TURF

Turf Upkeep & Robotic Fieldcare

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1. Motivation and Potential Applications

There is an increasing demand for automated solutions to household and commercial lawn care. While there are many robotic lawn mowers on the market, existing models remain limited in capability, often relying on expensive boundary installations or requiring frequent user intervention. Additionally, many are cost-prohibitive for average homeowners and small businesses. We seek to address these challenges by developing a low-cost autonomous lawn mower capable of navigating defined boundaries with minimal setup and operating safely and independently in outdoor environments. By integrating GPS-based or wireless perimeter enforcement and obstacle detection the system will provide a versatile platform for small-scale land management. This, along with a modular design and potential for automated docking, will allow the mower to function reliably without constant user interaction.

The motivation for this project lies in the broad range of individuals and industries that rely on regular grounds maintenance. Homeowners often spend significant time and resources mowing their lawns, while landscaping companies face rising labor costs and inefficiencies in routine maintenance. Beyond residential use, commercial and municipal applications exist in maintaining schoolyards, parks, athletic fields, and office campuses where consistent lawn care is essential for safety and aesthetics. A compact, low-cost, and customizable autonomous mower will create an alternative to expensive commercial systems and allow a wider range of users to access robotic lawn care technology.

Potential applications of our proposed design extend beyond simple lawn mowing. As autonomy and sensor technologies continue to improve, the rover could be adapted for related outdoor tasks such as garden maintenance, targeted watering or fertilization, and even environmental monitoring. By focusing on modularity and open-source design, our project seeks to fill a gap in the market for affordable, adaptable, and safe robotic lawn care systems that can scale from personal use to broader community applications.

2. Goals and Objectives

2.1. Goals

Basic Goals:

- Develop an autonomous rover capable of navigating within a defined lawn area.
- Implement path following and boundary enforcement
- Enable obstacle detection and emergency stop for safety.

Advanced Goals:

- Incorporate efficient path planning to optimize mowing coverage.
- Integrate real-time monitoring through a mobile/web interface (battery, status, and location).
- Implement automatic docking and charging functionality.
- Modularize the design to allow interchangeable tools (e.g., mower deck, trimmer head, or utility attachment).

Stretch Goals:

- Add computer vision for object detection and dynamic avoidance of pets, people, or foreign objects.
- Enable smart scheduling and weather-aware operation (pause/resume during rain).
- Add AI-based object recognition to allow cataloging of observed wildlife.
- Incorporate mapping features to log coverage areas for multi-session mowing.

2.2. Objectives

Basic Objectives:

- Design and fabricate a durable, weather-resistant housing for electronics and cutting mechanism.
- 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.

Advanced Objectives:

- Implement optimized path coverage algorithms to minimize missed or repeated areas.
- 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)

- Use ultrasonic rangefinder to stop before obstacles

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.

3. Requirement 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 ≥1 m away and stop within ≤0.5 m of obstacle.	Safety for humans, animals, and equipment is critical for adoption.
The mower should be easy to recharge and maintain.	Automated docking station for charging and clippings disposal; recharge time ≤10 hours.	Simplifies operation and maintenance for groundskeepers.
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.

Table 1: Requirement Specifications

Achieving these specifications is important to ensure the functionality of our system and its ability to complete tasks. Three specifications that we will be able to demonstrate in testing are the positional error, obstacle recognition, and automated docking and charge time as these are quantifiable measurements.

4. Previously Existing Products

Robotic lawn mowers have become increasingly common in recent years, with major brands such as Husqvarna, Worx, and Gardena offering consumer models (Husqvarna, 2025) (Worx, 2025). Most of these systems rely on boundary wires to define the mowing area, requiring lengthy installation and limiting flexibility if the yard layout changes. More advanced models integrate GPS navigation to remove the need for wires, but these still face issues with accuracy under tree cover or near buildings.

One of the main drawbacks of existing robotic mowers is their high cost. Entry-level models typically start around $800–$1,000, while higher-end systems with GPS guidance and larger battery capacity can exceed $3,000–$5,000. These prices make them inaccessible for many homeowners despite the convenience they offer.

