浙江大学伊利诺伊大学厄巴纳香槟校区联合学院
Zhejiang University-University of Illinois at Urbana Champaign Institute

Rudimentary Spherical Motor System for All-Terrain Vehicles

Project 37

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1 Introduction

Challenges with current motor design:

Traditional motors rely on bulky transmissions and steering systems, making vehicles heavier, less agile, and unable to achieve true omni-directional movement.

Goals:

Achieve multi-DOF actuation (target: $\geq$ 2 DOF).

Bridge theoretical innovation with practical applications.

2 Objective

Two designs:

Magnetic Reluctance Motor:

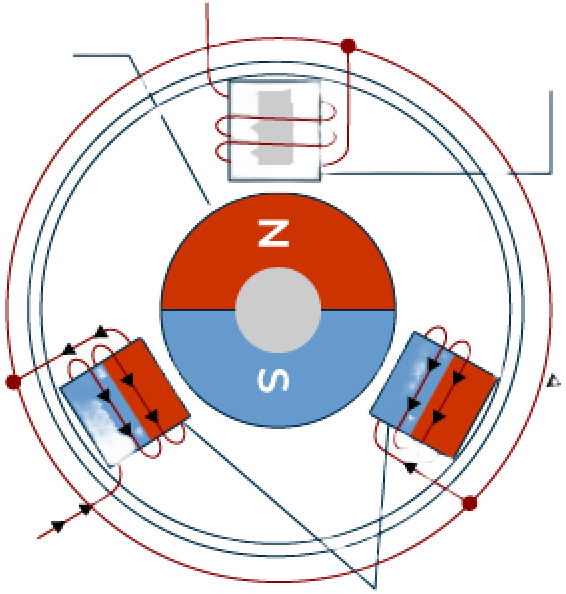
A proof-of-concept capable of 2 degrees of freedom, designed to explore spherical actuation using low-cost materials and custom magnetic field generation.

Friction-Driven ATV Motor:

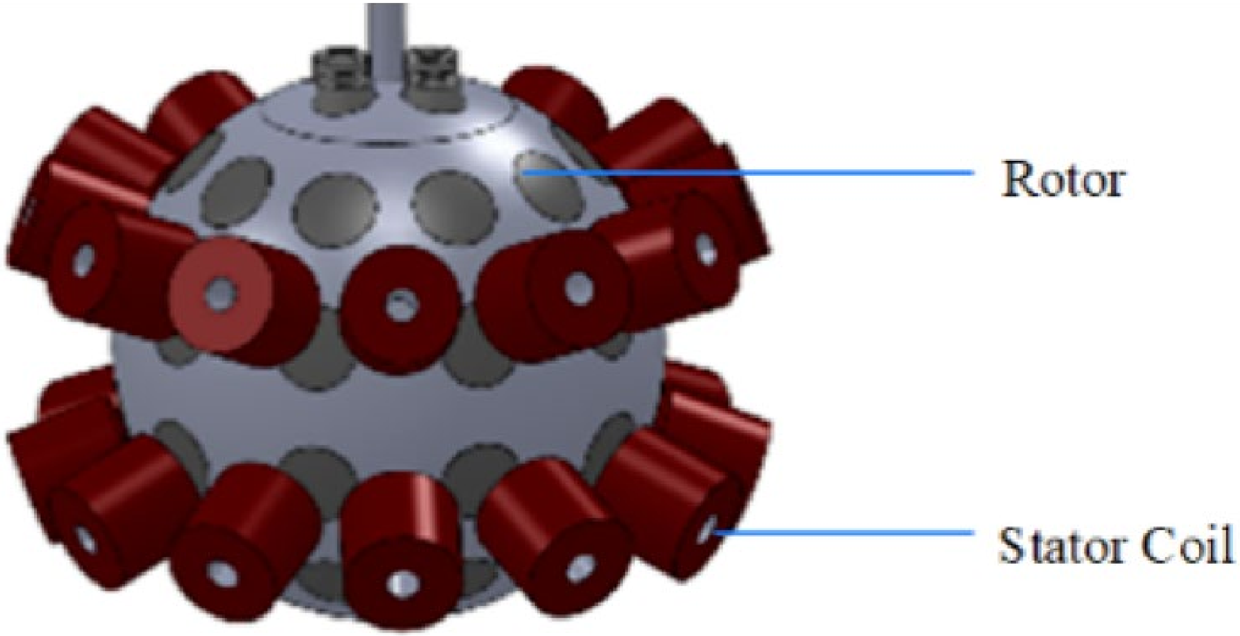
A practical implementation tailored for all-terrain vehicles, enabling full omnidirectional mobility through internal friction-based actuation and compact electronics integration.

