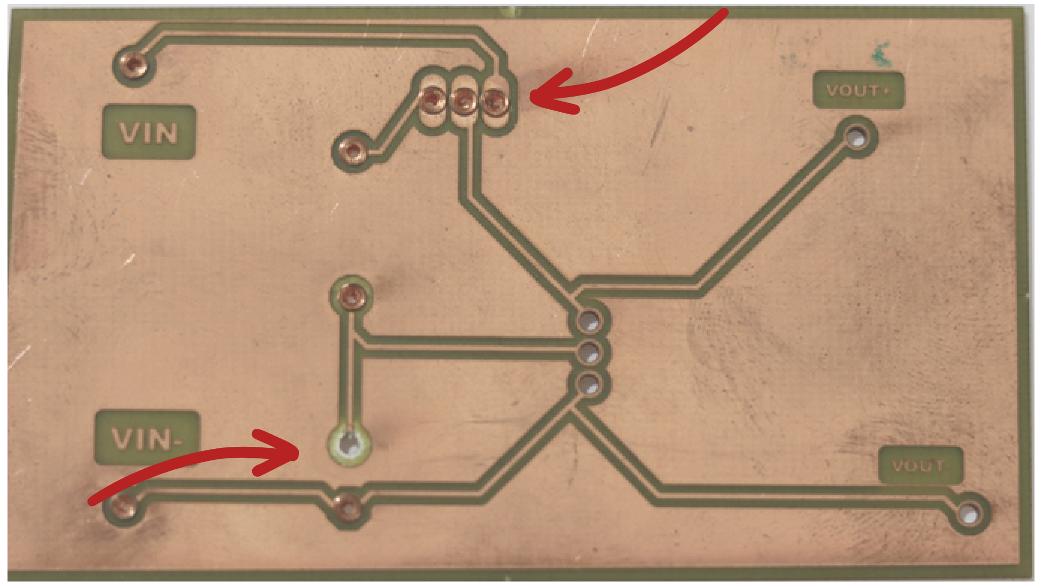
- Protects components from over current

OP-AMP CIRCUIT

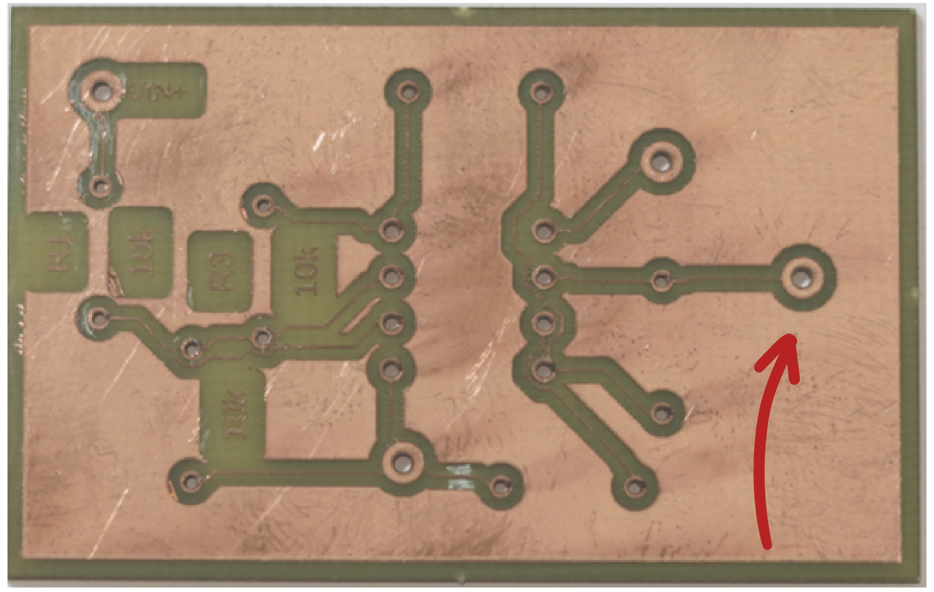
- All components fit perfectly
- Successfully amplified a 3.3v signal into a 9v signal
- Integrated well with the stepper motor driver



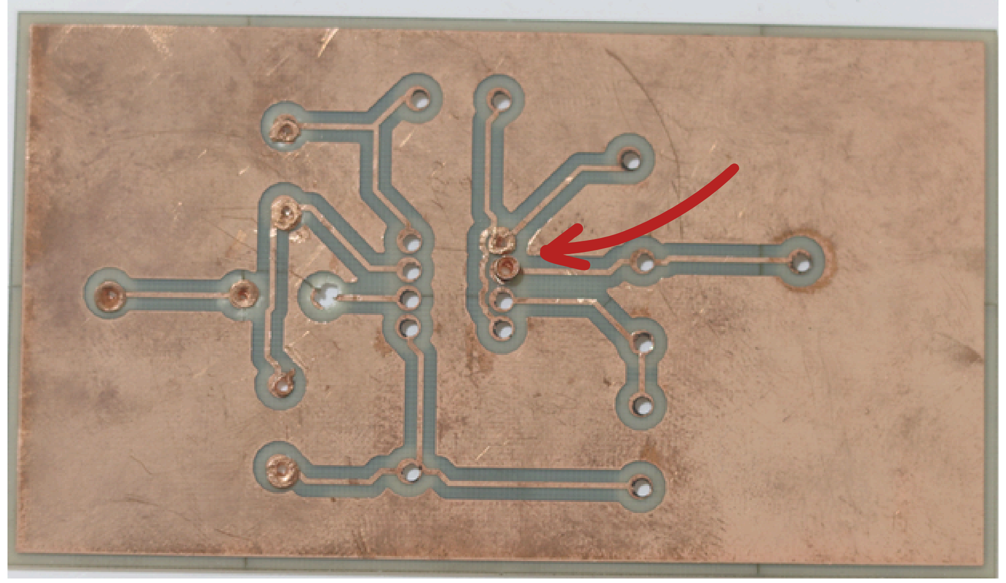
Op-Amp v3



Voltage Regulator v1



Op-Amp v1

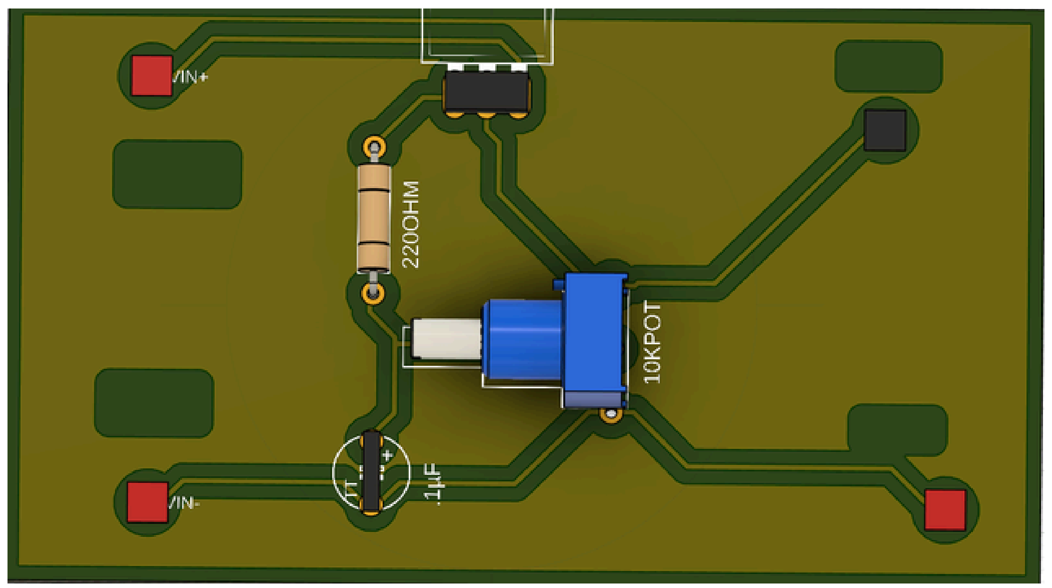


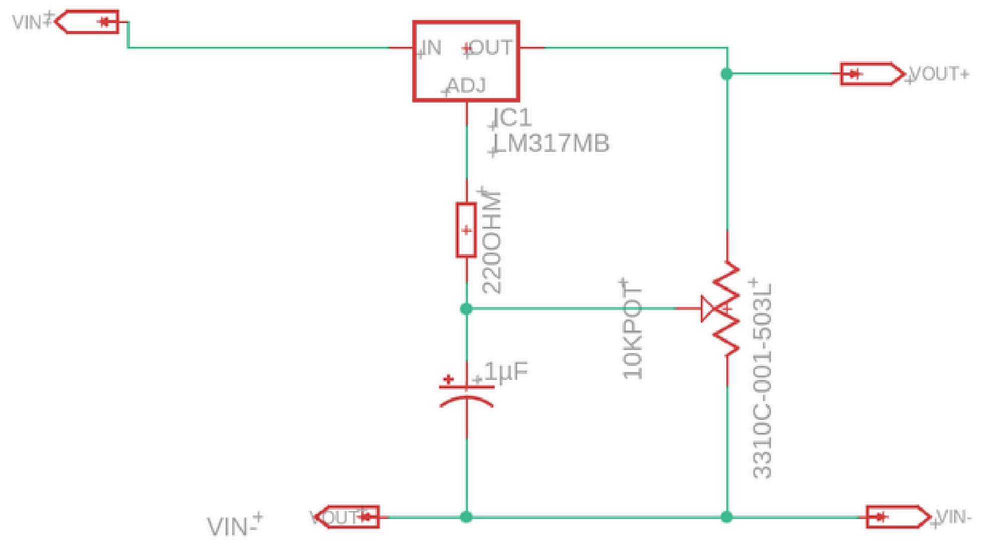
Op-Amp v2

IN-HOUSE BOARDS FINAL

VOLTAGE REGULATOR CIRCUIT

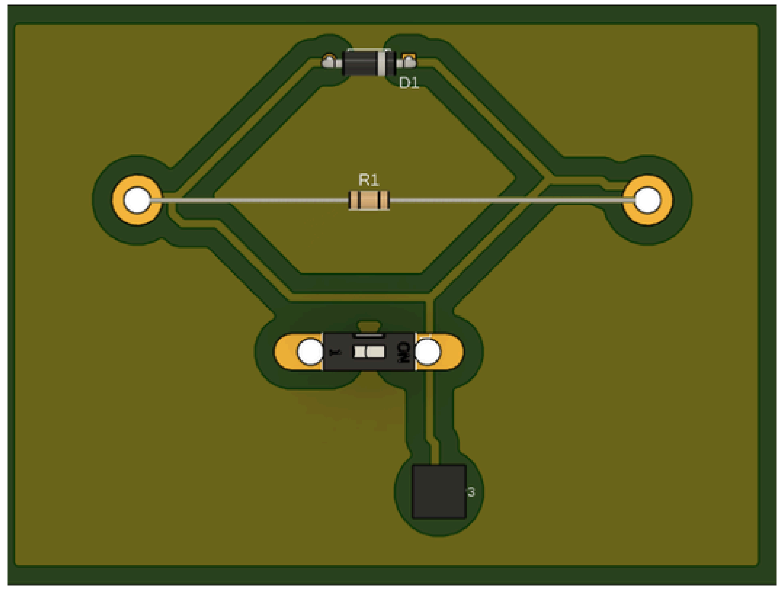
Voltage regulator is used for the stepped down voltage to the actuator

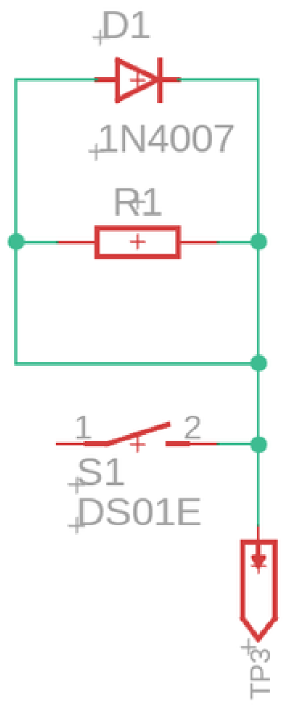




FUSE CIRCUIT

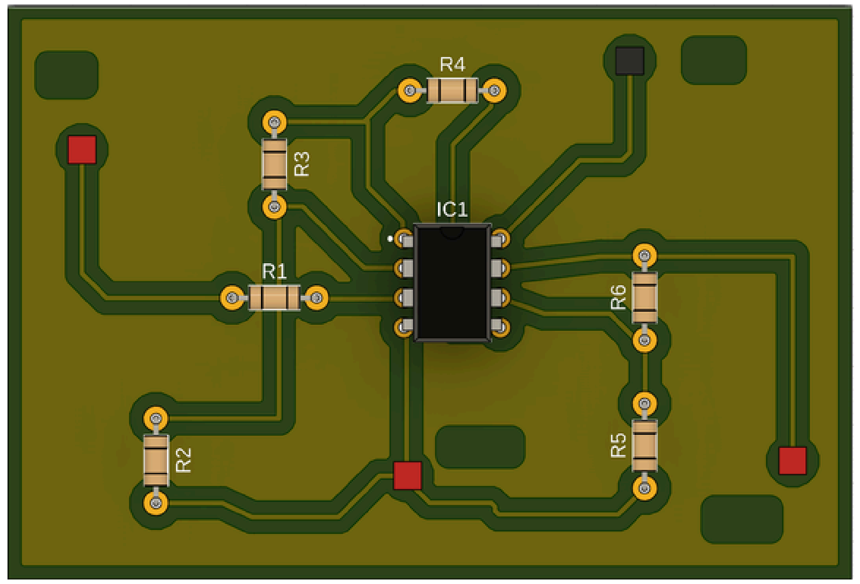
Fuse circuit is used for the protecting components from overloading current