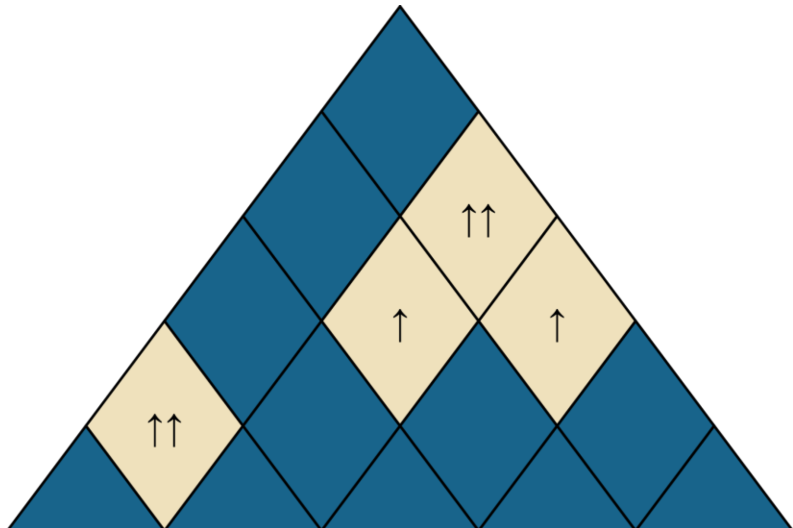
Our system is designed to provide similar automation benefits at a lower cost, while improving accuracy and adaptability compared to traditional boundary-wire solutions.

5. Engineering-Marketing Tradeoff Matrix

		Coverage Algorithm Accuracy (minimize overlap)	Localization Accuracy (minimize error)	Operation Time	Obstacle Detection	Docking and self-Maintenance
		–	–	+	+	+
1. Coverage	+	↑	↑	↑↑		↑↑
2. Mow Quality	+	↑	↑			↑
3. Time Efficiency	+	↑↑	↑↑			↑↑
4. Safety	+				↑↑	
5. Maintenance	–				↑	↑↑
6. Affordability (cost)	–	↓	↓	↓↓	↓	↓↓

Table 2: Tradeoff Matrix

6. House of Quality



		Coverage Algorithm Complexity	Localization Accuracy	Operating Time	Obstacle Detection	Docking and self-Maintenance
		−	−	+	+	+
1. Coverage	+	↑	↑	↑↑		↑↑
2. Mow Quality	+	↑	↑			↑
3. Time Efficiency	+	↑↑	↑↑			↑↑
4. Safety	+				↑↑	
5. Maintenance	−				↑	↑↑
6. Affordability (cost)	−	↓	↓	↓↓	↓	↓↓
Engineering Targets		≤10 cm overlap	≤20 cm error	≥30 min	≥1 m	0

