TURF

Turf Upkeep and Robotic Fieldcare

Group 20
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The Team

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Computer Engineering

Hardware and Firmware Design,
Main Board and Regulator

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Computer Engineering

Software and Firmware Design,
Mobile App Development

Andrew Koch
Electrical Engineering

Motor Subsystem

Motivation

Lawn care takes time and is costly

Mowing your lawn can waste hours of time
Paying a lawn care service is costly

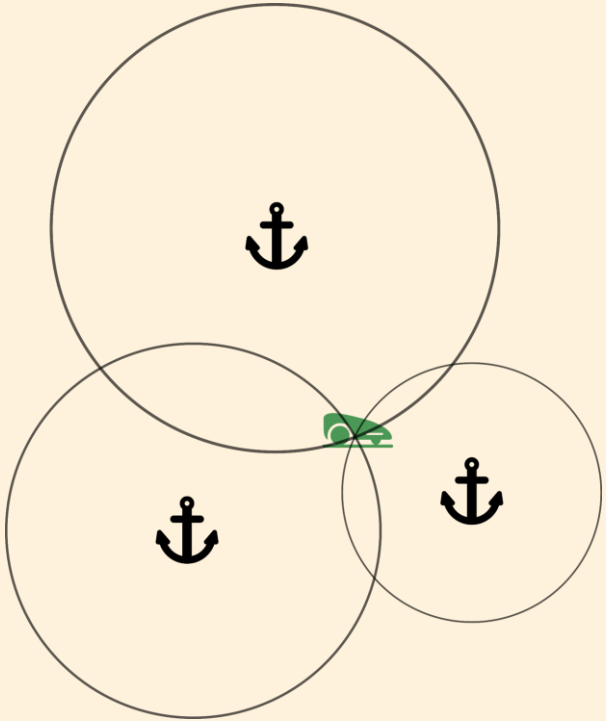
The Alternative is Expensive

Current autonomous lawn mowers are expensive to purchase and boundary wire systems incur additional setup costs

The Solution

Our solution is to build a robot using an affordable form of localization. Ultra Wideband Localization (UWB) is a cost effective and precise alternative to Global Navigation Satellite Systems (GNSS) or Light Detection and Ranging (LIDAR).

UWB localization works by measuring the roundtrip time of a message between the robot and several bluetooth anchors at known locations. Once we know how far the robot is from at least three coordinates, we can calculate its current 2D position.



Goals

Base Goals
- Develop an Affordable Autonomous Lawn Mower Capable of navigating a pre-programmed coverage area
- Implement Obstacle Detection and Emergency Stop
- Develop a Companion App

Advanced Goals
- Implement automatic docking and Charging
- Modularize the design to allow for interchangeable tools

Stretch Goals
- Enable smart scheduling and weather-aware operation (pause/resume when raining).
- Add computer vision for object detection and dynamic avoidance of pets, people, or foreign object

Objectives

Base Objectives

- Implement localization using UWB TOF (Ultra-Wide Band Time-of-Flight).
- Implement control system for propulsion, steering, and mowing motor
- Demonstrate at least 10 minutes of untethered autonomous mowing within a defined test plot.
- Use ultrasonic rangefinder to stop before obstacles
- Design and fabricate a durable, weather-resistant housing for electronics and cutting mechanism.

Advanced Objectives

- Build and demonstrate an automatic docking/charging station for the mower.
- Implement a mowing schedule (i.e. once a week the mower mows the backyard on its own)

Stretch Objectives

- Incorporate rain and weather detection to suspend mowing in unsafe conditions.
- Use computer vision (OpenCV) to detect people, pets, or foreign objects in the mowing area, and automatically modify path.