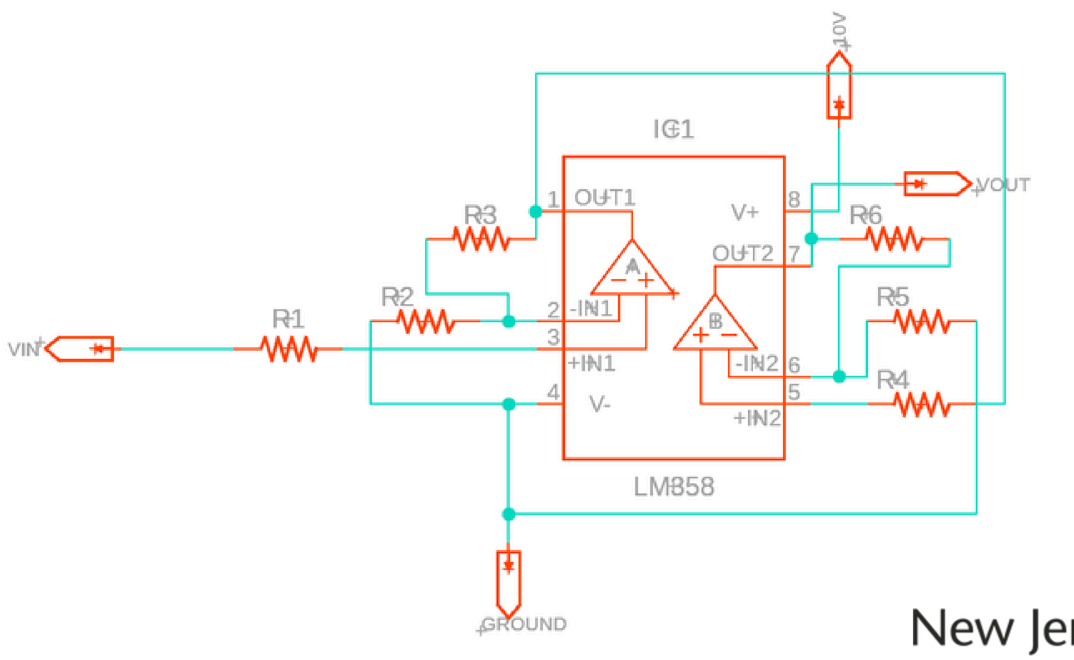




OP-AMP CIRCUIT

Op-amp is used for the stepper driver analog speed



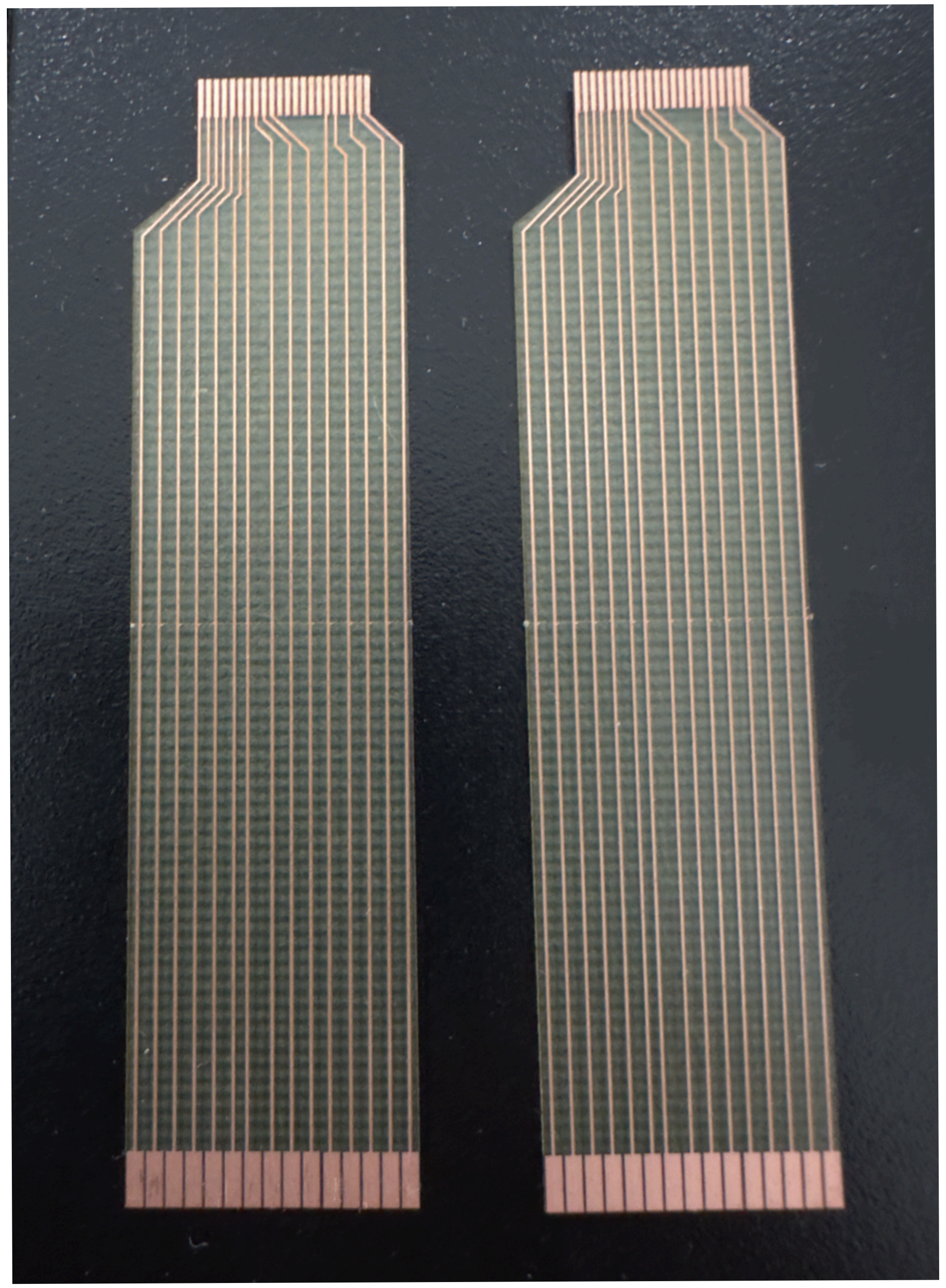


New Jersey Innovation Institute
An NJIT Corporation

IN-HOUSE RIBBON CABLE

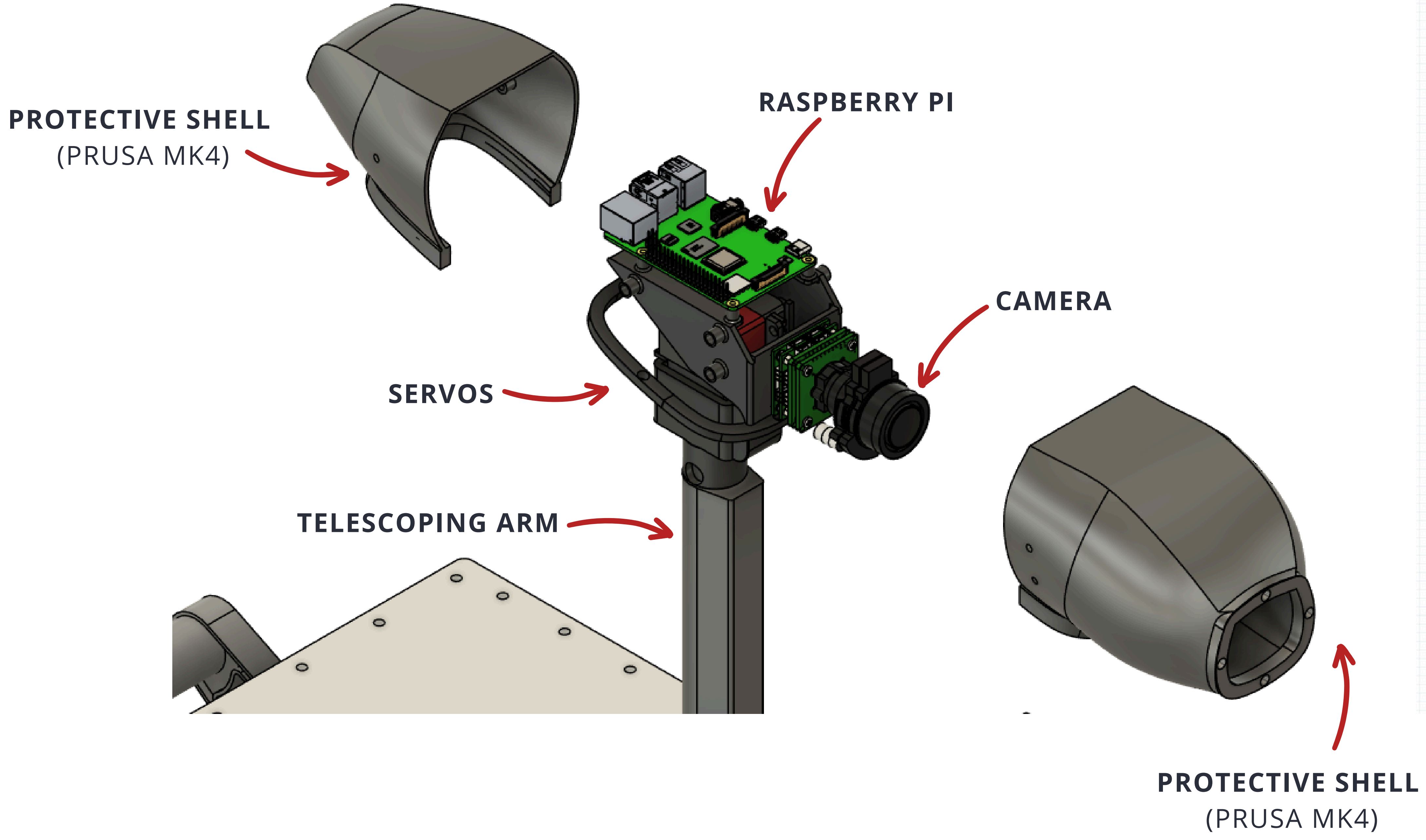
DAMAGED OFF THE SHELF RIBBON CABLE

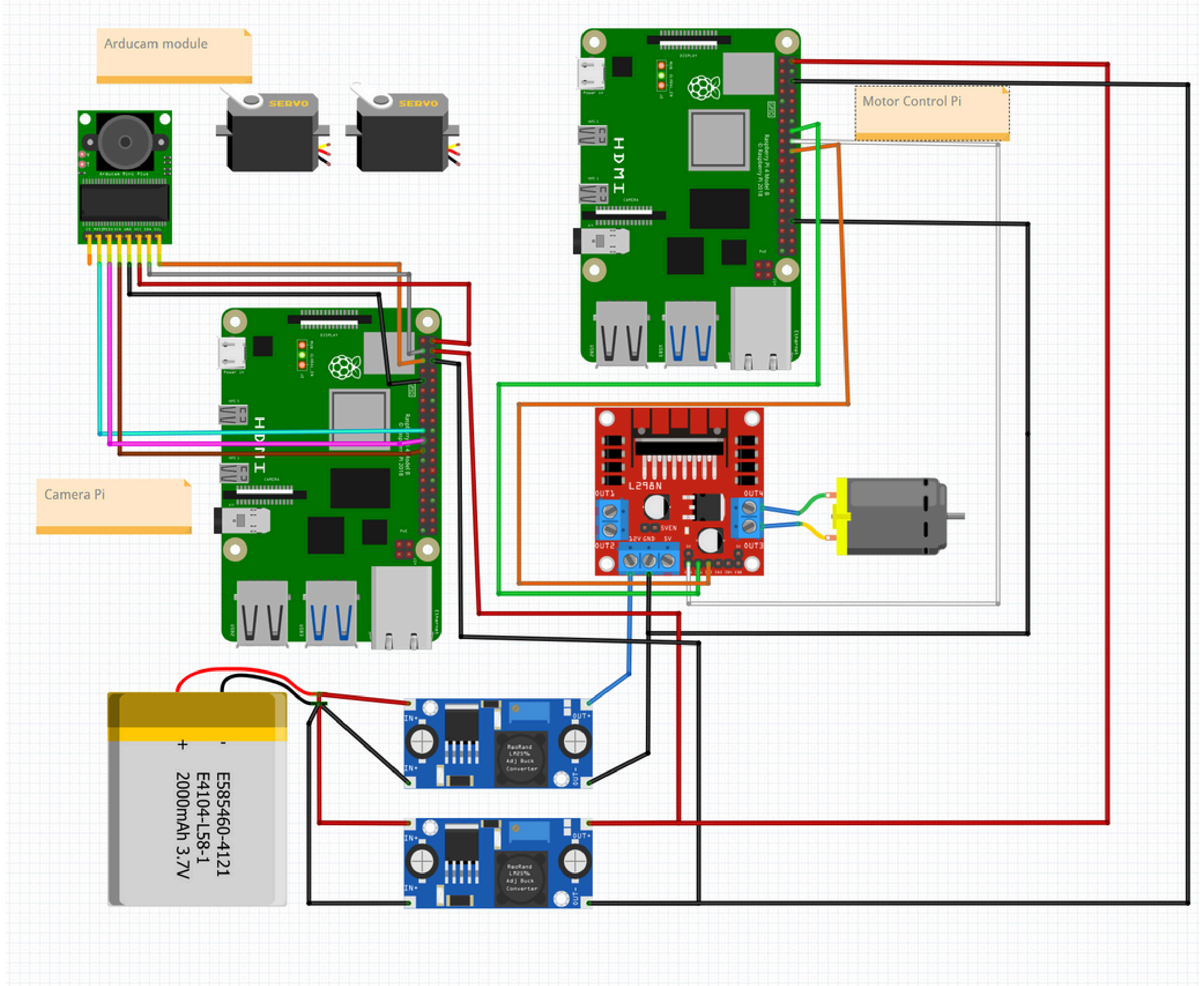
IN-HOUSE REPLACEMENT RIBBON CABLE



New Jersey Innovation Institute
An NJIT Corporation

CAMERA ACTUATOR ASSEMBLY





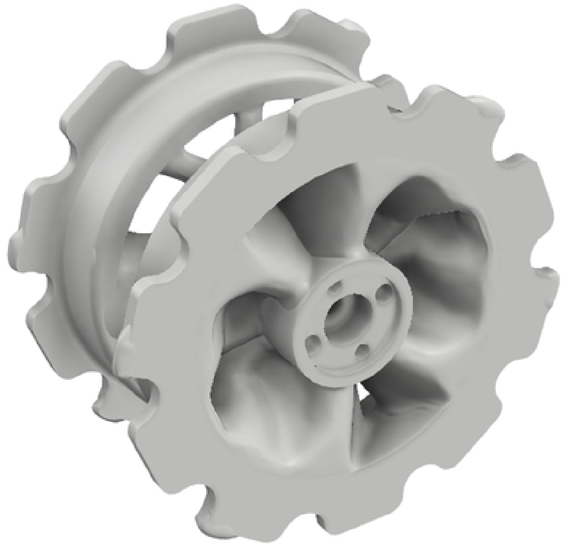
New Jersey Innovation Institute
An NJIT Corporation

GENERATIVE DESIGN

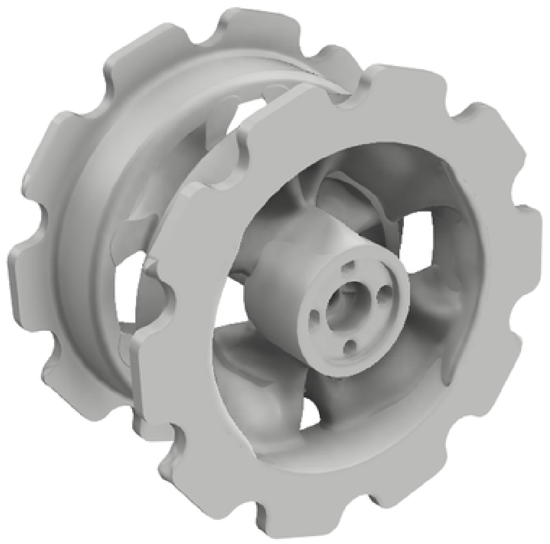
New Jersey Innovation Institute
An NJIT Corporation

Original Sprocket

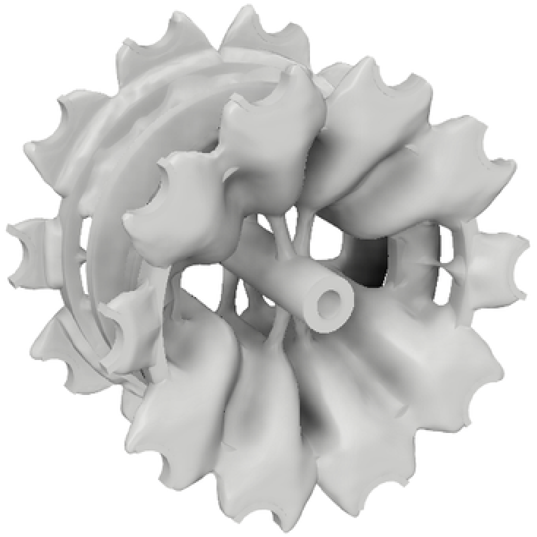
	Mass (g)	% of Original Mass	Minimum Safety Factor	Maximum Displacement (mm)