Table 3: House of Quality

7. Hardware Diagram

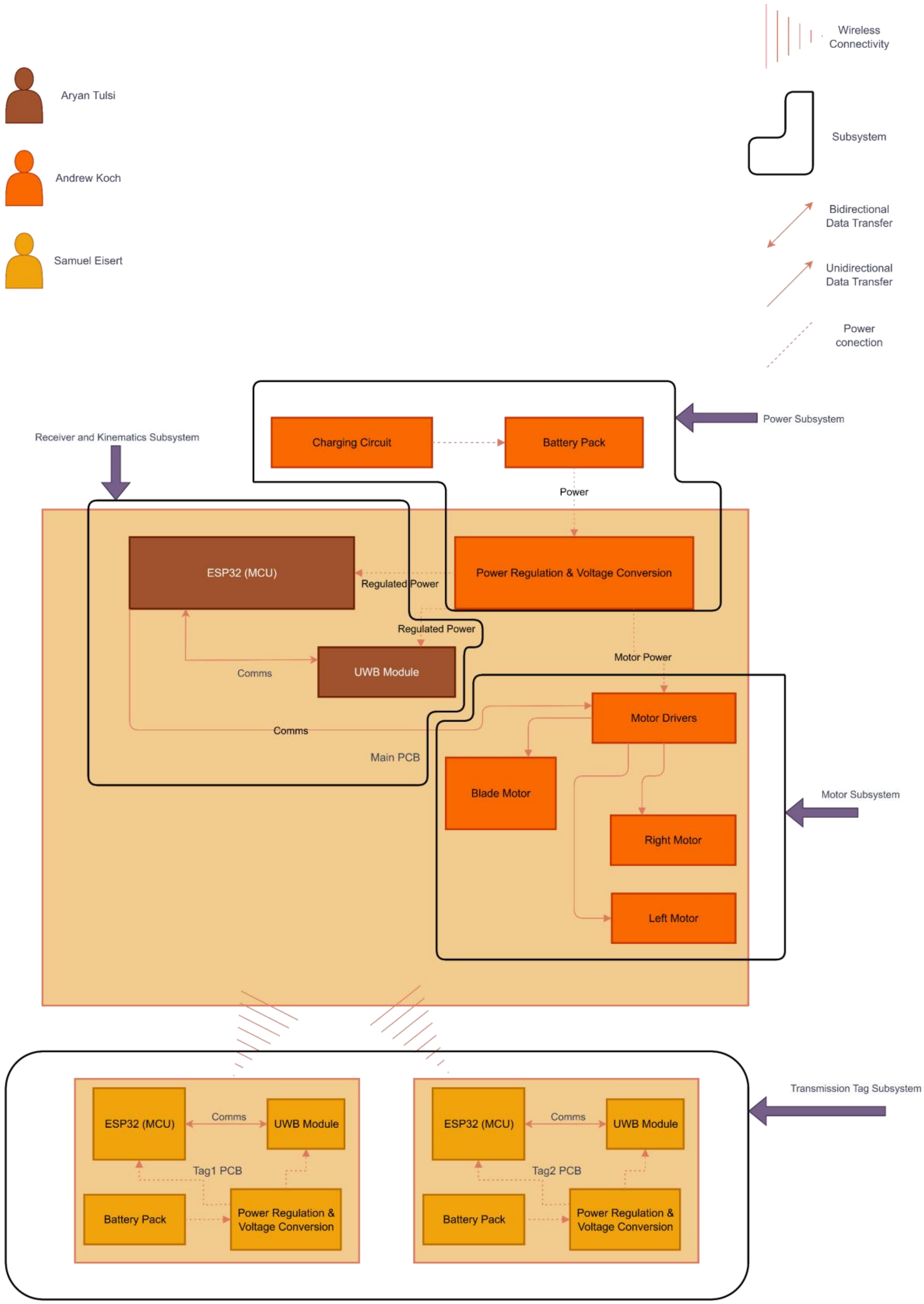


Figure 1: Hardware Diagram

The TURF system hardware shown in Figure 1, is divided into 4 main subsystems. The main mower PCB contains the Power, Receiver and Kinematics, and Motor subsystems. The anchor tag PCBs used for localization are considered their own subsystem.

At the core of the mower is the Main PCB, which integrates several critical components. An ESP32 microcontroller serves as the central processor, handling communication, localization, and control logic. A dedicated UWB module provides time-of-flight ranging capabilities to enable accurate localization relative to the external anchor tags. The PCB also includes motor driver circuits, which receive velocity commands from the ESP32 and regulate power delivery to the wheel motors and blade motor. Power is managed through a regulation and voltage conversion stage, which ensures that the ESP32, UWB module, and drivers receive stable, appropriate supply rails.

Externally connected to the PCB are the battery pack and the charging circuit, which together provide energy storage and replenishment. The battery supplies power through the regulation stage, while the charging circuit manages safe recharging during docking. The regulated outputs supply the ESP32, UWB module, and motor drivers.

In addition to the main mower board, the system includes two independent Tag PCBs placed at fixed locations in the environment. Each tag contains its own ESP32, a UWB module, a battery pack, and a power regulation stage. These tags communicate with the mower’s UWB module to exchange ranging pulses, allowing the mower to calculate its two-dimensional position. The tags are battery powered and are designed to operate with low-duty cycles, conserving energy by sleeping when the mower is inactive.

