XTreads

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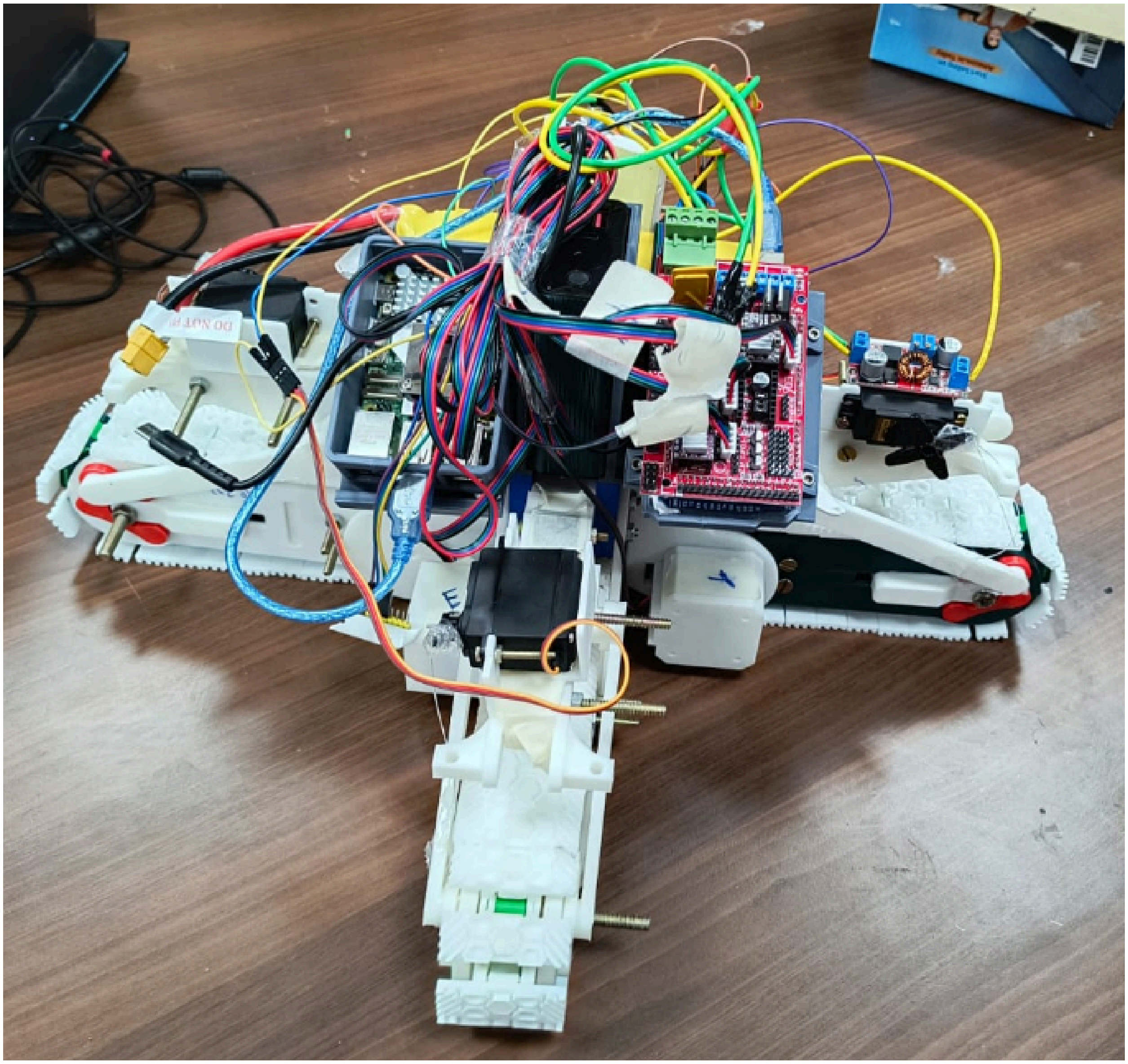

XTreads

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Introduction

Purpose

- An omnidirectional vehicle using innovative X-shaped treads for seamless 360° movement without yaw.
- High mobility and adaptability on uneven, loose, or confined terrains.
- A modular platform scalable for industrial, rescue, defense, and exploration applications.