Original Sprocket	741.659	100	7.12	0.066
Iteration 1	457.411	61.67	2.96	0.016
Iteration 2	335.206	45.2	0.19	0.172
Iteration 3	296.94	40.04	0.33	0.26
Iteration 4	135.359	18.25	1.43	0.244
Iteration 5	415.733	56.05	4.6	0.009
Iteration 6	517.42	69.76	1.35	0.04
Iteration 7	329.633	44.45	2.44	0.023
Iteration 8	322.405	43.47	1.01	0.315
Final Iteration	550.229	74.18	4.21	0.076



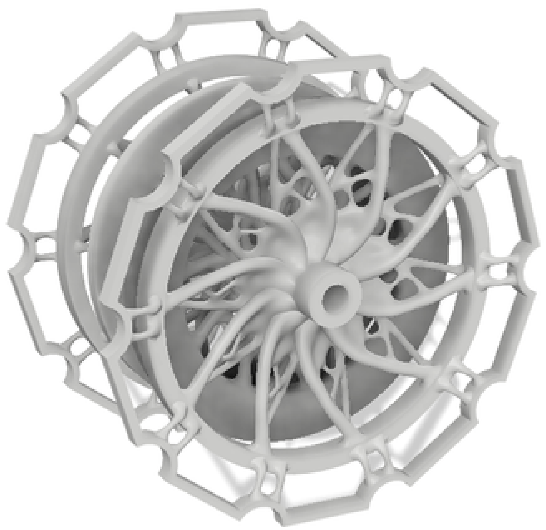
Iteration 1



Iteration 2

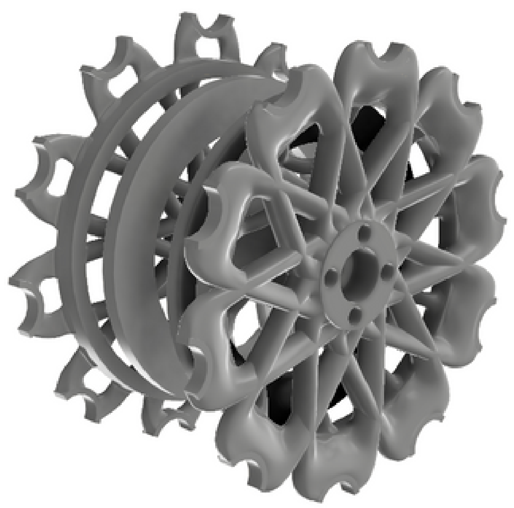


Iteration 3



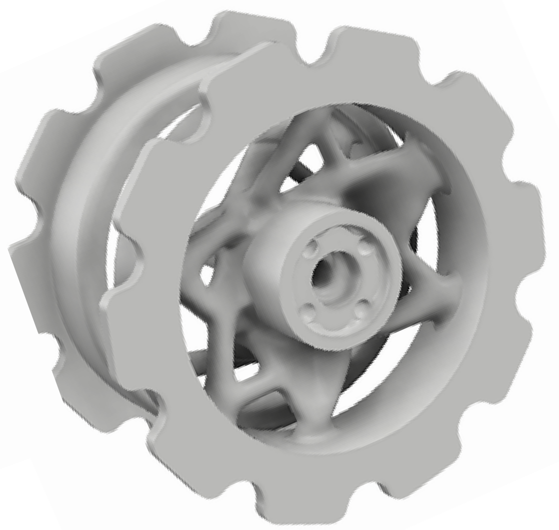
Iteration 4

Iteration 5



Iteration 6

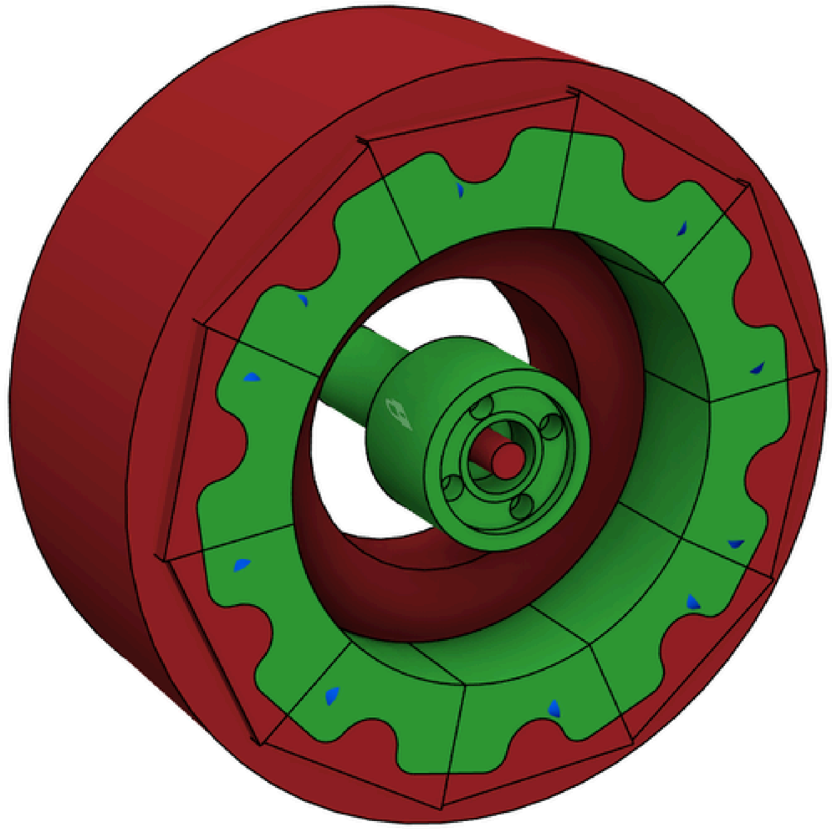
Iteration 7



Iteration 8

GENERATIVE DESIGN

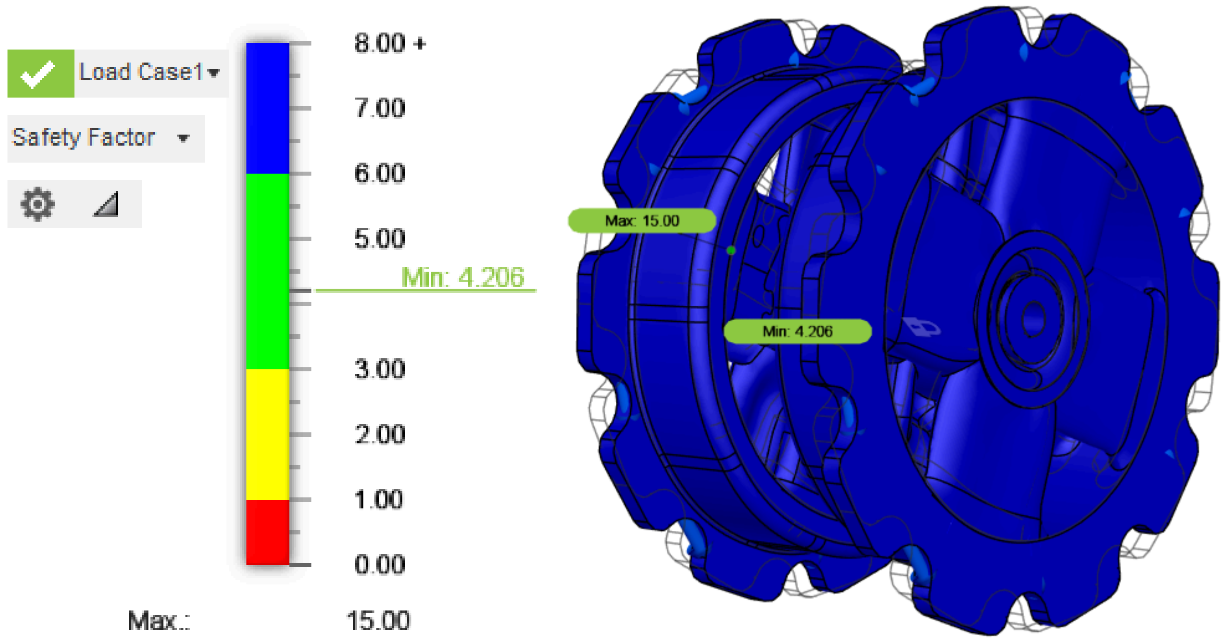
New Jersey Innovation Institute
An NJIT Corporation