3 Magnetic Reluctance Motor: Mechanical Design

Traditional Motor VS Spherical Motor



Traditional BLDC Motor



Spherical Motor

Rotor

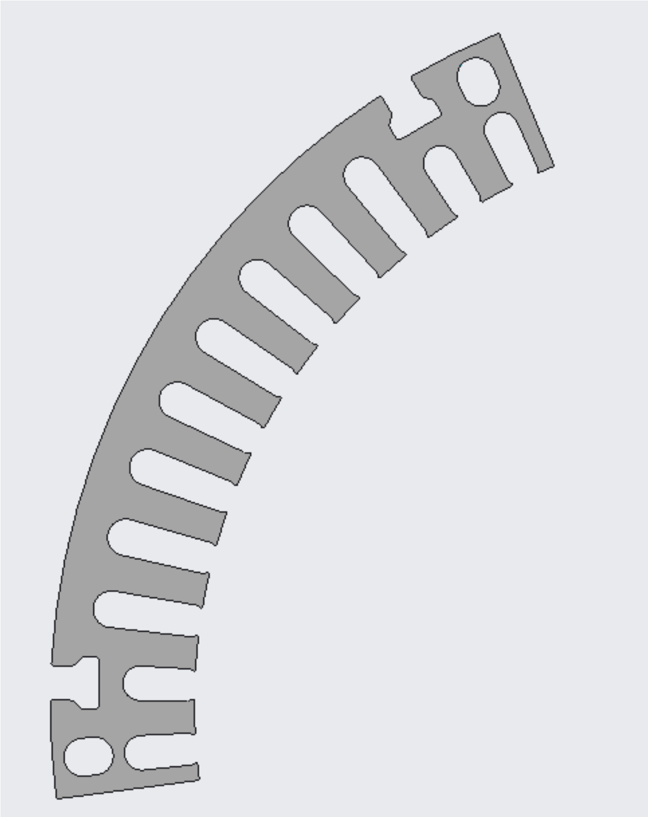
200 mm Diameter 8 mm Thickness Q235B

Machined, Polished

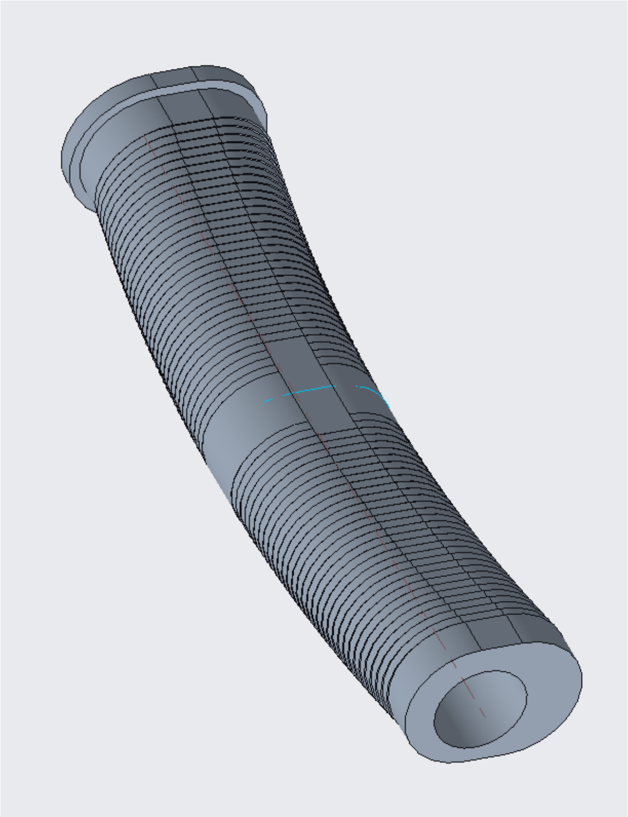
Stress-Relieved at 650 C

Polished via Sandpaper

Stator



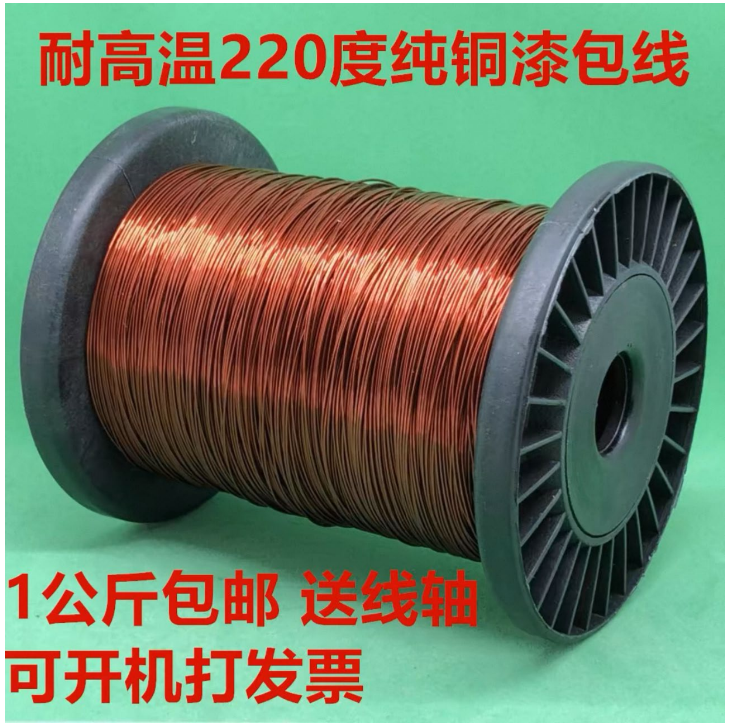
Non-Oriented Silicon Steel
Laser cut



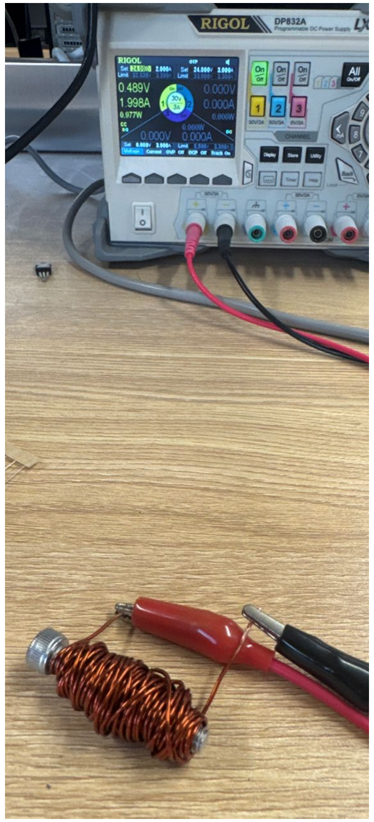
3D Printed Pin For
Conforming to the ball