8. Software Diagram

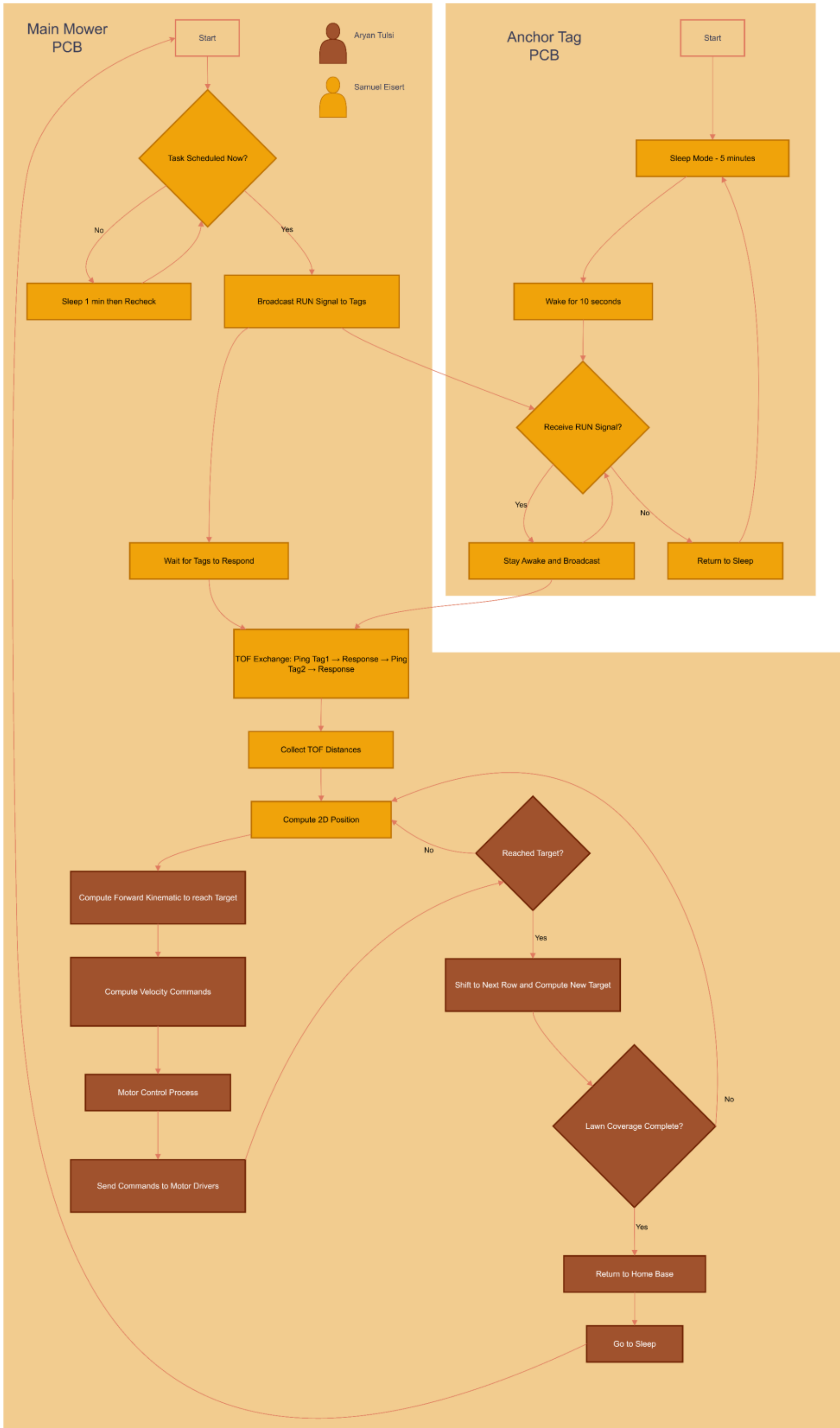


Figure 2: Software Diagram

The TURF system software shown in Figure 2, is divided into two cooperating components: the **anchor tags** and the **mower controller**.

The **anchor tags**, which are battery-powered, operate in a low-power cycle to conserve energy. Each tag remains in sleep mode for five minutes and then wakes for a ten-second listening period. During this window, the tags check for a RUN signal broadcast from the mower. If no signal is detected, they return to sleep; if the mower is active, they remain awake and continue broadcasting until the mower stops. This strategy balances responsiveness with extended battery life.

The **mower software** manages task scheduling, localization, navigation, and coverage. At startup, the mower checks whether a task is scheduled for the current time. If no task is present, it enters a one-minute sleep interval before rechecking. When a task is due, the mower broadcasts a RUN signal to wake the tags and waits for confirmation. Once communication is established, the mower initiates a time-of-flight (TOF) exchange: it sequentially pings each tag, collects the return signals, and computes its position based on the known anchor locations.

Using this localization data, the mower passes its position into the navigation process, which calculates velocity commands via the navigation stack. These commands are processed by the motor control system and translated into actuation signals for the motor drivers. The mower then advances toward its target.

At each step, the system verifies whether the target point has been reached. If not, the localization and navigation cycle repeats to refine movement until the target is achieved. Once a row is complete, the mower shifts laterally by one body width and continues in the opposite direction, following a boustrophedon coverage pattern. This process repeats until the entire lawn is covered. At the end of the task, the mower navigates back to its home base, docks for recharging and clipping disposal, and transitions into sleep mode until the next scheduled task.