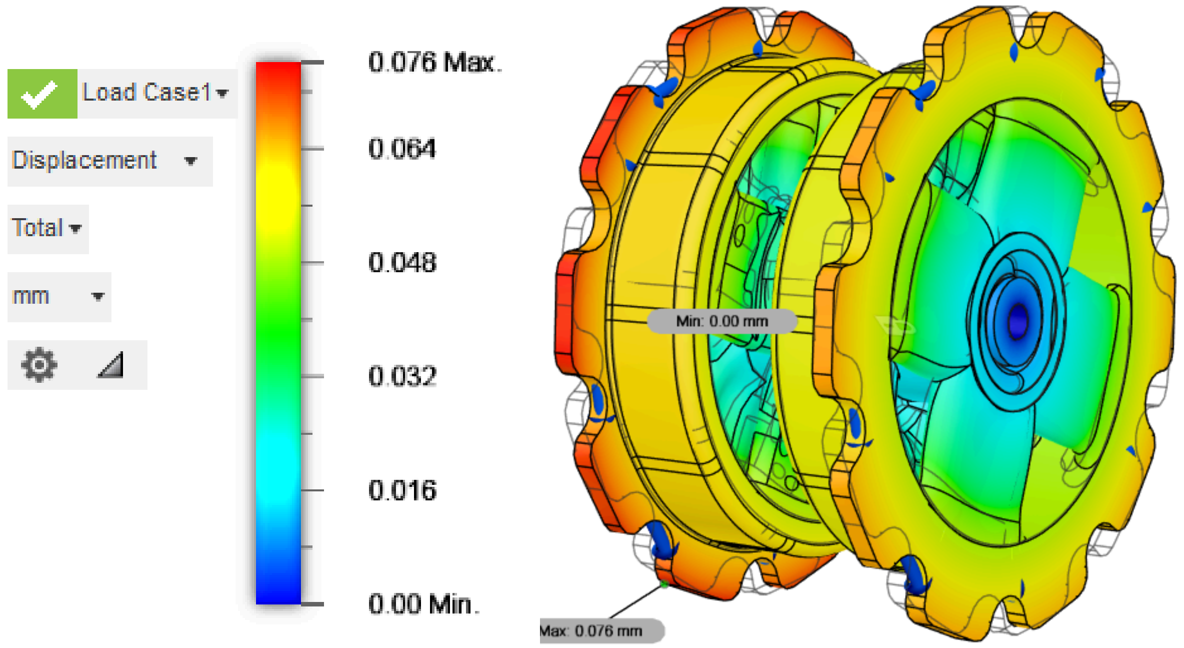
Generative Study Setup

Physical Part

550.229 g
25.82% less mass



Safety Factor Results



Displacement Results

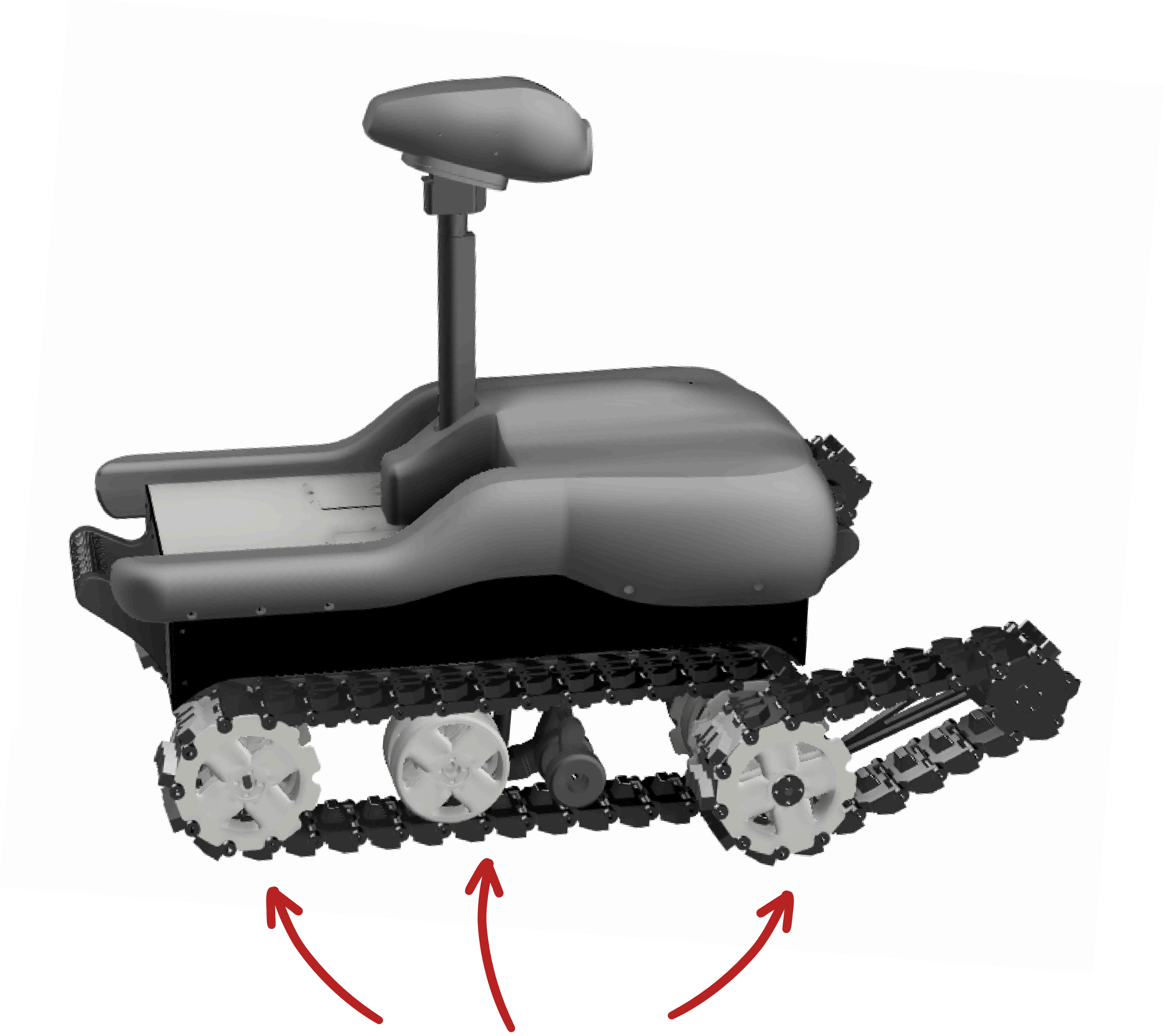
GENERATIVE DESIGN

Original Idler

572.952 g

Generated Idler

362.961 g
36.65% less mass



Total weight saved on all 4 sprockets and 4 idlers: 1.61 kg or 3.54 lbs

ABS ON STRATASYS FORTUS 450MC

New Jersey Innovation Institute
An NJIT Corporation

AERIAL DRONE

New Jersey
Innovation Institute
An NJIT Corporation

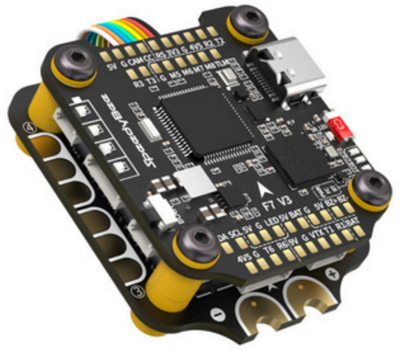
AERIAL DRONE GOALS

- Rover range extension
- Operation in Harsh Environments
- Easily manufacturable
- Power efficient
- Efficient packaging
- Simple controls
- Carry a payload
- Long flight time

New Jersey Innovation Institute
An NJIT Corporation

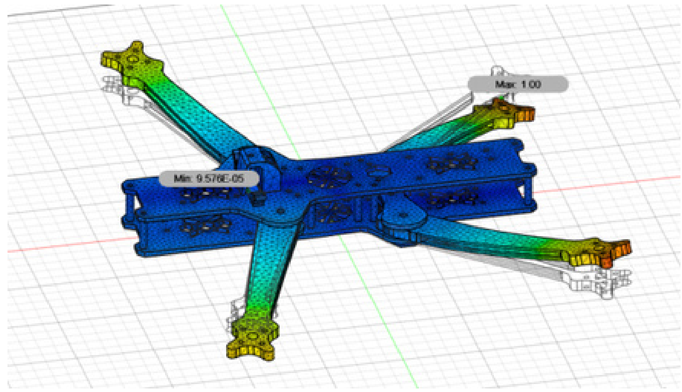
AERIAL DRONE OVERVIEW

Research



Select off the shelf test parts

Test C.O.T.S. drone

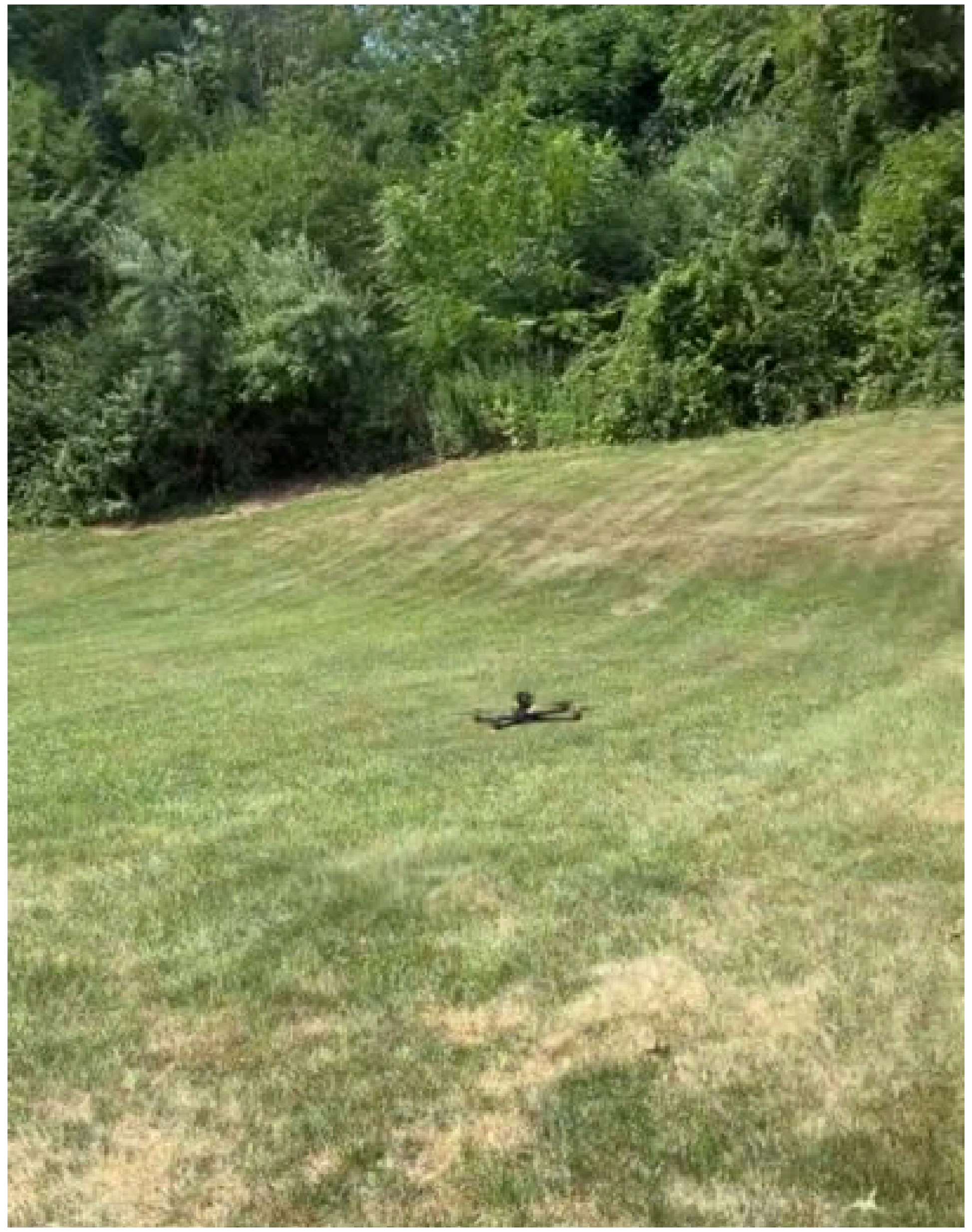


Design custom frame and arms, added more sensors

New Jersey Innovation Institute
An NJIT Corporation

C.O.T.S. TESTING

New Jersey Innovation Institute
An NJIT Corporation



FRAME DESIGN (Shapeoko 3 CNC)