72 x 0.5 mm Stator Ply's

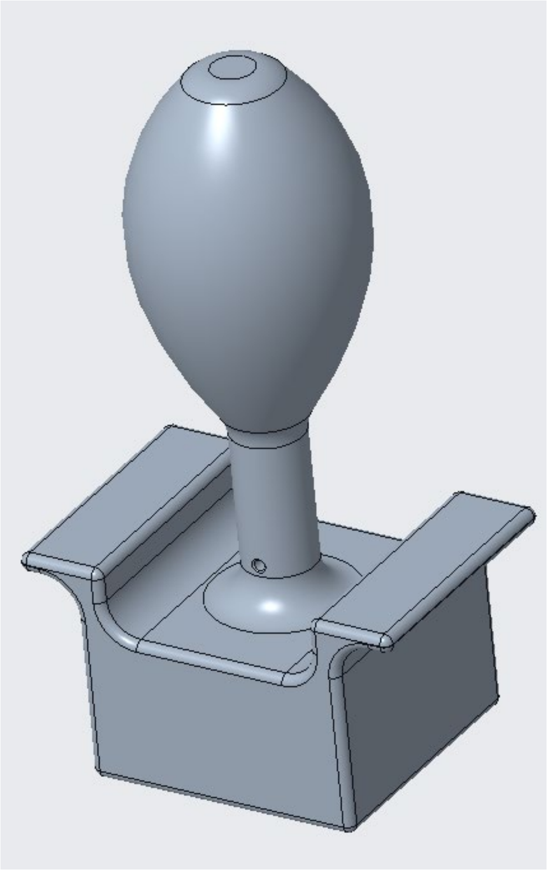
Wires



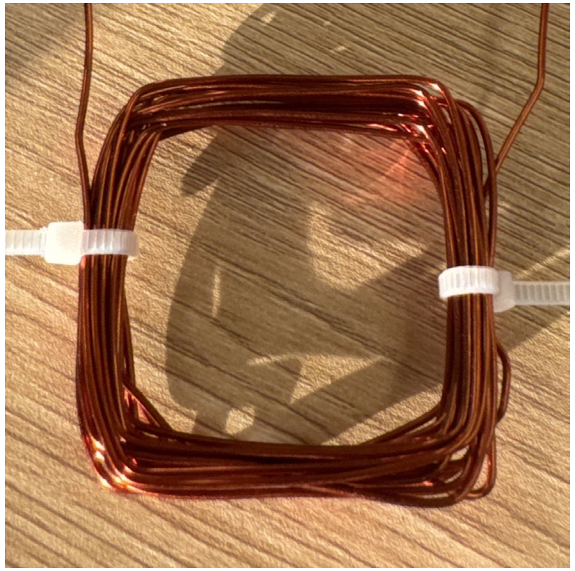
0.93 mm Enameled Copper Wire



Testing
Electromagnet



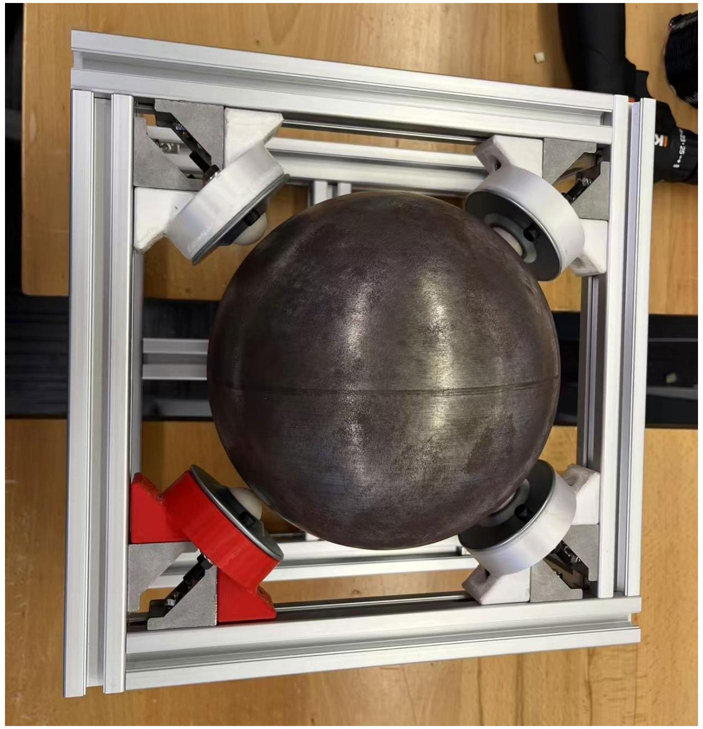
3D Printed Wire
Wrapping Tool



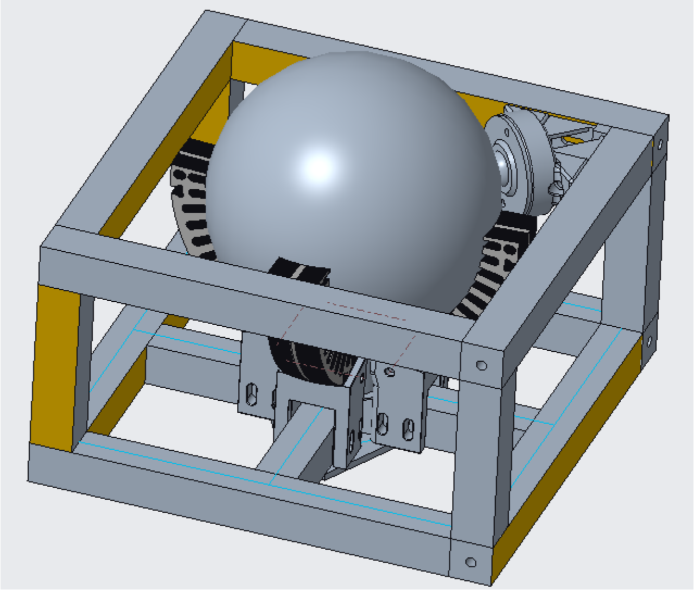
Wire Coil for
Stator

Assembly

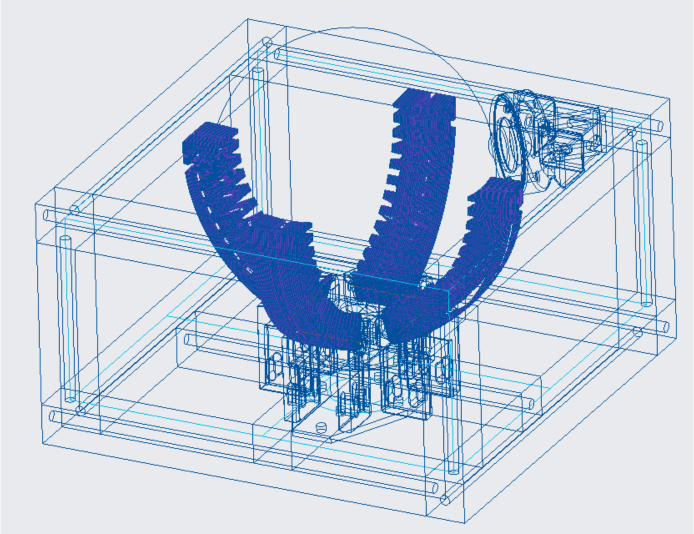
Delta Configuration

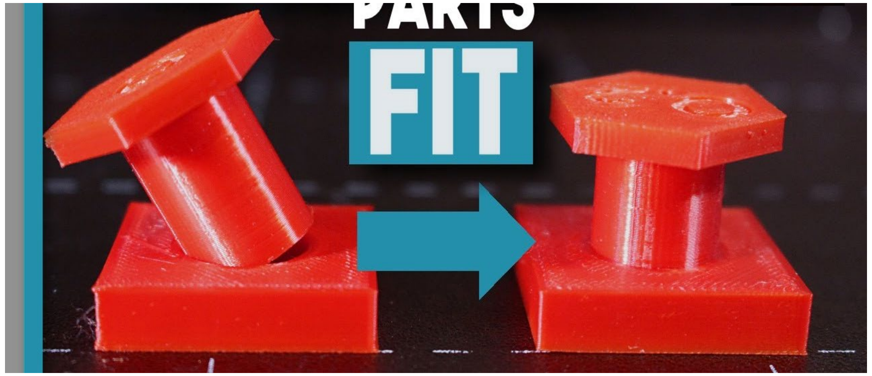


Nylon Ball Transfer, 3030 Aluminum

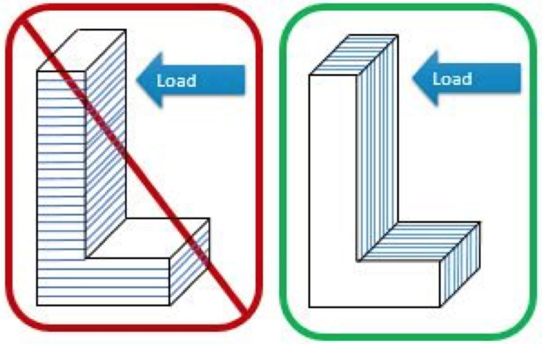


2 DOF

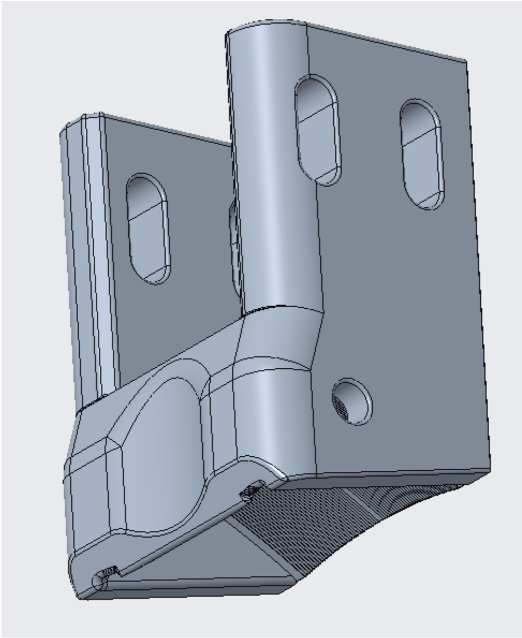




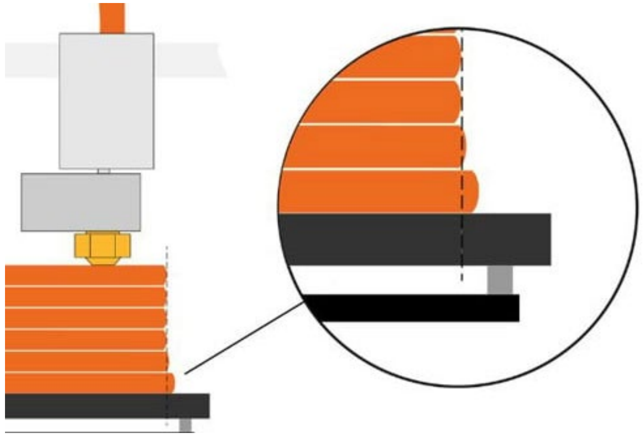
Tolerancing ~ 0.2 mm



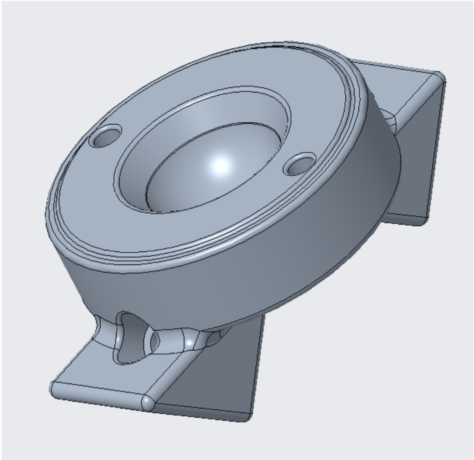
Print Orientation



