TOWARDS TERRAIN-ACCESSIBLE SMART WHEELCHAIR DESIGN USING POSABLE HUBS & MAGNETORHEOLOGICAL (MR)-FLUID BASED SEMI ADAPTIVE SUSPENSION

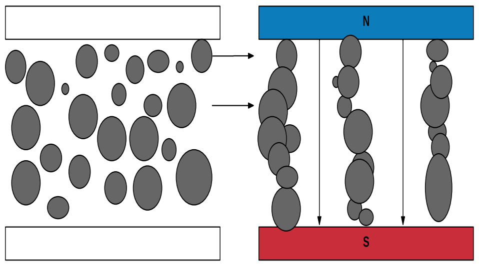
Late Day 2/4 Used

PROBLEM STATEMENT

- Most wheelchairs are hand operated or at best motorized with manual control
- In cases of complete voluntary muscular dysfunction, additional human support is required.
- Such mobility is also terrain restricted.
- The utility thus arises for a more terrain accessible smart wheelchair allowing for different degrees of autonomous behavior

PROPOSED SOLUTION

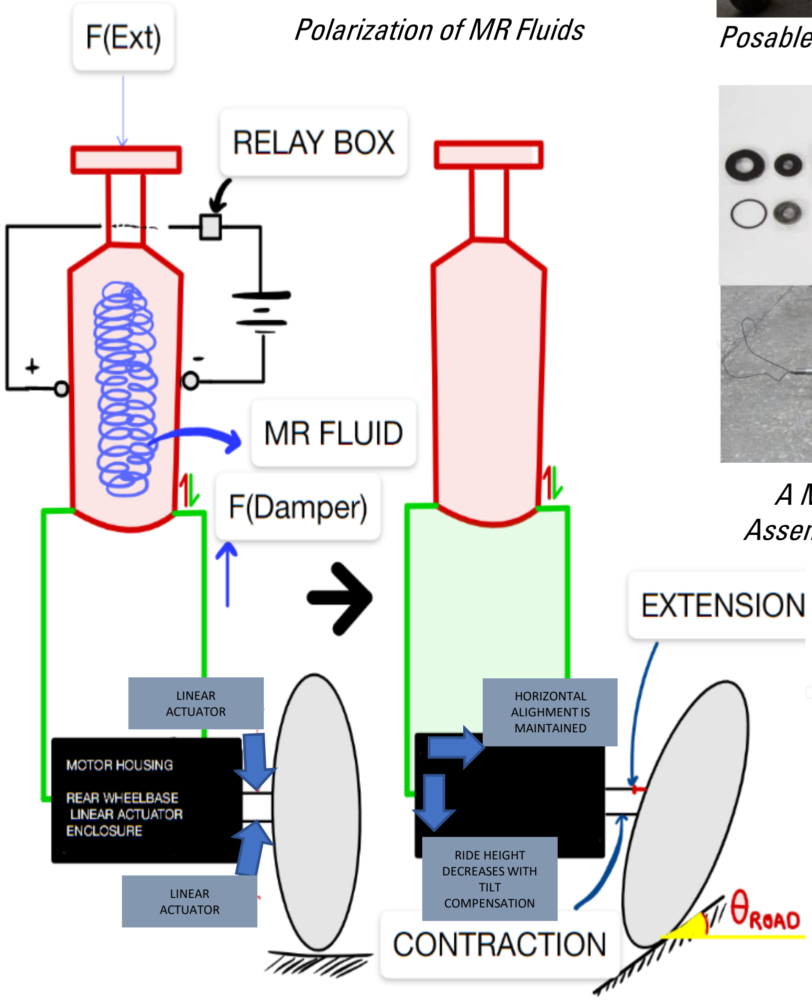
- MR Dampers are becoming popular in automotive designs due to fast response time and range of operability
  - Damper fluids are replaced with *colloidal ferromagnetic suspension* having customized permeance characteristics
  - Damping coefficient adjustment done through *axial electromagnetic fields* applied to damper external casing which controls stiffness of the enclosed suspension
- Posable hub designs are being used in specialized mobile robotics for space exploration and the automobile industry
  - Push pull linear actuation mechanisms allow for tilt compensation along the wheelbase based on a *rated incline value* along the wheel axis.
- Integration of these components with some degree of intelligence on-board the wheelchair can allow for shared control
  - Adaptive suspension based on manual preferences or IMU based vertical acceleration estimation
  - RGBD, IMU, and encoder odometry based short duration navigation capabilities in case of end user disability are implementable via Eye tracking apparatus