9. Prototype Illustrations[1]

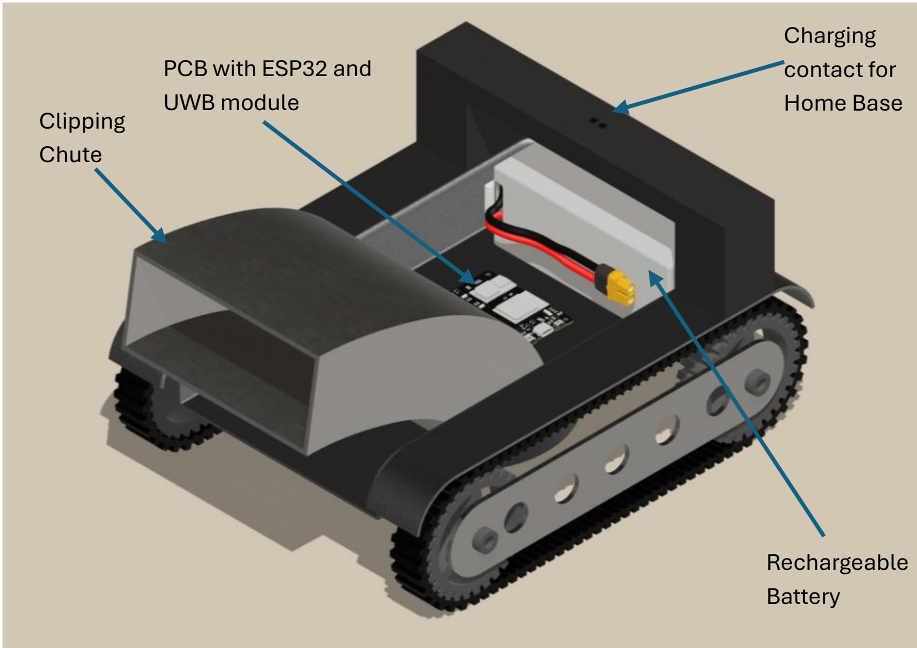


Figure 3: Top-Front-Left View

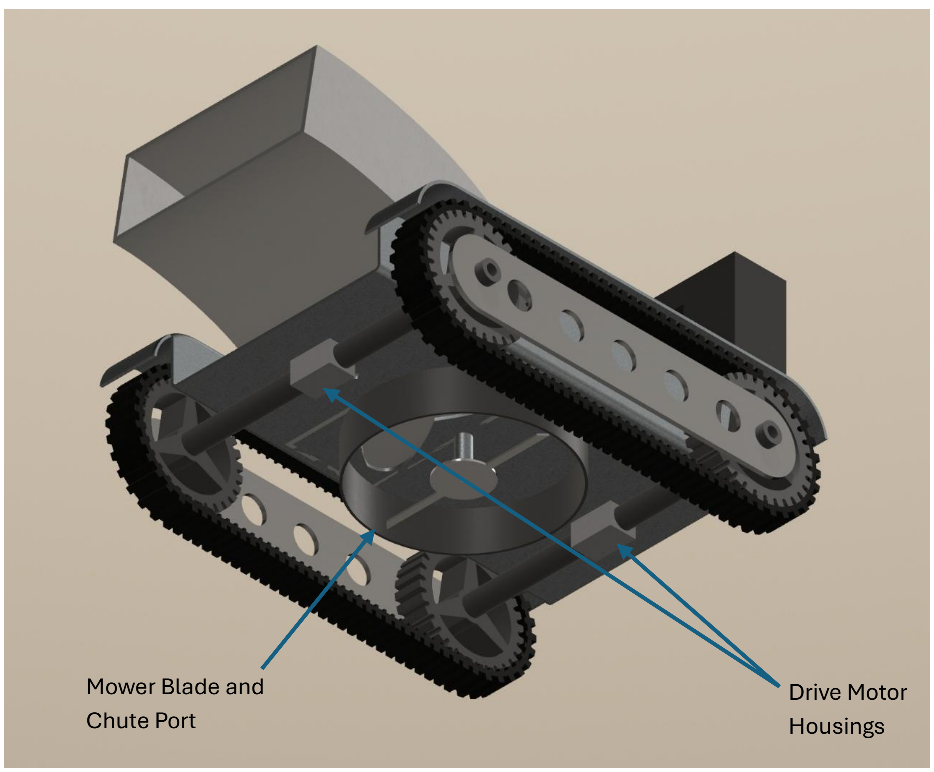


Figure 4: Bottom-Front-Left View

[1] Includes 3D models from (S, 2021) (Sains, 2022) (modified blade, 2023)