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Design Ideology

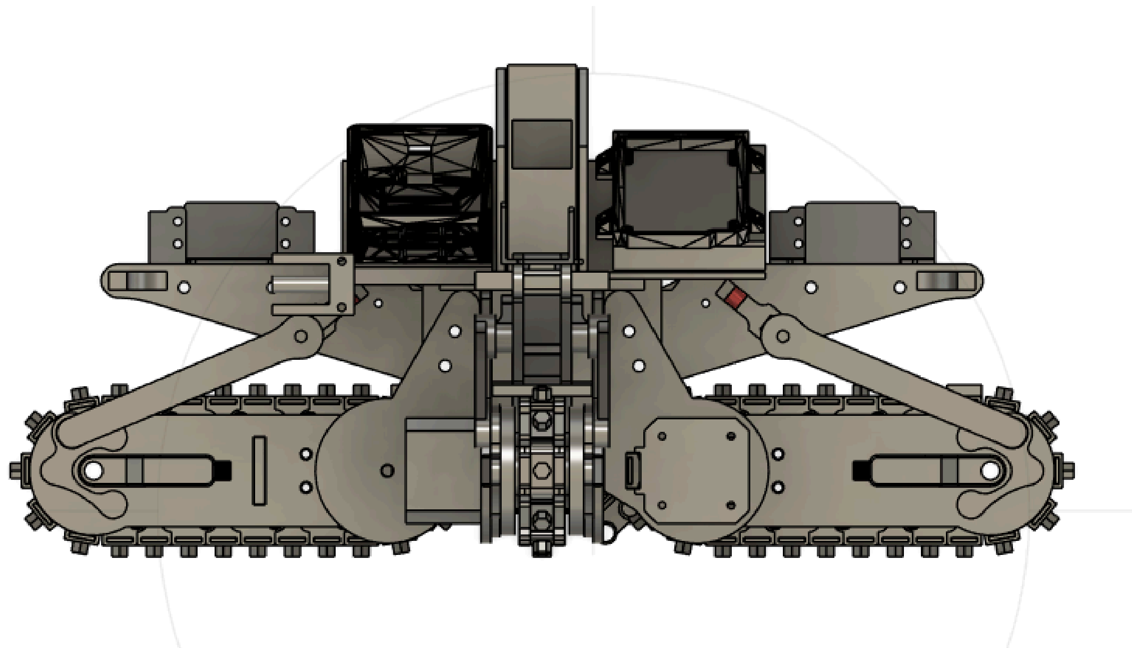
Background and Concept Origin

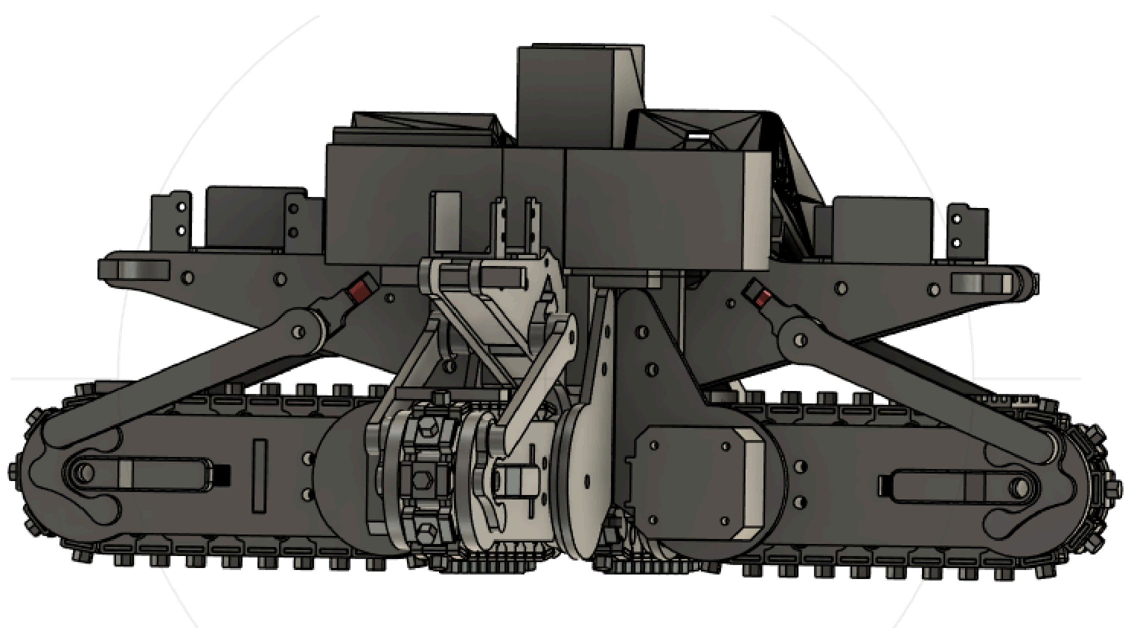
- The XTREAD concept originated after observing the lack of omnidirectional motion solutions for heavy-weight robotic applications.
- Conventional treaded mechanisms, while capable of handling higher loads, lack true omnidirectional motion as they rely on rotational alignment.
- The XTREAD system was conceptualized to address:
    - General unreliability of existing omnidirectional systems.
    - Poor performance of current omnidirectional systems on rough terrains.
    - Lack of suitable solutions for omnidirectional motion under heavy loads.

XTREAD Prototype Overview

- The prototype consists of four independently actuated treaded systems arranged in an X-shaped configuration.
- Actuation Method: Each tread is powered by a NEMA-17 stepper motor, providing torque and precise motion control.

