ECE445 Senior Design

Scorpion-Lift Ant-Weight BattleBot

Team 4:

Zixin Mao, Chen Meng, Zisu Jiang

ILLINOIS

Team Members

Zixin Mao

- PCB + Servos Integration
- Chassis, arms, tail
- Cost + R&V integration

Chen Meng

- Mechanical CAD + Fabrication
- Tracks & Mobility Subsystem
- Physical Integration

Zisu Jiang

- Firmware + wireless control
- Power design, ESP32, Wi-Fi
- Telemetry & test support

1. Introduction

UNIVERSITY OF
ILLINOIS
URBANA-CHAMPAIGN

Problem and Solution

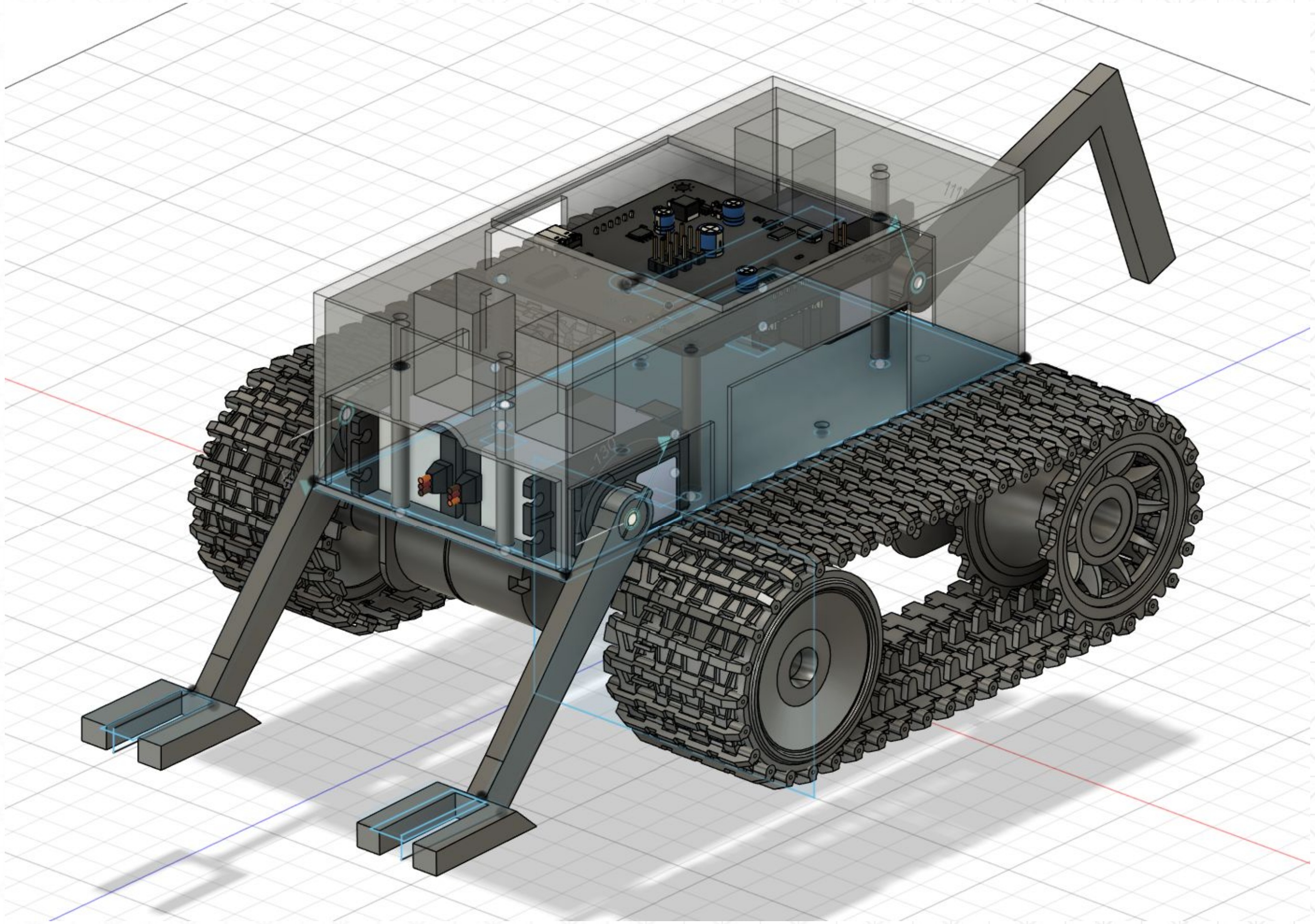
Typically Fail Due to:

- Traction Loss
- Backward Tipping During Lifts

Scorpion-Lift Design:

- Tracked Mobility System
- Dual Lifting Arms
- Rear Tail Brace

  (stability and flip-prevention)



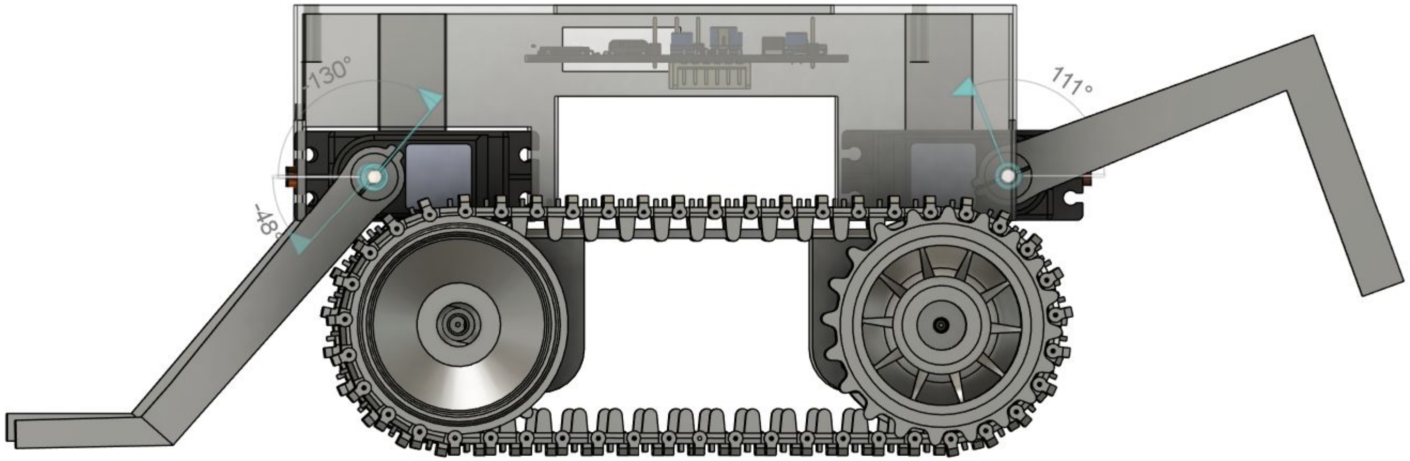
High-Level Requirements

- **Robust Tracked Mobility**
    - Achieve a straight-line speed of at least 0.5 m/s under full system load
    - Complete 5 consecutive full-differential turns without tread derailment
    - Maintain continuous operation without mobility failure during a 2-minute match
- **Opponent Control and Self-Stablizing**
    - Lift a 2 lb test load by at least 30 mm within 3 seconds
    - Resist backward tipping when an upward force is applied at the front
- **Wireless / Safety Reliability**
    - Maintain a stable WiFi connection at up to 10 m line-of-sight
    - Disable all motor and actuator outputs within 800 ms of signal loss