Stator Support



Elephant Foot



Ball Holder

Results and High Level Requirements

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Results

Slight Wiggle

2 Degree of Freedoms

9 Coils

Verification

2 out of 3 DOF

Much less Torque

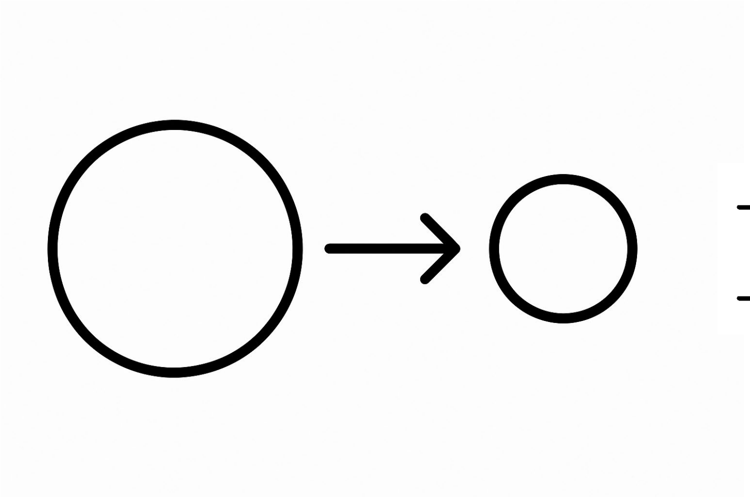
Instability on incline

$$B = \frac{\mu_0 \cdot NI}{g} \Rightarrow B = \frac{4\pi \times 10^{-7} \times 125}{0.005} \approx 0.0314\,\mathrm{T}$$

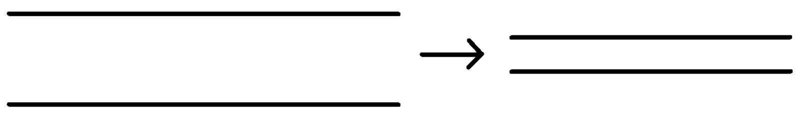
$$\tau = F \cdot r = 0.47 \cdot 0.1 = 0.047\,\mathrm{Nm}\ (1\ \mathrm{stator})$$

$$\omega = \alpha \cdot t = 1.28 \cdot 1 = 1.28\,\mathrm{rad/s} \Rightarrow \mathrm{RPM} = \frac{1.28 \cdot 60}{2\pi} \approx 12.2\,\mathrm{RPM}$$