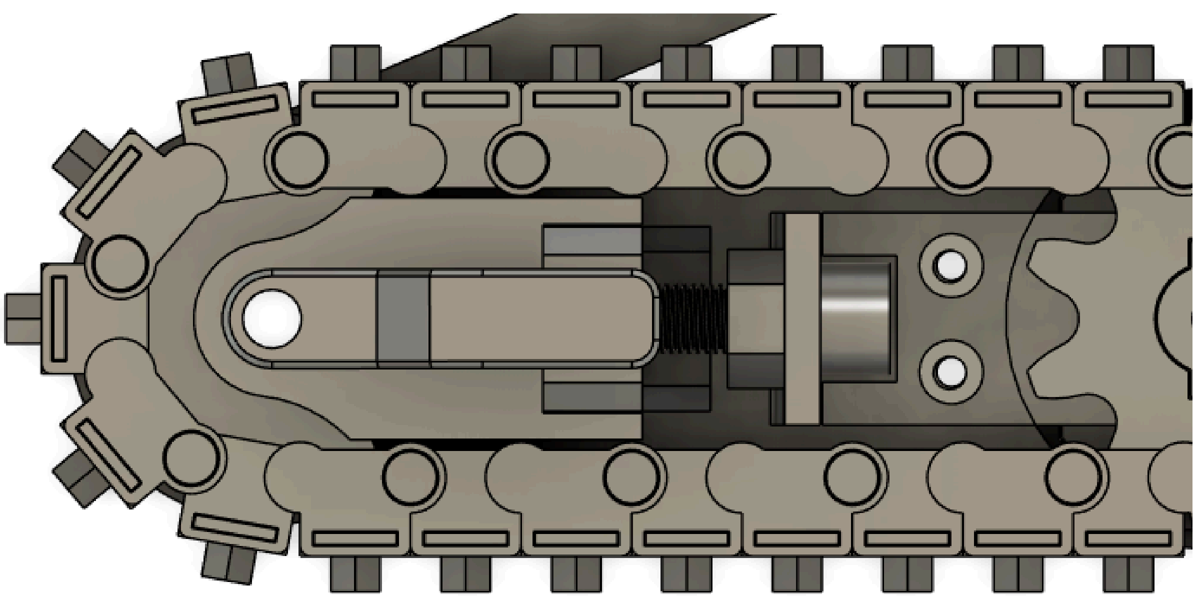
Tread Assembly Structure



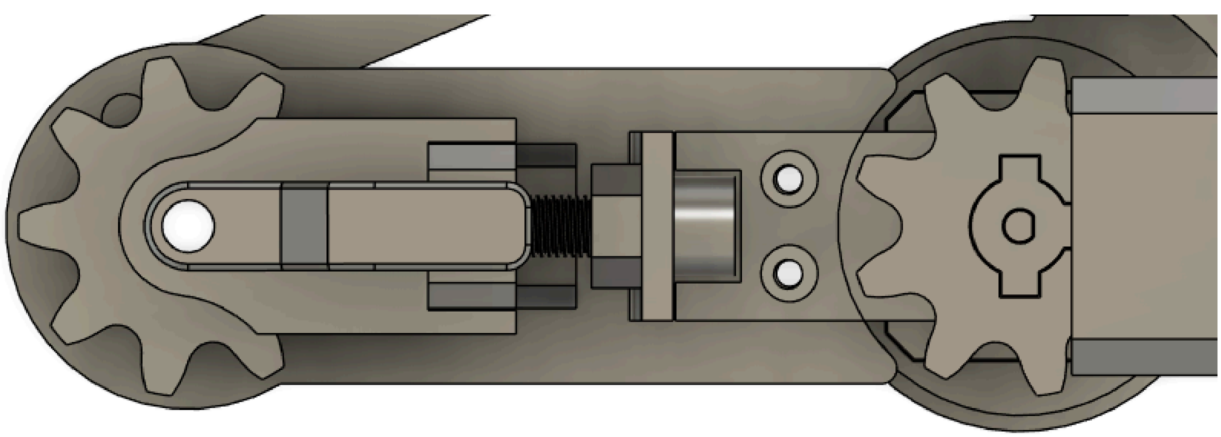


Each individual tread assembly consists of the following subassemblies:

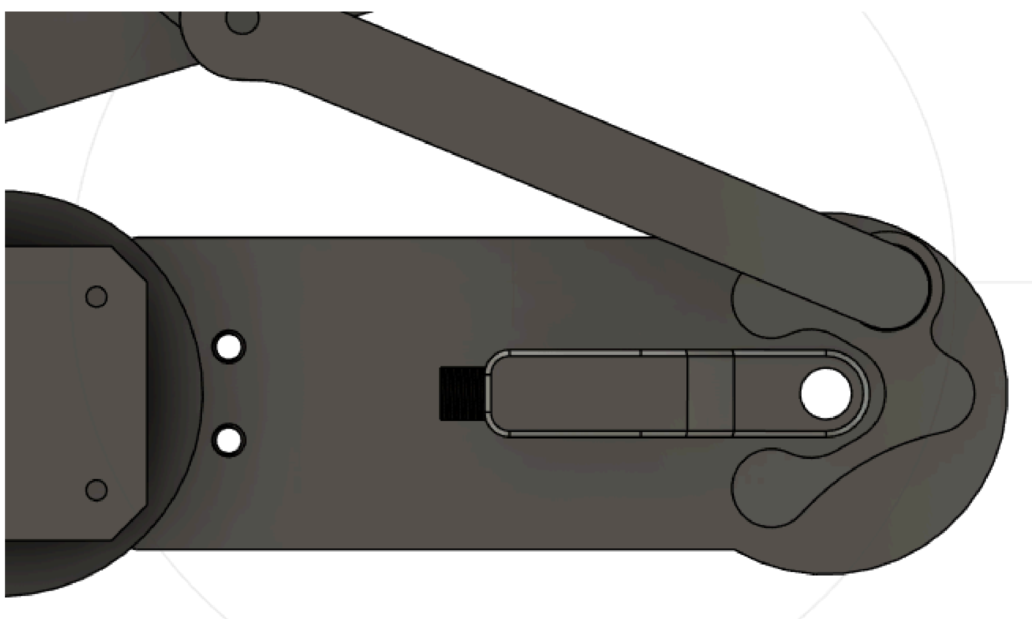
- **Chain Link and Driving Subassembly:**
  - The stepper motor is connected to the tread chain via a sprocket.
  - The chain is sized to wrap around two sprockets positioned with a 3 times the diameter distance, allowing smooth and continuous motion.
  - A screw-collar mechanism is embedded into the driving sprocket to secure it onto the shaft, ensuring efficient torque transmission.