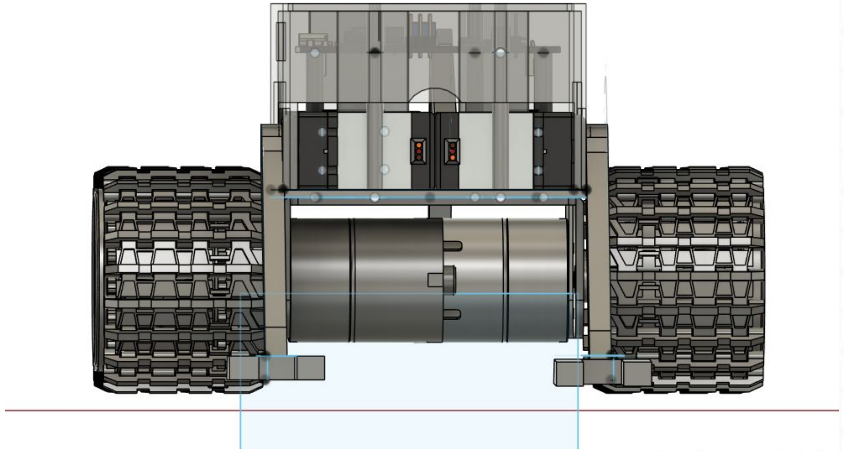
2.1 Hardware Design

UNIVERSITY OF
ILLINOIS
URBANA-CHAMPAIGN

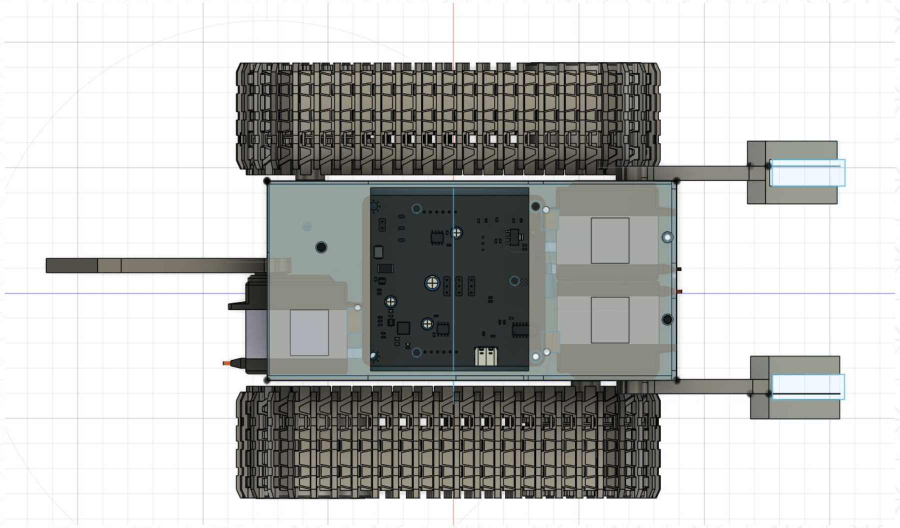
Hardware Design



Side View



Front View



Top View

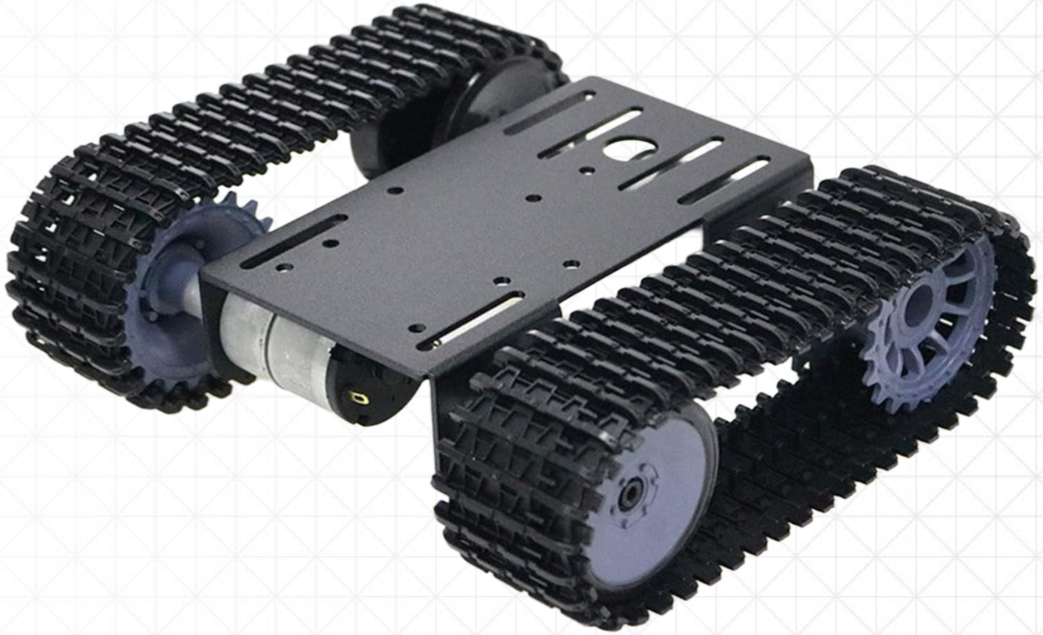
Design Optimization:

- ✘ Crowned-Pulley Tread Geometry
- ✔ Caterpillar Continuous Track
- + Extra under-board space for battery

*Modeling Software: Fusion 360

Hardware Design

Crowned-Pulley Geometry



Caterpillar Continuous Track

Image Reference: https://www.tec-science.com/mechanical-power-transmission/belt-drive/why-do-crowned-pulleys-keep-a-flat-belt-on-track/ “Why Do Crowned Pulleys Keep a Flat Belt on Track?"

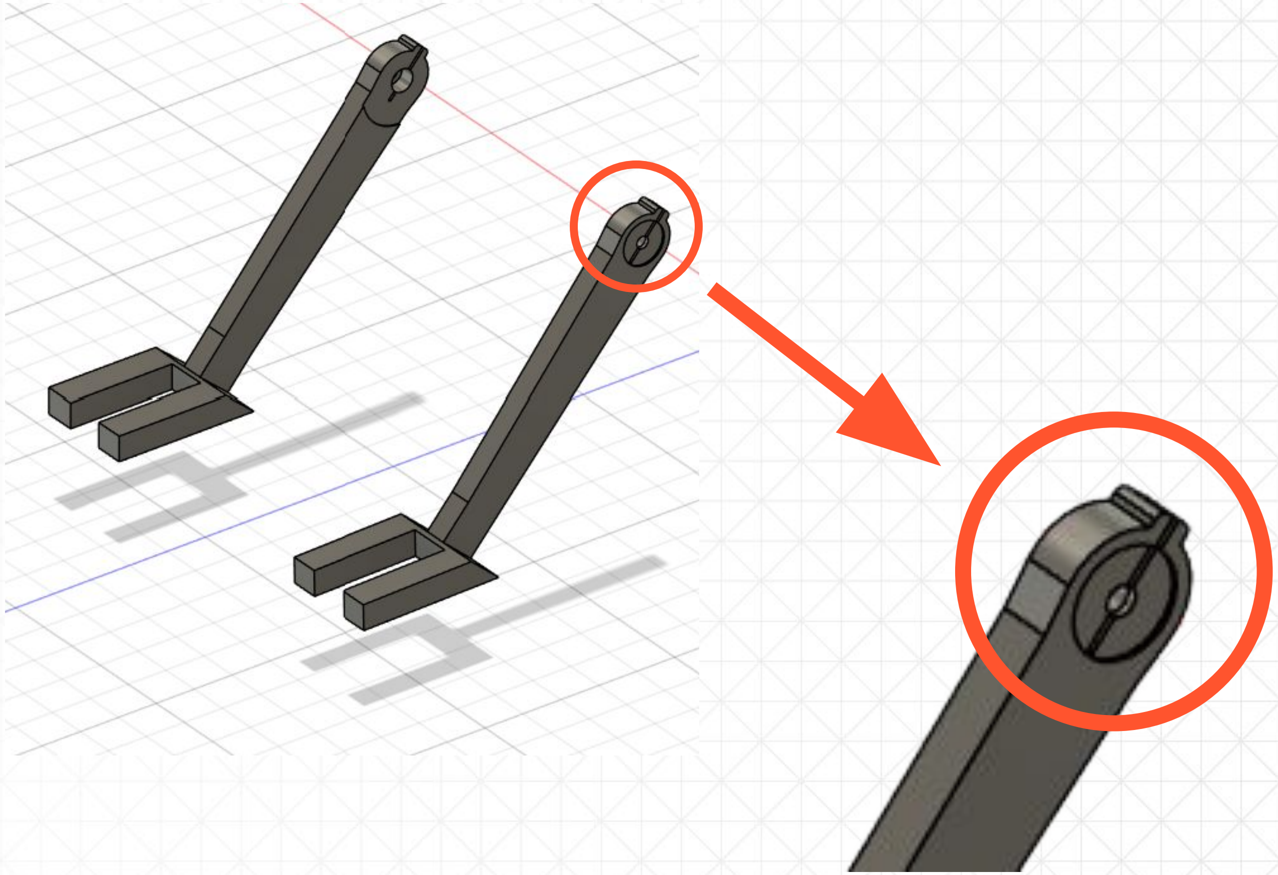
Hardware Design

Challenge:

- The slotted press-fit connection stripping
- Mechanical failure under the high torque of lifting large weights

Solution:

- Reduce the inner diameter of the spline hole in the CAD model by 0.05mm



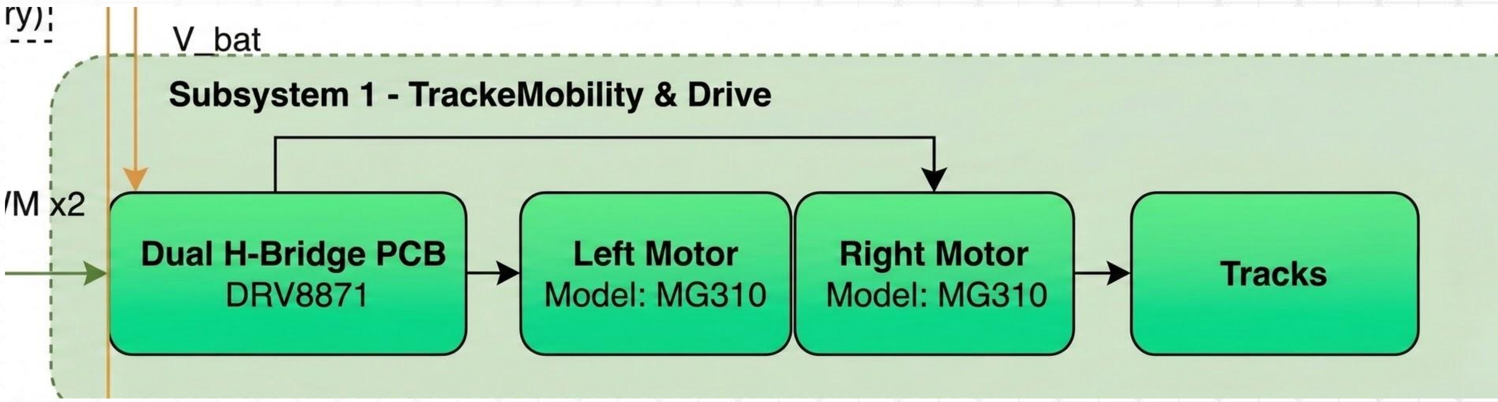
2.2 Subsystems

UNIVERSITY OF
ILLINOIS
URBANA-CHAMPAIGN

Subsystem 1 - Tracked Mobility

Components:

- 2 DC gearmotors
- DRV8871 integrated H-bridge driver
- Tracks



Subsystem 1 - Tracked Mobility

Reason and Comparison: No Over-Engineering!

	DRV8701	DRV8871
Footprint & PCB Complexity	Four discrete external NMOS. → Increases PCB footprint and design complexity.	MOSFETs built inside of the package. → Reduces design complexity.
Current Capacity vs. Requirement	Designed for high current (peak 50A+) and high power leads. → Over-engineering (our I_{peak} ~ 2.6A).	Up to 3.6A peak current. → Meets all requirements.

Design Optimization:

Motor Driver

✗ DRV8701 External H-Bridge Driver

✓ DRV8871 Internal H-Bridge Driver

Subsystem 1 - Tracked Mobility

Design Optimization:

Motor

✘ N20 DC Motor

✔ MG310 DC Motor

N20 DC Motor:

- Fragile copper leaf pins are small and unstable
- The plastic end cap is susceptible to thermal deformation when soldering

MG310 DC Motor:

- Robust metal solder tips
- Heat-resistant terminal assembly

Subsystem 1 - Requirements & Verification

Requirements	Verification
● Minimum straight-line speed of 0.5 m/s under full system load	● Drive 2 meters at full system load ● Record time for 3 trials ● Pass if average time is ≤ 4 s
● Tracks prevent tread derailment during full-differential turns	● Perform 5 consecutive full-differential turns ● Alternate left/right, 3 s per direction ● Pass if no derailment occurs in all trials

Subsystem 1 - Verification Results

<table>
<tr><th>Requirements</th><th>Results</th></tr>
<tr><td>

- Minimum straight-line speed of 0.5 m/s under full system load

</td><td>

- Testing Distance: 2.47 m

<table>
<tr><th></th><th>Time</th><th>Speed</th></tr>
<tr><td>Trial #1</td><td>3.56 s</td><td>0.69 m/s</td></tr>
<tr><td>Trial #2</td><td>3.42 s</td><td>0.72 m/s</td></tr>
<tr><td>Trial #3</td><td>3.47 s</td><td>0.71 m</td></tr>
<tr><td>Mean</td><td>3.48 s</td><td>0.706 m/</td></tr>
</table>

✓

</td></tr>
<tr><td>

- Tracks prevent tread derailment during full-differential turns

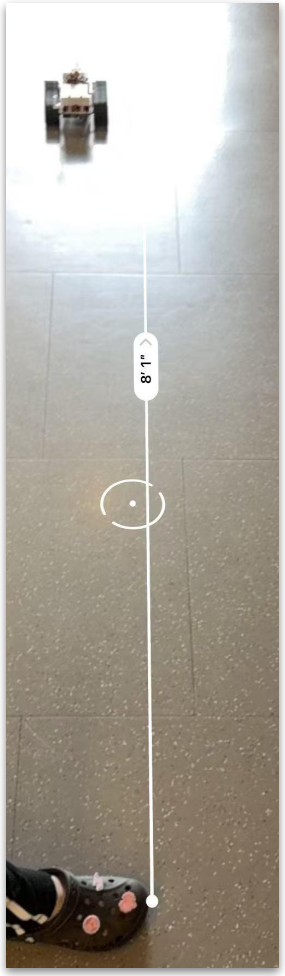
</td><td>

- No tread derailment detected in the turning process.

