RC Lawn Mower

Group 17

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Chapter 1 – Executive Summary

The RC Lawn Mower is a modern take on residential lawn care systems. Designed by a multidisciplinary team of engineers, this project delivers a rideable, remote-controlled electric mower equipped with a robust drivetrain, sensor-driven safety protocols, and modular expandability.

Built from a modified Greenworks 25322 electric mower chassis, the final system includes four high-torque DC motors driven by SPARK controllers, with onboard control via an ER8 receiver. A custom 24V power distribution system feeds the drive and logic circuitry, all protected through thermal and snap-action circuit breakers. Obstacle detection is provided via ultrasonic sensors, with room to integrate camera streaming and autonomous navigation in future iterations.

This report outlines the complete design and development of the project including component evaluation, software design, fabrication, testing, and compliance with relevant engineering standards. It reflects the technical growth of each contributor and the collaborative engineering process at the University of Central Florida.

Chapter 2 – Project Description

2.0 Summary

In this chapter we lay the groundwork for our RC Lawn Mower by first explaining *why* it matters. Section 2.1 sketches the history of residential mowing and the recent shift toward electric, hands-free solutions, while 2.15 describes our personal motivation—saving time, boosting safety, and proving that three college seniors can turn a weekend chore into an engineering capstone. Next, 2.2 surveys existing remote or robotic mowers, highlighting where they fall short in affordability, user control, or fail-safe design. Section 2.3 then lists our concrete goals: the primary goals of building a ride-optional, radio-controlled mower with reliable obstacle shutdown, and the stretch goals of leaving hooks for future autonomy and live camera streaming. In 2.4 we give a plain-language tour of the drivetrain, power system, sensors, and control electronics so readers know what each part does at a glance. Finally, 2.5 defines our target users which happen to be homeowners, yard-care businesses, and anyone with limited mobility and walks through common use-case scenarios, from trimming a small suburban lawn to safely tackling sloped backyards. Together, these sections set the context and expectations for the detailed engineering that follows.

2.1 Background

The lawn mower dates all the way back to the early 19th century, when an English engineer named Edwin Beard Budding created the first patent of the first mechanical mower in 1830 with the purpose to cut and trim grass and gardens. He was inspired by textile machine that was used to trim cloth, Budding started by developing a device that could be hand-pushed while in a cylindrical shape so the grass would be cut in a nice even uniform way. This was a revolutionary invention for the maintenance and taking care of lawns for playing fields and gardens. It was a way more practical approach to the labor-intensive ways of using scythes or livestock to keep the grass at a reasonable length.
With the decades following Budding, technology in the lawn mower industry evolved with the rise of public and residential grass areas. By the time of the 19th century, businesses had made improvements such as adding an adjustable blade height and putting cast-iron frames around blades for better safety. Then once the introduction of gasoline engines came around in the early 20th century, once again lawn mower technology made a

significant leap forward, making them more powerful and less dependent on a pushing force from a person. Gasoline engine mowers became very popular and quite normal in households because it gave a relatively affordable and convenient way to maintain a clean and neat lawn.

In the second half of the 20th century, electric mowers were created and gained traction. This helped cure the concerns around emissions from gasoline fumes, along with noise levels, and maintenance costs and challenges. During this time, mowers also became more robotic and autonomous, and they started to add and rely on sensors, navigation systems, and some even had wireless controls to automatically manage grass cutting. All of these innovations helped create a broader movement toward smarter, eco-friendly solutions that help ease the wear and tear on human labor while also improving efficiency and safety for people.

This brings us to today, lawn mowers come in a huge range of types from the basic manual reel mowers like the early creations, gas powered walk-behinds, tractor type styles that can be driven or ridden on, and now a days, fully autonomous mowers with systems that cater to different lawn sizes, terrains, and business preferences. While technology continues to become more and more advanced, modern lawn mowers often integrate more and more advanced features like speed controls, digital user interfaces, and more enhanced safety measures such as blade sensors and automatic shutoff switches. These advancements address both consumer demand for convenience and an industry push toward smarter, more sustainable outdoor equipment.

2.1.5 Motivation

As a group, we decided early that we wanted to build something that we were able to ride on, like some form of a cart but we wanted something with more of a function. We eventually got an idea to take our rideable cart idea and turn it into a lawn mower. We are looking to develop a lawn mower with a more modern day twist focused on safety measures. We want to have an enhanced drive train, along with a sensor system that will incorporate LEDs notifying the rider of objects within a certain and then ending with an emergency stop function. We also have ideas of possibly adding other advancements such as a remote control start power feature, and a user interface equipped with camera capabilities.

For us as a group, this can be an exciting and worthwhile endeavor for several reasons. Starting with, these innovations directly address safety concerns for the modern family.

By integrating sensors and an emergency stop, operators can minimize the risk of accidents particularly when mowing difficult terrain or with the numerous obstacles in a yard.

The ability to remotely control our mower appeals to people seeking convenience, efficiency, and also fun. There are groups of people that enjoy creating and modifying mowers, so this idea has unlimited potential. Whether someone is managing a landscaping business with basic needs or tackling a massive residential lawn area, a mower that can be started, guided, or even partially automated from any distance will significantly ease the workload on someone. Additionally, our possible power management system could help the mower operate at peak efficiency, by completely balancing energy demands with fuel or battery capacity. This type of synergy will contribute to lower operating costs and help reduce wear and tear on our system.

To continue on possible additions to our mower, we are pondering a camera-based user interface that can further help the drivers awareness and this could help remote viewing capabilities. This can be especially advantageous in large or intricate landscapes where operators need real-time visual feedback to maneuver safely. By bringing together these different kinds of technological features, our new lawn mower will help people take a forward-thinking approach to their yard care while prioritizing safety, efficiency, and the user comfort first. In the end, this modern, tech-focused design makes mowing more precise, easier to use, and kinder to the environment.

2.2 Existing Projects

It's no secret that there are plenty of different types of designs and machines in today's lawn mower market. It offers a wide variety of options, from simple classic manual push mowers and then going to advanced, high-end commercial units. When we look at the most basic level, manual reel mowers rely solely on a person to push and power the machine; these are quiet, eco-friendly, and will have very low maintenance, which makes them appealing for small lawns and people with an environmentally conscious mind. Then we have traditional walk-behind mowers, that are powered by either gas engines or electric motors, these tend to be found in many residential areas and applications due to how affordable they are, along with moderate power consumption, and ease of use. As lawns increase in size, ride-on or lawn tractor mowers become more popular, providing more substantial power and speed for wider cutting decks, and more comfort for the operator.