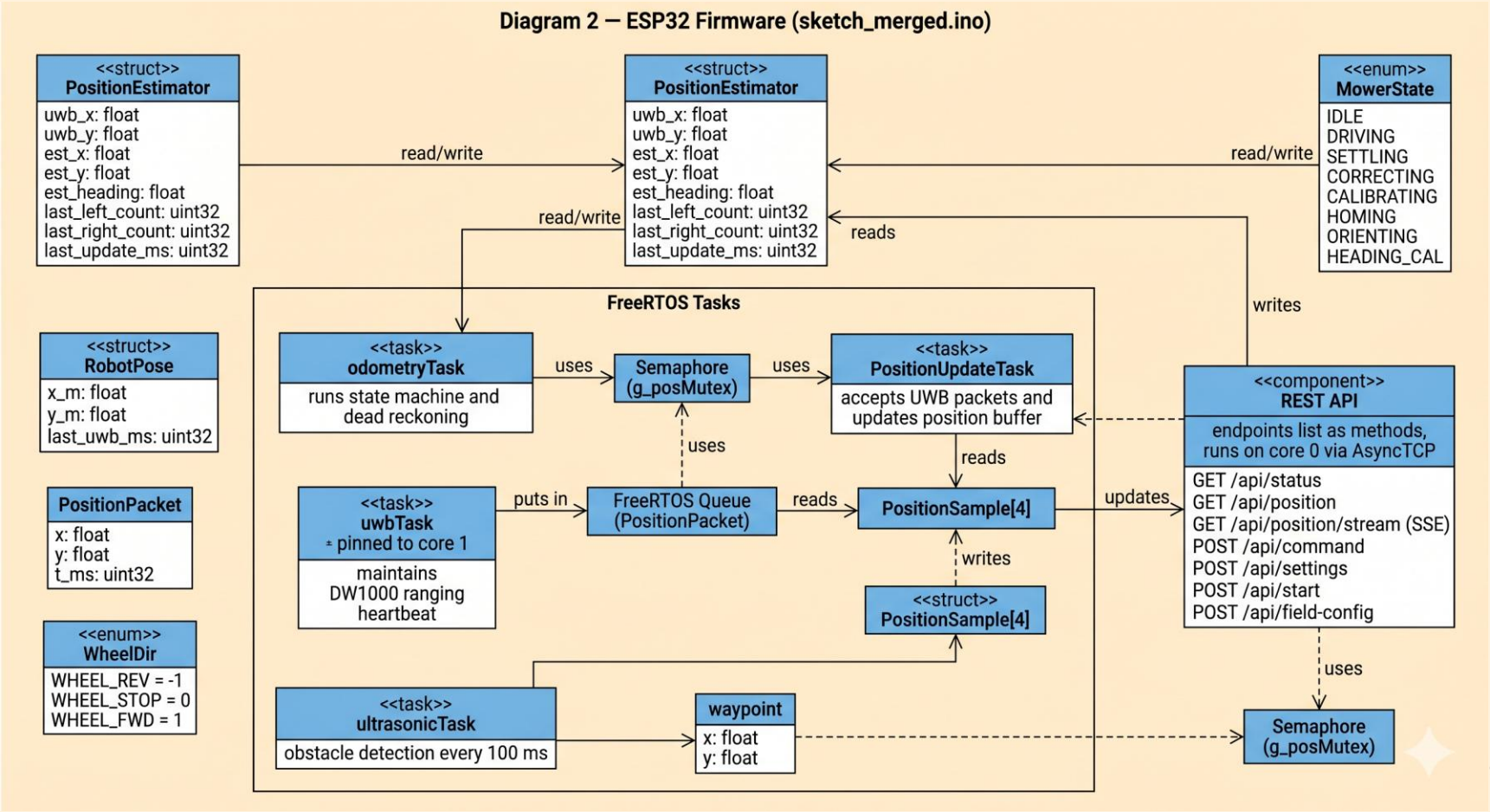
Requirements Specifications

Marketing Requirements	Engineering Requirements	Justification
The mower should be able to autonomously cover an entire home lawn.	Must implement a row-by-row coverage algorithm (boustrophedon pattern), with ≤10 cm overlap between passes	Ensures full and efficient lawn coverage without leaving uncut strips.
The mower should be able to navigate accurately across the lawn.	Position estimation error ≤20 cm relative to field anchors using UWB TOF localization	Accurate localization is necessary to keep mowing rows straight and consistent.
The mower should be energy efficient to maximize runtime.	Single charge operation time ≥30 minutes; system enters sleep mode when idle.	Allows TURF to complete a standard suburban lawn in one session. Sleep mode conserves energy when idle.
The mower should be safe to operate around people and obstacles.	Must detect obstacles 0.5m away and stop immediately	Safety for humans, animals, and equipment is critical for adoption.
The mower should be able to connect and respond to inputs from an app.	The mower should stop within 0.5s of the emergency stop in the app.	Simplifies operation for the operator and allows for wireless communication.
The mower should be affordable for small organizations (schools, clubs), and households.	Estimated BOM <$500 for prototype.	Ensures feasibility for small institutions and households with limited budgets.

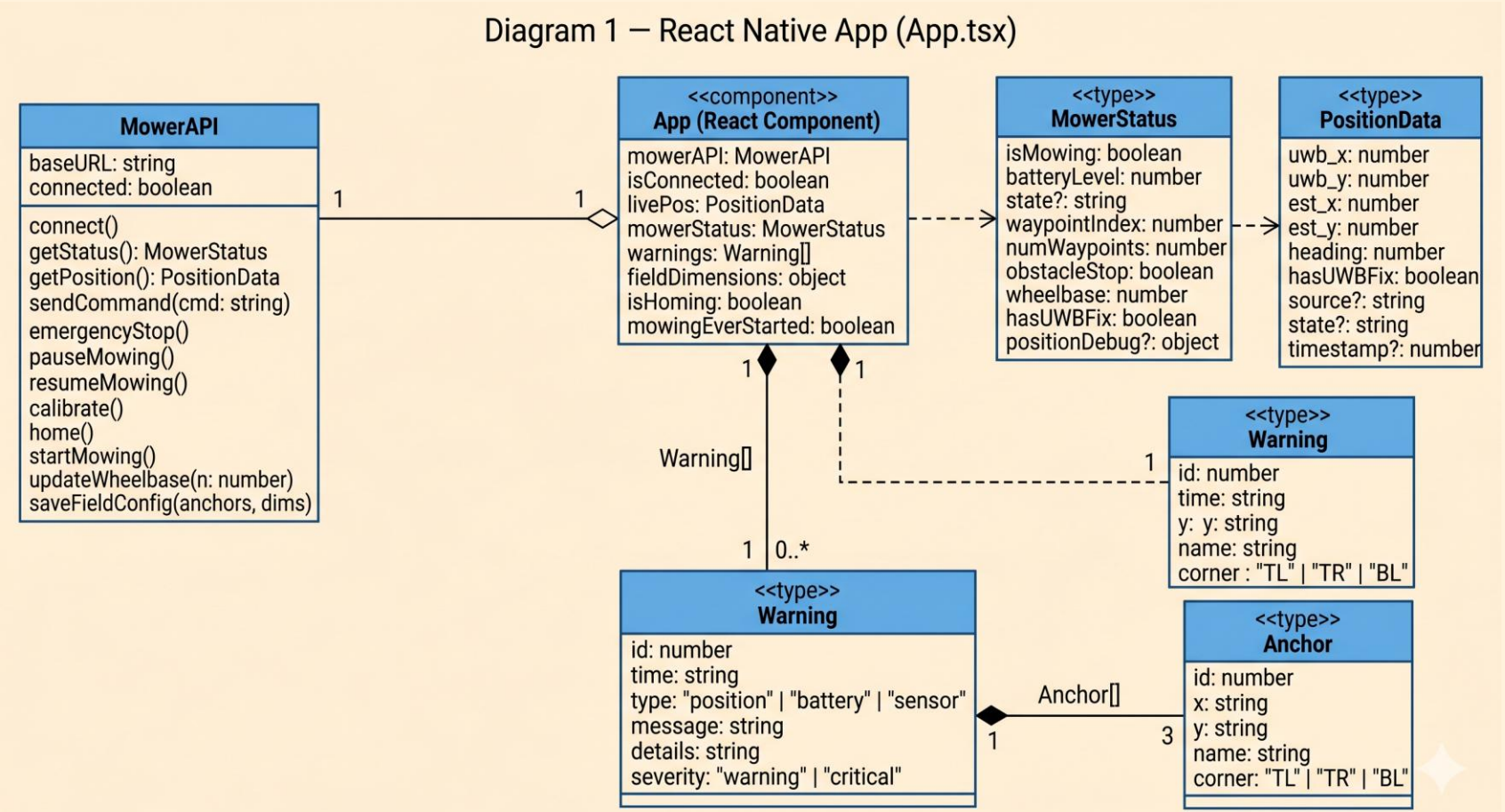
System Overview

Component	Technology Used	Functionality	Hardware
Mobile App	React Native ExpoGO EAS Build	User Interface Live Monitoring Area Visualization	Android
Firmware	C++	Motor Control Navigation Safety	ESP32 Microcontroller
Communication	Rest API (JSON)	Data Exchange	WiFi Hotspot
Positioning	Triangulation Algorithm Dead Reckoning	Locating Error Correction	GPS Anchors
Testing	Node.js	Software Simulation API Testing	Windows