Modeled custom frame

Design bottom plate

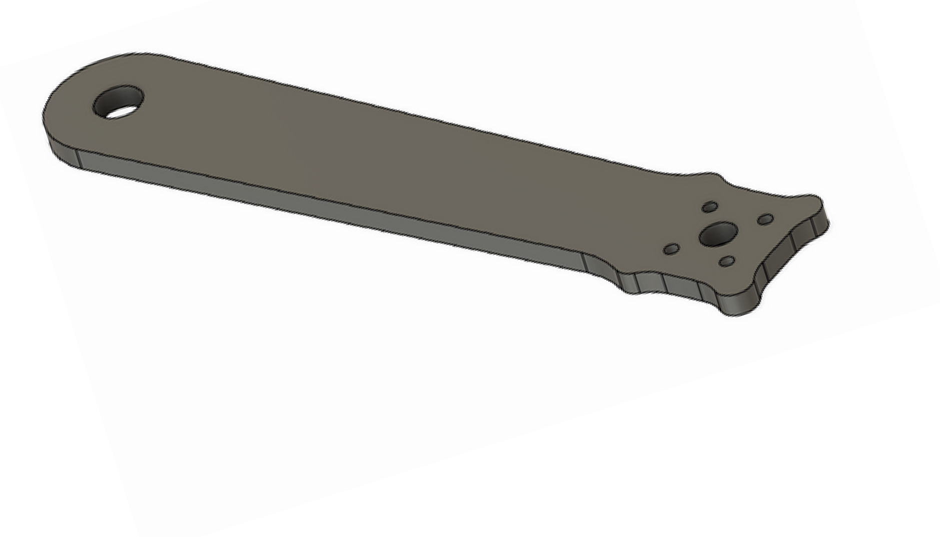
Add arm folding mechanism

Modify for machinability

New Jersey Innovation Institute
An NJIT Corporation

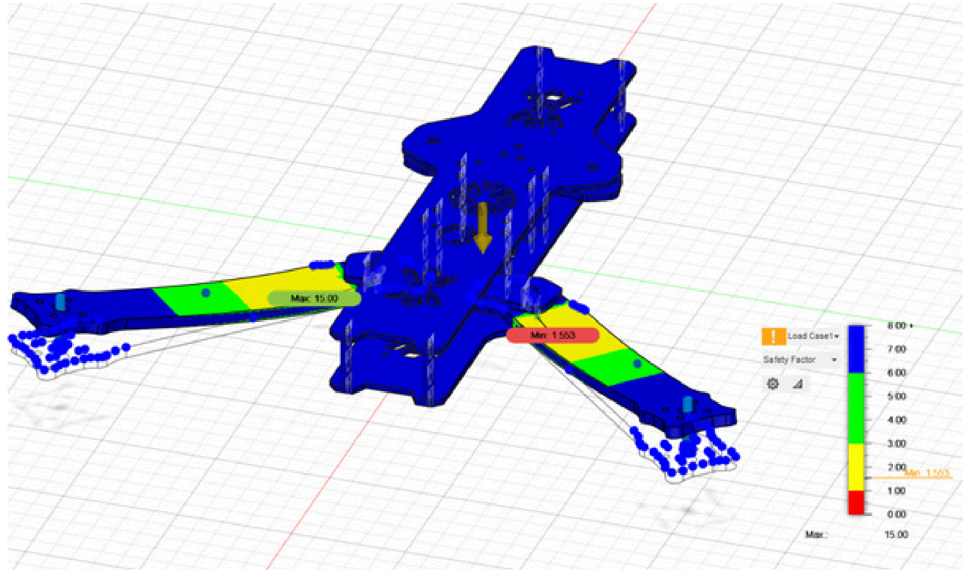
ARM DESIGN (Markedforged Mark 2)

Designed initial arm

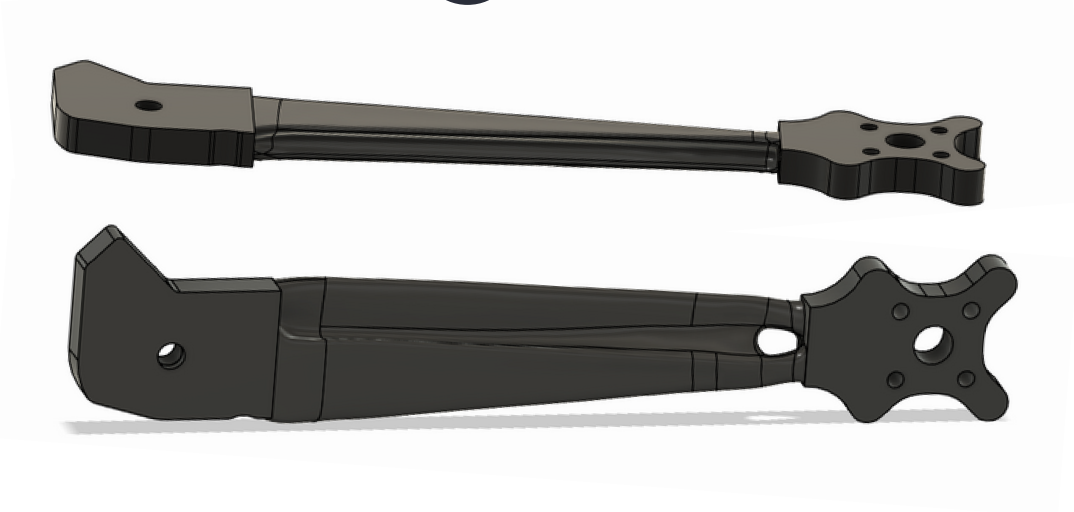


Adapted to fit folding mechanism

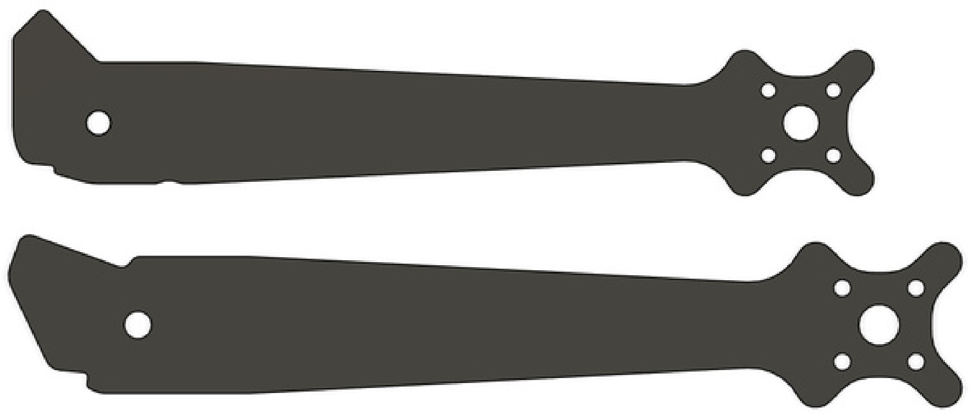
Stress analysis



Generative design



Final design



New Jersey
Innovation Institute
An NJIT Corporation

FINAL DESIGN

SIDE VIEW

VIDEO ANTENNA

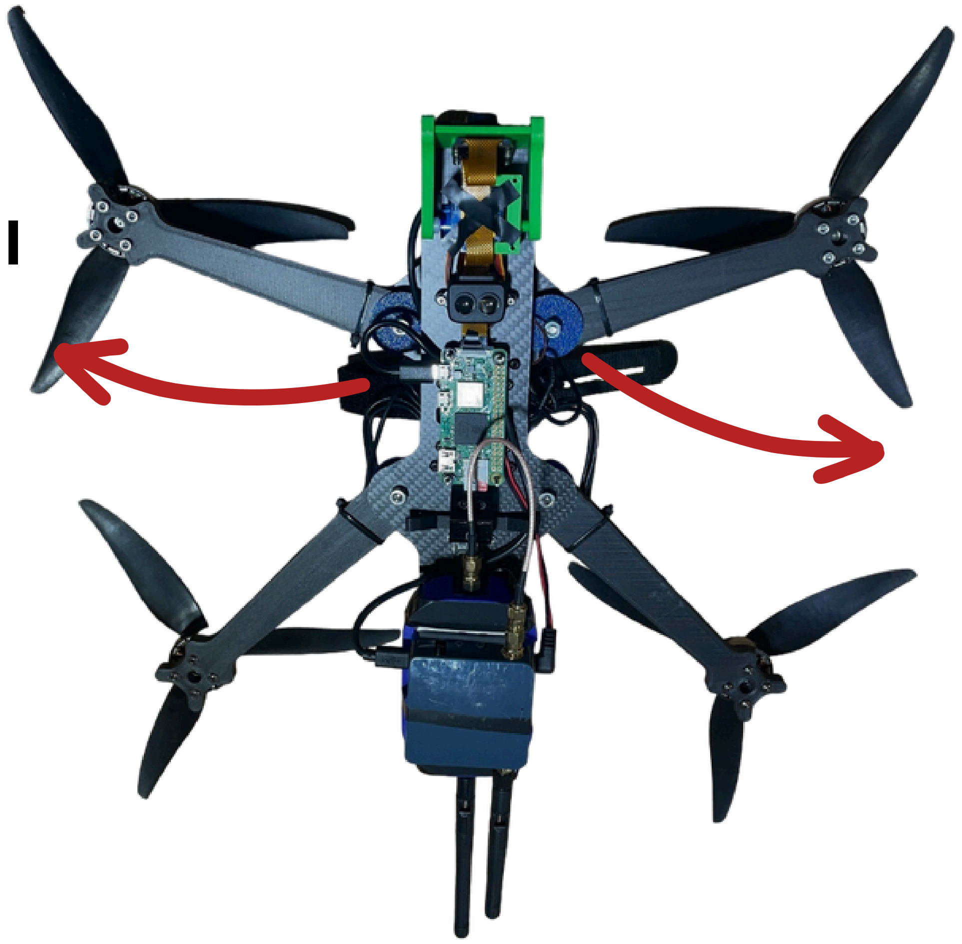
ANALOG CAMERA

DIGITAL CAMERA & SERVO SWIVEL

(PRUSA MK4)