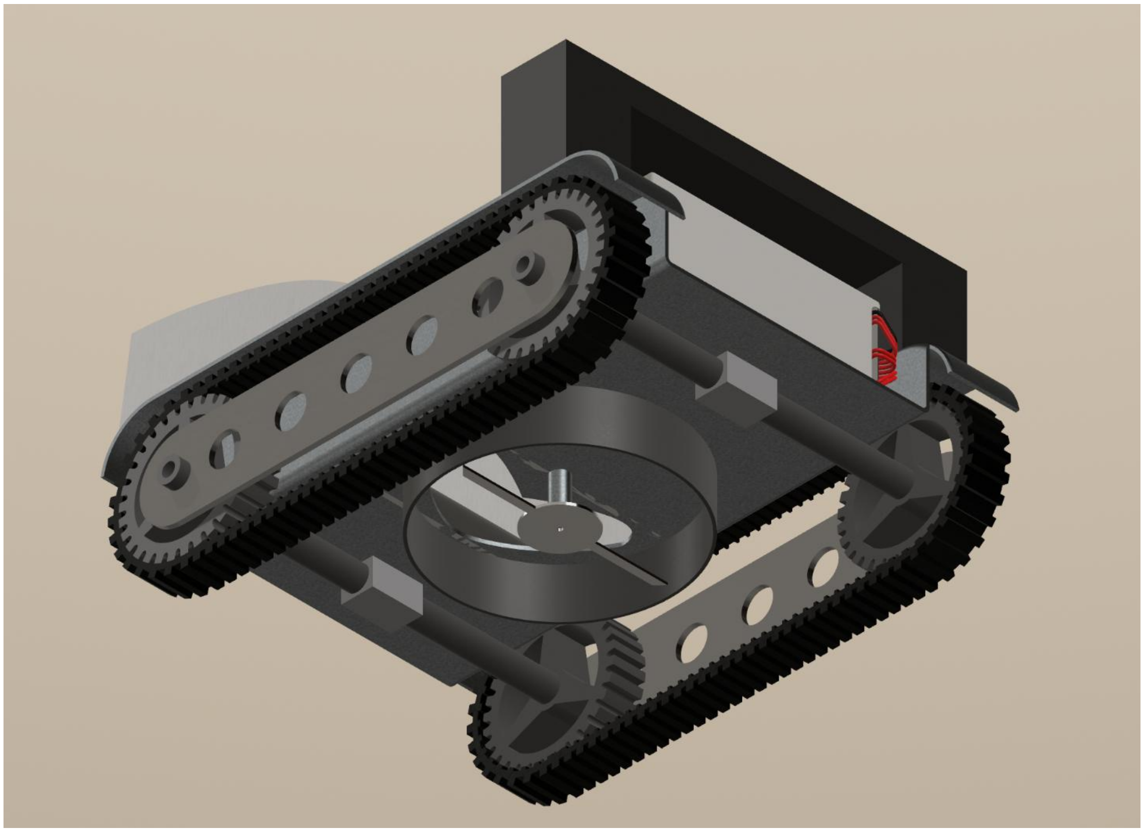


Figure 5: Bottom-Rear-Left View

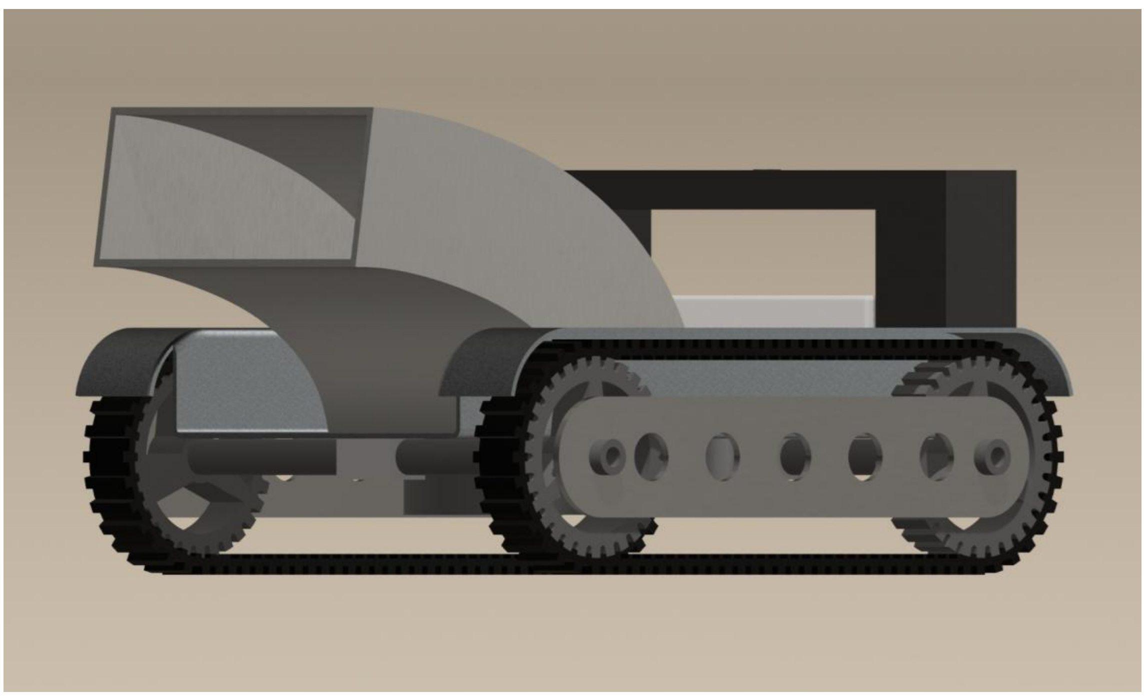


Figure 6: Front-Left View

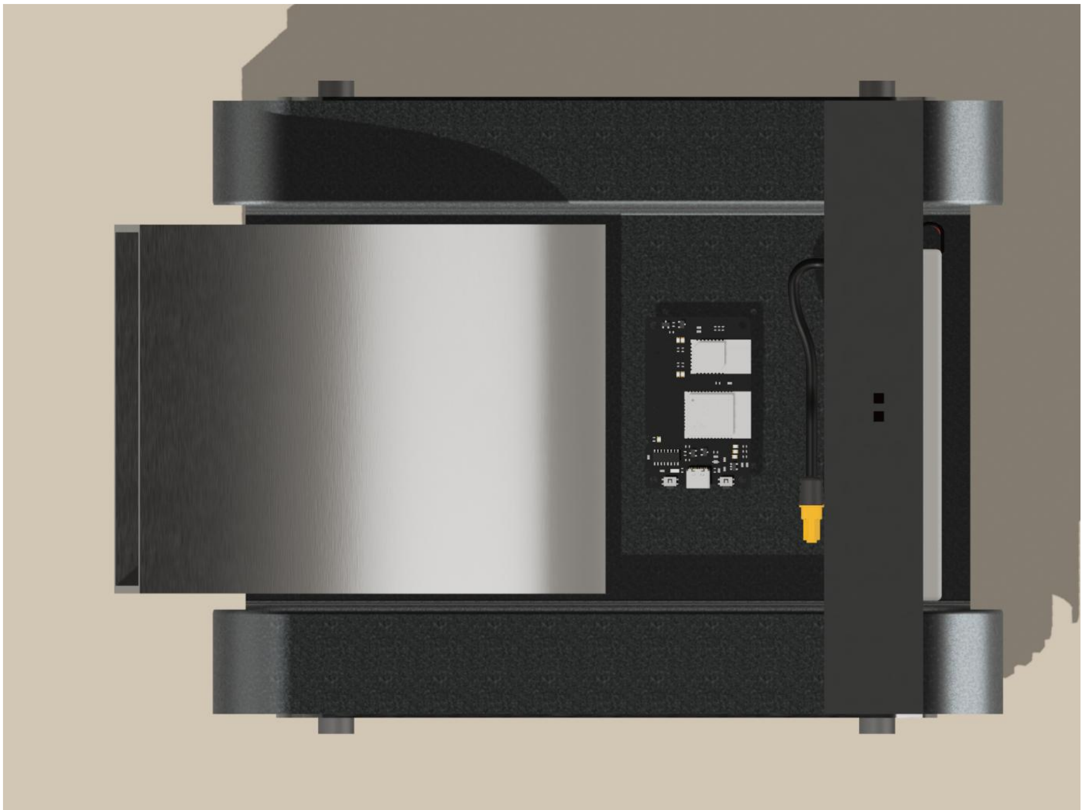


Figure 7: Top View

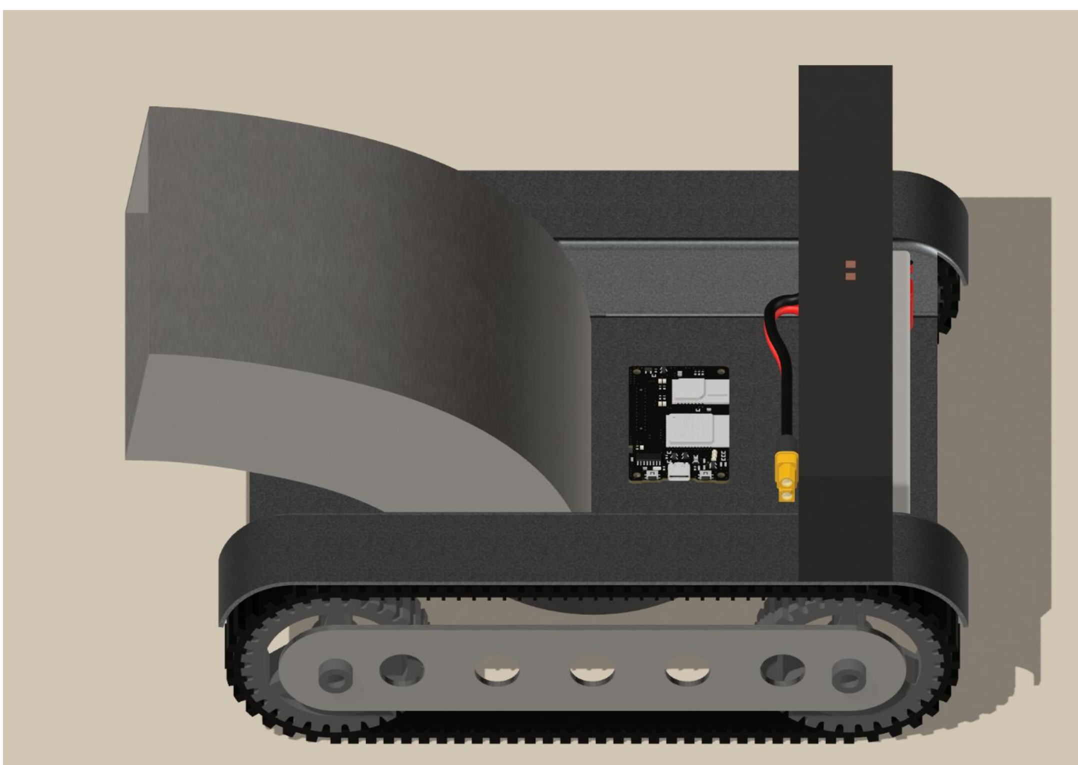


Figure 8: Top-Left View

10. Budget and Financing

Part	Quantity	Estimated Cost	Total Cost
Main PCB	1	$40	$40
ESP32 UWB Module	1	$40	$40
Antennae	2	$15	$30
Battery holder	1	$3	$3
Charging Pad PCB	1	$30	$30
Ultrasonic Modules	2	$10	$20
Battery Pack	1	$100	$100
Rover Shell	1	$50	$50
Miscellaneous	1	$50	$50
Total Cost			$816

Table 4: Budget and Financing

11. TURF System Project Milestones

11.1. SD1

Milestone Number	Milestone	Start Date	End Date	Deliverable
1	Group Formation and Idea Formation	9/1/25	9/5/25	Group Formed and Idea Agreed On