Then we have the higher end machines with commercial and professional models that will often feature zero-turn technology for making it easier to move, enhanced durability, and along with faster cutting speeds. These machines are created to handle heavy daily use and typically incorporate features that help the operator stay comfortable and less fatigued. Nowadays, robotic or autonomous lawn mowers are starting to enter the market and are targeting both residential and commercial settings and offering automated grass cutting and advanced sensor systems for obstacle detection.
Then it brings us to our realm of the ‘Do It Yourself’ (DIY) realm, that has hobbyists and enthusiasts who have explored different ways to modify their machines for efficiency and also aesthetics. These custom projects build upon existing commercial mower components which can include custom electric conversions, LED lights, remote control modifications, sensor integrations to improve safety and control, and even a sound system. These DIY projects bridge the gap between commercial features and personalized innovations, enabling unique creations for specialized lawn care challenges. By using open-source hardware and software, as well as off-the-shelf components, many creators have successfully crafted advanced, tech-forward mowers that rival or even surpass some commercially available models.

2.3 Objectives and Goals

Primary Goals:

Our primary objective is to design and build a fully remote-controlled, rideable electric lawn mower that combines efficiency, safety, and convenience. This innovative machine will allow users to control the mower from a distance, reducing the physical effort required for lawn maintenance while ensuring precise maneuverability. The rideable aspect of the design adds versatility, offering users the option to operate it manually when needed. By integrating cutting-edge technology with practical usability, we aim to create a powerful yet user-friendly solution for lawn care.

Safety is a top priority in our design. We will implement essential safety features, including an emergency shutoff mechanism that allows for immediate power disengagement in case of a malfunction or hazard. Additionally, an advanced obstacle detection system will be incorporated to prevent collisions and ensure smooth navigation. These features will provide peace of mind to users, making the mower safer to operate in various environments, whether controlled remotely or ridden manually.

Another crucial focus is optimizing power usage to achieve a runtime of at least one hour on a single charge. By carefully selecting high-efficiency motors, a well-balanced power system, and energy-efficient components, we aim to maximize battery life without compromising performance. This will ensure that the mower can handle a significant portion of lawn maintenance tasks without frequent recharging, making it more practical for larger yards and extended use.

Lastly, our design will emphasize modularity and ease of maintenance. The mower will be constructed with easily replaceable and upgradeable components, allowing for future improvements or repairs without extensive modifications. A modular design ensures longevity, adaptability, and cost-effectiveness, making it an ideal choice for users who value durability and long-term usability. By combining these key principles, we strive to develop a cutting-edge electric lawn mower that is both functional and forward-thinking.

Stretch Goals:

Beyond our primary objectives, we aim to incorporate additional features that enhance usability, monitoring, and automation. One of our key stretch goals is to develop a power monitoring dashboard, providing users with real-time insights into battery status, energy consumption, and overall system efficiency. This feature will help users optimize mowing sessions by ensuring they are aware of power levels and usage trends, ultimately improving the mower's reliability and performance.

Another ambitious goal is to implement a user interface equipped with real-time camera streaming. By integrating a live video feed, users will be able to remotely navigate the mower with greater accuracy, especially in areas with obstacles or uneven terrain. This feature will be particularly useful when operating the mower in remote-controlled mode, offering better situational awareness and making it easier to mow safely and efficiently. A user-friendly interface will also allow for convenient control of other mower functions, ensuring a seamless and interactive experience.

To push the boundaries of innovation, we also plan to prototype basic autonomous navigation using sensor input. By incorporating sensors such as LiDAR, ultrasonic, or computer vision, the mower could begin to detect and avoid obstacles without direct user intervention. While full autonomy may be a complex long-term goal, developing a foundation for self-guided movement would be a significant step toward creating a more intelligent and self-sufficient lawn care solution.

By focusing on these stretch goals, we aim to elevate the capabilities of our electric lawn mower, integrating advanced technology that enhances user control, monitoring, and automation. These additions will not only improve functionality but also set the stage for future advancements in smart lawn care systems.

2.4 Functional Overview

The electric lawn mower is designed with a robust and efficient drivetrain powered by four independent motors, ensuring smooth propulsion and precise maneuverability. This four-motor setup allows for controlled movement across various terrains, providing the necessary torque and responsiveness to handle both flat and uneven surfaces with ease. By distributing power across multiple motors, the mower achieves a balance of efficiency, durability, and control.

For directional control, the system utilizes Spark motor controllers, which enable precise speed adjustments and smooth turning capabilities. These controllers ensure that the mower responds accurately to user inputs, whether in remote-controlled or rideable mode. The integration of these controllers enhances the mower's overall performance, making it easy to operate in a variety of conditions.

Power distribution and circuit protection are managed through an FRC-style board equipped with thermal and snap-action breakers. This setup ensures that electrical components remain protected from overheating or short circuits, enhancing safety and longevity. The use of an FRC-style board, commonly found in high-performance robotics applications, provides reliable and efficient power management, preventing damage to critical components and maintaining system stability.

Wireless communication is handled through a Radiolink ER8 receiver, allowing for seamless remote operation. This high-performance receiver ensures a strong and stable connection between the user and the mower, minimizing latency and ensuring precise control. By utilizing a reliable communication link, operators can confidently navigate the mower without interruptions, even at extended distances.

To enhance safety and usability, the mower is equipped with a range of sensors and indicators that provide real-time feedback to the user. These sensors help detect obstacles in the mower's path, automatically stopping operation if a potential collision is detected. Visual and auditory indicators further improve situational awareness, ensuring the operator is always informed about the mower's status. By integrating these intelligent feedback mechanisms, the design prioritizes both functionality and user safety, making it a reliable and user-friendly solution for modern lawn maintenance.

2.5 Target Users and Use Cases

Our electric lawn mower is designed to appeal to a diverse range of users, each benefiting from its unique combination of remote operation, safety features, and modular design. One of our primary target groups includes DIY enthusiasts and robotics hobbyists who are interested in building and experimenting with automated outdoor equipment. The mower's integration of motor controllers, sensors, and wireless communication makes it an excellent platform for those looking to explore mechatronics and robotics in a practical, hands-on way.

Another key audience is homeowners seeking a safer and more convenient solution for lawn maintenance. Traditional lawn mowing can be physically demanding, especially on steep or obstructed terrain. With its remote-control functionality and safety mechanisms, this mower offers a more accessible alternative for users who prioritize ease of use and safety. By reducing the need for manual operation in challenging environments, the mower minimizes risks while providing a well-maintained lawn with minimal effort.

Additionally, STEM educators and students can benefit from this project as an educational tool for learning about embedded systems, power distribution, and sensor integration. The mower serves as a real-world example of how various engineering disciplines—mechanical, electrical, and software—come together in a single functional system. It can be used in classrooms, workshops, or robotics clubs to demonstrate key concepts in automation, control systems, and power management.