✓

</td></tr>
</table>

Subsystem 1 - Verification Results

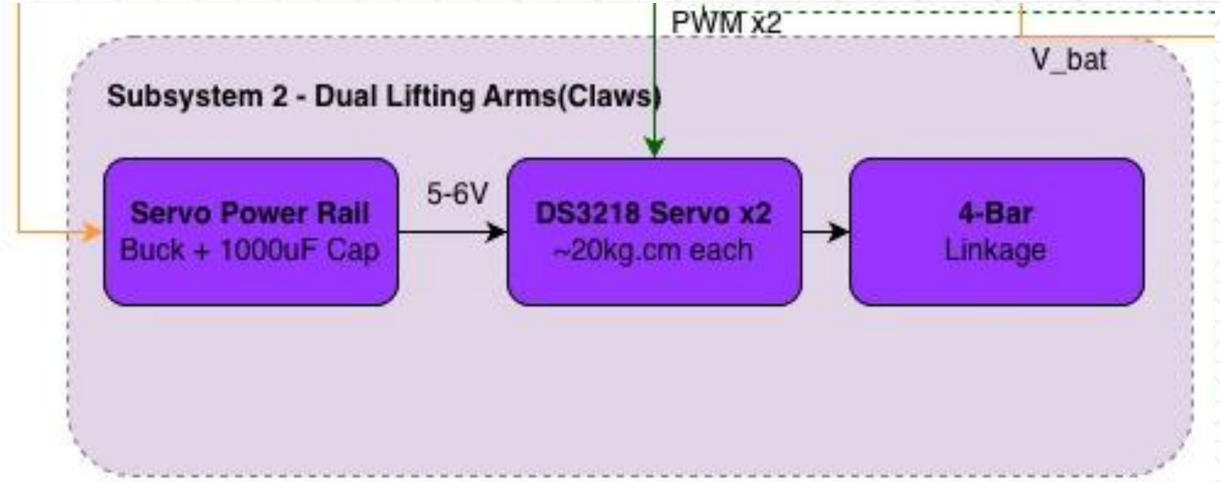


Verification of Straight-Line Speed

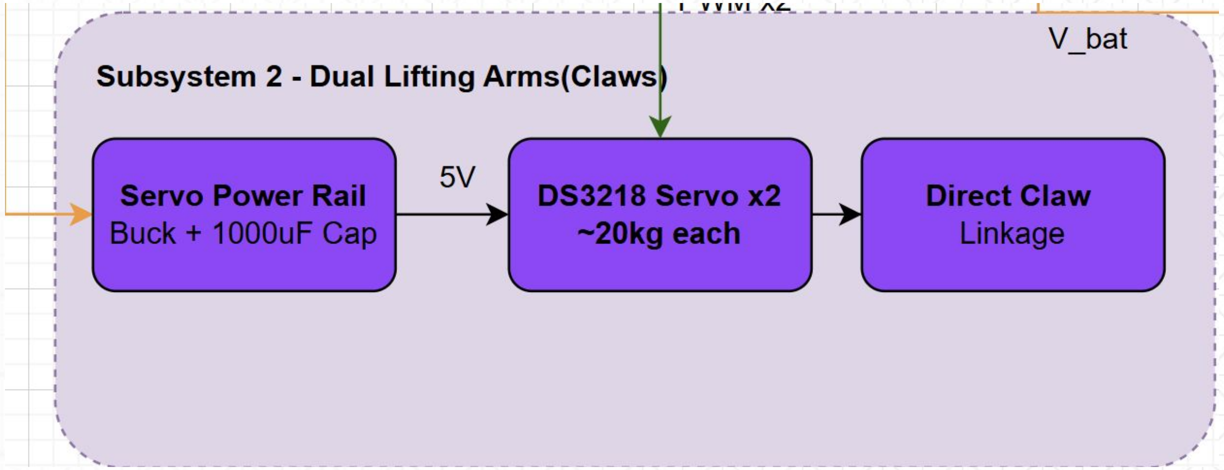
Verification of Tread Derailment Prevention

Subsystem 2 - Dual Lifting Arms

Old:



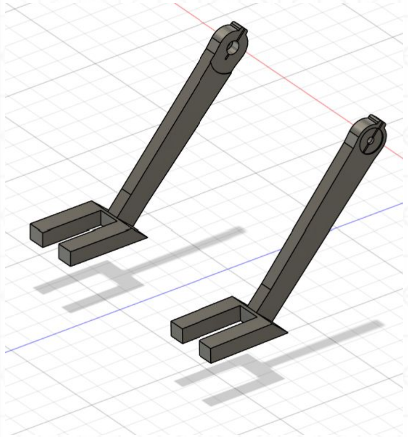
New:

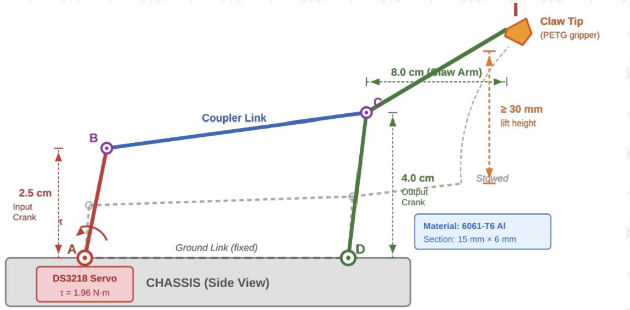


Subsystem 2 - Dual Lifting Arms

Why DS3218?

- 20 kg·cm torque margin
- Metal gears for shock resistnce
- Compact package
- Direct PWM control from ESP32
- Cost-effective within budget





✔Direct claw ✘4-bar linkage?

Direct claw has fewer joints than a 4-bar linkage, making it stiffer and more reliable with less backlash/binding under load.

Subsystem 2 - Requirements & Verification

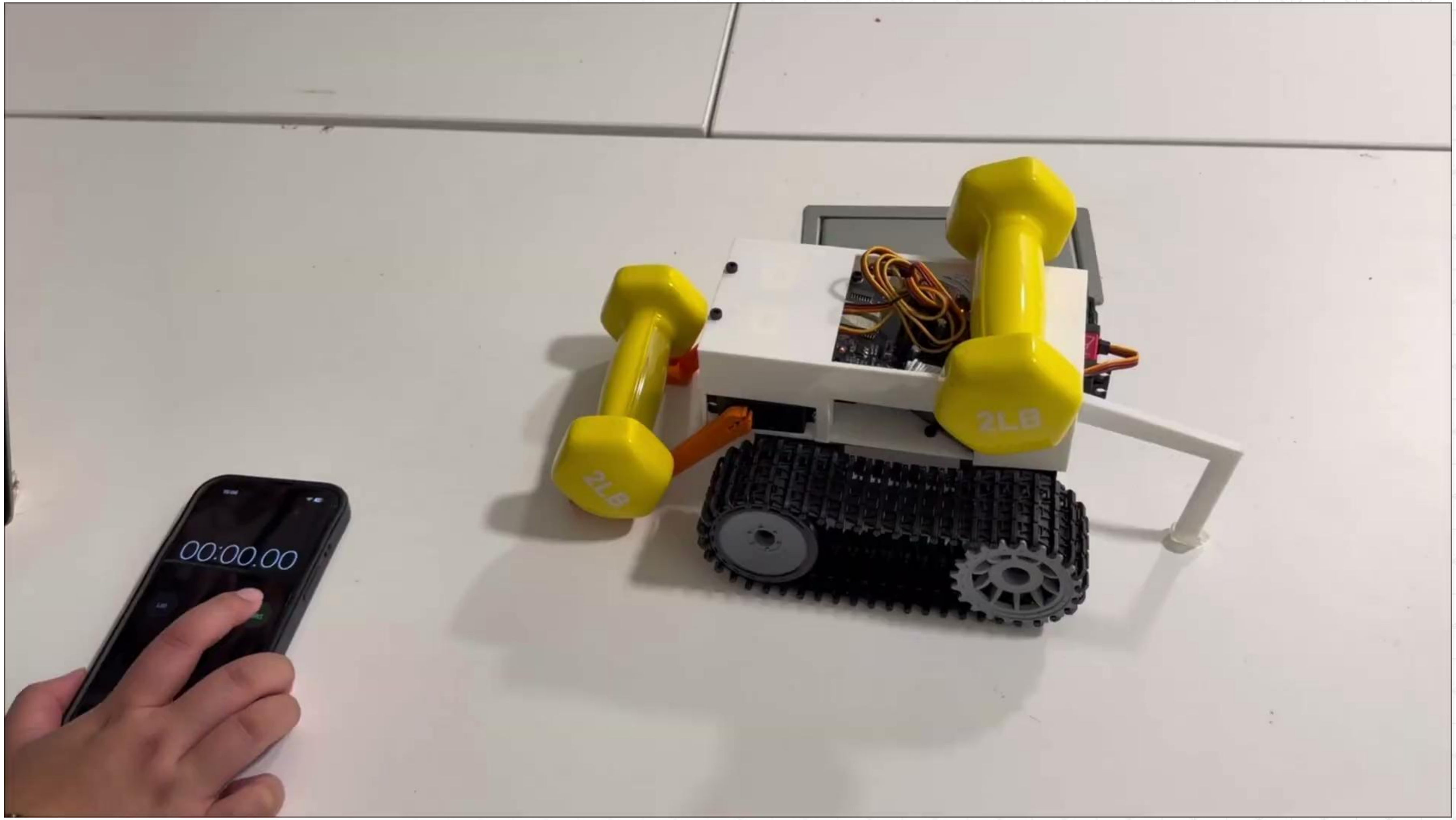
Requirements	Verification
● 2 arms lifts a 2 lb load by at least 30 mm within 3 s	● Place 2 lb weight on claw tip ● Command arm to lift and measure height with ruler ● Pass if load rises ≥ 30 mm within 3 s