- **Chain Tensioning Subassembly**:
    - To adjust slack in the chain, the driven sprocket is mounted on a **movable tensioning system**.
    - **Mechanism**:
        - A nut is embedded in the bracket holding the driven sprocket.
        - A screw passes through a hole in a vertical plate and threads into the bracket nut.
        - Rotating the screw moves the bracket along the screw, adjusting the chain tension.
        - A secondary locking nut is provided to lock the bracket securely after achieving the desired tension.



- **Tread Angle Subassembly**:
    - This sub assembly enables the tread to **pivot and lift off** the ground when required.
    - The tread pivots about the main driving sprocket, allowing dynamic adjustment of contact with the ground.
    - A **linkage system** connects the main superstructure to three distributed points around the driven sprocket to control and stabilize this pivoting motion.



- **Slider Spring Suspension Subassembly:**
    - This assembly provides suspension to the tread, improving manoeuvrability over small obstacles and uneven surfaces.
    - It is directly connected in line with the angling linkage and is housed inside the superstructure.
    - A spring mechanism allows vertical movement, absorbing shocks and maintaining consistent tread contact with the ground.

- **Servo Angling Subassembly**:
    - This system enables **controlled lifting** of the tread using a servo motor.
    - A high tensile strength **nylon wire** is wound onto the servo horn and linked to the tread angle subassembly.
    - The system is designed for **one-way force transfer**, meaning it lifts the tread when actuated but relies on gravity and spring action for downward motion.

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Hardware

The **X-Treads Project** employs a carefully structured and reliable electronics architecture to power and control a mobile robotic platform. The design ensures modularity, efficient power management, and smooth communication between all hardware components. Below is a detailed overview of the hardware and their functionalities:

Power System

The system is powered primarily by a **4S LiPo Battery**, chosen for its high discharge rates and energy density, making it suitable for robotics applications requiring high torque and power. The battery voltage is regulated through two **buck converters**:

- The **12V Buck Converter** supplies consistent voltage to the **RAMPS 1.4** motor driver board.
- The **5V Buck Converter** powers servos and other control electronics where lower voltage is necessary.

A **20,000 mAh power bank** is dedicated to the **Raspberry Pi 5**, ensuring isolated and stable power supply for computational tasks and minimizing the risk of noise or voltage dips affecting sensitive digital electronics.

Arduino Mega 2560 + RAMPS 1.4

The combination of **Arduino Mega 2560** and **RAMPS 1.4** forms the stepper motor control unit.

- The **Arduino Mega 2560** acts as the main low-level controller, handling real-time control of the motors. It is well-suited for this task due to its large number of GPIO pins and reliable serial communication capabilities.
- The **RAMPS 1.4 (RepRap Arduino Mega Pololu Shield)** sits on top of the Arduino, providing easy connections for stepper motor drivers (DRV8825), endstops, and power inputs. RAMPS simplifies high-current connections and signal routing for up to five stepper motors.

The Arduino receives high-level commands for directions from the Raspberry Pi 5 over **serial communication** (UART), interprets them, and converts them into precise step/direction signals for the stepper motor drivers. This allows for real-time, deterministic motor control, essential for stable locomotion.

Stepper Motors Controller

The four **Stepper Motors** are crucial for the X-Treads' mobility, offering precise control over position, speed, and torque. Stepper motors operate through discrete step signals, allowing fine-grained control which is ideal for applications like tread-based navigation where stability and precise movement are key. The RAMPS 1.4 provides the necessary infrastructure to deliver these signals reliably.

Servo Motor Controller

In addition to the primary drive motors, the system uses **Servo Motors** for fine actuation tasks, possibly for steering mechanisms, suspension adjustments, or sensor positioning. These servos are powered through the 5V Buck Converter and receive PWM control signals, controlled through Raspberry Pi 5. Servo control offers smooth and variable positioning, essential for parts of the robot that require dynamic adjustment rather than continuous rotation.

Raspberry Pi 5

The **Raspberry Pi 5** acts as the **central brain** of the X-Treads system. It handles high-level computation, user input interpretation, and overall mission planning.

- It communicates with the Arduino Mega through a serial link, sending commands such as speed, direction, and special maneuver instructions.

- It also interfaces with an **IMU Controller** to gather orientation and motion data, which could be used for closed-loop control, navigation, and stabilization.