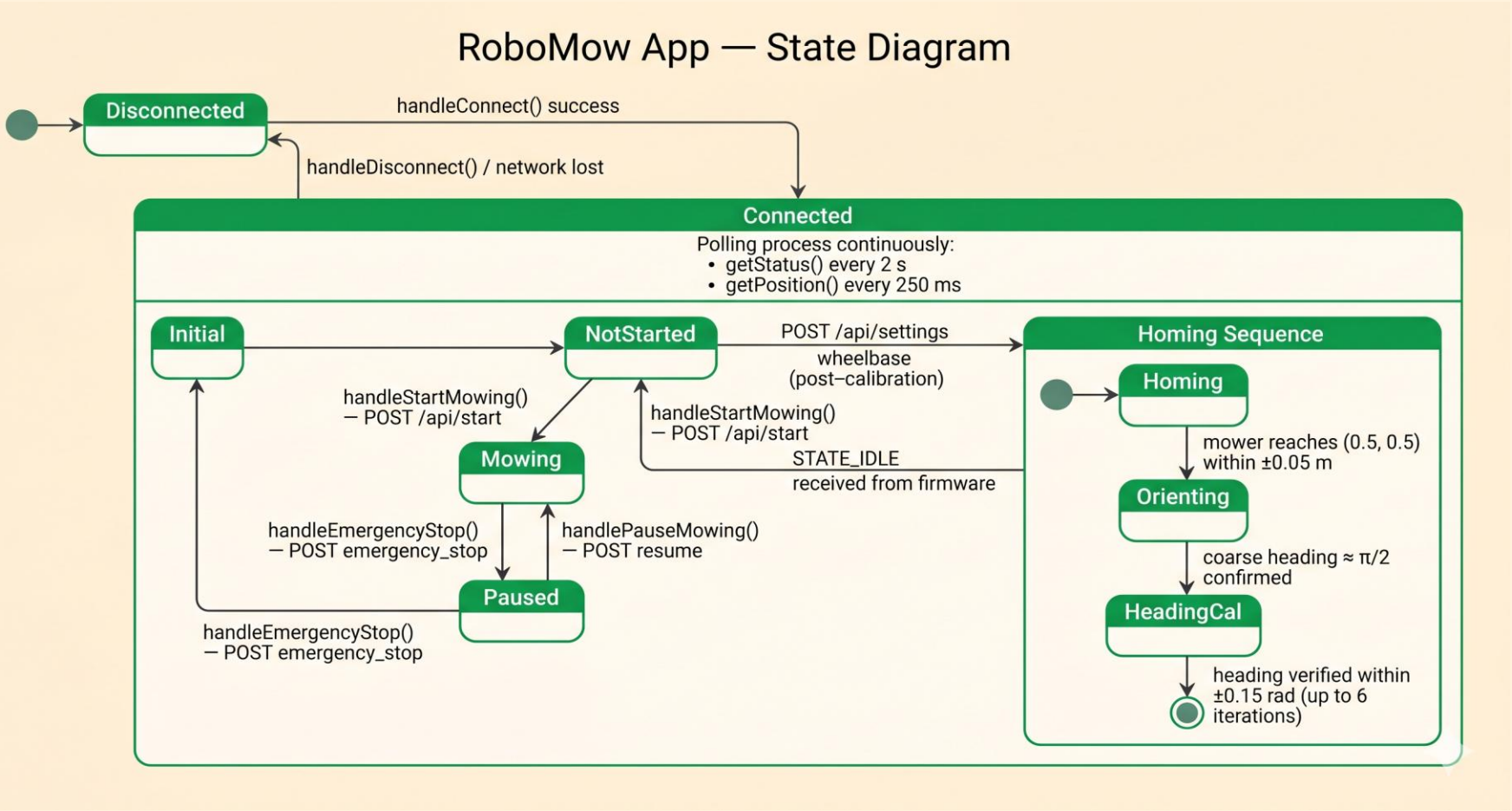
Class Diagram (Firmware)



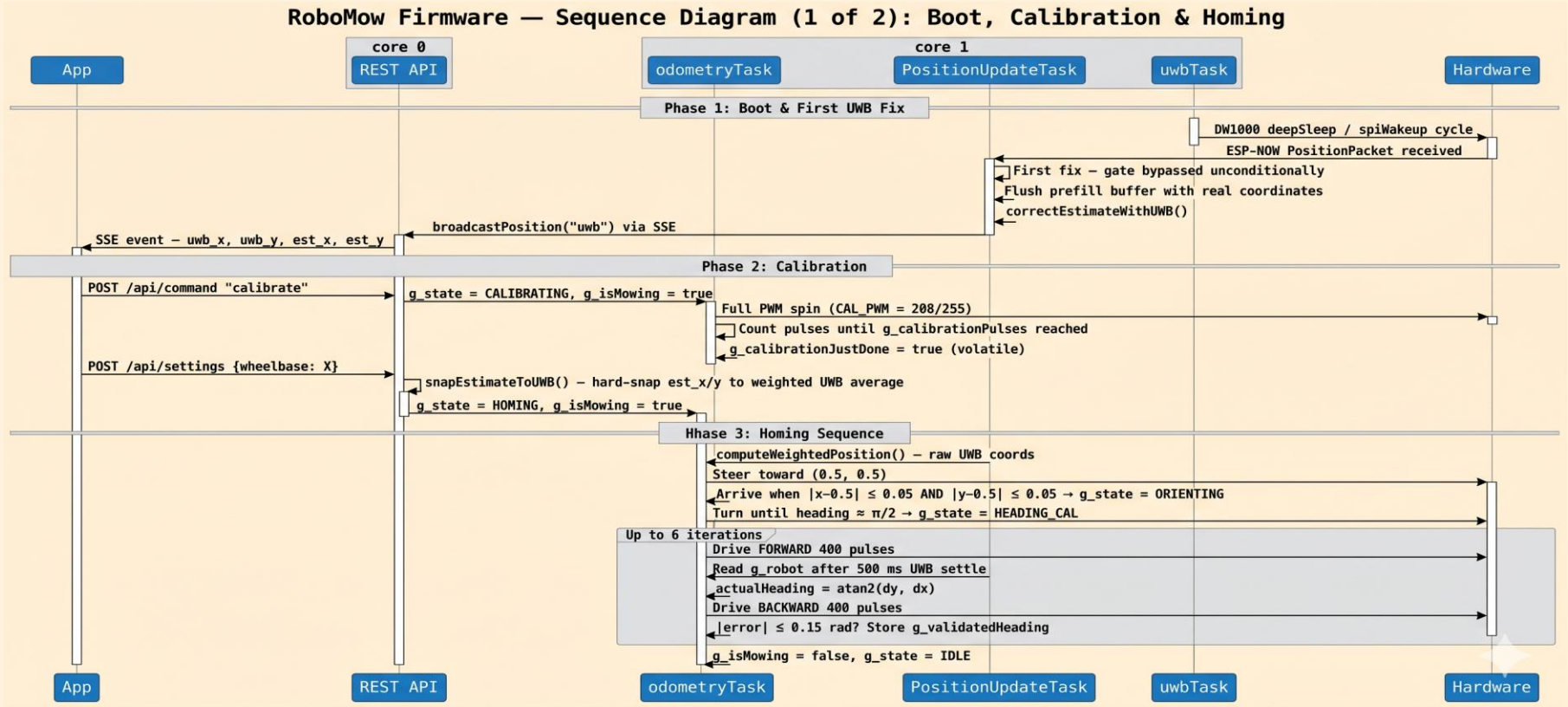
Class Diagram (Mobile App)