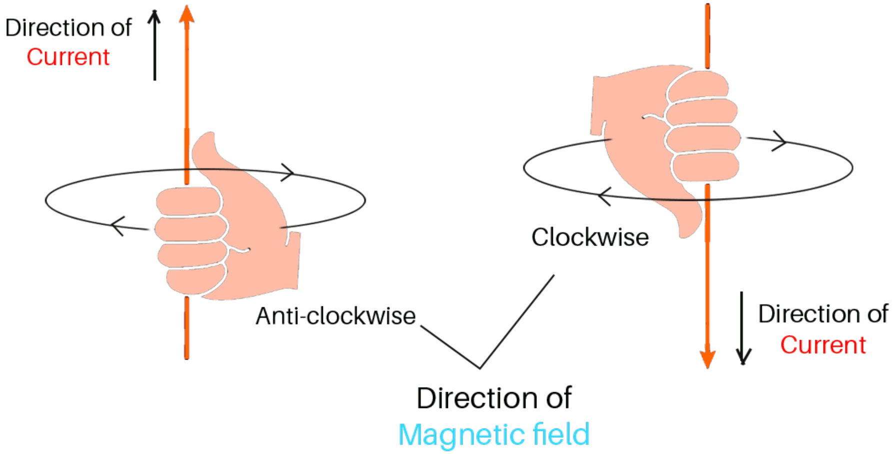
Future Work



Thinner Diameter,
More Turns



Reduce Gap

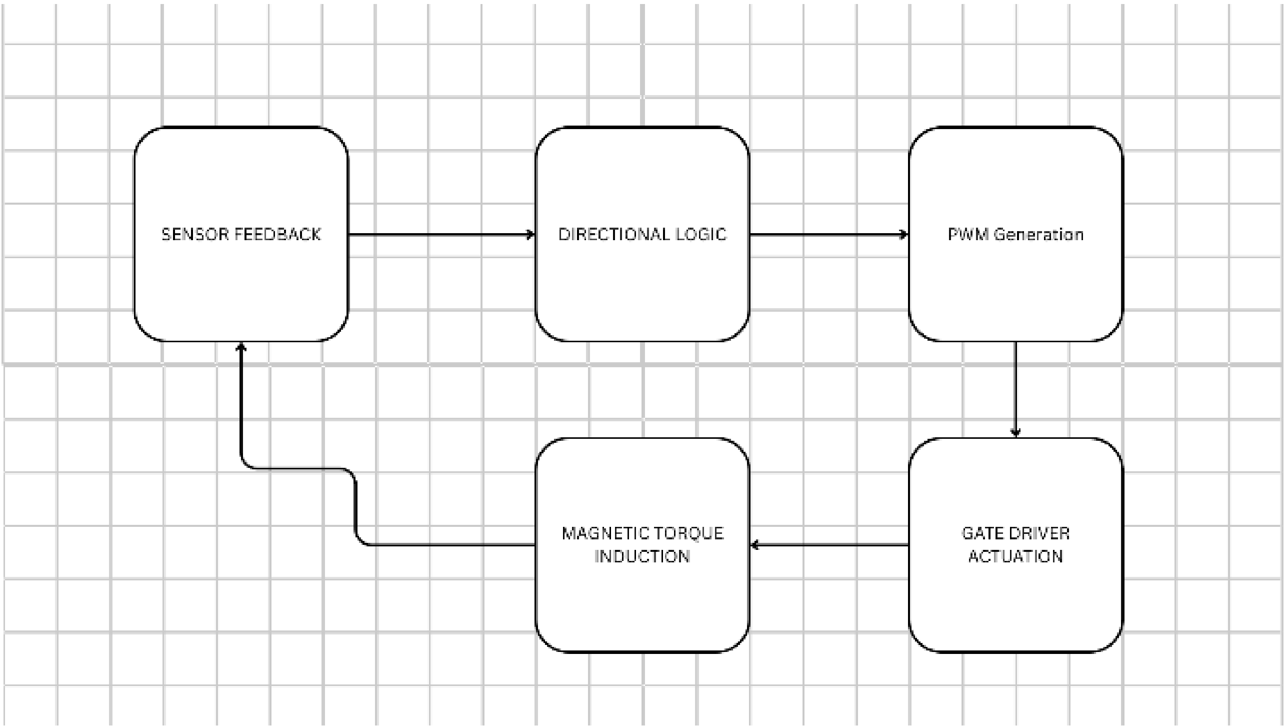


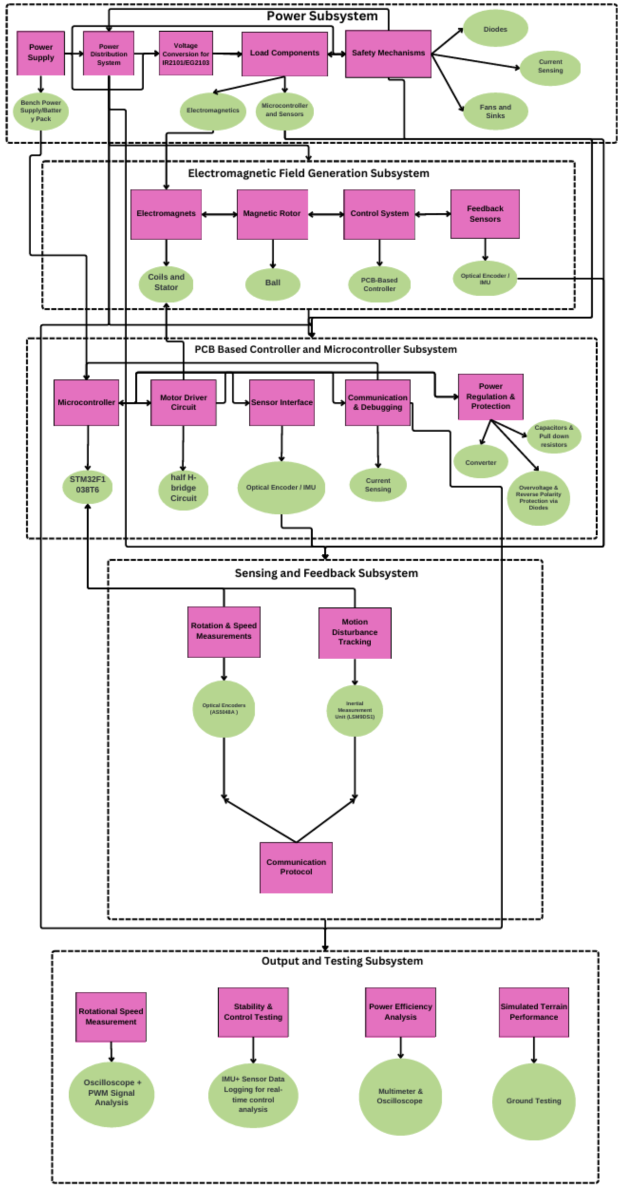
Make sure coils face same direction

$$\tau = F \cdot r = 8.46 \cdot 0.1 = 0.846\,\mathrm{Nm}\ (\text{per stator})$$

4 Magnetic Reluctance Motor: Electronic & Software Design

Block Diagram





Control

- **STM32F103C8T6 Microcontroller**
  - Inputs: IMU (BNO055), Optical Motion Sensors
  - Outputs: 6 PWM signals per stator (HIN/LIN x 3 phases)
- **PWM Generation Module**
  - Dead-time insertion
  - 120° phase shift logic
  - Directional grouping logic
- **Gate Drivers (IR2101/EG2101)**
  - Interface between MCU PWM signals and power MOSFETs
  - Bootstrap capacitors for high-side driving
- **Half-Bridge Circuits (IRF540N x 2 per phase)**
  - 3 half-bridges per stator
  - Switches current through stator windings
- **Feedback Loop**
  - BNO055 (orientation) + Optical Sensor (surface motion)
  - Real-time adjustment of duty cycle and phase alignment
  - Future: PID loop tuning for closed-loop torque control

PCB Architecture

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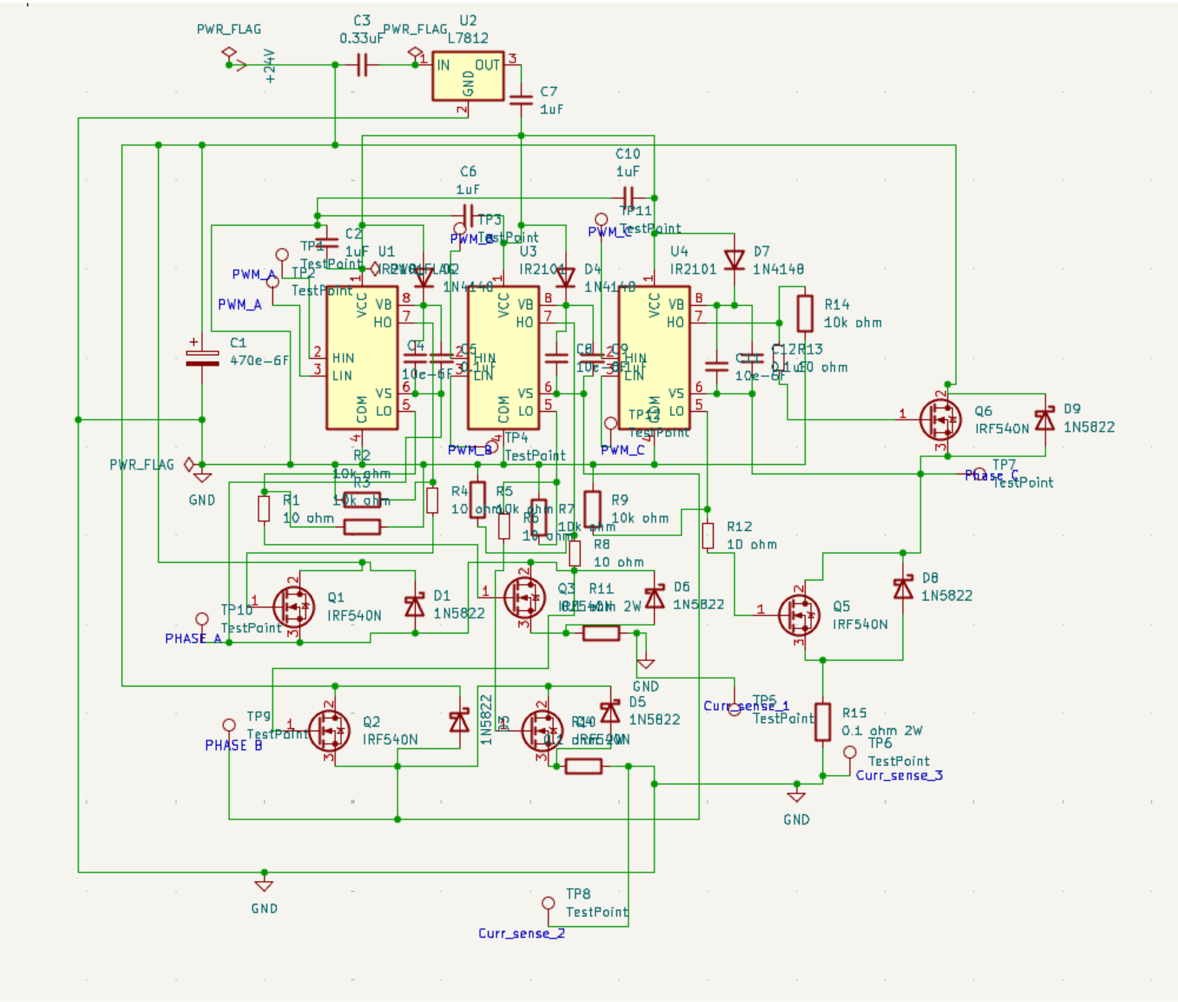