BOTTOM VIEW

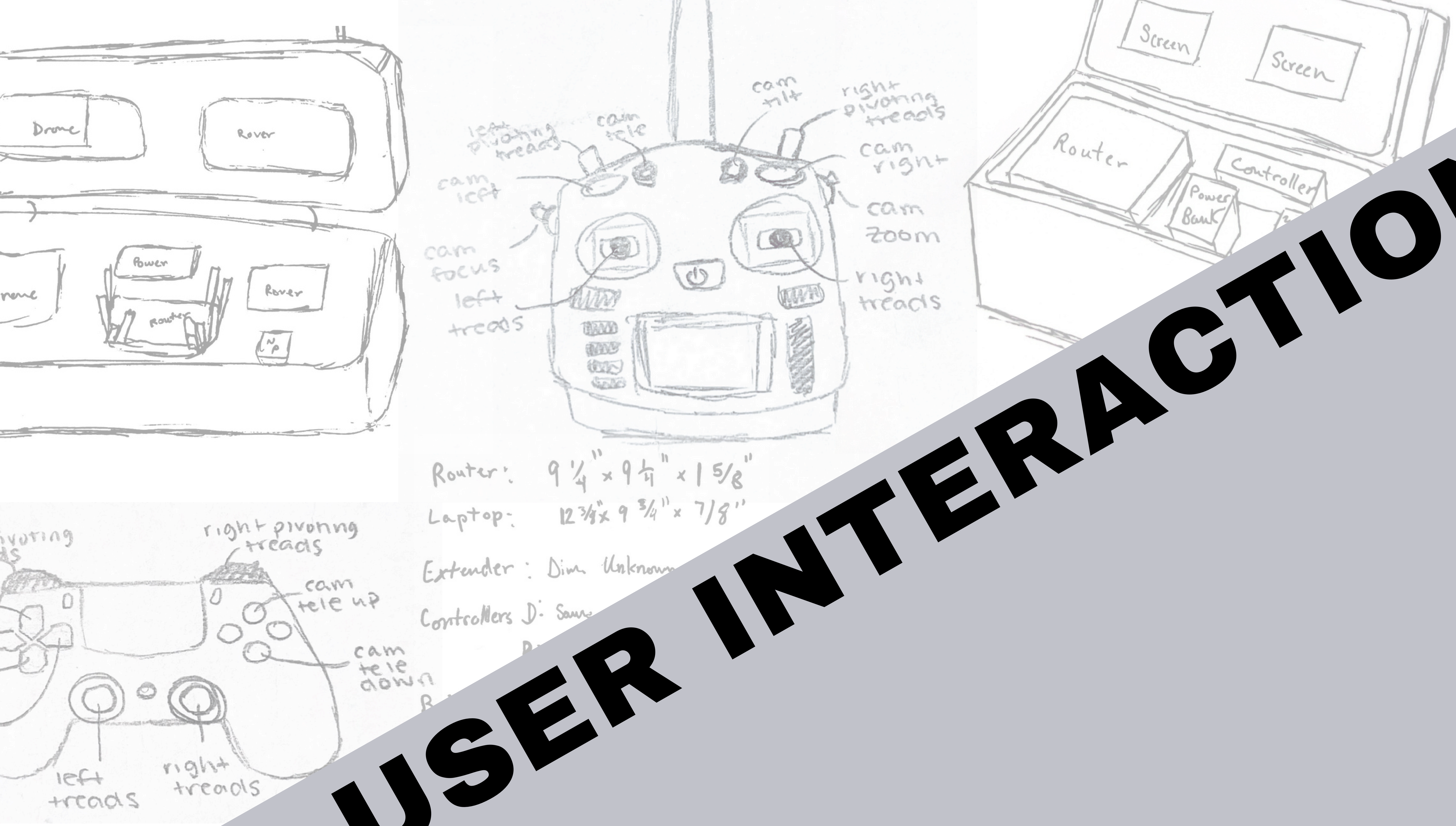
RASPBERRY PI ZERO



LIDAR SENSOR

WI-FI ROUTER AND EXTENDER

New Jersey Innovation Institute
An NJIT Corporation

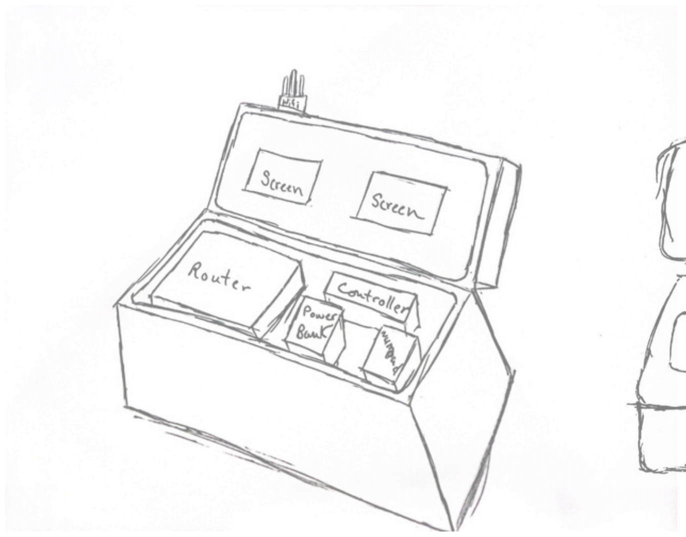


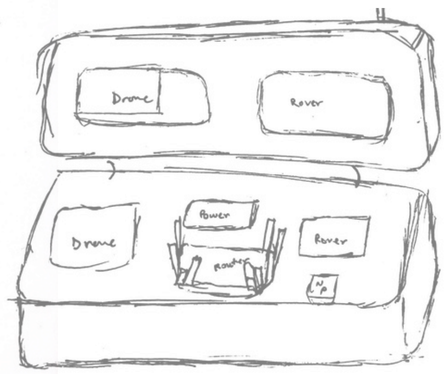
USER INTERACTION

New Jersey Innovation Institute
An NJIT Corporation

GROUND STATION GOALS

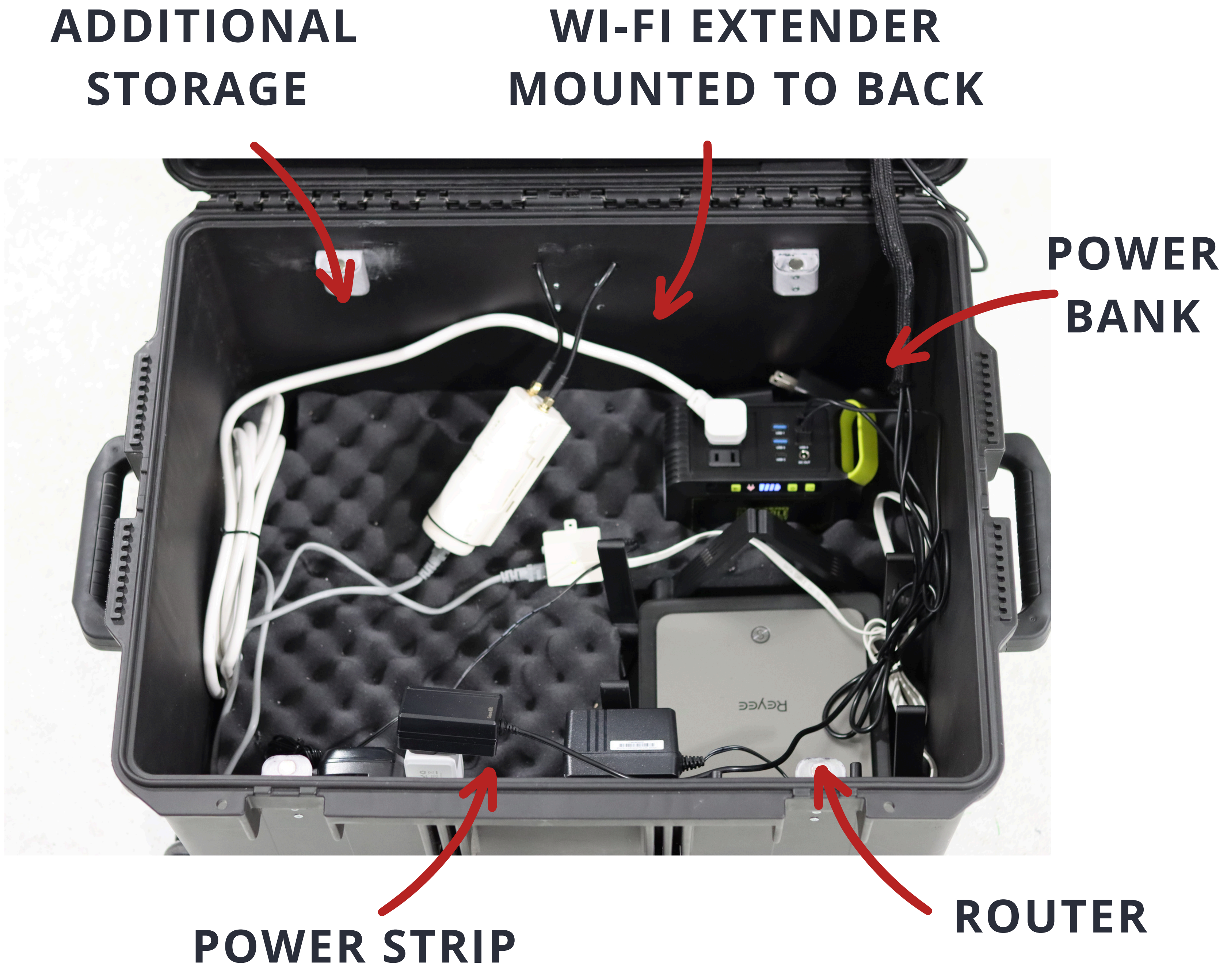
- EXAMINED CONTROL STATIONS CURRENTLY USED BY THE **U.S. MILITARY**
- FULLY INTERNAL AND READY-TO-USE **CONTROLS**, **POWER**, AND **SCREENS**
- NEEDS TO MEET MILITARY STANDARDS, IDEALLY **MIL-STD-810** FOR **ENVIORNMENTAL** CONSIDERATIONS



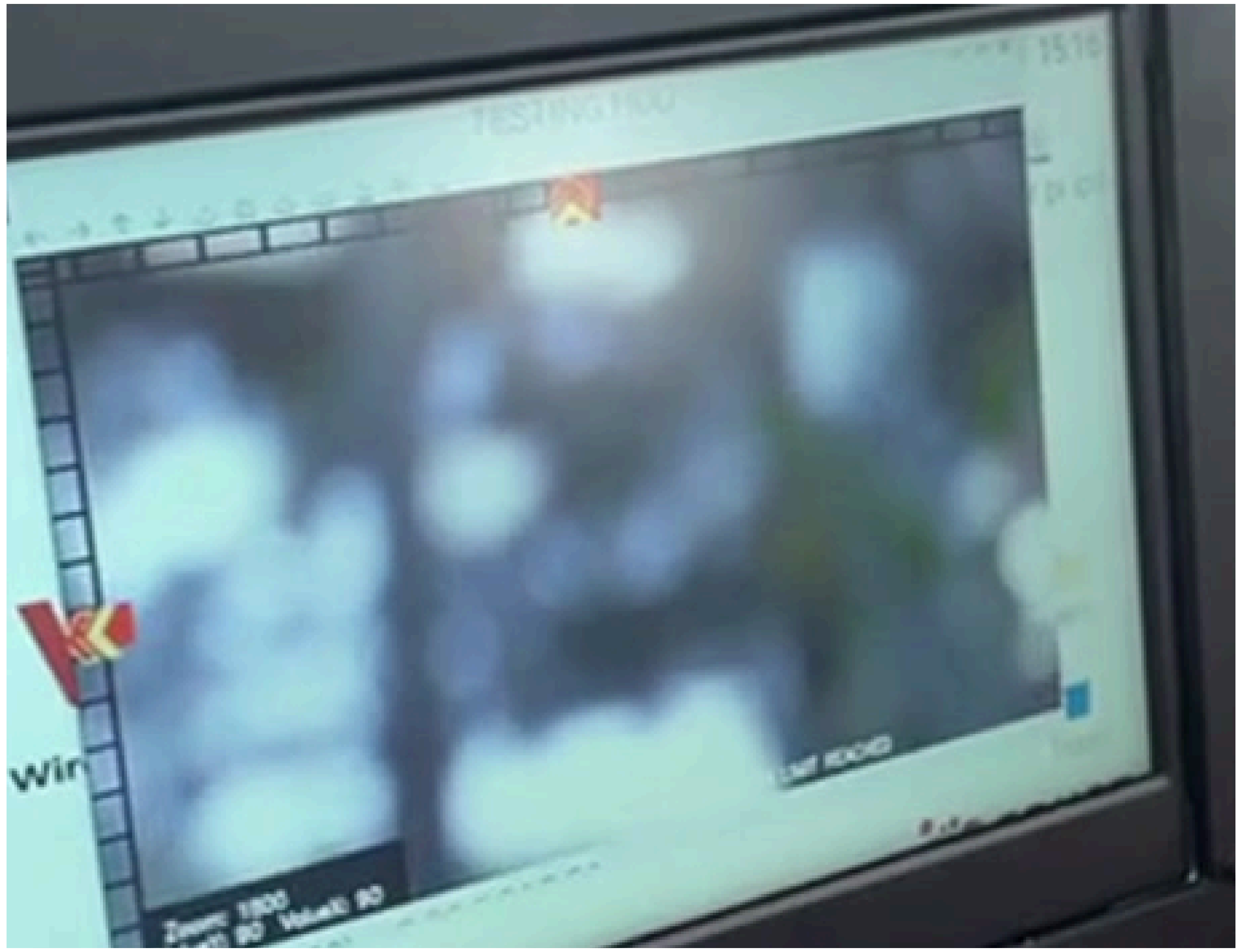


Router: 9 1/4" x 9 1/4" x 1 5/8"
Laptop: 12 3/4" x 9 3/4" x 7/8"
Extender: Dim. Unknown
Controllers D: Same as Rover
R: 6 1/2" x 4" x 2 1/2"
Battery: 6 1/2" x 4 2/5" x 3 1/10"