Software Design



Sequence Diagram



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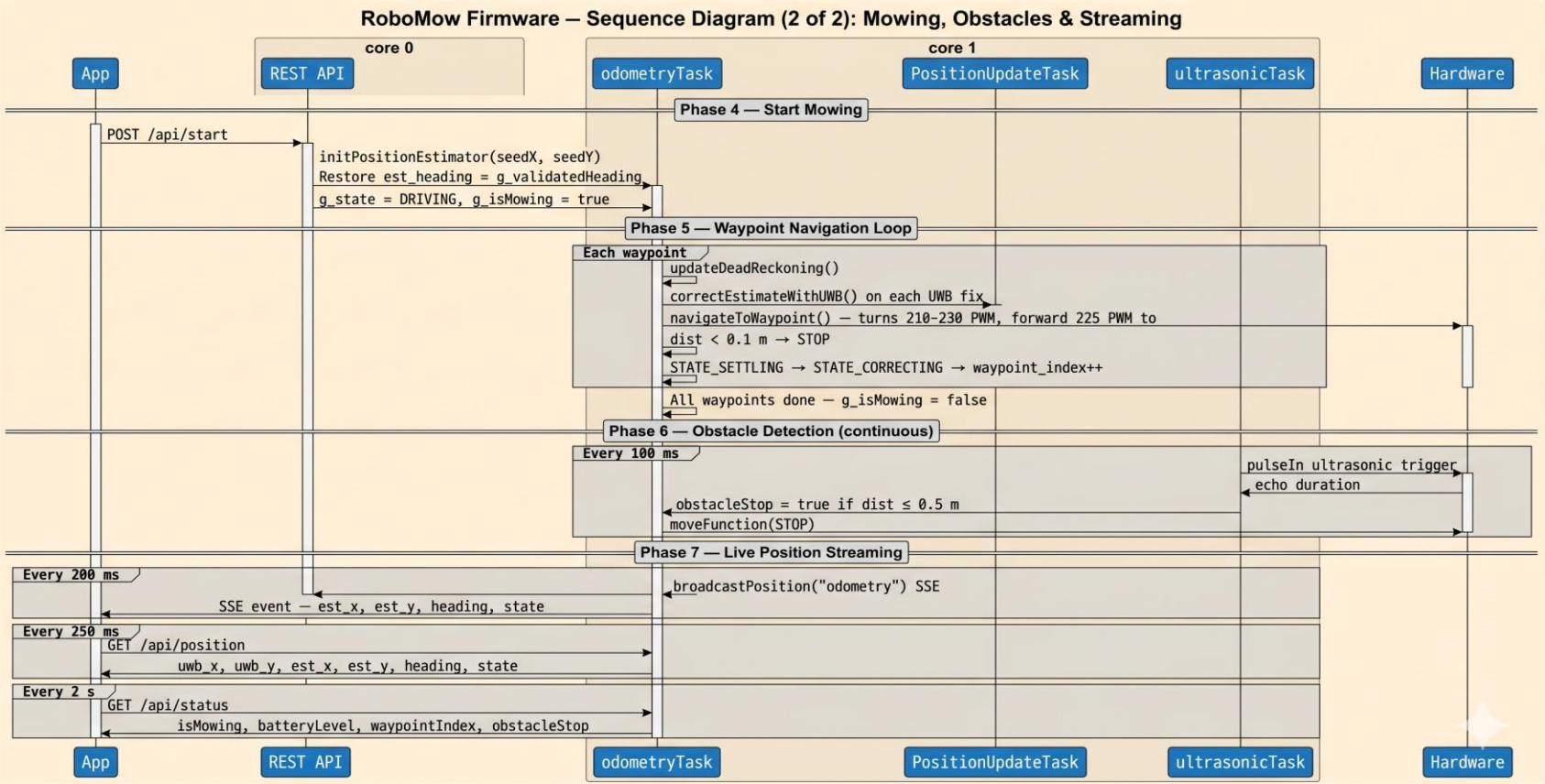


Software Test Results

Test Case	Criteria	Result	Notes
API Connection	Loading time < 2 seconds	PASS	Connection to Test Server Confirmed
Emergency Stop	Latency < 50 ms	PASS	Motor Control Stop Confirmed
Position Accuracy	Drift < 0.5 Meters	PASS	Used Dead Reckoning to Confirm Position
APK Install	Installed and Operated on Android Device	PASS	APK Downloaded and Installed
Hotspot Connection	Data Transfer Success	PASS	Tested With Windows Hotspot to Simulate ESP32

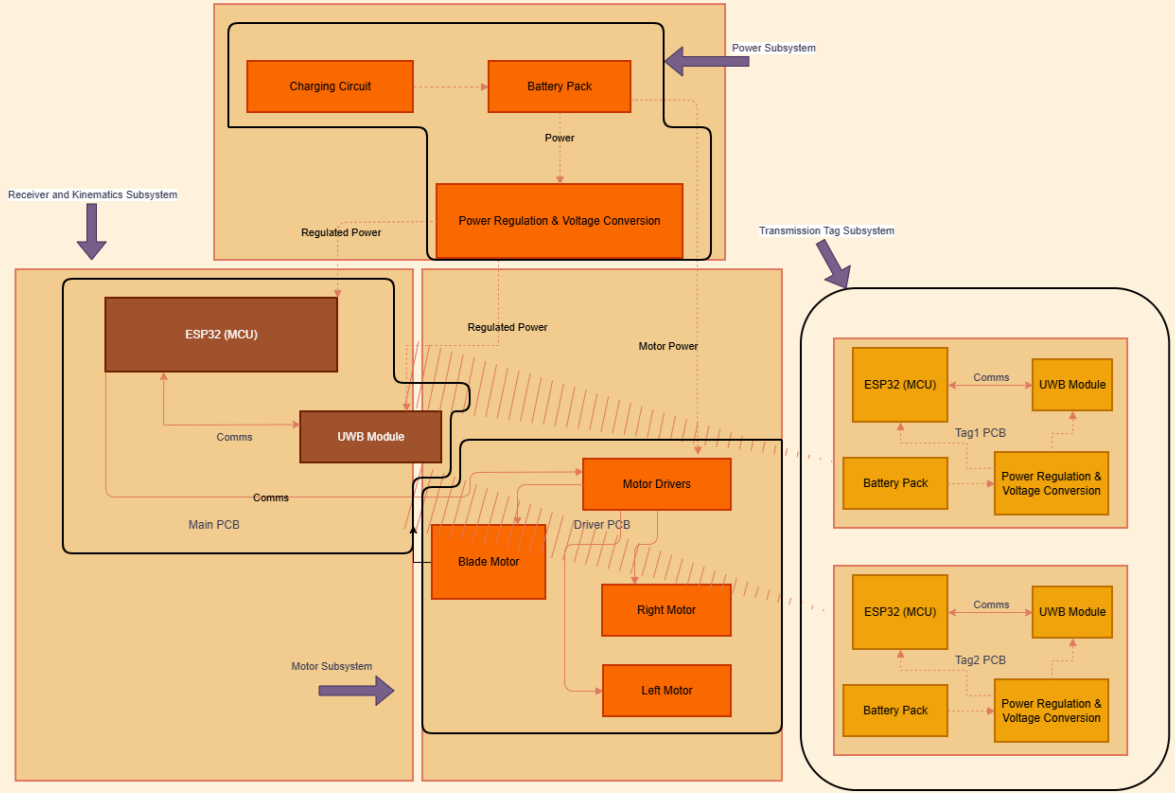
Software Selection (Firmware)

Software	Pros	Cons	Selection
ESP-IDF	Native Development Language for ESP32 Advanced RTOS features	Complex Setup Compared to Arduino	Not Selected
C++/Arduino	Direct Hardware Access via GPIO Pins JSON Library Integration Small Memory Footprint	Manual Memory Management Low Level Syntax	**Selected**
MicroPython	Simple Syntax Rapid Prototype Development	Slow Execution Compared to C++ High Memory Usage Limited Library for ESP32	Not Selected

Software Selection (Mobile App)