Subsystem 2 - Verification Results

Requirements	Results
● Each arm lifts a 2 lb load by at least 30 mm within 3 s	● Both arms lifted a 2 lb load by ≥ 30 mm ● Lift time: 0.76 s. ● Result: PASS (meets ≥ 30 mm within 3 s)

✓

Subsystem 2 - Verification Results



Subsystem 2 - Challenges and Solutions

Challenge:

- Arm spline/gear joint was too loose and slipped under load.
- Print tolerance made the spline hole slightly oversized

Solution:

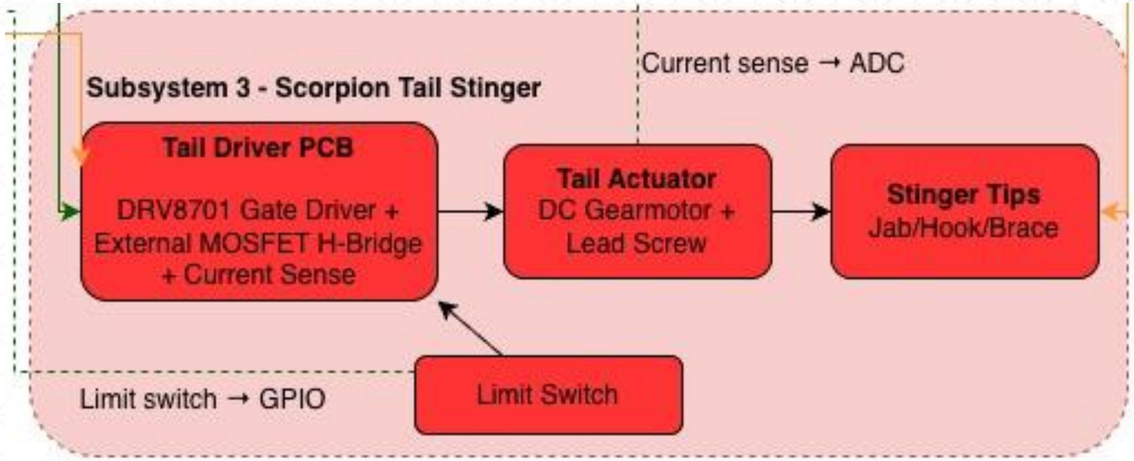
- We reprinted multiple arms with tighter spline fit.
- The new arms removed slipping and fixed the issue

Subsystem 3 - Scorpion Tail Stinger

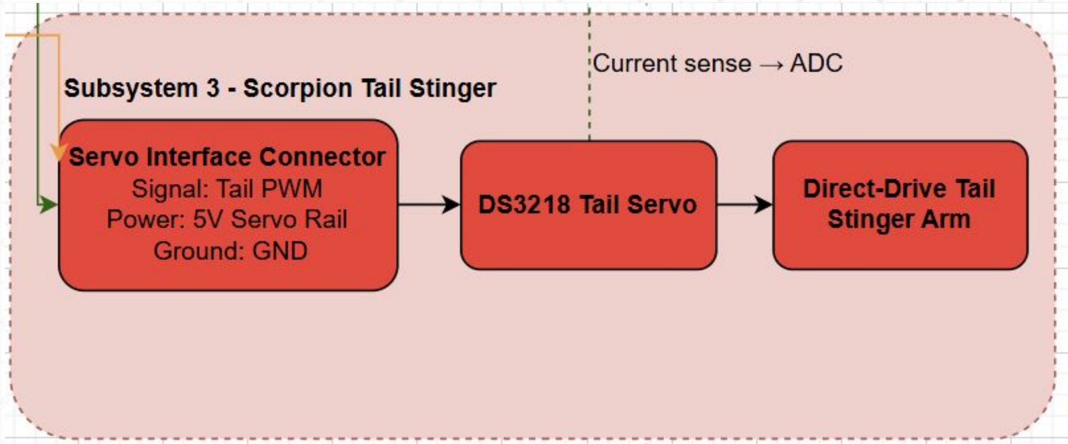
Components:

- 1× **DS3218** high-torque servo
- Direct-drive tail stinger arm
- PLA+ structural tail link
- 5V servo power rail
- Servo PWM signal from ESP32
- Servo interface connector

Old:



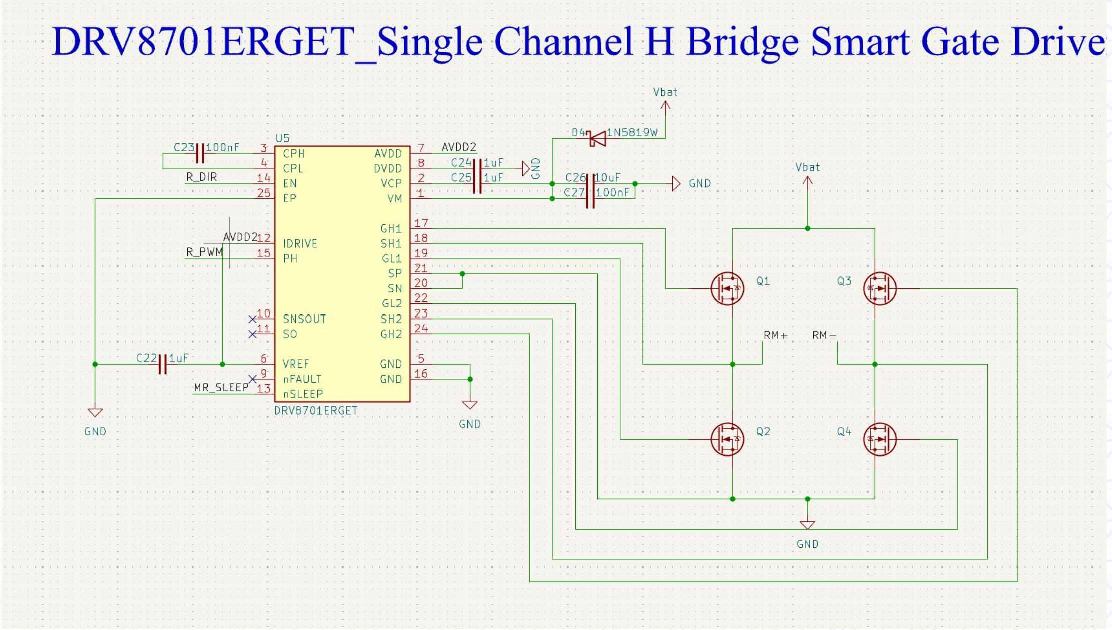
New:

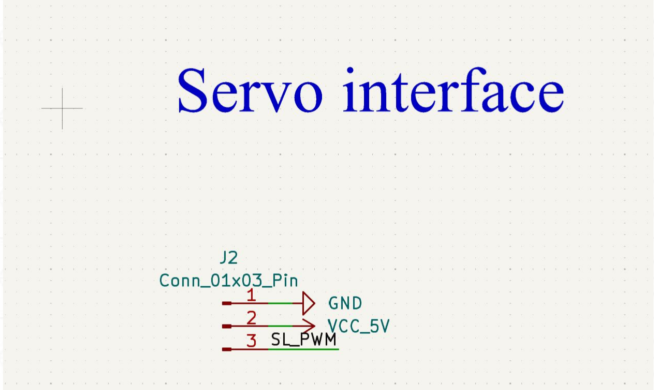


Subsystem 3 - Scorpion Tail Stinger

✗ **Tail Driver PCB (DRV8701 + MOSFET H-bridge)**
✓ **DS3218 tail servo (direct-driver):**
We simplified the power electronics and reduced integration risk by using a plug-and-play servo.