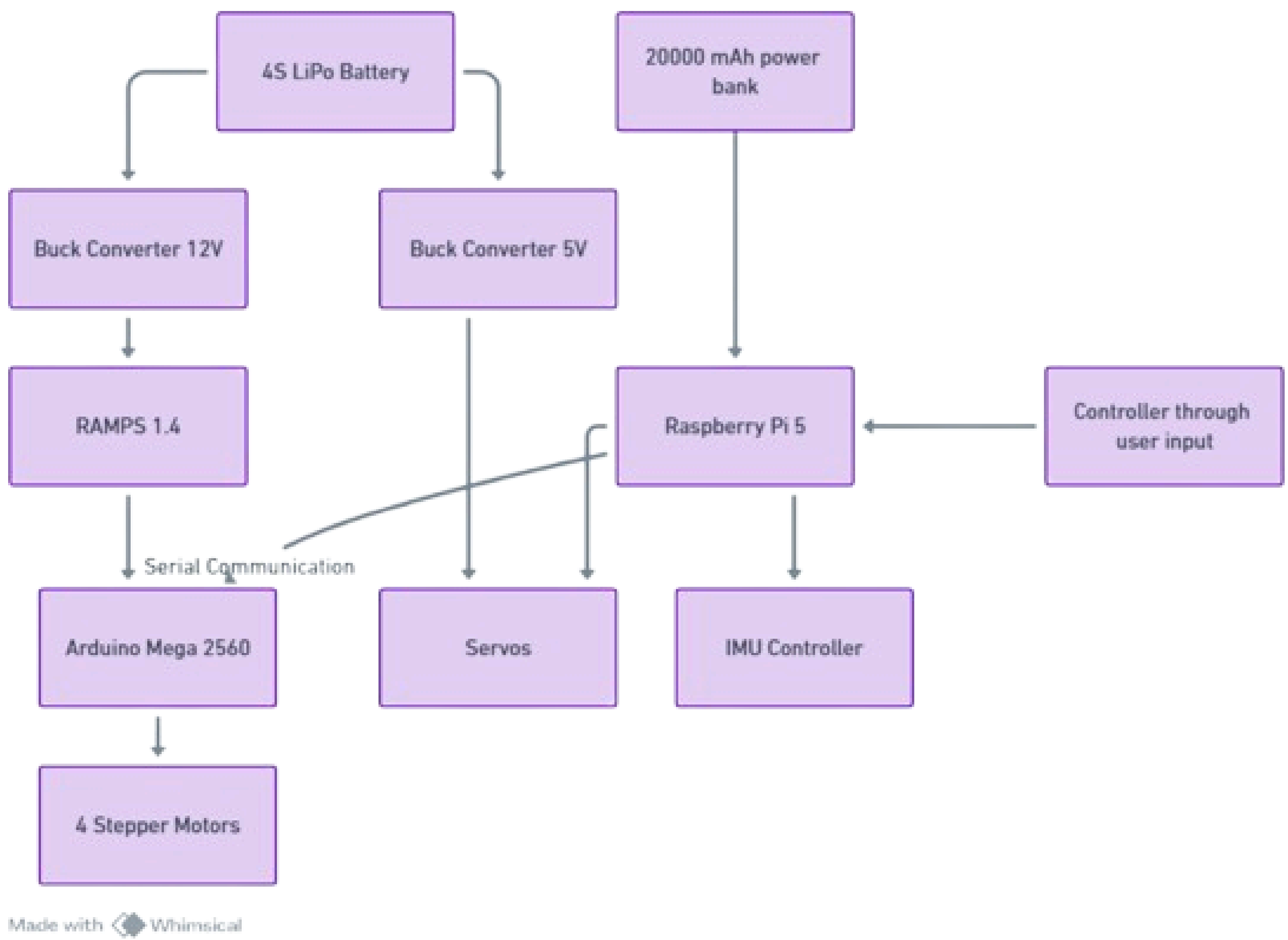
- Additionally, the Raspberry Pi 5 connects to a **user controller**, interpreting commands and converting them into movement or operation instructions.

- It also provides a user-friendly GUI which houses functionality for arrow key control, servo calibration, IMU data monitoring, and serial monitor data acquisition.

The Pi's powerful processing capability enables it to run sophisticated algorithms such as sensor fusion, path planning, and communication handling, enhancing the autonomy and intelligence of the platform.

IMU Controller

The **IMU (Inertial Measurement Unit) Controller** is responsible for capturing real-time orientation, acceleration, and angular velocity data. This data is vital for maintaining balance, detecting obstacles, or implementing advanced movement strategies such as path correction and self-stabilization. The IMU is powered by the Raspberry pi 5 and takes the 5V input from the Rpi only.



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Control Strategy

The movement control logic is divided into two primary tasks:

- **Direction-Based Actuation**
    - Upon receiving a direction command (e.g., Forward, Backward, Left, Right) from the Raspberry Pi:

- Relevant treads are lowered using the corresponding servo motors.
- Redundant treads are lifted to reduce drag.
- DRV8825 stepper motor drivers are enabled, and step pulses are generated to drive the vehicle accordingly.

Feedback Control Loop:

Real-time orientation and acceleration data from the MPU6050 is utilized to:

- Stabilize the vehicle against tilt, vibration, or disturbances.
- Adjust motor commands dynamically if the vehicle deviates from the expected motion trajectory.

Communication Protocol

- **Serial communication** is established between the Raspberry Pi and Arduino Mega over USB.
- The Raspberry Pi sends **ASCII command characters** (e.g., 'F', 'B', 'L', 'R'), which are interpreted by the Arduino Mega to execute appropriate actions.