Software	Pros	Cons	Selection
React Native (ExpoGO)	Single Codebase for iOS and Android Development EAS Build Cloud Development Previous Experience	Dependent on ExpoGO Tools	**Selected**
Flutter	Better UI Performance Single Codebase for iOS and Android	Larger APK Sizes No Cloud Building	Not Selected

Hardware Design



Logic Processor Considerations

Technology Type	Single-Board Computers (SBCs)	Microcontrollers (MCUs)
Example Device Family	Raspberry Pi	ESP32
Processing Capability	Very High (>1 GHz multi-core CPU)	Moderate (100–300 MHz)
Power Consumption	High (5–10 W typical)	Low (<1 W)
Operating System Support	Full OS (Linux, Windows IoT)	Bare-metal / RTOS (FreeRTOS)
Hardware Integration Complexity	High – requires external RAM, storage, and I/O support	Low – single IC integration
Cost Range (USD)	$35 – $100	$3 – $15
Real-Time Performance	Non-deterministic scheduling	Deterministic scheduling
Suitability for TURF	Powerful but complex; excessive for simple real-time tasks	**Selected – meets cost and real-time requirements**

Microcontroller Selection

MCU	ESP32-WROVER-E-N16R8	ESP32-WROOM-32	ATmega328P
CPU / Clock Speed	Dual-core Xtensa @ 240 MHz	Dual-core Xtensa @ 240 MHz	8-bit AVR @ 16 MHz
Flash / RAM	16 MB Flash / 8 MB PSRAM	4 MB Flash / 520 kB SRAM	32 KB Flash / 2 KB SRAM
Wireless Connectivity	Wi-Fi + BLE	Wi-Fi + BLE	None (requires external)
RTOS Support	Native FreeRTOS	Native FreeRTOS	Limited
Approx. Cost (USD)	$7 - $8	$5–6	$2–3
Strengths	High performance, large memory, multitasking	Proven platform, inexpensive	Low cost, easy to program, mature ecosystem
Limitations	Slightly higher cost	Limited RAM; unsuitable for heavy concurrent tasks	Insufficient performance, no wireless
Suitability for TURF	**Selected – meets all performance and integration needs**	Acceptable fallback option	Unsuitable

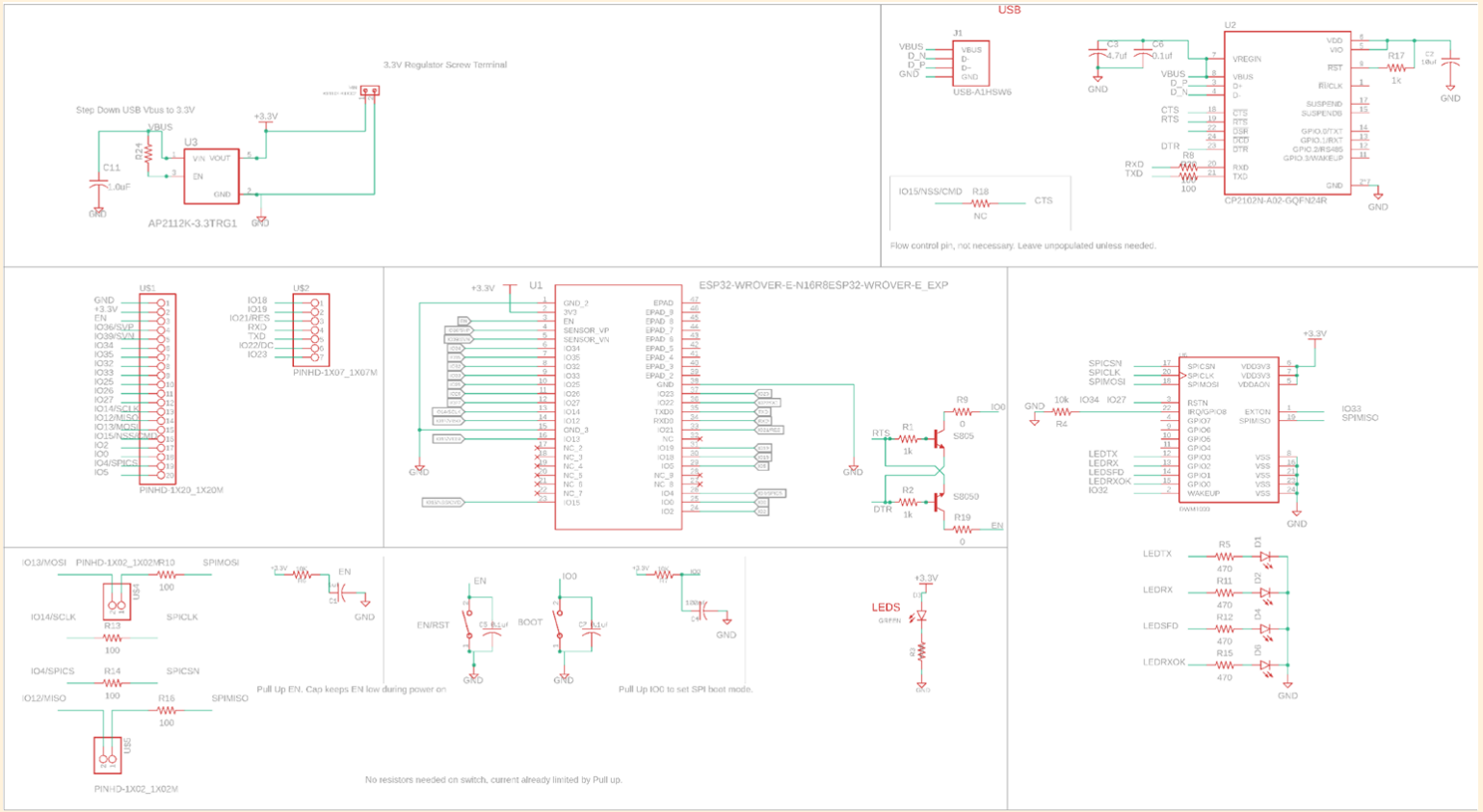
Localization Method Considerations

Parameter	Dead Reckoning	GNSS / GPS	Ultra-Wideband (UWB)
Principle of Operation	Integrates encoder and IMU motion data	Satellite based	Time-of-Flight ranging between fixed anchors and mobile tag
Accuracy	Low (drift accumulates over time)	Moderate (1–3 m typical)	High (<10 cm typical)
Infrastructure Requirement	None	None (requires satellite access)	Requires ≥ 3 anchors within range for triangulation
Cost Level	Low	Medium	Medium–High (cost increases with larger areas and more anchors)
Strengths	Simple implementation; low hardware overhead	Wide coverage; global positioning	Centimeter-level precision; reliable short-range positioning
Limitations	Cumulative error; unreliable for long durations	Not precise enough for lawn boundaries	Limited range; requires fixed anchor network
Suitability for TURF	Supplementary only (for short-term estimation)	Unsuitable for fine-grained navigation	**Selected – provides required precision for confined fields**

UWB IC Selection

IC	Standard	Accuracy	Power	Cost	Ecosystem Maturity	Suitability
DW1000	IEEE 802.15.4-2011 UWB	10cm	Low	$9	HIgh	**Selected – best cost and community support**
DW3000	IEEE 802.15.4z UWB	10cm (greater interference resistance)	Very Low	$10	Low	Potential for future system upgrades / iterations