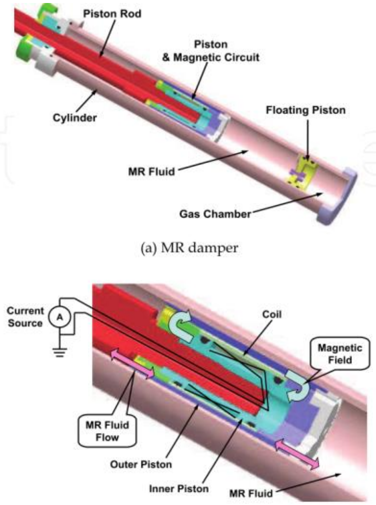
Polarization of MR Fluids

Posable Hubs in the Automotive Industry

A Magnetorheological Damper Assembly and Cross-Sectional View



Hand-drawn Representation of the Proposed Mechanism



COMPONENT LISTING: POWER SOURCES | SENSING | COMPUTATION | PROPULSION | MISCELLANEOUS

POWER SOURCES:
- Primary Battery (Propulsion): Gel Type Lead Acid
- Secondary Battery (Sensor Subsystem): LiFePO4 (4s1p)

SENSING:
- Eye Tracking for shared control: Tobii Eye Tracker
  - Allows for tracking gaze and identifying target coordinates of where the user is looking at based on body frame
- Depth Sensing using a RGBD camera: Structure Core (Integrated IMU, used for redundancy and cross validation)
  - Allows for short duration depth map formation and also act as a UI input while displaying
- IMU (Primary)
  - To sense vertical acceleration modes and wheelbase tilting

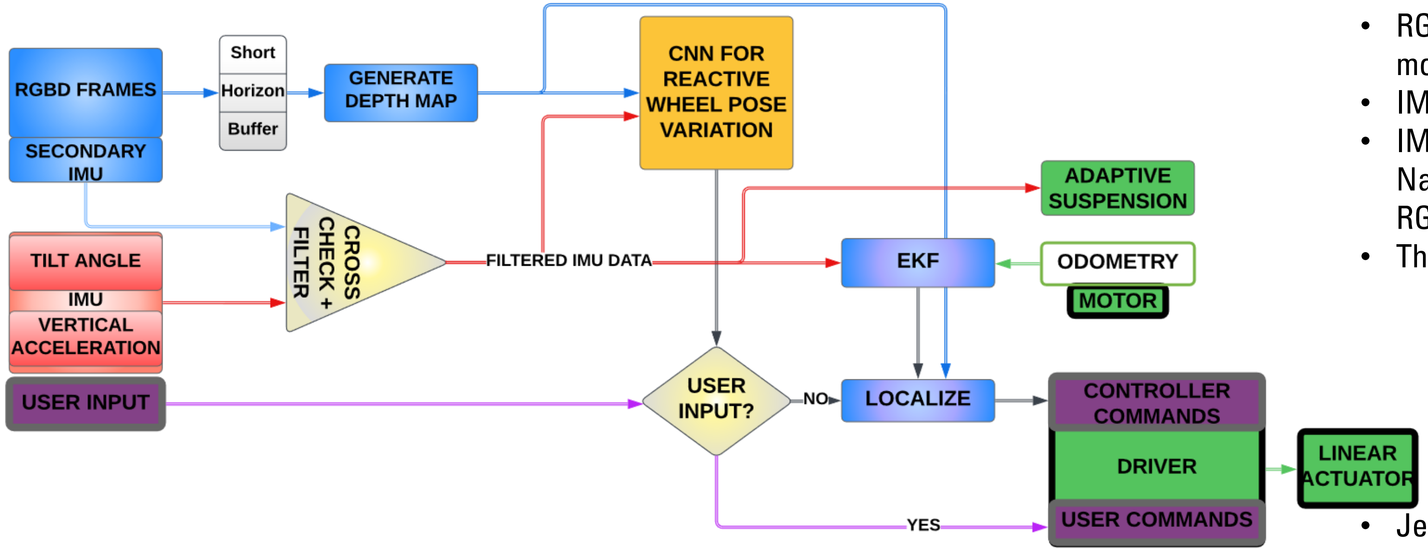
COMPUTATION:
- UI: Screen connected from tracker camera to a display via HDMI
- Tracker camera feed to computation module
- Computation Module: Shared control with NVIDIA Jetson module for navigation and path planning
  - Runs a CNN to determine most optimal trajectory towards where the user is focusing
  - Fuses IMU data, and LIDAR to generate Trajectory
- All software backend to execute as ROSPy nodes