Power Architecture

All components are powered using a **single 4S LiPo battery (14.8V nominal voltage)**. Power distribution is as follows:

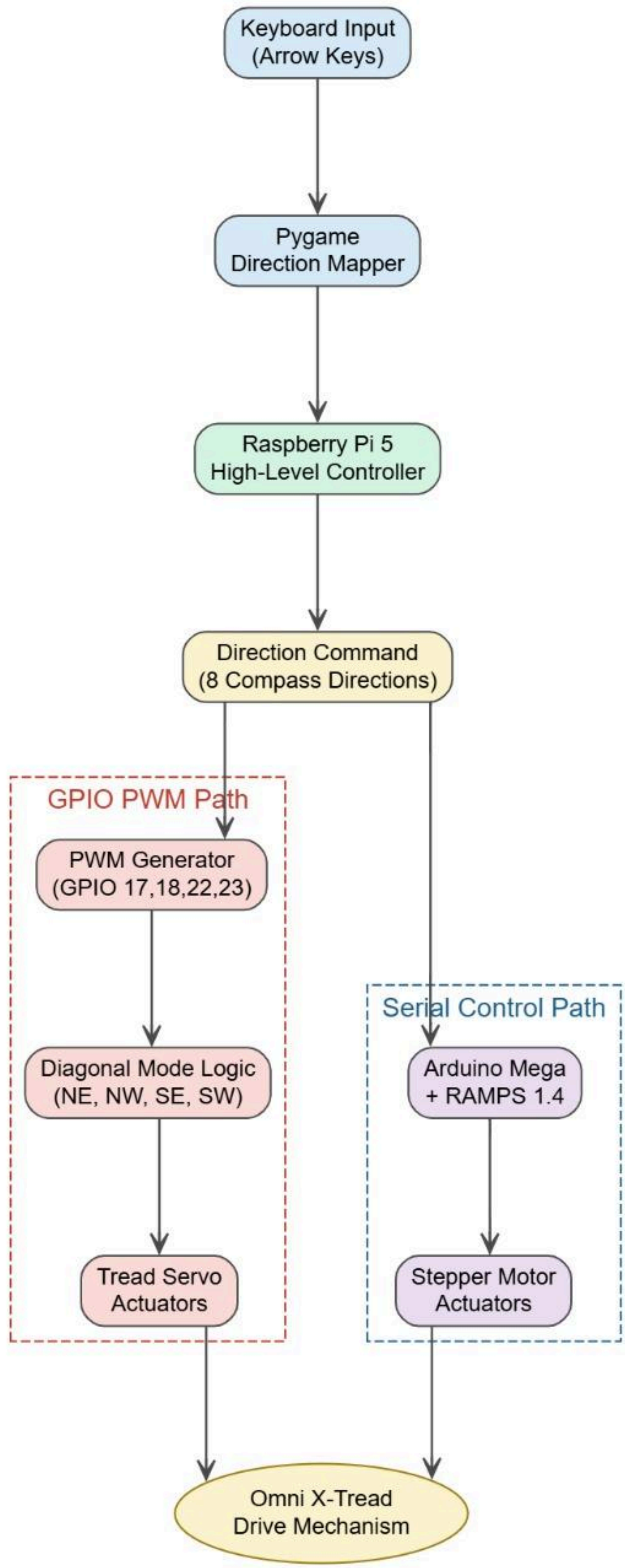
- **Stepper Motors (via DRV8825 drivers)**: Powered directly from the 4S battery (12–16.8V range).

- **Servo Motors**: Powered through a 5V 3A BEC (Battery Eliminator Circuit) connected to the 4S battery.

- **Arduino Mega**: Powered either through the BEC or from the Raspberry Pi's USB output.

- **Raspberry Pi 3B+**: Powered through a step-down (buck) converter (5V 3A) sourced from the 4S battery.

- **MPU6050 Sensor**: Powered from the Arduino Mega (using 3.3V or 5V supply lines).


Keyboard Input
(Arrow Keys)
Pygame
Direction Mapper
Raspberry Pi 5
High-Level Controller
Direction Command
(8 Compass Directions)
GPIO PWM Path
PWM Generator
(GPIO 17,18,22,23)
Diagonal Mode Logic
(NE, NW, SE, SW)
Tread Servo
Actuators
Serial Control Path
Arduino Mega
+ RAMPS 1.4
Stepper Motor
Actuators
Omni X-Tread
Drive Mechanism