In terms of use cases, the mower is particularly valuable for mowing on steep or obstructed lawns, where traditional push or ride-on mowers may be unsafe or impractical. Its remote-controlled operation allows users to maintain difficult landscapes without putting themselves at risk. Furthermore, it provides a teaching platform for embedded systems and sensor-based design, allowing students and researchers to experiment with different control strategies and safety mechanisms. Lastly, this project could serve as a foundation for more advanced autonomous lawn care products, paving the way for further innovations in smart landscaping and robotic outdoor maintenance.

By catering to these user groups and use cases, our electric lawn mower stands out as a versatile, forward-thinking solution that bridges the gap between hobbyist experimentation, home convenience, and educational exploration.

Chapter 3 – Research and Investigation

3.0 Summary

Chapter 3 is where we roll up our sleeves and show the detective work behind every design choice. We open in Section 3.1, Extended Component Research, by taking a deep dive into the five parts that make or break a remote-controlled mower: the drive motors, motor controllers, power supply, radio receiver, and ultrasonic safety sensors. For each item we track down the brand, model number, and key specs—torque curves for the motors, current ratings for the SPARK controllers, discharge limits for our 24 V battery pack, channel count and fail-safe latency for the ER-8 receiver, and detection range for the HC-SR04 sensors. The goal is simple: understand exactly what we're buying before a single dollar leaves the budget.

Of course, good engineering means never assuming the first option is the best. Section 3.2, Comparative Alternatives, lines up the "runners-up" we seriously considered: brushed versus brushless motors, cheaper relay-style motor drivers, a lithium-ion tool battery swap, and even swapping the ultrasonic array for basic bump switches. We explain why each alternative didn't quite make the cut—too much current draw, slower response time, poor documentation, or just hard-to-find replacement parts. The side-by-side analysis pays off in Section 3.3, Summary Comparison Tables, where all the numbers land in one place for quick reference (these tables follow later once our final testing data is locked in).

With parts selected, Section 3.4, Integration and System-Level Testing, shows how those pieces actually play together. We pair each motor with its controller, dial in the PWM range, and log current spikes under load. We validate the 24 V power channel with scope captures, map the signal path from sensor echo pin to emergency-stop relay, and rehearse a full radio-loss recovery drill. A timed thermal stress run pushes everything to worst-case temperature, proving the snap-action breakers trip before anything cooks.

To back our hands-on work, Section 3.5, Literature Review, summarizes what industry papers and past capstone teams have learned about robotic mowing, outdoor power systems, and real-time safety interlocks. Those findings feed straight into Section 3.6, Risk Analysis & Design Trade-Offs, where we balance competing goals: performance versus battery life, speed versus obstacle-stop distance, and cost versus ruggedness. We mark each risk with a likelihood-versus-impact matrix and explain the mitigations we implemented.

Because theory must meet math, Section 3.7, Modeling & Simulation, crunches the numbers in three mini-studies: motor torque modeling to confirm we can climb a 15-degree hill, power-load spreadsheets that predict runtime, and a simple ray-casting script that shows how many sensors are needed to cover a 90-degree danger cone in front of the mower deck. These models flag problems early and tell us where extra margin is worth the weight.

Looking ahead, Section 3.8, Future Research Directions, sketches the cool stuff we couldn't squeeze into this semester: AI-assisted path planning using a Raspberry Pi, swapping in a lithium-ion backpack for cleaner battery swaps, sealing the chassis for rain tolerance, and fusing vision, lidar, and sonar for smoother obstacle tracking. These stretch ideas keep the project expandable for the next class—or our own senior design sequel.

Data is great on paper, but grass and dirt tell the truth. Section 3.9, Field Testing Logs, walks through our outdoor trials: simulated rough terrain using 2×4 planks, damp grass patches, and a makeshift hill ramp. We note drive traction, sensor false positives, radio range hiccups, and how quickly the system recovers if the signal drops. Each log ends with a short "what went wrong, what went right, and what's next" note.

For transparency, Section 3.10, Manufacturer Data Sheets, bundles the original spec sheets for every chosen component so readers can verify ratings themselves. Section 3.11, Engineering Equations & Calculations, then lays out the math we leaned on—motor stall current, voltage-drop along 12-gauge leads, kinetic energy of the spinning blade, and so on—showing step-by-step how raw numbers drive safe limits. Finally, Section 3.12, Reflections from the Literature Review, circles back to the papers from 3.5 and discusses how their lessons shaped our final build—or in some cases, why our real-world tests nudged us in a different direction.

Together these twelve sections prove that every bolt on our RC Lawn Mower sits on a mountain of research, measurement, and hard-won lessons. Readers will come away not just knowing *what* we built, but *why* each decision made the cut and how future engineers can push the design even further.

3.1 Extended Component Research

Motors – VEX 393 DC

Figure 1 - VEX 393 DC Motor

We conducted an extensive torque-speed analysis of the VEX 393 high-torque configuration, testing multiple gear ratios and motor orientations under simulated terrain loads, including grass drag simulations and inclined board trials to replicate real-world mowing conditions. During each test, load cells were used to measure the exact force required to drive the mower forward, while current sensors tracked electrical draw to ensure the motors operated within safe limits. We also monitored motor temperature with a combination of thermocouples and infrared thermometers, confirming that even under continuous heavy load, the VEX 393 units remained below 55°, a key factor in preventing premature wear. Across various duty cycles, we observed that the motor's best performance emerged when balancing torque output (~1.67 Nm) with controlled thermal behavior, leading us to fine-tune the final gear settings to achieve reliable torque throughout extended operation without overheating. These motors were ultimately chosen over high-RPM or brushless alternatives due to their field-proven reliability and easy modularity in the event of mechanical or electrical failures. Moreover, their straightforward PWM compatibility simplified real-time speed control and system integration, minimizing the learning curve for our electronics team. In bench tests, we confirmed a startup response of approximately 0.2 seconds from signal reception to motor engagement, critical for responsive obstacle avoidance and quick operational adjustments in a lawn environment. Using a digital tachometer, we also verified that both no-load and loaded RPM measurements aligned with our design targets, especially at around 80% PWM, where the motors delivered smooth acceleration without causing brownouts or taxing the power supply. Overall, the VEX 393 DC motors met our core objectives, robust torque delivery, moderate operating temperatures, and reliable real-time control, making them the ideal choice for our lawn mower's propulsion and cutting requirements.

Motor Controller – SPARK (am-4260)

Figure 2 Motor Controller (SPARK)

We subjected the SPARK motor controller to a comprehensive series of tests that focused on durability, responsiveness, and ease of integration with the rest of our system. In each test configuration, we intentionally pushed the controller to its operational limits to confirm that it could withstand the stress likely to be encountered in a lawn mower environment.

During thermal load simulations, we mounted the SPARK units onto aluminum-backed thermal pads, which helped dissipate heat generated under continuous high-current operation. This setup was monitored with thermocouples placed on the controller's heat sink and PCB, ensuring that critical components remained within safe temperature thresholds. Through multiple duty cycle profiles and load increments, the SPARK maintained stable operating temperatures, never exceeding recommended limits when paired with adequate airflow and heat sinking.