2	D&C First Draft and Meeting	9/1/25	9/10/25	D&C Document written and reviewed
3	Advising Committee Formation	9/1/25	9/12/25	Agreement from 3 members to join the committee
4	Midterm Report	10/1/25	10/31/25	Report written and submitted
5	Final Report	11/1/25	11/25/25	Report written and submitted
6	Mini Demo	11/1/25	11/25/25	Demo video recorded and presented

Table 5: SD1 Milestones

11.2. SD2

Milestone Number	Milestone	Start Date	End Date	Deliverable
1	Hardware Components Collected	1/12/26	1/16/26	Hardware components ordered and collected
2	System Design Prototyped	1/19/26	2/6/26	First prototype built and functional
3	System Testing	2/9/26	2/20/26	First prototype tested, issues and areas for improvement noted
4	System Revision	2/23/26	4/10/26	Improved Prototypes built, tested, and critiqued
5	Final Documentation	4/13/26	2/30/26	All documentation of project finalized for presentation
6	Final Presentation	5/1/26	5/1/26	Project is presented in a live demonstration to advisors and professors

Table 6: SD2 Milestones

12. References

Husqvarna. (2025). *Robot Lawn mowers*. Retrieved from Husqvarna: https://www.husqvarna.com/us/robotic-lawn-mowers/

modified blade. (2023, September 8). Retrieved from GrabCAD Community: https://grabcad.com/library/modified-blade-1

S, H. (2021, February 7). *Track wheel bot*. Retrieved from GrabCAD Community: https://grabcad.com/library/track-wheel-bot-1

Sains, I. (2022, August 9). *Cerdas UWB Tracker ESP32 DWM1000*. Retrieved from GrabCAD Community: https://grabcad.com/library/cerdas-uwb-tracker-esp32-dwm1000-1

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