ADAPTIVE SUSPENSION AND POSE CONTROL:
- 4 counts of custom MR Fluid filled dampers
  - MR Dampers change stiffness based on a proportional voltage across the diameter of the damper cylinder.
  - Can be used to adjust for ride comfort on various terrains
- 4 counts of Linear Actuators for pose control

PROPULSION:
- Gross system mass ≈ 100kg
  - Average weight of wheelchair user: 50kg
  - Battery Weight ≈ 30Kg (3x SLADC12-35J)
  - Wheelchair Weight + Suspension: 10Kgs
  - Motor Weight: 1.25kg x 4 = 5kg
  - Sensors: 1Kg
  - Actuators= 1kg x 4 = 4 kgs
- Wheelbase radius: 0.15m
- Max Speed needed: 5Kmph = 1.4ms^-1= 90 rpm
- Max Acceleration time: 5 seconds
- Max Incline Angle: 5°
- Operational surface rolling friction (worst Case): 0.015 (good concrete)
- Torque & Speed requirements:
  - Selected drive motors: 4 Tokushu Denso 9K24F Brushed DC Motors.
  - Transmission loss coefficient ≈**1.1**
  - Maximum torque requirement per motor ≈ 5N-m
  - Torque Output (Max, vanilla gearbox (1:23)) = 43kg-cm = 4.2Nm
  - Max RPM (Vanilla gearbox) = 150 rpm
  - Additional customized gear reduction R = 3:5
  - Customized torque = 7N-m, Customized RPM = 90Rpm

MISCELLANEOUS:
- Motor Driver: 6 Counts of BTS7960 dual H Bridge DC motor drives
- Buck convertors: 6 Counts of 36V to 3.3V-34V step-down convertors
- Wheelchair frame made of carbon fiber rods
- Alloy wheel hubs with rubber tubeless tires