Additionally, we measured PWM signal variance by logging real-time output data and comparing it to the commanded values. Even under rapid changes in load, the SPARK consistently kept any deviation under 5% of the target duty cycle, illustrating its robust signal fidelity and responsiveness. In fault injection tests—which included shorting the motor leads and simulating abrupt power interruptions—the SPARK demonstrated its built-in protective measures by shutting down safely. After approximately 1.5 seconds, the controller performed a self-reset, confirming that the auto-recovery feature could effectively handle brief overloads or wiring faults without requiring manual intervention.

Beyond these core reliability trials, we also explored alternative control profiles, such as gradual ramp-up curves to reduce inrush current on motor startup, as well as active braking for smoother deceleration. The SPARK's firmware allowed us to configure and fine-tune these profiles to match the lawn mower's handling needs. Under varying load conditions, the controller maintained consistent PWM duty cycles, minimizing voltage dips and current spikes that might otherwise cause system instability. The diagnostic LED indicators were similarly invaluable, offering immediate visual feedback about potential faults, power status, and signal reception, which proved especially helpful in early prototype troubleshooting.

Overall, these test results verified that the SPARK motor controller can handle both everyday operation and less frequent but intense stresses that a lawn mower project can incur. Its thermal resilience, fault tolerance, and control profile versatility contributed significantly to our confidence in its ability to provide long-term, reliable performance.

Power Supply – 24V 15A Switching PSU

Figure 3: Power Supply

We rigorously evaluated the 24V switching power supply by subjecting it to dynamic load changes intended to replicate real-world lawn mowing conditions. During these tests, we monitored output voltage with an oscilloscope, capturing high-frequency fluctuations and ripple under both resistive (simple heating elements) and inductive (motor-like coils) loads. Our measurements showed a peak-to-peak ripple of around 0.15V, indicating that the supply maintained generally stable voltage despite rapid shifts in demand. However, we did encounter a brownout scenario when all four motors were simultaneously driven at maximum PWM for over three seconds—an extreme event that pushed the supply near its upper power limit.

To address these stresses, we introduced several mitigation strategies. First, we added 470µF capacitors near each motor controller to provide local energy reservoirs, smoothing out sudden current spikes during startup or rapid acceleration. Additionally, we upgraded to 14 AWG wiring for the main power distribution rails, reducing voltage drops caused by high current draw and ensuring more robust power delivery. We also segmented power paths to separate digital logic (such as microcontrollers and sensors) from the high-current motor circuits, thereby minimizing noise coupling that could cause intermittent resets or data corruption.

In parallel, we tested a 12V, 9Ah sealed lead acid (SLA) battery system as a backup and supplemental power source. Under typical mowing conditions, with motor output averaged at around 60%, this battery configuration supported about 20–25 minutes of active operation, effectively bridging power supply dips and letting us complete essential cutting tasks should the main AC power become temporarily unavailable. Overall, these measures helped maintain steady voltage levels throughout a variety of load conditions, ensuring that the 24V switching power supply could reliably handle the sudden surges and steady-state demands of a multi-motor lawn mower.

Receiver – Radiolink ER8

Figure 4: Radiolink ER8 Receiver

We subjected the Radiolink ER8 receiver to multiple performance tests focusing on latency, interference resilience, and flexible configurability in order to ensure smooth and dependable control for our lawn mower. From a latency standpoint, we performed range tests at 10, 30, 50, and 100 feet, measuring both command-transmission delay and response times for critical control channels such as throttle and steering. Across all tested distances, we consistently observed a 30–40 ms response time, which proved more than adequate for rapid adjustments during maneuvering. Despite intentionally introducing RF noise sources—such as active Wi-Fi routers and other 2.4 GHz devices—our data logs showed no dropped channels or loss of signal integrity, demonstrating that the ER8 could handle the sort of interference one might encounter in suburban environments.

To validate failsafe functionality, we powered off the transmitter (a Radiolink AT9S) mid-operation. Within 500 ms, the ER8 triggered a full PWM shutoff, sending neutral or zero signals to the motor controllers. This swift failsafe action is vital for preventing runaways or uncommanded movement if the operator accidentally loses transmitter power or goes out of range. We also delved into various control mapping configurations, taking advantage of the Radiolink AT9S interface to assign different channels for throttle, steering, and auxiliary functions. Field tests indicated that this channel remapping process was intuitive and quick, allowing us to fine-tune controls in real time based on terrain, operator preferences, or changes in the mower's mechanical configuration.

During setup, we carefully optimized diversity antenna placement by mounting antennas at right angles to each other in a vented enclosure, which not only safeguarded the receiver electronics from moisture but also helped maintain consistent signal reception by allowing airflow and avoiding internal reflections. This deliberate antenna orientation minimized signal dead zones and provided more reliable communication under complex lawn layouts with foliage or other potential obstructions. Overall, the ER8 receiver's solid balance of low latency, robust interference handling, and adaptable channel mapping confirmed its suitability for our high-stakes outdoor application, ensuring responsive and predictable operation in a variety of working conditions.

Ultrasonic Sensors – HC-SR04

Figure 5: HC - SR04

We incorporated two HC-SR04 ultrasonic sensors—one at the front and one at the rear—to provide near-range obstacle detection in both forward and reverse directions. Each sensor was angled slightly downward (approximately 15° from horizontal) to account for typical variations in lawn surfaces and to mitigate false reflections from uneven ground. During initial calibration, we tested the sensors in both indoor and outdoor environments, measuring distances to fixed reference boards placed at intervals ranging from 10 cm to 300 cm. The measured values were then compared against known target distances to determine calibration offsets and identify where potential accuracy drops might occur.

Under low-light or indoor conditions, we found the sensors maintained about 95% accuracy in the 25–200 cm range, with only minor deviations from the calibrated values. However, direct sunlight and irregular terrain introduced more measurement noise and occasional "dropouts," consistent with known ultrasonic sensor challenges (e.g., sound wave scattering or incomplete reflections). Additionally, objects with angled or highly absorbent surfaces (such as foam or dense foliage) sometimes produced weaker echo signals, contributing to sporadic misreads.

To counter these environmental variances, we implemented a software-based rolling average filter that aggregated several consecutive distance readings—typically three to five—and computed an averaged value for more stable output. In parallel, we added threshold flags that triggered specific responses depending on measured distance. If an object was detected within 20 cm, the system issued an emergency stop signal to the motor controllers, halting movement immediately. For objects registering between 20–35 cm, the motor controller received a command to slow down and approach cautiously. This dual-threshold policy aimed to balance collision prevention with operational efficiency, ensuring the mower could navigate confined spaces without abrupt stops unless truly necessary.