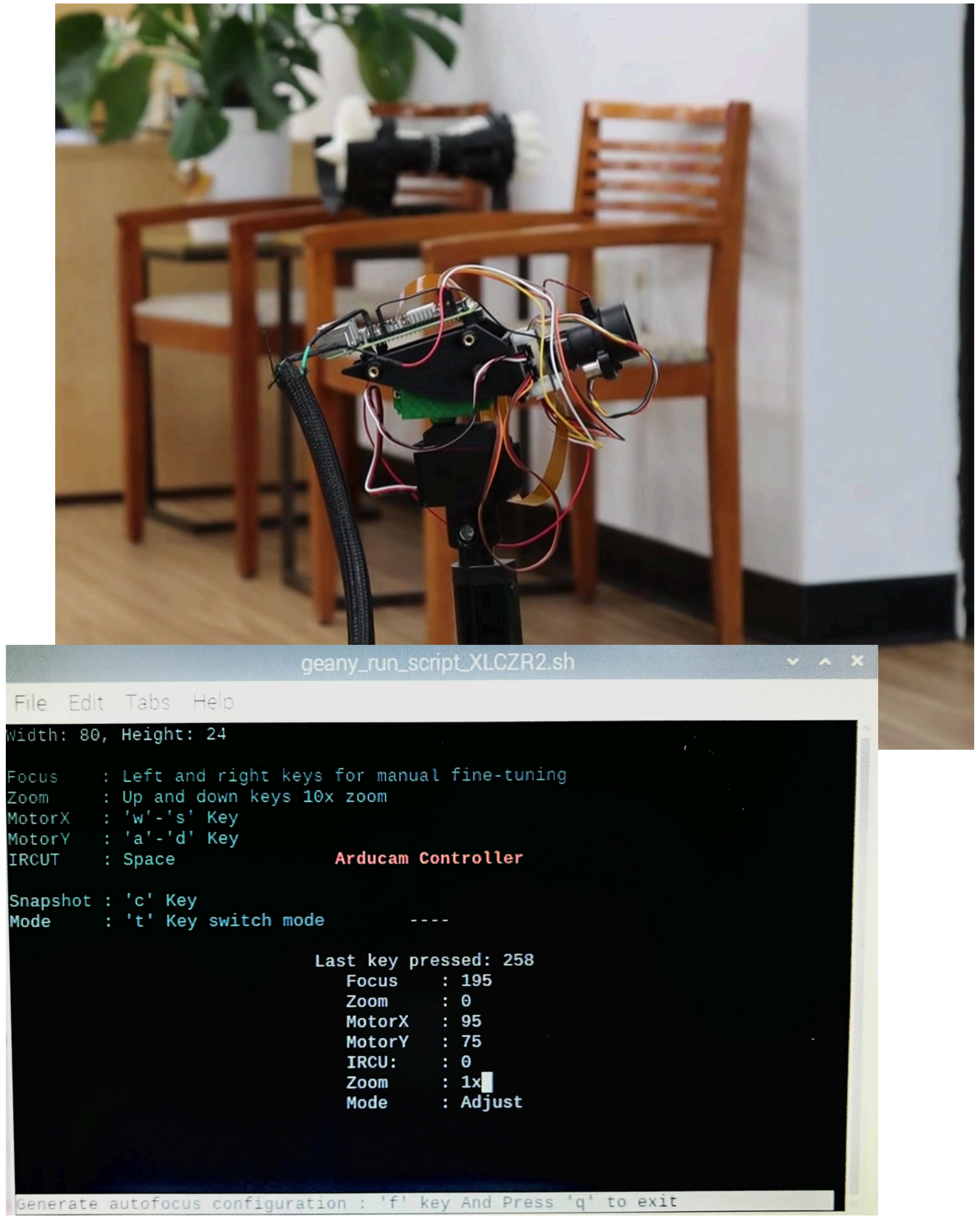

GROUND VEHICLE FEED
EXTRA MONITOR
W.A.R.D.E.N.
W.A.R.D.E.N.
DRONE FEED
DRONE VIDEO RECEIVER
DRONE CONTROLLER
ROVER CONTROLLER
KEYBOARD
MOUSE


ADDITIONAL STORAGE
WI-FI EXTENDER MOUNTED TO BACK
POWER BANK
POWER STRIP
ROUTER

GRAPHICAL USER INTERFACE



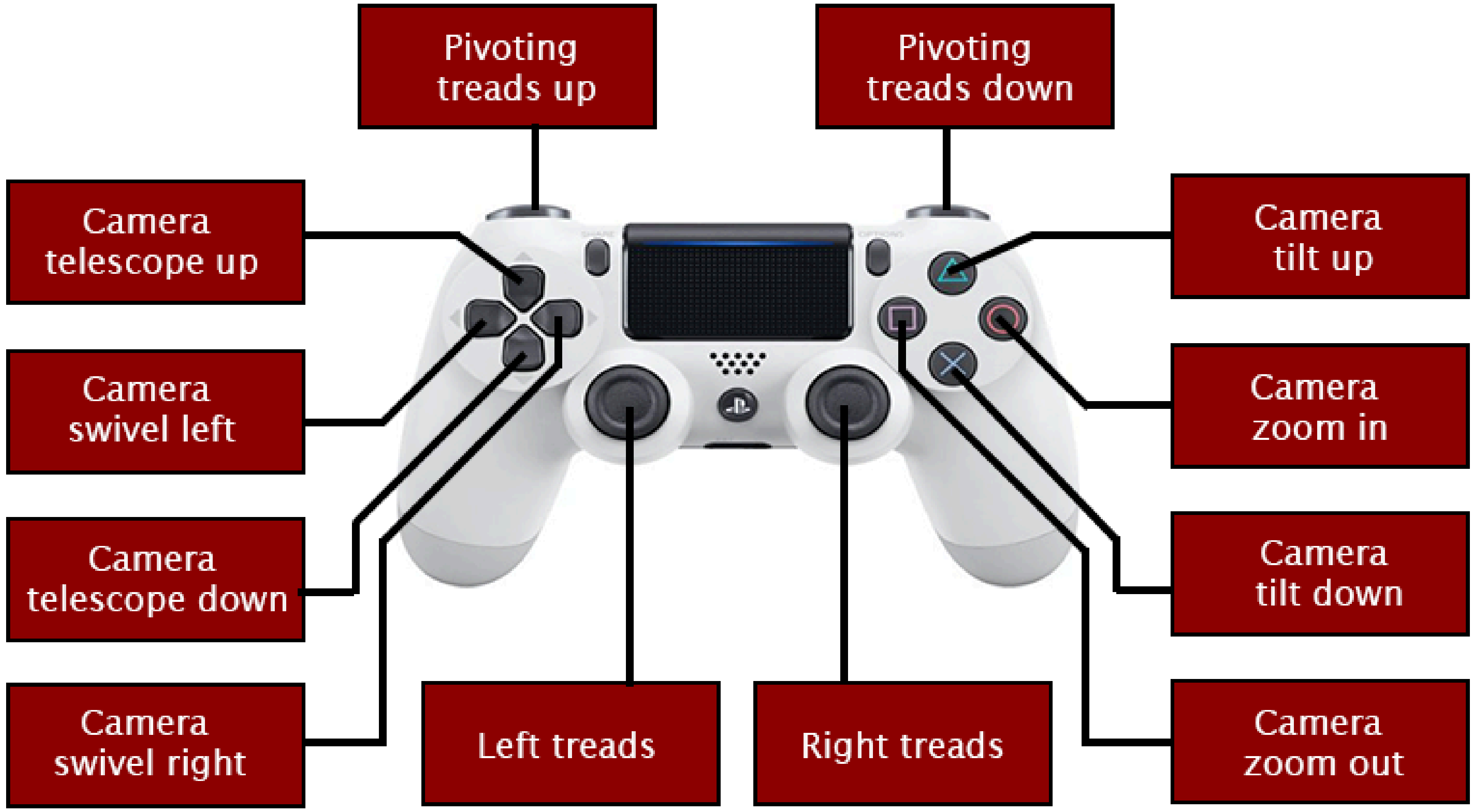
Live Ground Vehicle Video Feed

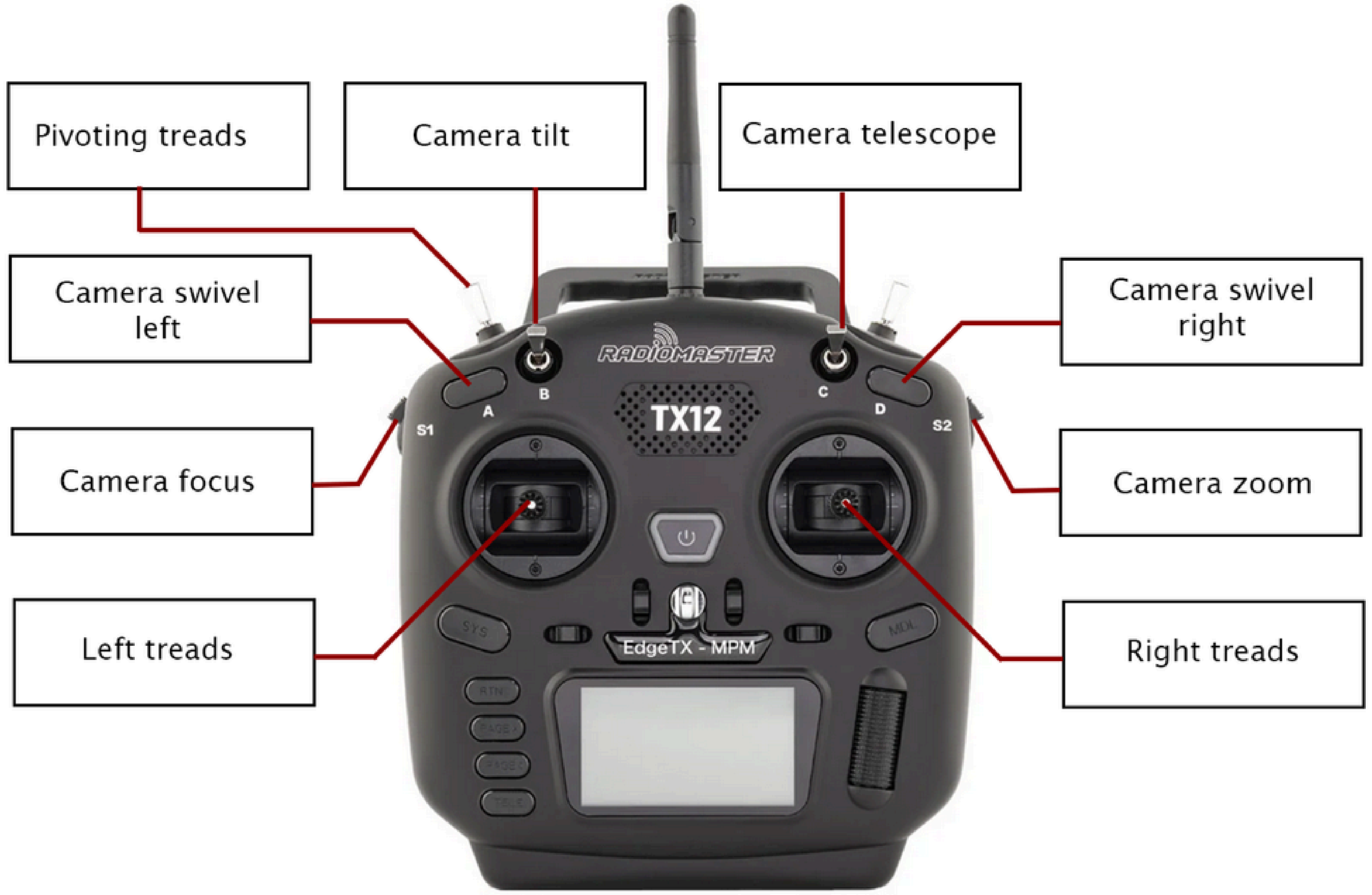


Camera Controls UI

New Jersey Innovation Institute
An NJIT Corporation

UGV CONTROLLER



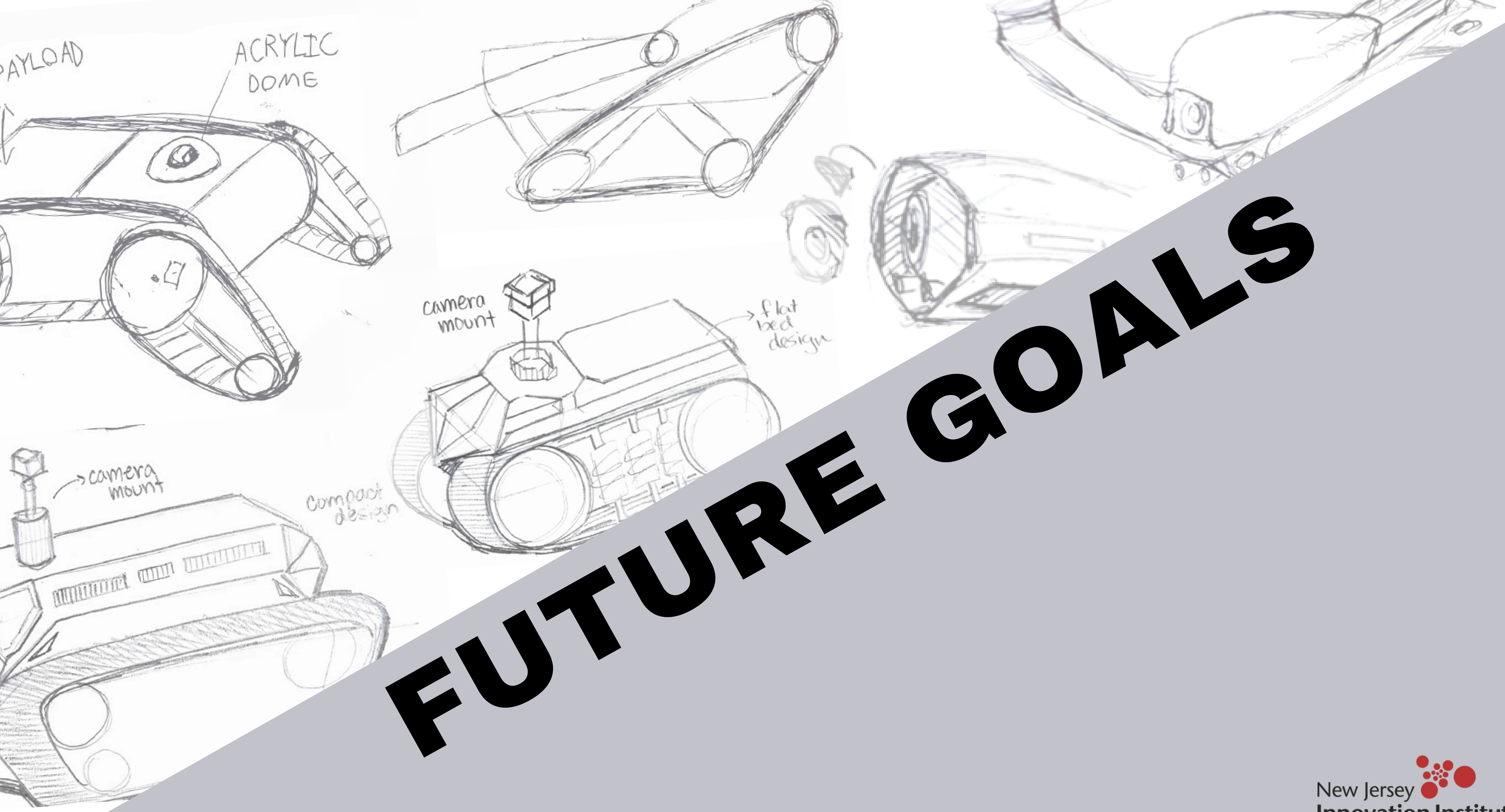


- More intuitive
  - Buttons for toggles, press and hold
  - Easy to pick up (video game controller)