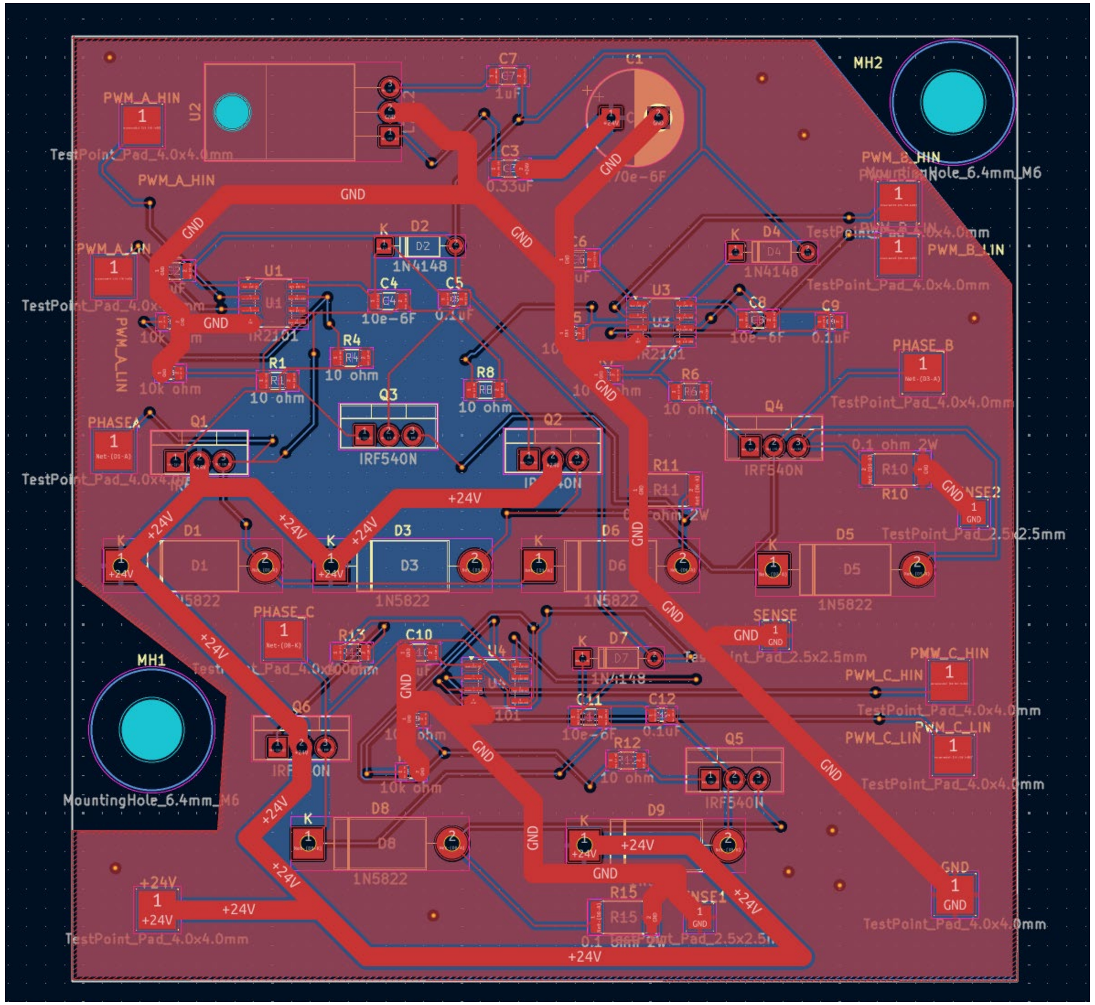

- **Voltage Input:**
- 24V main rail input → buffered by large electrolytic capacitors
- L7812 linear regulator steps down to 12V for IR2101s/EG2101
- **Power Stage:**
- 3 × Half-bridge MOSFETs per stator (x4 stators = 12 bridges)
- Gate drivers (IR2101) positioned near MOSFET pairs to reduce gate trace length
- Bootstrap caps (1μF) and decoupling (0.1μF + 0.33μF)
- **Control Lines:**
- STM32 GPIOs connect to IR2101 HIN/LIN through test points
- Pull-down resistors on HO and LO lines to prevent floating gates
- **Current Sensing:**
- 0.1Ω resistors at each low-side source → routed to STM32 ADCs
- Enables current feedback and protection logic
- **Thermal Management:**
- Copper pour around MOSFETs
- Passive heatsinks for continuous load operation

System Requirements & Specs

Parameter	Value
Input Voltage (V_in)	24V DC
Logic Voltage	3.3V (STM32), 12V (Gate Drivers)
Max Current per Phase	~2.5–8.0 A (limited during test)
PWM Frequency	~1 kHz
PWM Duty Cycle Range	80–95%
Number of Stators	4 (3-phase each)
Air Gap	~1–2.5 mm
Rotor Material	Solid steel sphere (~5.5 kg)
Sensor Inputs	BNO055 IMU, PMW3901 Optical
Thermal Handling	Copper pour + passive heatsinks

Results and High Level Requirements

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Results and Verification

- 2DOF ability through PWM cycle
- Torque: T = 0.01 · r ≈ 0.001 Nm/phase, where F ≈0.01 N, r = 0.1 m
- Magnetic Field Generation
- Feedback Loop: Optical Sensors
- 100 ms Latency

Future Work

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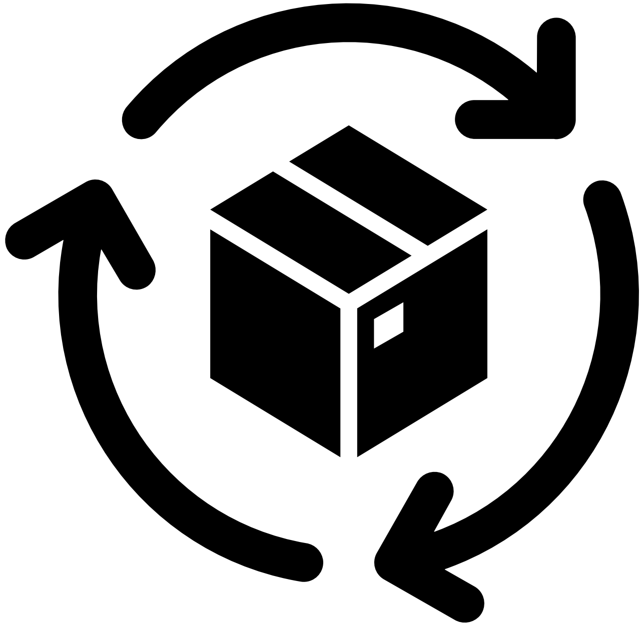
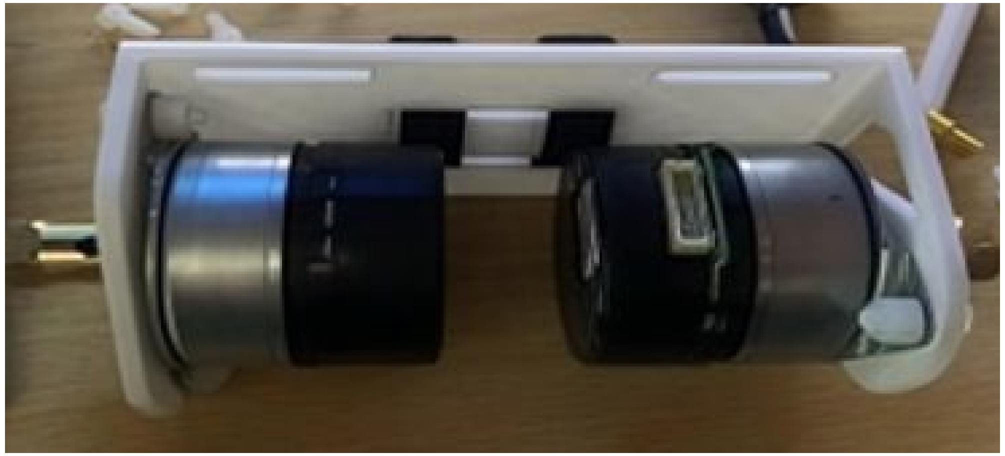
- **Challenges and Future Work**
  - IMU Integration for balancing
  - Power Supply Portable Conversion
  - Neat Scalable Control Unit
  - 3 DOF



5 Friction-Driven ATV Design

Friction-Driven ATV Design: Mechanics

- **Mechanical Design:**
  - **Outer Shell:** Acrylic, 180 mm, low-friction, durable.
  - **Inner Structure:** Modular, supports motor and circuit board alignment.
  - **Propulsion:** Friction-driven internal motor for omnidirectional movement.
  - **Components:** 3D-printed mounts, integrated circuit board for control.