NAVIGATION SUBSYSTEM FLOW

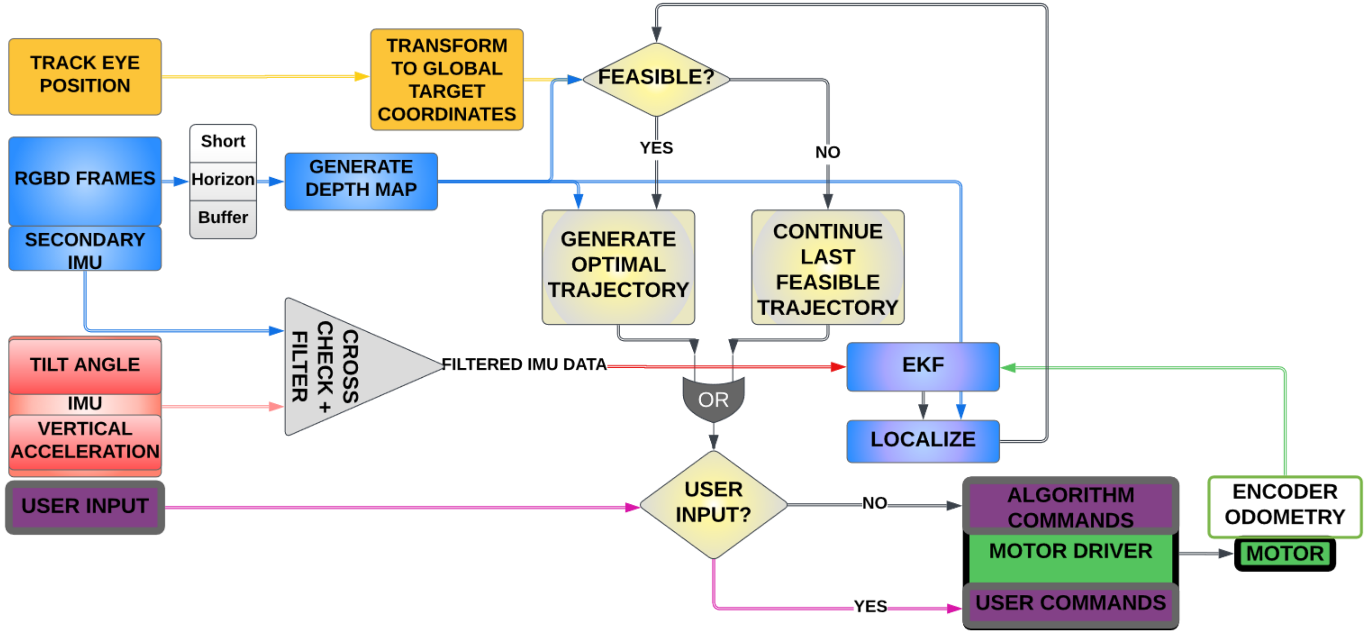


WHEELBASE POSE VARIATION AND MR FLUID SUSPENSION STIFFNESS CONTROL

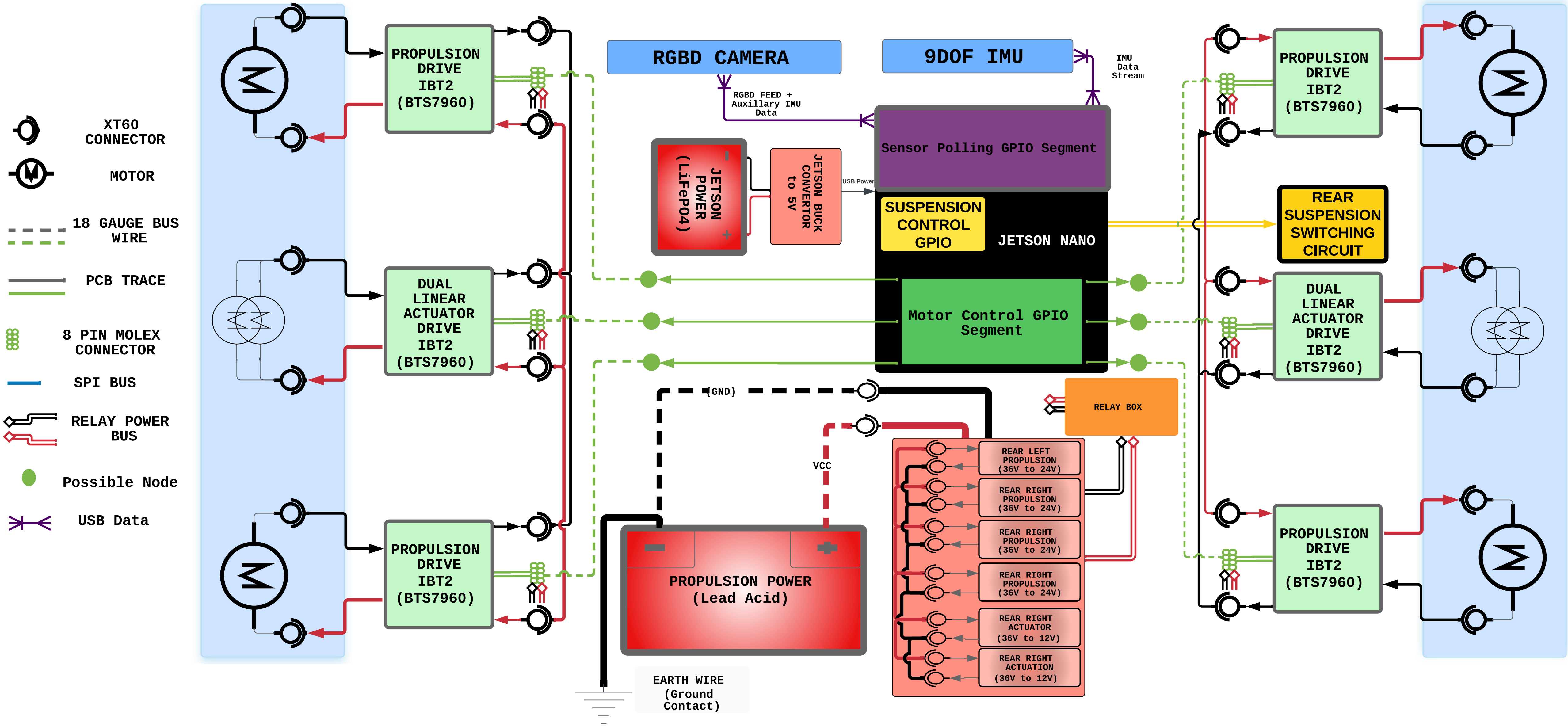
- RGBD Camera provides a short duration depth mapping of an extended FOV by being mounted on a rotating frame
- IMU + Camera IMU are cross verified and low-pass filtered
- IMU data and encoder odometry is fused using a Kalman filter running on the Jetson Nano to help localize the body frame within the short duration mapping provided by the RGBD Sensor
- The suspension control and tilt compensation are addressed in the following way
  - Adaptive suspension control is kept as purely reactive. Only filtered IMU data is utilized to change damping
  - Tilt compensation involves prediction based on localized coordinates in the current depth map due to slow travel of the linear actuators. CNN based control commands depending on potential sloped regions from the RGBD data actuate the posable hubs
- Jetson module GPIO polls and prioritizes manual user input at every time step, and if no input is detected, executes automated control commands