✗ **Stinger tips (jab/hook/brace)**
✓ **Single direct-drive tail stinger arm**
A single arm is lighter and more consistent under impact with fewer parts to break. Also for a jab or hook shape, it will loss the ability to prevent chassis from tipping backwards





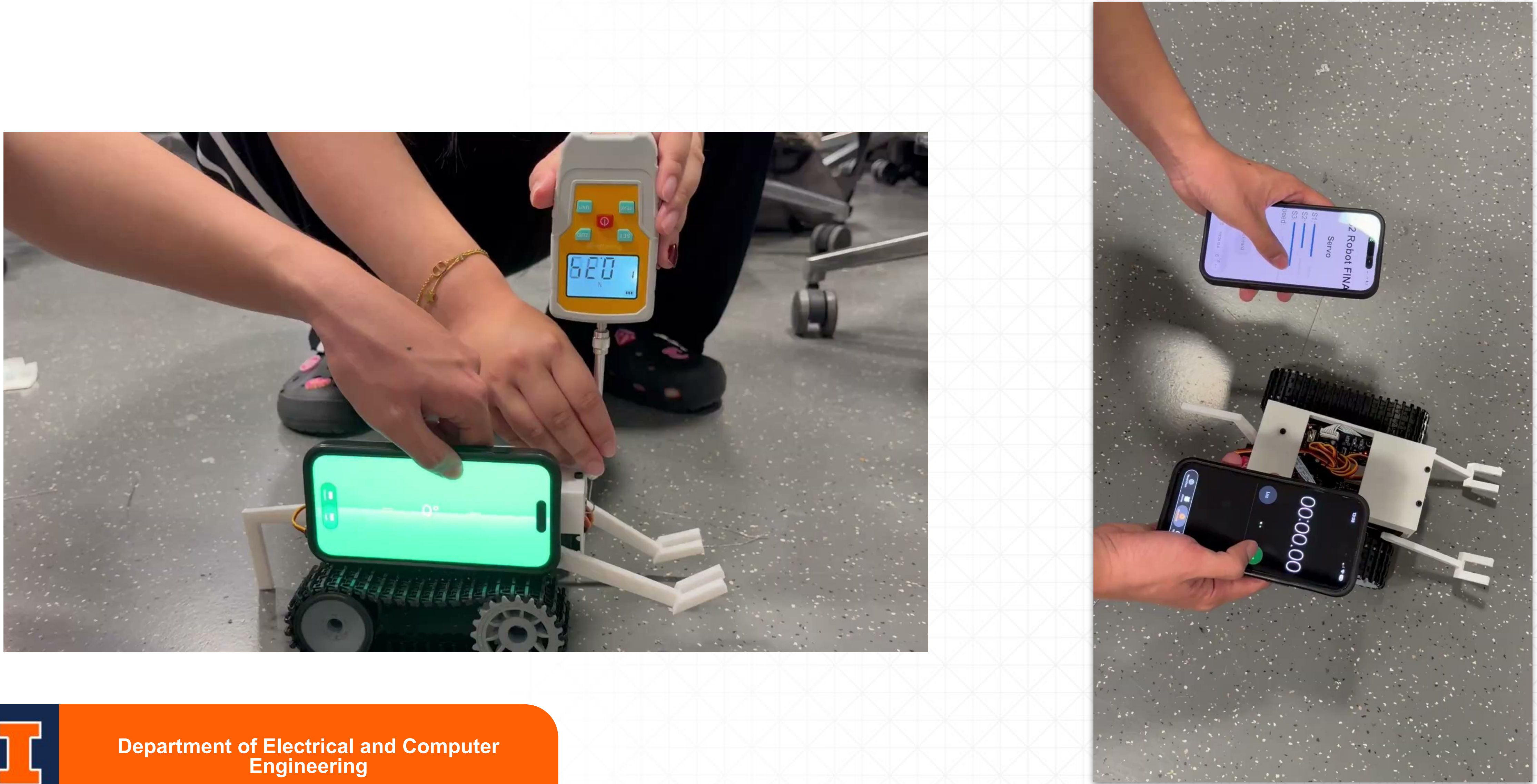
Subsystem 3 - Requirements & Verification

Requirements	**Verification**
- The tail shall prevent the chassis from tipping backward when being lifted from the front by the opponent.	- Place robot on flat surface and deploy tail brace - Apply 5.0 N upward force at the front using a spring scale - Hold force for 5 seconds - Pass if pitch ≤ 45° and no full tip-over
- Tail moves from stowed to bracing position in ≤ 1.0 s	- Command full tail deployment - Measure motion time with phone stopwatch - Pass if transition completes in ≤ 1.0 s

Subsystem 3 - Verification Results

Requirements	Results
● The tail shall prevent the chassis from tipping backward when being lifted from the front by the opponent.	● Withstood an average front lift force of 5.0 N (max: 5.5 N) ● Average chassis pitch angle observed:29°(max: 31°) ● No full tip-over occurred during testing ● Requirement satisfied with margin (angle well below 45°) ✓
● Tail moves from stowed to bracing position in ≤ 1.0 s	● Measured tail deployment time: 0.76 s ● Timing taken using a phone stopwatch ● Transition completed within required 1.0 s ✓

Subsystem 3 - Verification Results



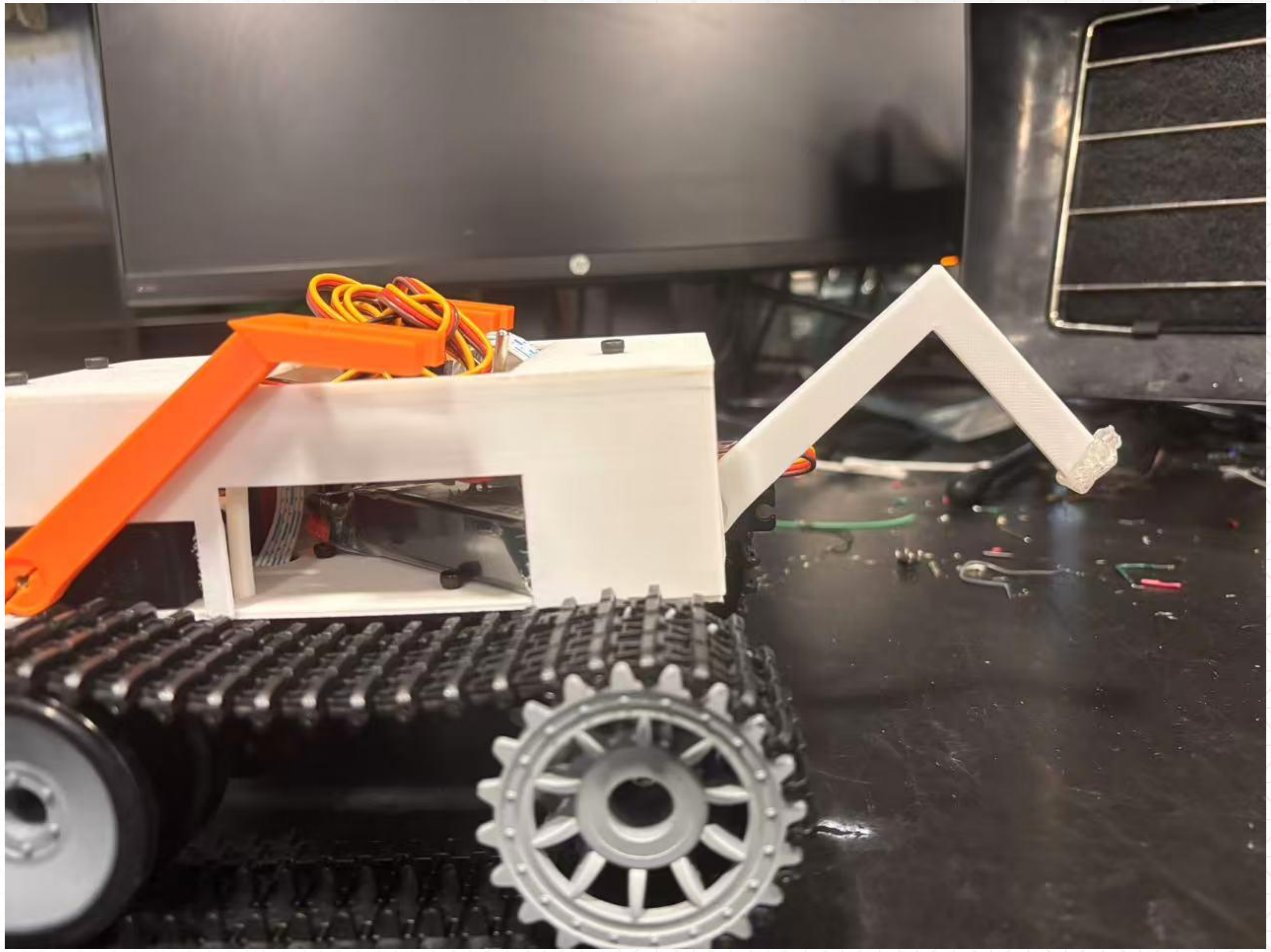
Subsystem 3 - Challenges and Solutions

Challenge:

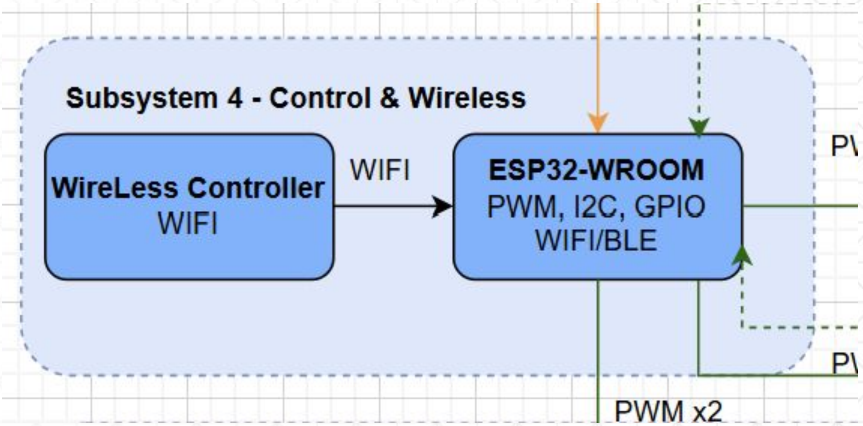
- The tail tip was bare 3D-printed PLA and had very low friction.
- The tail contact point slipped on the floor during bracing tests.

Solution:

- We added double-sided tape to the tail tip surface.
- The tape increased friction and reduced slipping during ground contact.



Subsystem 4 - Wireless Control



Original Design

- ESP32 as the main controller
- Bluetooth controller to operate
- Wi-Fi to get telemetry data such as volatge
- PWM outputs for:
    - 2 drive motors
    - 3 servos

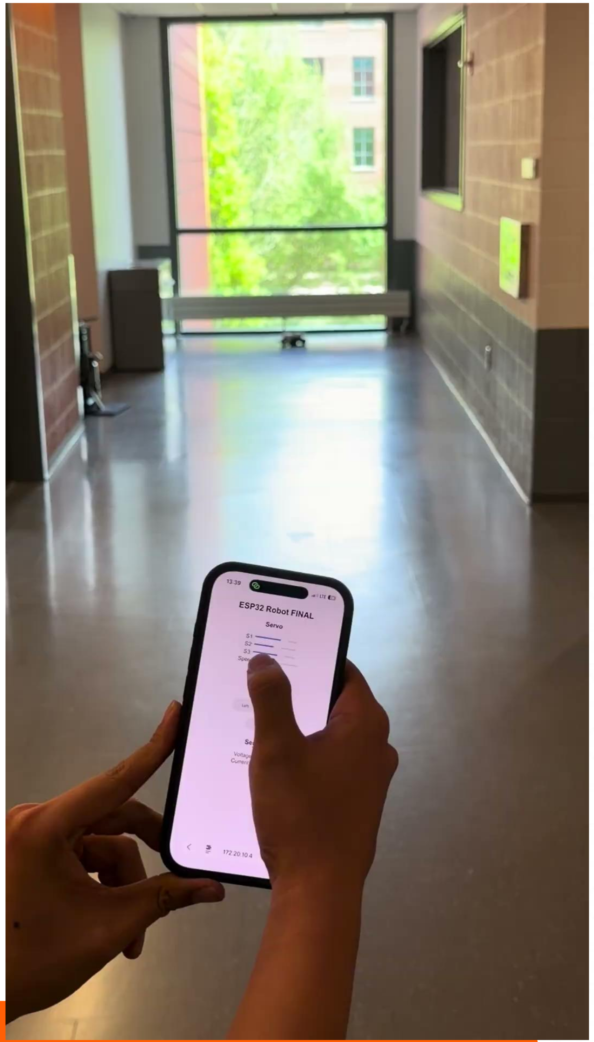
Final Design changes

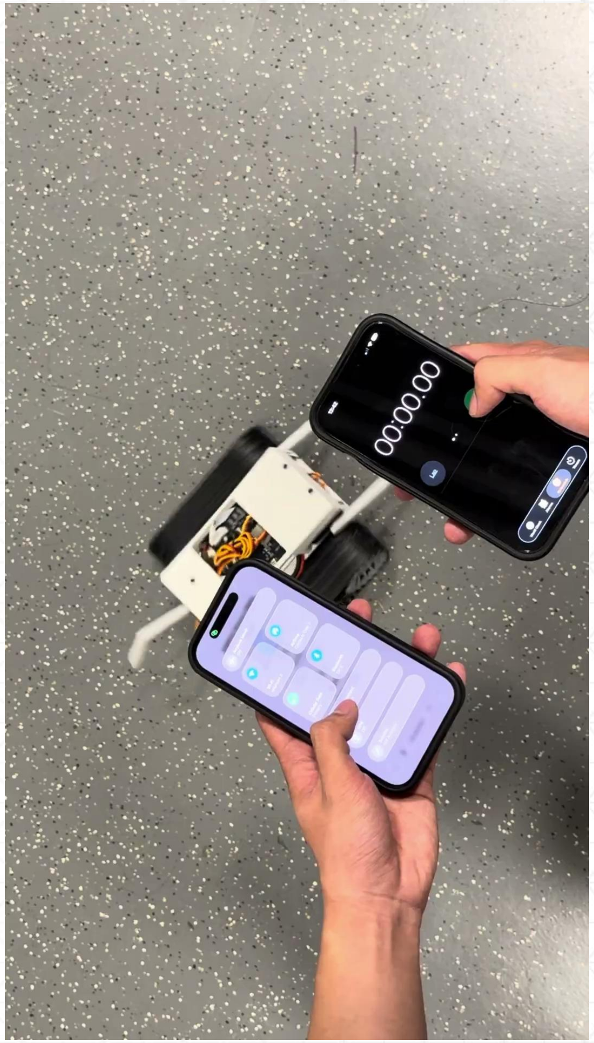
- Switched from Bluetooth control to Wi-Fi webpage communication
    - Stable connection
    - Simplified user interface
    - Combination with telemetry output

Subsystem 4 - Verification Results

Requirements	Results	
● Wireless link maintains stable connection up to 10 m line-of-sight	● The operator can maintain reliable wireless control at **10 m** line-of-sight without noticeable command loss.	✓
● Heartbeat failsafe disables all outputs within 500+300 = 800 ms of signal loss	● When no valid control packet was received, drive motors were automatically set to **0** speed after t = **580** ms.	✓