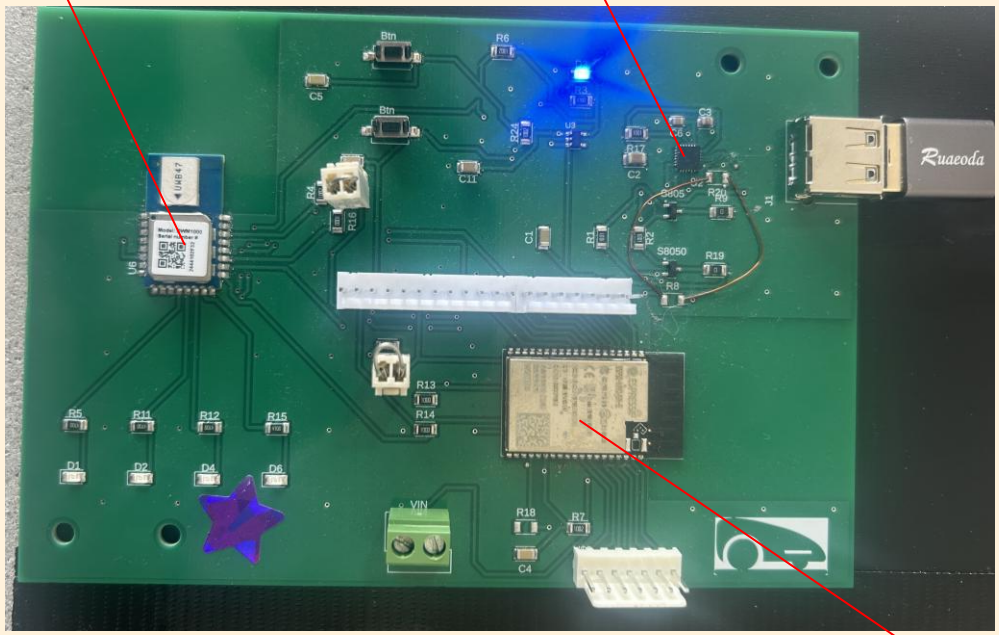
Main PCB Design



Main PCB Design

DW1000 UWB Module

CP2102 USB to UART Bridge



The Main Board is used for both the robot and for anchors

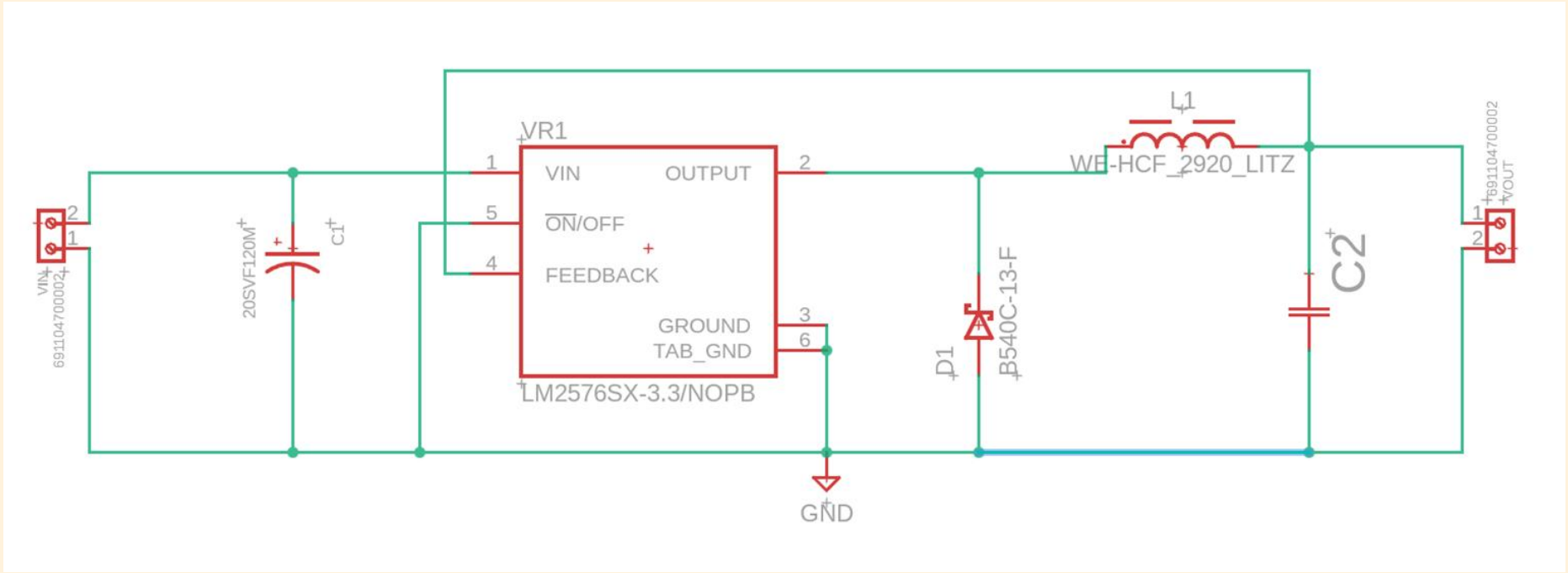
- Reduces development and Testing time
- Marginally increases costs.

ESP32-WROVER

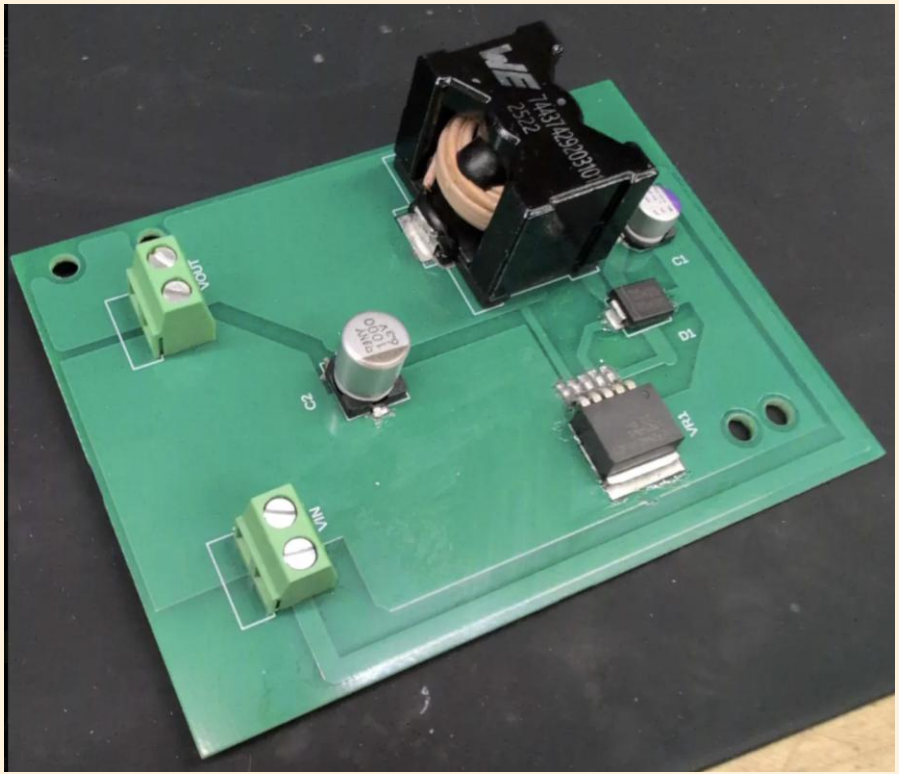
3.3V Regulator Selection

IC	Efficiency	Frequency	Suitability
LMR60440	88.1%	2.15 MHz	Not suitable. Switching Frequency too high.
LM2576	80.5%	52 kHz	**Selected for lower switching frequency and better stability**