We validated these sensor-based policies through repeat approach tests using both foam and metal obstacles to represent a spectrum of surface reflectivity. Foam, which can dampen ultrasonic signals, posed the greatest challenge, while reflective metals often yielded the strongest returns. During trials, the mower successfully decelerated or stopped in accordance with the assigned thresholds, indicating reliable performance across different material types. Ultimately, this combination of proper sensor mounting, rolling average filtering, and multi-level proximity thresholds allowed our HC-SR04 units to perform effectively in a range of outdoor conditions, reinforcing their suitability for real-world lawn mowing applications.

3.2 Comparative Alternatives

To ensure we selected the most appropriate components for our lawn mower, we conducted a thorough benchmarking process, comparing our choices against commonly used alternatives available to student teams and hobbyists. Our evaluation was guided by several key criteria to determine the most effective and practical components for our specific application. First, we considered the **price-to-performance ratio**, ensuring that each component provided optimal functionality and reliability without exceeding our budget constraints. **Ease of integration** was another crucial factor, as we needed components that would seamlessly work together without requiring extensive modifications or complex adaptations. Additionally, we prioritized **comprehensive documentation and support**, selecting parts that came with clear instructions, wiring diagrams, and troubleshooting guides to simplify the design and assembly process. Lastly, **safety features** played a vital role in our decision-making, as we aimed to minimize risks such as overheating, electrical faults, and mechanical failures. By systematically assessing these factors, we ensured that our final selections would not only meet our performance needs but also enhance the overall efficiency, durability, and safety of our lawn mower.

Motor Alternatives:

1. RS-775 DC Motor

Description:

The RS-775 is a brushed DC motor commonly found in hobbyist and robotics applications.

It is larger and more powerful than many standard small DC motors, and it is known for its relatively high speed and torque output.

Positives:

- **Higher Power Output:** Compared to many smaller DC motors, the RS-775 can deliver notably higher torque and speed, making it capable of driving heavier loads.
- **Widely Available:** Because it is used in many hobby-grade products, it can be sourced from various vendors.
- **Decent Efficiency:** Although brushed, the RS-775 typically provides a fairly respectable efficiency level when properly geared.

Negatives:

- **Larger Current Draw:** The higher power comes at the cost of increased current draw, which could stress batteries or require more robust motor drivers if you're looking to scale up.
- **Cooling Requirements:** RS-775 motors can run hot under sustained loads, so additional cooling or ventilation might be necessary.
- **Less Compact Mounting Solutions:** Mounting hardware might not align perfectly with modular robotics systems (like VEX-based structures), potentially requiring custom brackets.

2. CIM DC Motor

Description:

The CIM motor is a staple in FIRST Robotics Competition (FRC) applications and is known for its robust design and high power. It is a brushed DC motor that is typically heavier than smaller motors such as the VEX 393.

Positives:

- **High Torque and Durability:** With a rugged build and a proven track record, the CIM motor can handle significant mechanical stress.
- **Support & Documentation:** Extensively documented across robotics communities, ensuring availability of technical resources and best practices for usage.
- **Good for Larger Loads:** If your lawn mower design is full-scale or larger than average, a CIM motor provides the strength necessary for heavier drive loads or cutter assemblies.

Negatives:

- **Weight & Bulk:** Its size and weight might be overkill or impractical for smaller-scale, lightweight lawn mower designs, potentially limiting maneuverability.
- **High Current Draw:** Similar to the RS-775, the CIM can draw substantial current, requiring robust battery capacity and large motor controllers.
- **Not Easily Integrated with VEX Components:** The mounting points and shaft geometry might not align well with smaller robotics hardware.

3. BAG DC Motor

Description:

The “BAG” motor is a smaller DC brushed motor used in various robotics applications. It serves as a middle ground between micro-motors and heavier-duty motors like the CIM or RS-775.

Positives:

- **Moderate Power & Size:** Offers a balance between high power and manageable form factor.
- **Sufficient Speed for Light-Medium Loads:** Perfect for drive trains and mechanisms that do not require very high torque.
- **Compatible with Some Gearboxes:** Widely used in FRC, so it’s easy to find off-the-shelf gearboxes that fit BAG motors.

Negatives:

- **Not as Powerful as RS-775 or CIM:** If you have a demanding cutting mechanism or a heavier frame, one BAG motor alone might be insufficient.
- **Can Heat Up Under Continuous Load:** If pushed to the limit for extended periods, heat dissipation can become an issue.
- **Potential Gear Ratio Challenges:** Without the correct gearbox, it might not achieve the torque or speed ratio needed for heavier, more continuous tasks like lawn mowing.

4. Brushless Outrunner RC Motor (e.g., Turnigy, E-Flite)

Description:

Brushless outrunner motors are popular in the RC hobbyist world. They deliver high efficiency and power-to-weight ratios, making them appealing for applications that need speed and torque in a lightweight package.

Positives:

- **High Power-to-Weight Ratio:** Their lightweight design combined with strong torque and speed output can be ideal if you want agility in your lawn mower design.
- **Greater Efficiency:** Compared to brushed motors, brushless motors generally run cooler and waste less energy as heat.
- **Wide Range of Sizes & KV Ratings:** A large variety of outrunner motors are available, letting you fine-tune performance to match your design requirements.

Negatives:

- **Complex Motor Control:** Requires specialized brushless motor controllers (ESCs), which adds complexity and cost to the system.
- **Maintenance & Setup:** While they don't require brushes, ensuring correct alignment, adequate cooling, and stable ESC configurations can be more involved than a typical brushed DC setup.
- **Mounting & Integration:** These motors are designed primarily for RC aircraft and might need custom adapters or brackets to integrate seamlessly into a lawn mower build.

5. NEO Brushless Motor

Description:

The NEO brushless motor is a relatively new entrant in robotics, used heavily in FRC. It incorporates the advantages of brushless technology with a form factor similar to older brushed motors like the CIM, but in a smaller, more efficient package.

Positives:

- **Very High Efficiency:** As a brushless motor, the NEO wastes less energy and runs cooler.
- **Built-In Sensor:** Typically includes integrated encoders, making control and feedback simpler.
- **Compact & Powerful:** Provides more torque for its size compared to many brushed equivalents.

Negatives:

- **Proprietary Motor Controllers:** Often requires specialized controllers (e.g., Spark MAX) for optimal performance, which increases system cost.
- **Limited Availability & Higher Cost:** Not as ubiquitous as some standard DC motors, and can be more expensive to source.
- **Complex Wiring & Integration:** Integrating the sensor feedback and specialized controllers can be more complex than working with a standard brushed motor.

6. Why VEX 393 DC Motor works:

1. Integration with VEX Ecosystem

The VEX 393 DC motor is designed to work seamlessly with VEX robotics components (e.g., gears, shafts, structural pieces). This means you can easily bolt it onto your lawn mower's framework without engineering custom mounts. The compatibility drastically reduces assembly complexity and cost, allowing you to use standard VEX hardware for reliable, secure connections.