- Less intuitive
  - 3-way switches instead of buttons
- Spare parts
  - Same as drone controller

New Jersey Innovation Institute
An NJIT Corporation

FUTURE GOALS

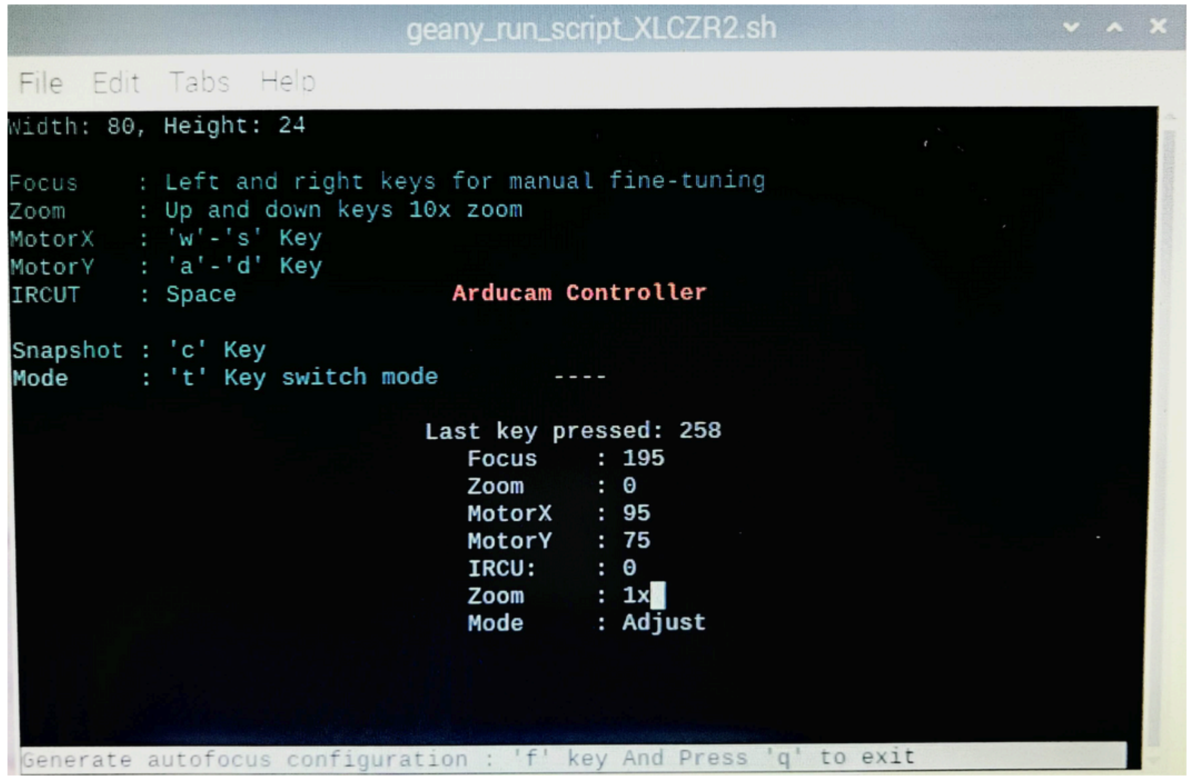


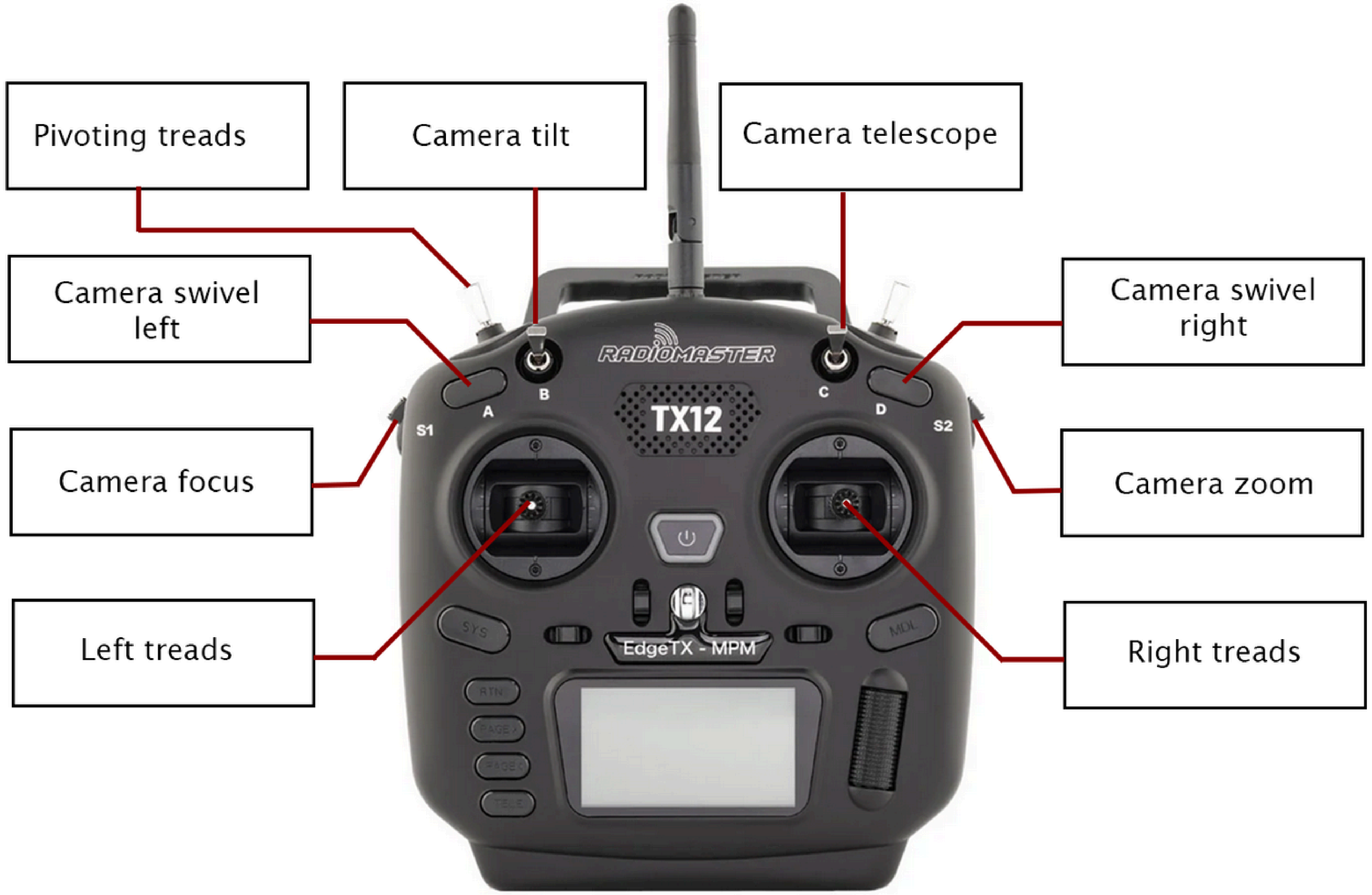
New Jersey Innovation Institute
An NJIT Corporation

UGV CAMERA CONTROLS

Move camera controls from ground station terminal to UGV controller

- Single user
- More intuitive





New Jersey Innovation Institute
An NJIT Corporation

AI, AUTONOMY, AND COMPUTER VISION

IMAGE GENERATION

- Use **AI** for computer vision and onboard image processing

Use computer vision and AI for **object detection, autonomy, and path generation**

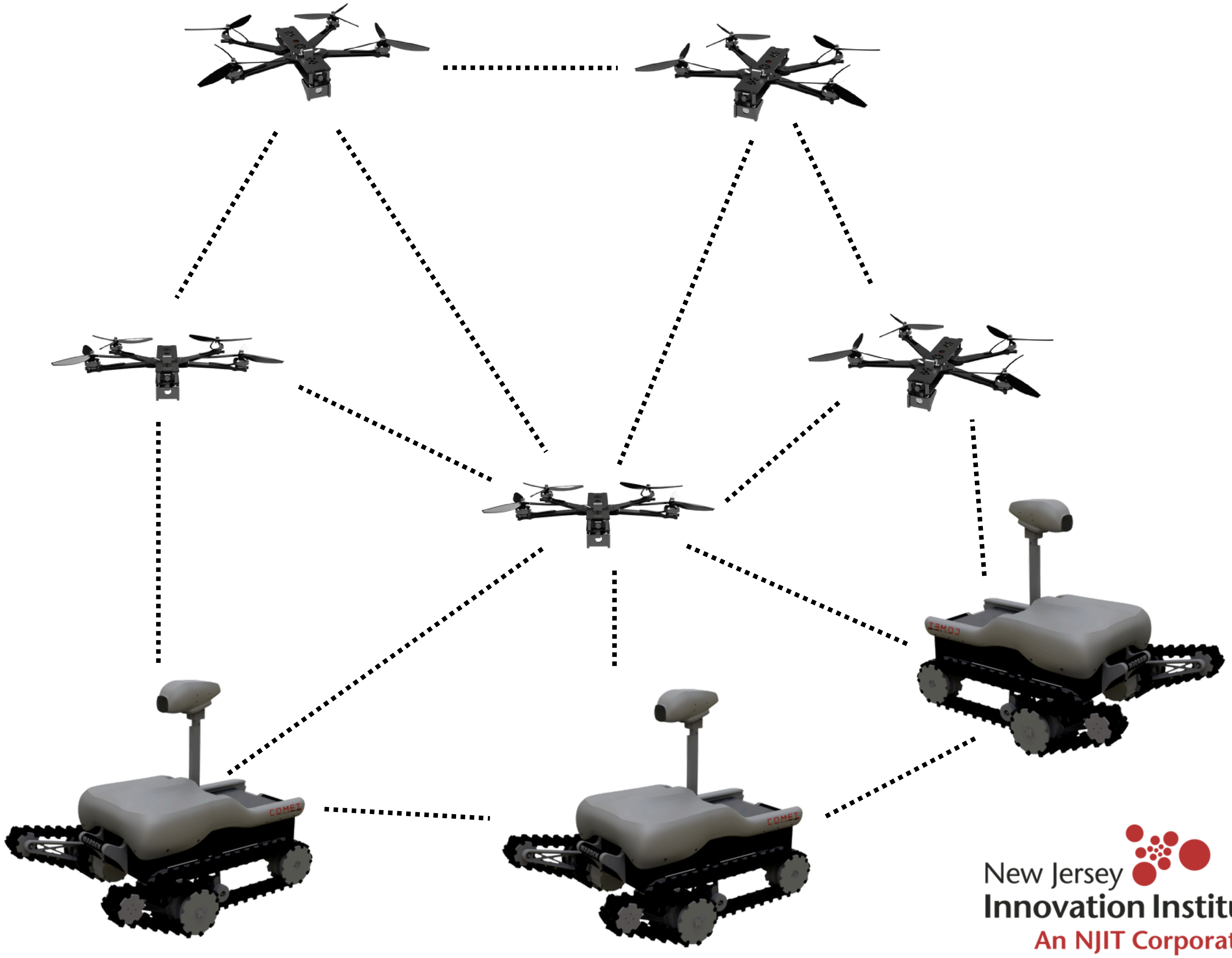
NVIDIA Jetson Object Detection

New Jersey Innovation Institute
An NJIT Corporation

AUTONOMOUS NETWORK

SWARM SYSTEM

- System of **many deployable unmanned robots**
- Cheap and easily manufactured
- Integrated communication between all subsystems for **total reconnaissance**
- **Extend range** even farther by having each drone act as a network repeater



New Jersey Innovation Institute
An NJIT Corporation

SUMMARY

THE PURPOSE

To conduct **reconnaissance** in **dense jungle terrain**

THE SYSTEM

A **mesh network** of an unmanned ground vehicle (UGV) and aerial drone in which the drone **extends the UGV's communication range**

THE FUTURE

To create a larger **swarm system of drones** that incorporates **autonomy** and **computer vision**