3.3V Regulator Selection



3.3V Regulator Selection



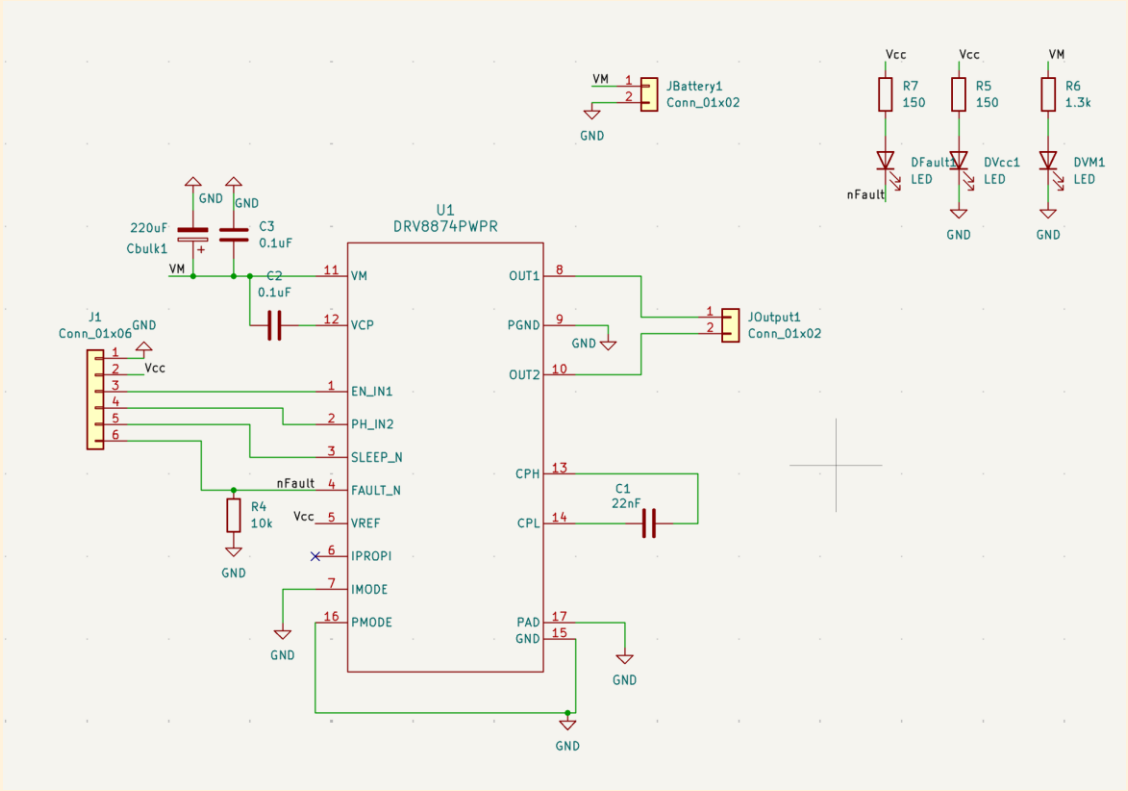
Motor Considerations

Motor Type	Brushed DC Motor	Brushed DC Motor with Hall Sensors	Brushless DC (BLDC) Motor	Stepper Motor
Control Method	PWM (open-loop)	PWM + feedback	Electronic commutation	Step/direction (open-loop)
Feedback Capability	None	Velocity & direction	Integrated (electronic)	Implicit step counting
Strengths	Simple, low cost, high torque	Enables closed-loop control	Efficient, long lifespan	Precise positioning no encoder needed
Limitations	No speed feedback; brush wear over time	Slightly higher cost and wiring complexity	Complex drivers, excessive for low-speed use	Low efficiency, higher current draw
Suitability for TURF	Good baseline but imprecise	Selected. Cost-effective, high precision	Suitable for high-end or future expansion	Unsuitable for battery-powered mobile platforms

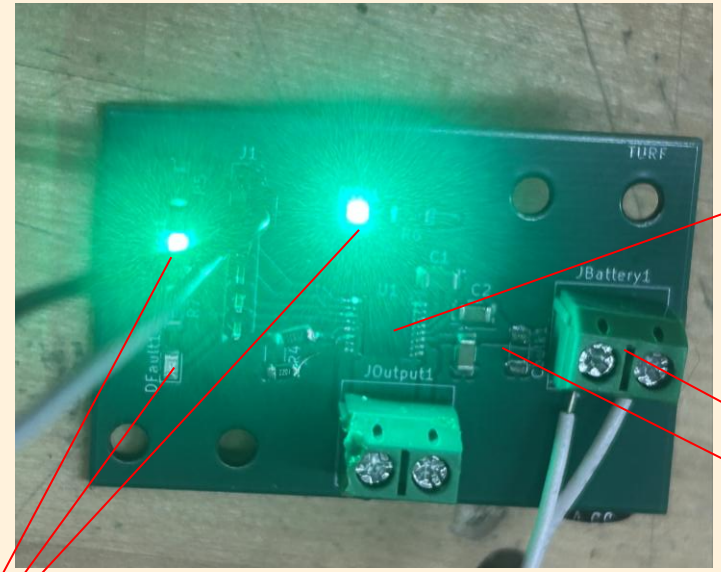
Motor Driver Selection

Feature	DRV8874	L6206
Supply Voltage	4.5–37 V	8–52 V
Control Interface	PH/EN or PWM	IN1/IN2 logic inputs
Protections	UVLO, OCP, TSD, charge-pump UV	OCP, TSD, cross-conduction protection
Efficiency	High (low RDS(on))	Moderate (higher RDS(on))
Integration Level	High	Moderate
Ideal Use	**Selected – Best for 12 V robotics, efficient drive**	Higher-voltage