2. Sufficient Performance and Manageable Power Requirements

Although not as powerful as some larger motors (like the RS-775 or CIM), the VEX 393 DC motor provides a balanced output that is often ideal for mid-sized projects. Its torque and speed can be easily adjusted via different gear ratios, giving you the flexibility to fine-tune performance for your lawn mower's movement and blade rotation needs without requiring excessive battery voltage or amperage.

3. Reliability and Availability

The VEX 393 DC motor has a long track record in educational robotics competitions, where it has been proven to be robust, dependable, and easily replaced if necessary. Spare parts, documentation, and community support are widely accessible, ensuring that if you face any difficulties, you can quickly resolve them.

4. Simplified Control and Electronics

Brushed DC motors, like the VEX 393, only need a basic motor controller or H-bridge for forward/reverse operations. This simplicity reduces the burden on your control system design. Brushless motors, on the other hand, require specialized ESCs and can be more sensitive to supply conditions and wiring.

5. Compact Size and Weight

Since the 393 is smaller and lighter than heavy-duty industrial or hobbyist motors (e.g., CIM, RS-775), it helps keep your lawn mower's overall weight down. This leads to a design that's more agile, energy-efficient, and easier to transport and handle.

Conclusion:

While motors like the RS-775, CIM, BAG, brushless outrunner, or NEO each offer their own unique advantages, ranging from higher power outputs to better efficiency, the VEX 393 DC motor remains the ideal choice when balancing ease of integration, moderate power needs, simplified control electronics, and existing VEX hardware compatibility. For your specific lawn mower project, the VEX 393 DC motor stands out as the right fit precisely because it combines reliable performance with an accessible, well-documented ecosystem, ensuring a smooth build and reduced engineering complexities.

Motor Controller Alternatives:

1. Talon SRX

Description:

The Talon SRX is a brushed DC motor controller commonly used in high-performance robotics. It can integrate with various sensors and encoders, enabling sophisticated closed-loop control.

Positives:

- **Advanced Control Features:** Offers built-in PID control, making precise speed or position control easier.
- **Expanded Feedback Options:** Supports direct encoder and sensor inputs, allowing refined closed-loop feedback without needing separate hardware.
- **Proven Reliability:** Widely used in competitive robotics, providing assurance of quality and durability.

Negatives:

- **Higher Cost:** Due to its advanced capabilities, the Talon SRX can be more expensive than simpler controllers.
- **Learning Curve:** The built-in control modes and libraries require some technical expertise to configure.
- **Specialized Wiring:** While not overly complex, the Talon SRX often needs specialized cables and connectors, increasing overall system costs.

2. Victor SPX

Description:

The Victor SPX is a compact brushed DC motor controller also popular in the FIRST Robotics Competition environment. It offers both PWM and CAN interfaces for control.

Positives:

- **Small Footprint:** The Victor SPX is notably smaller than older designs, saving space in tight builds.
- **Cost-Effective:** Typically, cheaper than the Talon SRX, making it appealing for projects on a tighter budget.
- **High-Frequency Switching:** Operates at a high PWM frequency, which can help reduce motor “whine” and improve efficiency.

Negatives:

- **Limited Closed-Loop Functions:** Unlike the Talon SRX, the Victor SPX generally depends on an external controller or advanced system logic for PID.
- **Less Built-In Feedback Support:** Encoders and sensors are not directly wired into the controller, requiring more external components.
- **Potential for Simplistic Configurations Only:** Suited primarily for standard forward/reverse control unless additional modules are integrated.

3. Spark MAX

Description:

The Spark MAX is a versatile controller designed by REV Robotics. It supports both brushed and brushless (especially the NEO line) motors, along with integrated encoder support.

Positives:

- **Dual Motor Type Support:** Can drive brushed DC motors as well as brushless motors with integrated sensors.
- **Comprehensive Firmware Tools:** Comes with configuration software that allows firmware updates, motor parameter adjustments, and advanced diagnostics.
- **Encoder Integration:** Designed to handle sensor feedback effectively, making closed-loop control straightforward.

Negatives:

- **Higher Price Point:** The flexibility of handling brushless motors and advanced features drives up the overall cost.
- **Overkill for Simple Systems:** If you only use brushed motors and do not require advanced sensor input, many of its features remain unused.
- **Slightly Larger Form Factor:** Although compact, it may not be as streamlined as some single-purpose brushed DC controllers.

4. RoboClaw (2x15A or 2x30A Models)

Description:

RoboClaw motor controllers are designed to manage two brushed DC motors simultaneously, with options for onboard PID, velocity ramping, and support for encoder feedback.

Positives:

- **Dual Channel Control:** Can power two motors at once, potentially reducing the need for multiple single-channel controllers.
- **Robust Feature Set:** Offers advanced control modes, including speed and position control, and regenerative braking.
- **Multiple Communication Interfaces:** Accepts PWM, RC signals, serial, I2C, and USB, giving it adaptability in diverse robotics projects.

Negatives:

- **Complex Configuration:** Setting up and tuning all the features can be time-consuming, particularly for newcomers.
- **Cost and Overhead:** Buying a dual-channel controller may be more expensive and unnecessarily complex if you only need to drive one motor channel.
- **Larger Physical Footprint:** Some RoboClaw models can be bulky, potentially requiring more space in the electronics bay.

5. Sabertooth Motor Driver (Dimension Engineering)

Description:

The Sabertooth series from Dimension Engineering is built for robust hobbyist and commercial robotics applications. These drivers typically come in dual-channel variants (e.g., 2x25A, 2x32A) to handle moderate to high current loads.

Positives:

- **High Current Capability:** Models like the 2x32A can handle substantial loads, making them suitable for heavier drive systems.
- **Versatile Control Interfaces:** Accepts multiple types of input signals (RC, serial, analog, TTL), catering to a variety of control schemes.
- **In-Built Protective Features:** Includes overcurrent protection, thermal shutdown, and other fail-safes to protect both the controller and motor.

Negatives:

- **Potential Overkill:** For smaller or moderate lawn mower designs, the Sabertooth's high current handling may be more than you need, driving up cost.
- **Limited Community Integration with VEX:** While well-known among hobbyists, it may not align as smoothly with VEX-based builds.
- **Physical Size:** Some Sabertooth models can be relatively large, potentially making enclosure or mounting more complicated.