Friction-Driven ATV Design: Mechanics

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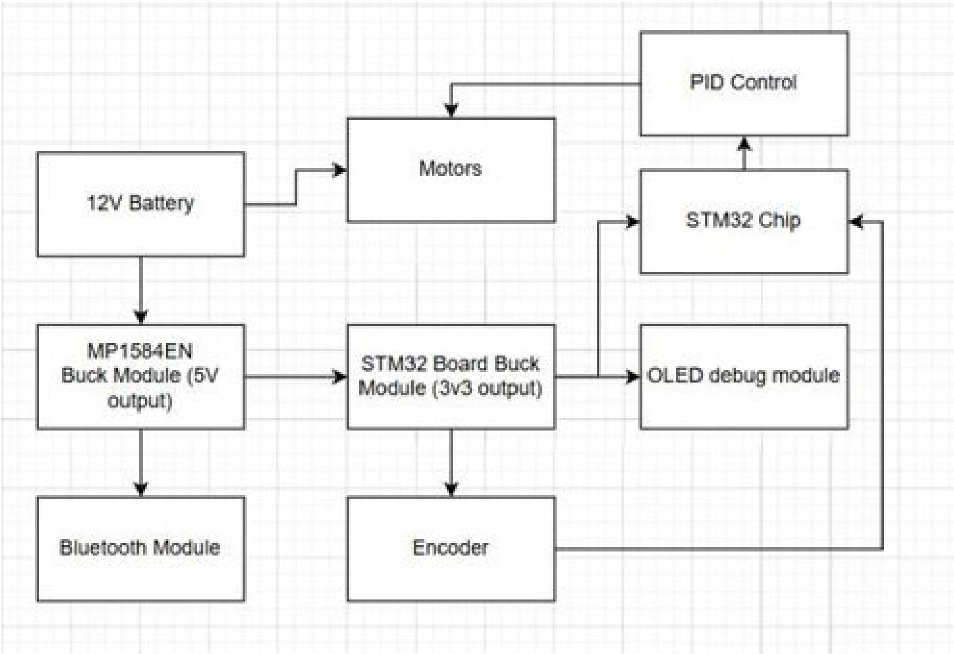
- **Microcontroller:** STM32F103C8T6, PID control via PWM.
- **Feedback:** Encoder for precise speed measurement.
- **User Interface:**
  - JDY-31 Bluetooth module for wireless control.
  - 0.96” OLED display for speed, battery status.
- **Power:** 11.1V battery, MP1584EN buck converter (5V rails).



Friction-Driven ATV Design: Control System

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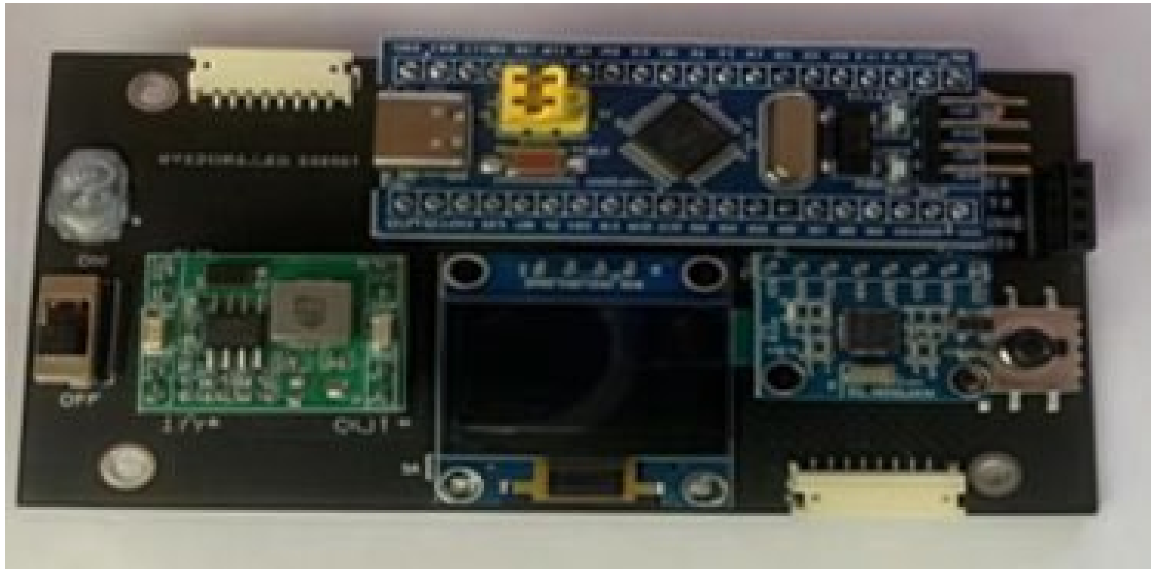
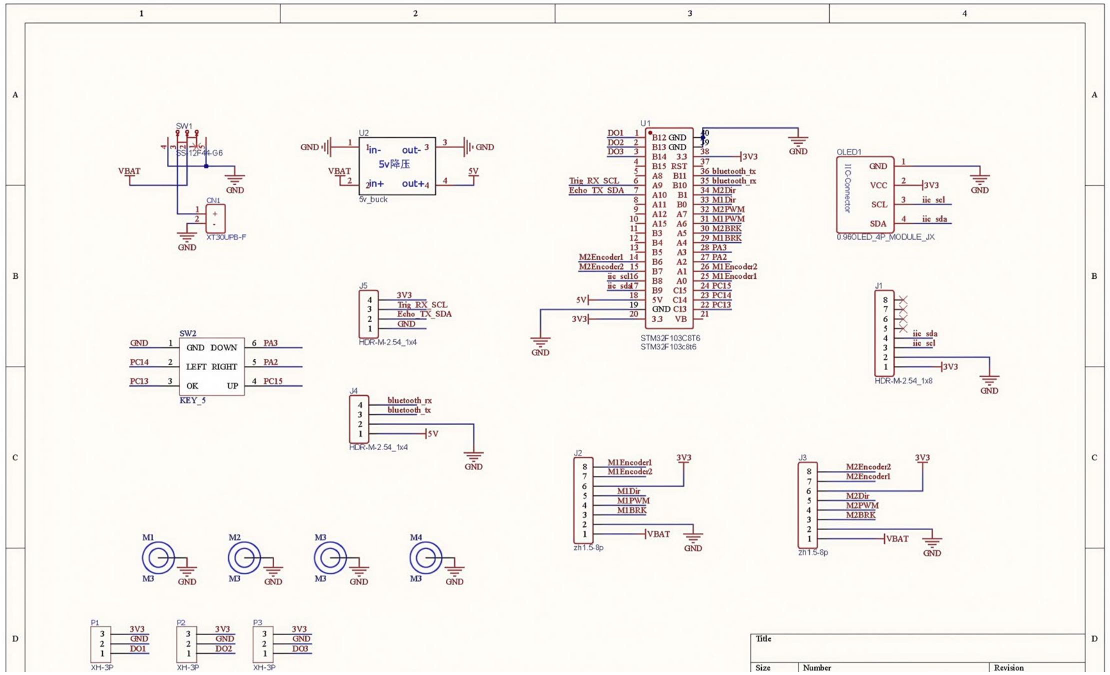
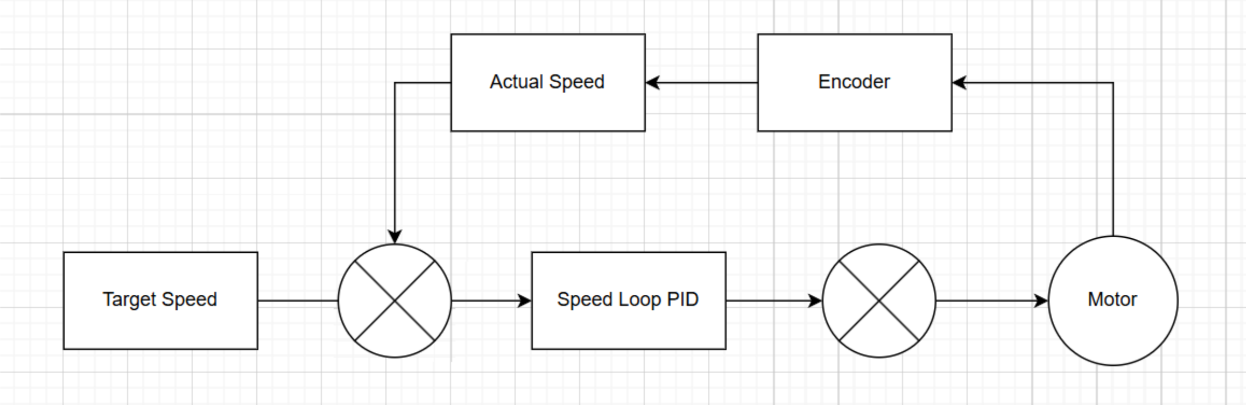
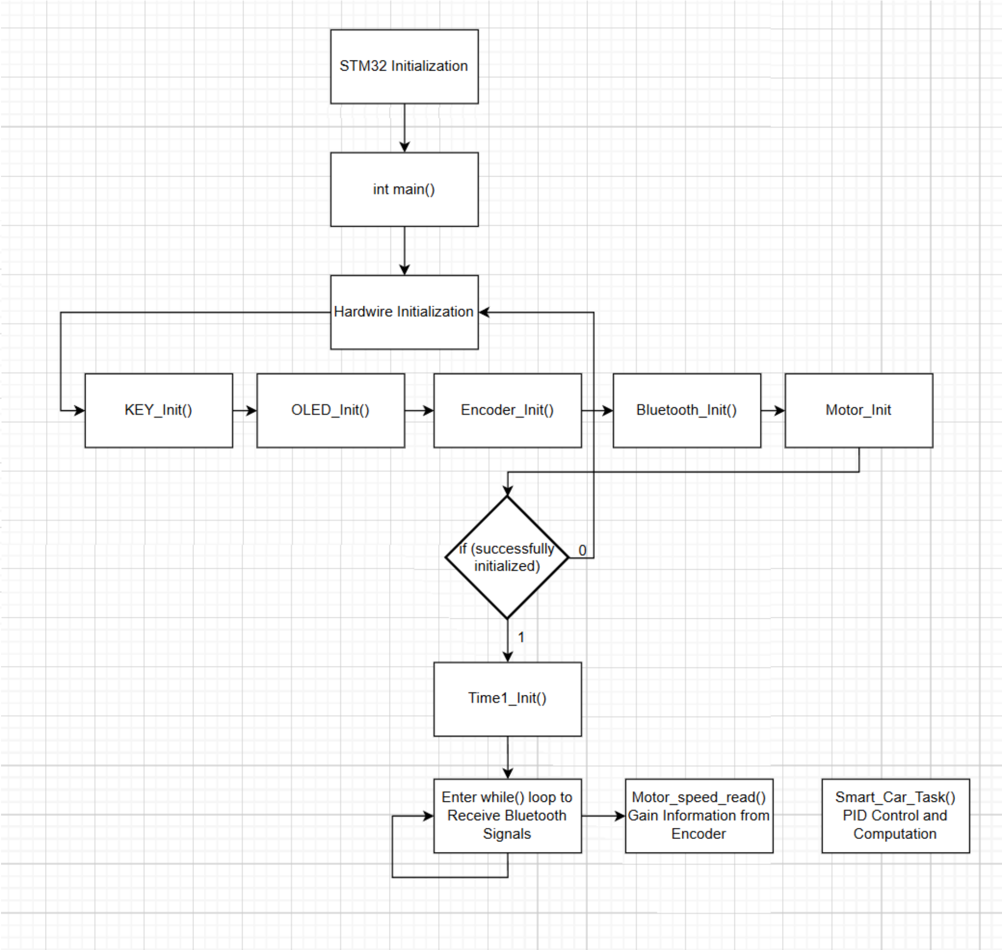