Subsystem 4 - Verification Results

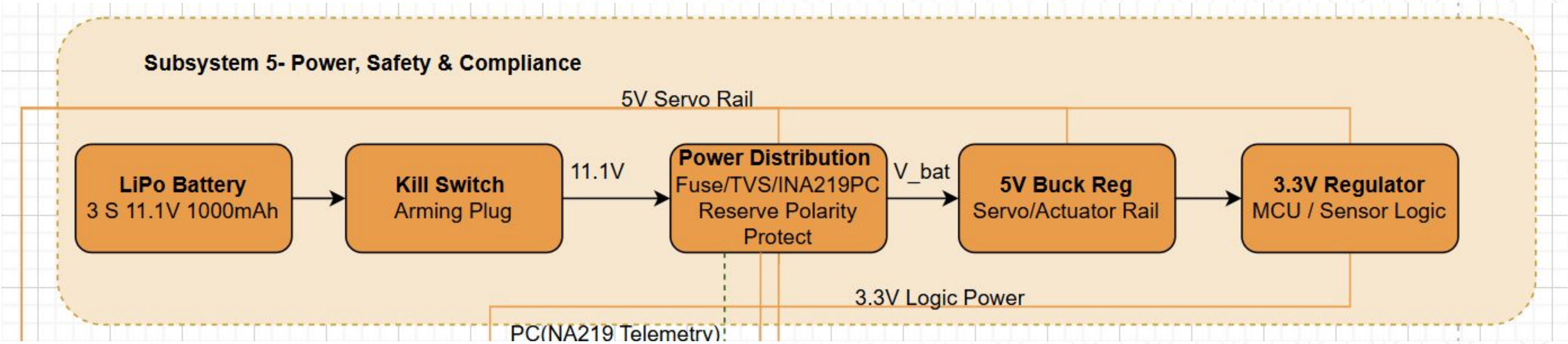




Subsystem 4 - Challenges and Solutions

- **Challenge:**
    - **Wireless safety risk** – if communication was lost, the robot could continue executing the last command.
    - **Arm control synchronization** – commanding both arm servos simultaneously caused current spikes, leading to voltage sag and ESP32 resets.
- **Solution:**
    - Implemented a **heartbeat timeout failsafe** to stop all outputs when connection is lost.
    - Used **software-staggerd servo updates** so the two servos were driven sequentially instead of at the exact same instant.

Subsystem 5 - Power Architecture



Original Design:

- 1000 µF bulk capacitor - engineering choice
- Separate logic and servo rails
- Low-voltage cutoff (9.9V)

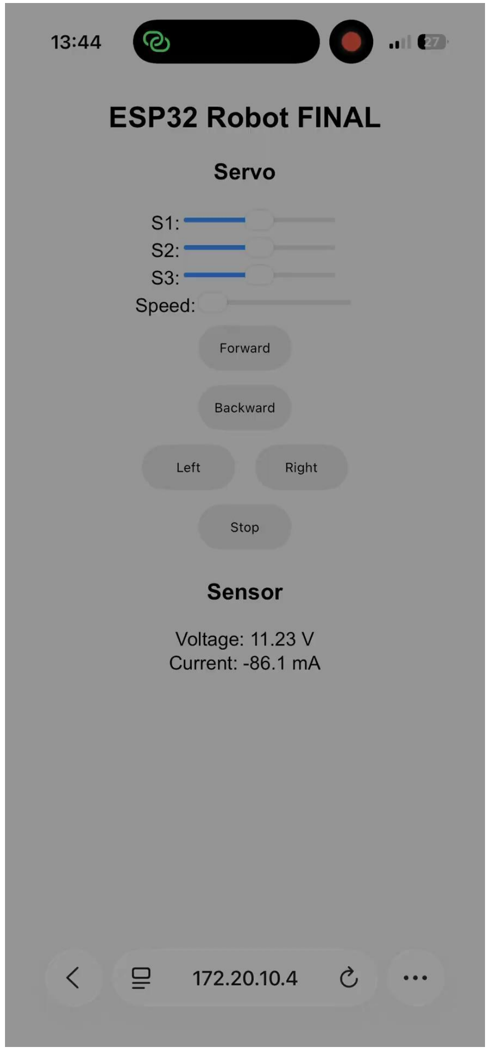
Design Changes:

- Smaller Battery to fit into the chassis
- Battery discharge rate from 15C to 35C to leave margins for higher current peak ~22A

Subsystem 5 - Verification Results

Requirements	Results
The battery power system shall supply sufficient current for all subsystems during peak operation without shutdown or brownout.	INA219 current monitor measured peak battery current of **2601** mA during simultaneous drive + servo operation with no ESP32 reset, shutdown, or brownout occurred ✓
Sufficient to run all subsystems for ≥ 2mins continuously.	Robot operated continuously for full **2-minute** test duration under active drive and actuator load with no communication loss or power interruption observed. ✓

Subsystem 5 - Verification Results



13:44

ESP32 Robot FINAL

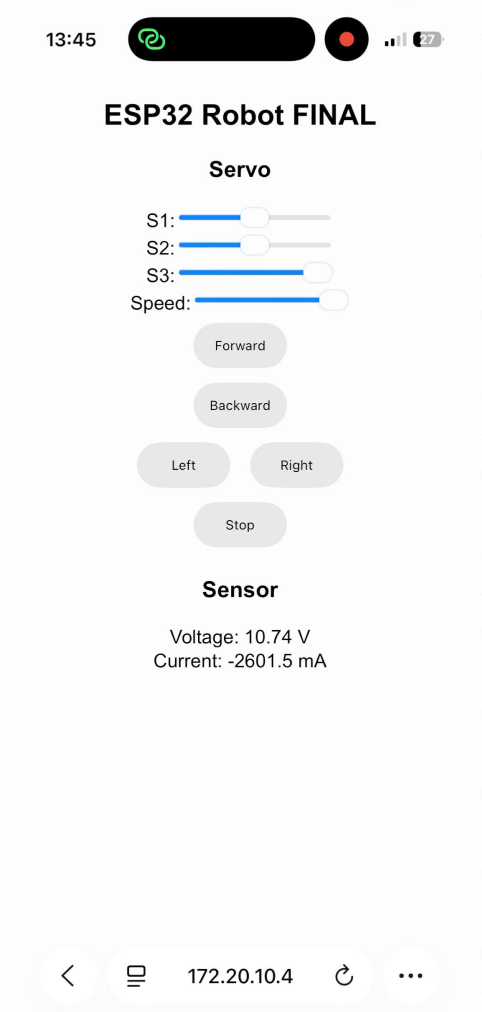
Servo

S1:
S2:
S3:
Speed:

Sensor

Voltage: 11.23 V
Current: -86.1 mA

172.20.10.4



13:45

ESP32 Robot FINAL

Servo

S1:
S2:
S3:
Speed:

Sensor

Voltage: 10.74 V
Current: -2601.5 mA

172.20.10.4

Subsystem 5 - Challenges and Solutions

- Challenge:
  - **INA219 voltage reading had limited usefulness:** Battery voltage stayed near 11.1 V during short tests, providing little insight into system loading.
  - **Mixed USB + battery power paths during debugging:** ESP32 USB power and battery power created ambiguous system states.
- Solution:
  - **Repurposed INA219 verification metric** from voltage monitoring to real-time current measurement.
  - **Standardized testing procedure**: USB for programming only, battery for full-load validation.

3. Conclusion

What We Learnt & What We Could Do Better

What We Learned

- Circuit Design
- PCB Board design / Soldering
- 3D printing / CAD design
- Hardware Implementation
- ESP32 / software implementation

What We Would Do Differently

- rearward center-of-gravity redesign
- Level up control interface design
- Detailed CAD design (especially for arms)
- Enhance PCB Design (add additional buck circuit for supporting 5 V for 2 servos)

4. Recommendations for Further Work

Recommendations for Future Works

- Improved weight distribution
- Stronger self-righting capability
- More robust claw / tail brace design
- Closed-loop control and sensing

References

Battlebots Inc., “Competition Rules and Event History,” battlebots.com, 2024.

R. Ciarcia, “Design Challenges in Small Combat Robots,” Make Magazine, vol. 78, pp. 42–49, 2023.

IPC, “IPC-2221B: Generic Standard on Printed Board Design,” 2012.

Pololu, “100:1 Metal Gearmotor 37Dx73L mm 12V with 64 CPR Encoder (Helical Pinion),” pololu.com, product #4755.

DSSERVO, “DS3218 datasheet (Product datasheet, DS3218),” dsservo.com, 2018-07-30.

Espressif, “ESP32-WROOM-32E Datasheet,” espressif.com, v1.2, 2023.

Texas Instruments, “INA219 Bidirectional Current/Power Monitor Datasheet,” ti.com, SBOS448G, 2015.

Pololu, “Pololu 30T Track Set - Black,” pololu.com, product #3033.

Pololu, “50:1 Metal Gearmotor 37Dx70L mm 12V with 64 CPR Encoder (Helical Pinion),” pololu.com, product #4753.

Thanks!