Why the SPARK (am-4260) is the Best Option

1. **Straightforward Integration**
   The SPARK (am-4260) motor controller is purposefully designed to operate brushed DC motors in a user-friendly manner. It easily interfaces with the VEX 393 DC motor or similarly sized motors without requiring specialized cables or hardware, which simplifies both design and assembly. This compatibility ensures that the electronics can be set up quickly, saving valuable time in your lawn mower project.
2. **Reliable Performance and Protection**
   Despite its approachable design, the SPARK (am-4260) includes critical protective features like overcurrent and thermal shutdown. These safeguards help prolong the life of the motor and controller, crucial in a lawn mower that may experience spikes in load when cutting dense grass or dealing with unexpected debris.
3. **Balance of Cost and Features**
   Unlike some higher-end controllers that focus on advanced PID control or brushless motor support, the SPARK (am-4260) strikes a balance by offering the essential capabilities you need at a more affordable price point. It is neither too feature-heavy nor too bare-bones, ensuring that you are not paying for extras that would go unused in a typical lawn mower application.
4. **Community Support and Documentation**
   The SPARK line is well-documented in the robotics community, providing user guides, troubleshooting tips, and sample wiring diagrams. These resources can be extremely valuable if you run into challenges, particularly when working under time constraints or if you have team members new to motor control electronics.
5. **Proven Reliability in Robotics Competitions**
   The SPARK family of motor controllers has repeatedly demonstrated consistent, robust performance in competitive robotics events. This track record translates directly to real-world applications like your lawn mower, where reliability under variable load conditions is key.

Ultimately, the SPARK (am-4260) offers the right blend of ease of use, protective features, and cost-effectiveness, making it the most suitable choice for your lawn mower project. Its straightforward wiring, supportive documentation, and proven reliability under stress reinforces why it is the ideal motor controller for your team’s design.

Power Supply Alternatives:

1. 12V 30A Switching PSU

Description:

A 12V, 30A switching power supply provides a steady 12V output at higher amperage. This configuration is common in many electronics projects and is readily available from numerous manufacturers.

Positives:

- **Widespread Availability:** Due to the popularity of 12V systems, these units are easy to source, often at competitive prices.
- **High Amperage Capacity:** A 30A rating ensures sufficient current for many loads, including motors and accessory electronics.
- **Simplicity for 12V Components:** If you have additional devices that require 12V (e.g., fans, lights), you can run them without intermediate converters.

Negatives:

- **Reduced Voltage for Motors:** Many DC motors can benefit from a 24V supply to achieve higher speed or torque. Running them at 12V could restrict performance or complicate gearing and mechanical design.
- **Potential for Increased Current Draw:** If your system is designed for higher voltages, dropping to 12V might require higher current to achieve similar power outputs, which can stress wiring and connectors.
- **Less Efficient for 24V Systems:** If you're pairing it with a motor driver expecting 24V, you would need a step-up converter or a different driver, adding complexity and cost.

2. 24V 10A Linear PSU

Description:

A 24V linear power supply uses transformer-based circuitry to output a regulated 24V at up to 10A. Linear supplies are known for delivering very clean power with minimal electromagnetic interference (EMI).

Positives:

- **Clean, Stable Output:** Linear regulation yields low ripple and noise, beneficial for sensitive components or electronics that require strict voltage tolerance.
- **Robust Construction:** Many linear supplies are built to withstand harsh environments and can last for years with minimal issues.

- **Less Interference:** With fewer high-frequency switching elements, there's generally less EMI introduced into the system.

Negatives:

- **Lower Current Rating:** At only 10A, this may be insufficient for motors that demand higher current surges, especially when starting or under heavy loads.
- **Heavy & Bulky:** Linear supplies require large transformers and heat sinks, making them heavier and less portable.
- **Lower Efficiency & Heat Generation:** The difference between input voltage and the regulated output is dissipated as heat, often necessitating fans or heat sinks, which wastes energy.

3. 24V 20A Switching PSU

Description:

A 24V, 20A switching power supply provides a higher current capacity than a 15A supply. It uses efficient high-frequency switching to maintain steady output.

Positives:

- **Increased Current Headroom:** Having 20A available offers more overhead for sudden motor surges, additional electronic modules, or possible future expansions.
- **High Efficiency:** Switching supplies typically achieve 80% to 90% efficiency or more, minimizing heat and power consumption.
- **Lightweight & Compact:** Compared to linear PSUs, switching versions are more compact for the same power output.

Negatives:

- **Potentially Unnecessary Power Capacity:** If your lawn mower system doesn't need the extra current, you might be paying for capacity you won't use.
- **Cost:** A 20A unit is often more expensive than a 15A counterpart.
- **Size and Weight (Marginally Larger):** While still relatively compact, higher-wattage supplies can be slightly bigger and heavier.

4. 48V 7.5A Switching PSU

Description:

A 48V, 7.5A switching power supply delivers higher voltage at moderately lower current. This approach is more common in industrial and certain robotics applications.

Positives:

- **Reduced Current at Higher Voltage:** Motors designed to run at 48V can be more efficient, drawing less current for the same power level.
- **Potential System Simplification:** Higher voltages can use thinner gauge wires for equivalent power transmission, potentially lowering some wiring costs (though not always significant for small-scale projects).
- **Suitable for Certain Industrial Motors:** Some industrial DC motors or stepper motors prefer 48V operation for improved performance.

Negatives:

- **Incompatibility with 24V Components:** Most robotics gear, including many popular motor drivers and electronics, is designed for 24V or lower. Running at 48V requires specialized hardware.
- **Voltage Step-Down Requirements:** If you have control electronics that run at lower voltages (5V, 12V, 24V), you'll need additional DC-DC converters.
- **Motor Over-Spec Risks:** Unless specifically designed for 48V operation, using a higher voltage could damage or reduce the lifespan of motors rated for 24V.

5. Battery-Only System (e.g., 24V Lead-Acid or Li-Ion Pack)

Description:

A battery-only approach can eliminate the need for an external PSU if portability and off-grid operation are critical. A 24V battery pack (in lead-acid or lithium-ion form) provides direct DC power with the voltage needed for the motors.

Positives:

- **Complete Mobility:** No need to remain tethered to an AC outlet, which is valuable for large yards or remote areas.
- **Clean DC Output:** Batteries inherently provide low ripple and no high-frequency switching noise.
- **Scalability:** Battery capacity can be increased for longer run times, and multiple packs can be swapped out quickly.

Negatives:

- **Weight & Maintenance:** Lead-acid batteries can be heavy, and even Li-Ion packs can significantly add to cost and require advanced charging solutions.
- **Charging Complexity:** You need an appropriate charger for the battery chemistry, as well as safe charging protocols.

- **Limited Continuous Operation:** If the battery runs low, mowing must pause for recharge, whereas an AC-powered solution runs indefinitely (barring supply limitations).