AUTOMATED PROPULSION WITH SHARED CONTROL

- Eye tracking system allows generation of coordinates of gaze focused regions with respect to the base frame.
  - Regions are classified based on hard threshold factors of 1) Distance & 2) Elevation as feasible or infeasible
  - Trajectories are updated after preset buffer periods (to allow smooth state transitions) based on if the new trajectory is feasible
- Filtered IMU + Camera IMU used as measurements for the Kalman filter, with wheel encoders providing odometry predictions. This is used to localize the base frame in the generated depth map and calculate trajectories to the target pose.
  - Continuous polling of manual velocity commands are prioritized over automated controller commands



SYSTEM LAYOUT: SENSING, COMPUTATION & ACTUATION SUBSYSTEMS



POWER BUDGET AND COST SHEET

Calculation Source
(E-Estimated | DS- Data Sheet | A- Assumption | R- Research Study)
Not used in power calculation (wattage sourced from μC)
η considered in scaled power usage of connected components

Type	Component	Unit Price ($)	Operating Current (mA)	Operating Voltage (V)	Duty Cycle (%)	Efficiency (η)	Max Power Consumed Per Unit (mW)	Average Power Consumed Per Unit (mW)	Scaled Max Power Consumed Per Unit (mW)	Net Scaled Average Power Consumed (mW)
Wheelbase	Propulsion Motors (x4)	50	5000-7500 (E)	24 (DS)	100% (A)	0.85 (A)	180000 (E)	120000 (E)	910000	610000
	Linear Actuator (x4)	151	2000-9000 (DS)	12 (DS)	20% (DS)	0.90 (A)	108000 (DS)	24000 (E)	520000	115000
	Adaptive Suspension (x4)	-	200-600 (E)	36 (A)	25% (A)	0.70 (A)	21600 (E)	7200 (E)	125000	41100
	H_Bridge Motor Drivers (x6)	11	3.0 (Logic)(DS)	5 (DS)	Variable	0.98 (Motor) (A)	-	-	-	-
			43000 (DS) (max limit)	6V-29V (DS)		1.0 (Logic) (A)	-	-	-	-
Sensing	VN-100S (Primary IMU)	450	40 (DS)	5 (DS)	100% (A)	-	-	220 (DS)		
	Structure Core (RGBD + Redundancy IMU)	400	400 (E)	5 (E)	100% (A)	-	3100 (DS)	2000 (DS)		
	Tobii Eye Tracker	260	400 (E)	5 (DS)	100% (A)	-	6000 (DS)	2000 (DS)		
Computation μC	Jetson Nano (Sensor Polling & Motor Control)	100	2000-4000 (DS)	5 (DS)	100% (A)	0.98 (A)	20000 (DS)	10000 (DS)	21500	10750
Convertors	36V→ 24V (x4)	5	-	-	100% (A)	0.95 (A)	-	-	-	-
	36V→12V (x1)		-	-	100% (A)	0.95 (A)	-	-	-	-
	12.8V →5V (x1)		-	-	100% (A)	0.95 (A)	-	-	-	-
Total Average Wattage (mW)										Primary source: 766100mW Secondary source: 10750mW

Cost and power consumption analysis of electrical subsystem at max speed and incline (S.T.P)

Battery runtime duration at Max speed and Forward Incline (@ S.T.P)

Payload Power Specifications	Component	Voltage (V)	Max Discharge Current (A)	Efficiency (η)	Depth of Discharge (%)	Capacity (W-h)	Average Power Consumption (mW)	Run Time
	Gel Type Lead Acid (x3 6s1p)	36V (Nominal) 18V (Minimum) (DS)	289.2 (DS)	0.75 (E)	50% (A)	1260 (36V × 35Ah) (E)	766100	1.6 Hours At max rated speed and max rated incline
	LiFePO4 (4s1p)	12.8V (Nominal) 10V (Minimum) (DS)	46.0 (DS)	0.90 (E)	100% (A)	38.4 (12.8A ×3V) (DS)	11000	3.5 hours on average