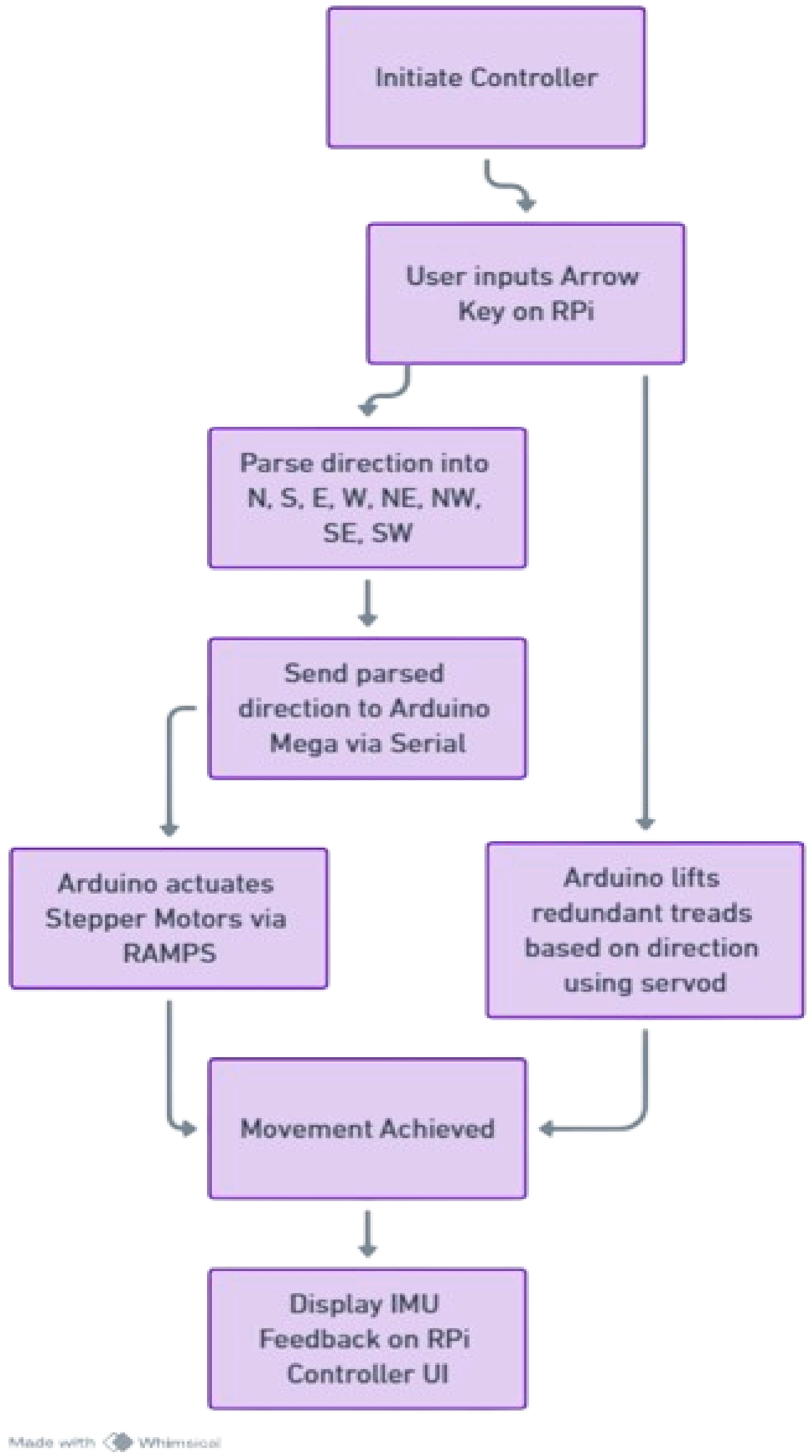
Pin Allocation (Arduino Mega)

- **Servo Motors**:
    - Servo 1: Pin 4
    - Servo 2: Pin 5
    - Servo 3: Pin 6
    - Servo 4: Pin 7

Stepper Motors:

- Stepper 1: STEP — Pin 22, DIR — Pin 23
- Stepper 2: STEP — Pin 24, DIR — Pin 25
- Stepper 3: STEP — Pin 26, DIR — Pin 27
- Stepper 4: STEP — Pin 28, DIR — Pin 29

Block Diagram of Controller:



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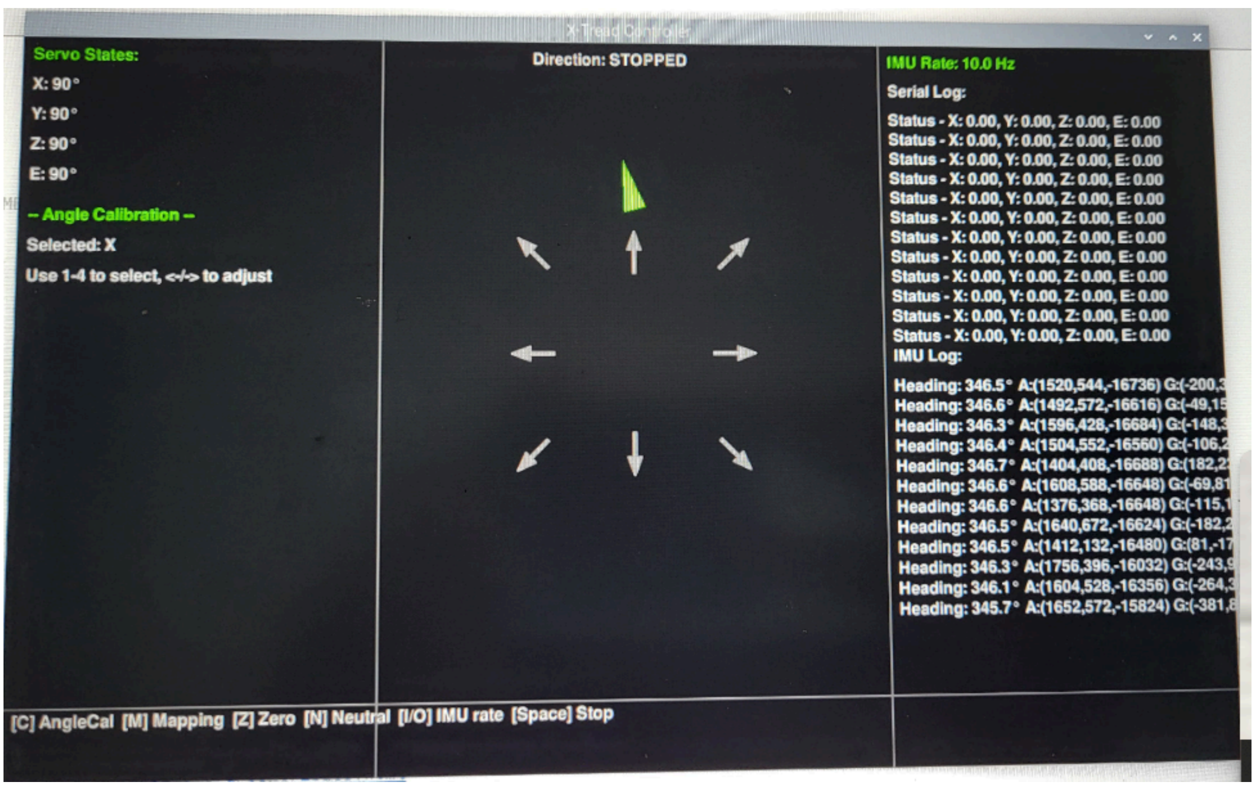
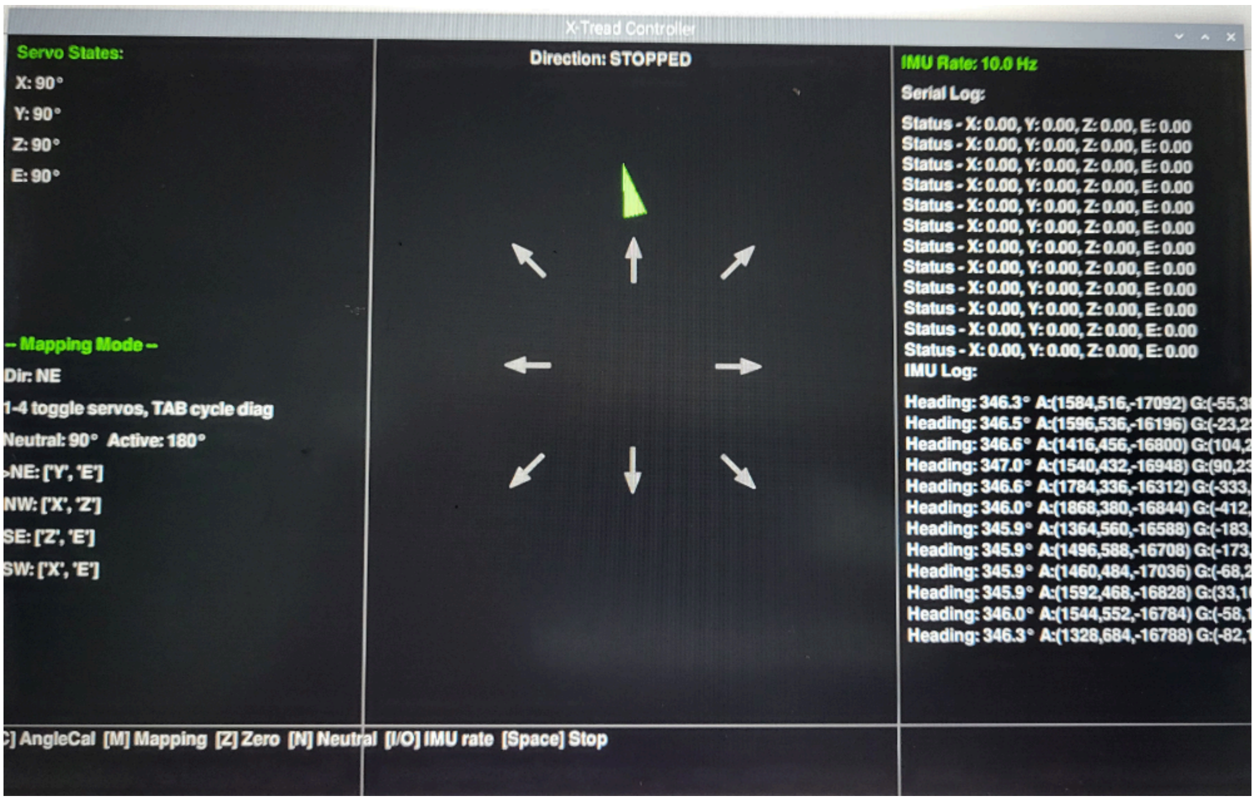
GUI:



Features:

1. Indicator for 8-directional arrow navigation.

2. IMU heading indicator
3. Serial Monitor and IMU log remote access.
4. Functionality for Angle and Servo caliobrations
5. Mapping of Servo actuation for specific directional commands.
6. Specific Commands for Neutral, Zero angle Actuations for all servo motors.



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Future Prospects

Building upon the current platform, several enhancements are envisioned to improve performance, versatility, and adaptability:

- **Reduce Vehicle Height:**
  Lower the profile to allow sliding under low ground-clearance vehicles.

- **Switch to High-Torque DC Motors:**
  Replace NEMA-17 steppers with DC motors for higher power and simpler driver electronics.

- **Discretize Hardware:**
  Use smaller boards (ESP32, compact Arduinos) with independently mounted motor drivers to save space.

- **Decentralize Power Architecture:**
  Shift from a single large LiPo battery to distributed arrays of Li-Ion cells for better weight distribution and reliability.

- **Adopt Three-Point Mounting:**
  Implement a 3-point mounting system for all components, especially between the superstructure and the central chassis.

- **Integrate High-Torque Servos:**
  Mount higher torque servos inline with superstructure flanges to save space and enhance performance.

- **Use Lightweight Materials:**
  Transition to a carbon fiber and aluminum frame to

reduce weight while maintaining strength.

- **Enhance Autonomy:**
  Develop features like real-time terrain mapping and autonomous route planning.

- **Develop Application-Focused Iterations:**
  Create specialized versions for load handling, terrain maneuverability, explosive deployment, and stealth missions.