Friction-Driven ATV Design: Control System



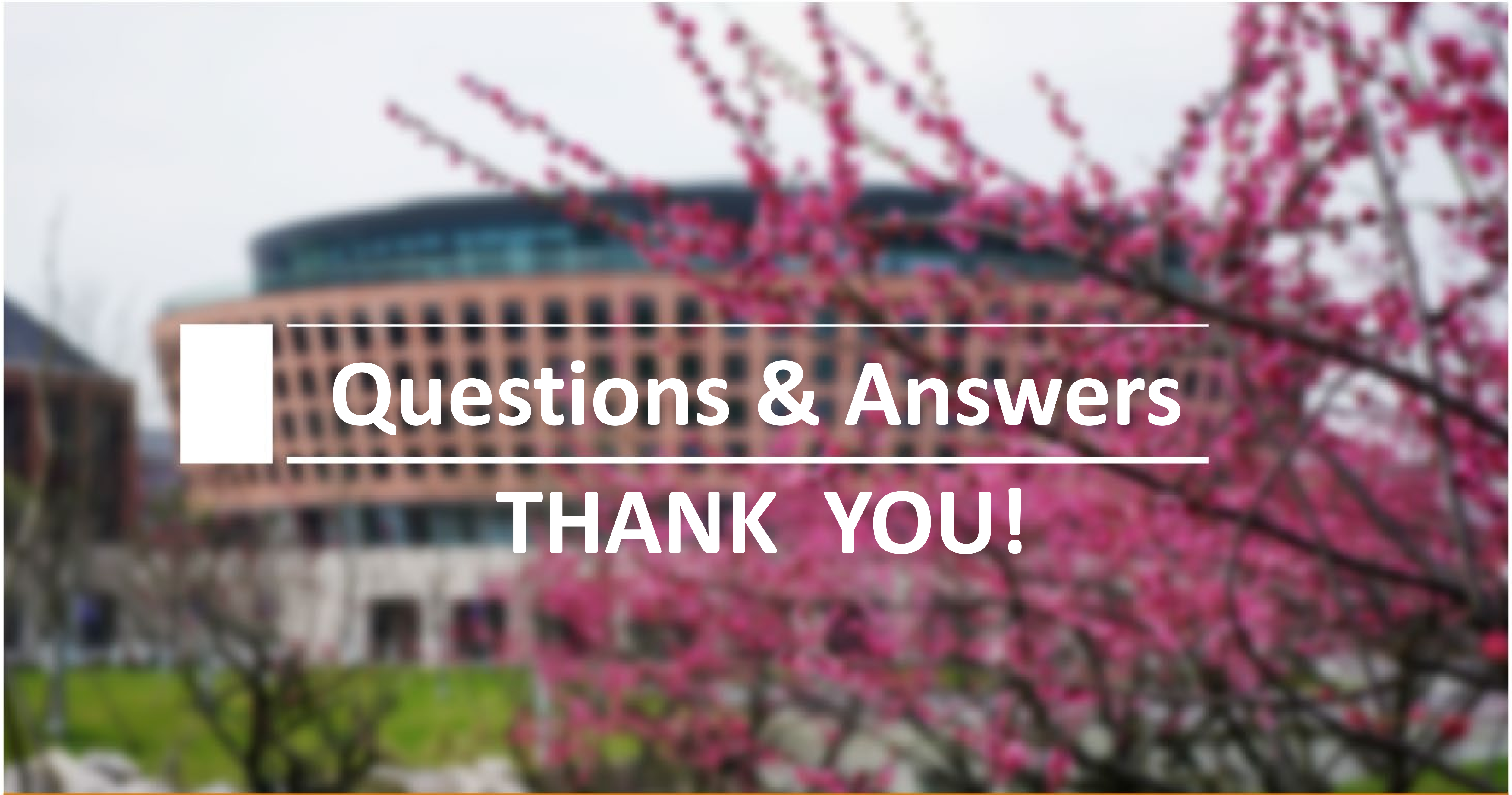


• Results & High-Level Requirements

- **Achievements:**
  - Omnidirectional movement on flat surfaces.
  - Stable friction-based torque transfer.
  - Compact integration of motor and control board.
- **Challenges:**
  - Posture instability at high speeds.
  - Occasional slippage during rapid directional changes.
  - Friction Propulsion: Consistent torque.
  - Stability: Partial; slippage at high speeds, motion capture.

• Future Work

- Enhance friction surfaces to reduce slippage.
- Integrate advanced sensors (e.g., gyroscopes) for posture control.
- Test on varied terrains for robustness.



Questions & Answers

THANK YOU!