Motor Driver Schematic



Motor Driver PCB Design



DRV8874 Motor Driver

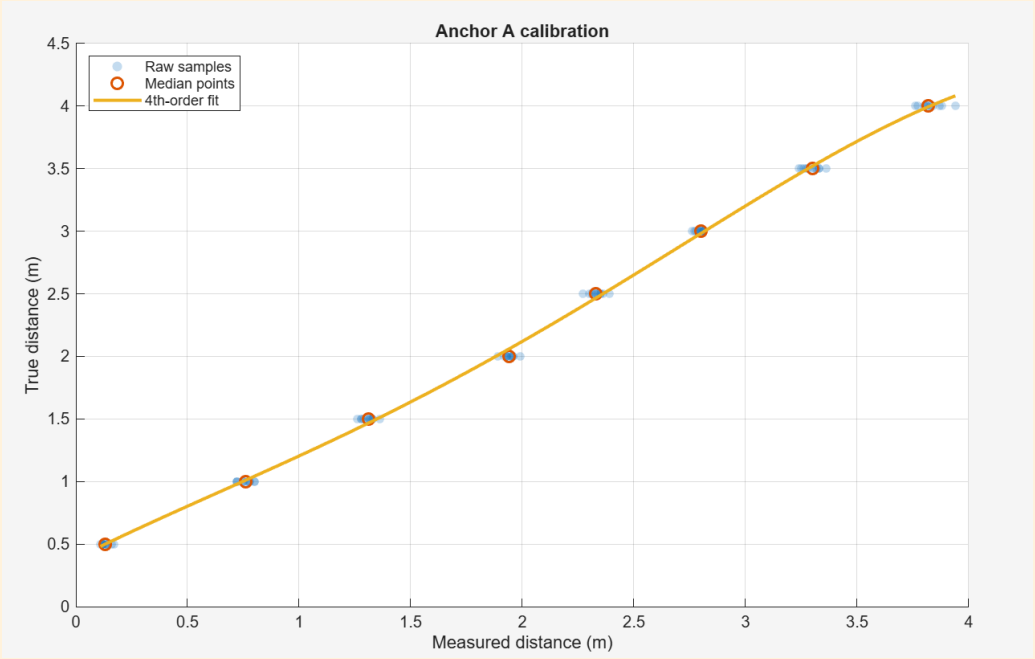
Battery Input &
Decoupling Capacitors

Test LEDs

Hardware Testing and Performance Evaluation

- The robot has been assembled and all components integrated
- We have tested the robot's ability to localize itself according to the UWB poles and navigate a pre-defined grid in a boustrophedon pattern

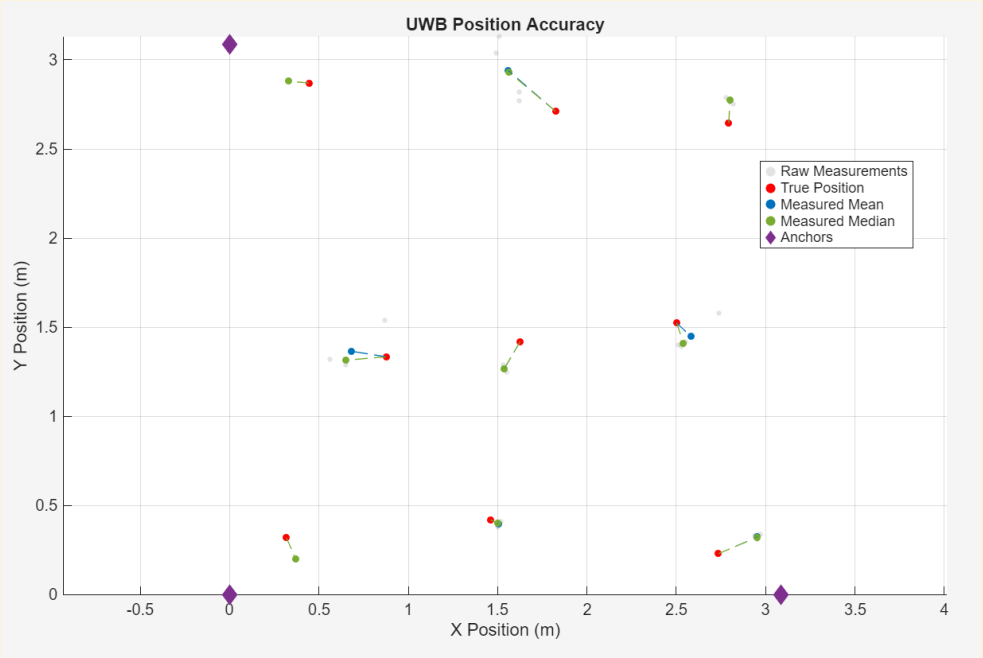
Ultra-Wideband Performance Calibration



- The UWB System is precise, but not accurate. To compensate, the robot was moved between 0m and 4m from an anchor at intervals of 0.5m.
- Eleven randomly selected measurements were taken at each point and recorded.
- The values were then plotted, and a best fit function was found, where f(measured distance) = true distance.
- This was repeated for all three anchors
- The resulting correction functions produced Root Mean Square Errors as follows:

  Anchor A: 0.0286 m
  Anchor B: 0.0246 m
  Anchor C: 0.0270 m

Ultra-Wideband Performance Calibration



- After calibration, the localization system was tested.
- 9 locations were chosen on a 3m x 3m test grid, and 4 measurements were taken at each location.
- This plot shows the collected information. We can see one location of decreased accuracy at the top center. This was likely due to a large metal object near that point.
- Root Mean Square Errors were calculated on the Mean and Median Values. The obtained values are as follows:

  Mean RMSE: 0.1850 m
  Median RMSE: 0.1873 m

Budget and Costs

Item	Unit Price	Quantity	Total Cost
ESP32-WROVER-E	$6.13	4	$24.52
DWM1000	$23.62	4	$94.48
Chassis	$19.17	1	$19.17
PCBs (with Shipping)	NA	NA	$149.85
Miscellaneous Parts	NA	NA	$186.82
Sub Total (Before Tax and Tariffs)			$474.84
Total after Taxes and Tariffs			$512.78

Our Budget is $1000, with the goal of a final Prototype costing less than $500.

Current Total Cost reflects the purchase of many spare parts.

Work Distribution

Task	Team Member
Mobile App Development	Samuel Eisert
Microcontroller Firmware	Samuel Eisert Aryan Tulsi Andrew Koch
Main Board Development	Aryan Tulsi
Regulator Board Development	Aryan Tulsi
Motor Driver Board Development	Andrew Koch

Main PCB
Enables movement and UWB localization

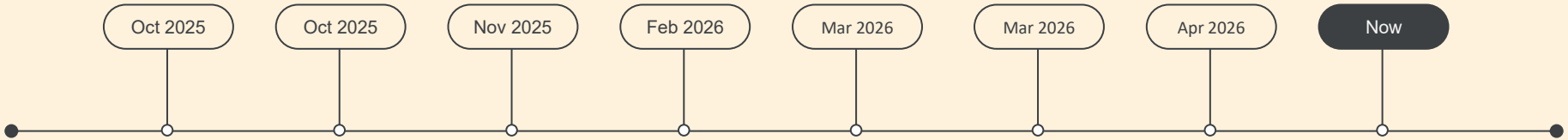
Voltage Regulator
Provides 3.3V output for the ESP32

Tracked Wheels
Improves traction on different surfaces

Motor Drivers
Converts 3.3V logic pulses to 12V

Ultrasonic sensor
Enables safety stop feature

Progress and Milestones



System Architecture Finalized

Complete hardware block diagram, software flowchart, and finalized engineering specifications

Component Selection

All major components (MCU, sensors, actuators, power system, communication modules) selected

Breadboard prototyping

Motor system, MCU integration, localization modules tested

PCBs and Parts Ordered

Orders have been placed

PCBs Assembled and Testing Begins

PCBs assembled and are integrated with breadboards

Software Ready for Integration

Software design is complete and ready to be integrated with the system

Hardware & Firmware Integration & Testing

Everything is soldered and connected. Software is uploaded

Preparations for Final Demo

Minor debugging and calibrations. Preparing our presentation to the reviewers.