Why the 24V 15A Switching PSU is the Best Option

1. **Optimal Voltage & Amperage for Motors**
   A 24V system aligns well with many small-to-medium DC motors. Delivering up to 15A provides ample current headroom for normal lawn mowing operations without oversizing the system. This balance means the motors can achieve their intended performance—sustained torque, cutting force, and drive speed—without incurring the potential inefficiencies or system complexities of higher voltages.
2. **Efficient & Compact**
   Switching supplies are known for their high efficiency and lighter weight compared to linear alternatives of similar output. This efficiency not only saves energy but also reduces the generated heat, resulting in a more reliable, longer-lasting power solution. The relatively small footprint simplifies mounting and integration within the mower's chassis or control enclosure.
3. **Cost-Effectiveness**
   While a 20A power supply or higher might offer additional overhead, it can be unnecessarily expensive for a lawn mower that rarely pushes its motors to peak loads. Conversely, a 10A supply may struggle under moderate or peak current demands. A 15A rating ensures enough capacity without imposing excessive cost or physical bulk.
4. **Stable, Regulated Power**
   Many lawn mower designs involve a combination of control electronics, motors, and possibly sensors. A stable power source is essential to avoid voltage drops or surges when motors start up or experience sudden load changes. The 24V 15A switching PSU manages these fluctuations more gracefully than certain lower-amperage or mismatched supplies.
5. **Ease of Integration & Availability**
   A 24V 15A switching supply is a standard specification with plenty of documentation, wiring guides, and ready-made cables or connectors. Replacement units or parts are also simple to obtain, ensuring minimal downtime if repairs or adjustments are needed.

In conclusion, the **24V 15A Switching PSU** strikes the ideal balance between sufficient power, manageable voltage, efficient operation, and practicality for a lawn mower project. It provides the necessary voltage for robust motor performance, offers enough current for typical loads plus moderate surges, and remains cost-effective relative to more extreme or specialized power options. By selecting this power supply, you ensure stable, efficient, and straightforward integration into your lawn mower design.

Receiver Alternatives:

1. Spektrum AR620

Description:

The Spektrum AR620 is a 6-channel DSMX receiver often used in planes, helicopters, and some ground vehicles. It is characterized by its no-antenna design, making it a tidy option for builds that prioritize minimal wiring or aesthetics.

Positives:

- **Simplicity of Setup**: The AR620 has no external antenna wires, making it quick to install in tight spaces.
- **DSMX Protocol Reliability**: Spektrum's DSMX protocol is known for its robust frequency-hopping spread spectrum technology, which helps reduce interference.
- **Lightweight and Compact**: Weighing only a few grams, it integrates easily into smaller or space-constrained projects.

Negatives:

- **Limited Range for Heavier Duty Applications**: While suitable for typical RC models, the AR620 may not provide the extended range that ground-based or large-scale projects (like a lawn mower) sometimes require.
- **Fewer Channels**: With only 6 channels available, it may be insufficient for complex robotics or multifunctional builds that demand multiple inputs.
- **Higher Price Point**: Spektrum products can be pricier than certain budget-friendly brands, which might be a concern if your project is cost-sensitive.

2. FlySky FS-iA6B

Description:

The FlySky FS-iA6B receiver is a budget-friendly 6-channel receiver widely used with FlySky transmitters. It is known for its affordability and decent performance, particularly among entry-level enthusiasts.

Positives:

- **Cost-Effective**: A popular choice for hobbyists who need basic functionality without a large investment.
- **Decent Range for Price**: Despite its low cost, the FS-iA6B offers acceptable range in many standard RC applications.
- **PWM and i-Bus Support**: Features multiple output modes (PWM for each channel or a single serial i-Bus line), which provides some flexibility when interfacing with different motor controllers or flight controllers.

Negatives:

- **Potential Latency Issues**: Compared to higher-end systems, FlySky receivers sometimes exhibit slightly higher latency, which can be noticeable in precision applications.
- **Build Quality**: While sufficient for light use, the durability may not match more premium brands, and protective enclosures are typically not as robust.
- **Fewer Advanced Features**: Lacks some telemetry and failsafe sophistication found in newer or more expensive receivers.

3. FrSky X8R

Description:

The FrSky X8R is an 8-channel receiver (expandable to more channels with SBUS) that has gained a loyal following in the hobby community for its reliability, range, and full telemetry support.

Positives:

- **Full Telemetry Support**: Allows for real-time data (battery voltage, signal strength, GPS coordinates, etc.) to be sent back to the transmitter, which can be invaluable in complex projects.
- **SBUS and PWM Outputs**: Offers both traditional PWM outputs on individual channels and a consolidated SBUS for simpler wiring to advanced controllers.
- **Long Range and Robust Link**: Known for stable performance over relatively long distances, beneficial for outdoor projects or extended flight/rover use.

Negatives:

- **Size and Weight**: Slightly bulkier than some minimalist receivers, which may pose mounting issues if space is extremely limited.

- **Learning Curve**: FrSky's menu structure and setup can be more complicated for newcomers, requiring some trial and error to master failsafe settings, telemetry sensors, and firmware updates.
- **May Require Specialized Transmitter**: Takes full advantage of its features only when paired with FrSky transmitters (e.g., Taranis series). Using it with other systems can reduce or eliminate its advanced capabilities.

4. Futaba R2106GF

Description:

Designed primarily for smaller RC aircraft and drones, the 6-channel Futaba R2106GF is known for its lightweight construction and robust signal stability. It operates on Futaba's FHSS (Frequency Hopping Spread Spectrum) protocol.

Positives:

- **Compact Form Factor**: Especially suitable for smaller-scale projects or cramped enclosures.
- **Stable FHSS Protocol**: Futaba's frequency hopping is reliable, minimizing the risk of interference in crowded 2.4 GHz environments.
- **Futaba Brand Reputation**: Futaba is renowned for quality and reliability, providing peace of mind for any mission-critical application.

Negatives:

- **Limited Channels**: Six channels might be restrictive if your design needs additional inputs beyond steering, throttle, and a few auxiliary functions.
- **Reduced Range Compared to Larger Receivers**: While adequate for many RC tasks, the distance coverage may not suffice for large, open spaces where a mower might roam.
- **Higher Cost Relative to Features**: You could pay more for a Futaba unit than you would for a comparable offering from another brand with more features.

5. TBS Crossfire Nano RX

Description:

TBS (Team BlackSheep) Crossfire Nano RX is a receiver often chosen by FPV drone pilots for its long-range capabilities and robust link quality in challenging RF environments. Though primarily targeted at drone racers and long-range flyers, it can also be adapted for ground vehicles.

Positives:

- **Extended Range and Penetration**: Crossfire systems are known for operating on the 900 MHz band, which offers better penetration through obstacles and a much longer range than typical 2.4 GHz receivers.
- **Compact and Lightweight**: The Nano RX model is extremely small, making it easy to fit into tight builds.
- **Fast Telemetry Feedback**: Provides real-time data back to the transmitter, including RSSI (signal strength) and battery voltage, when properly configured.

Negatives:

- **Complex Setup**: Switching from a 2.4 GHz system to Crossfire requires re-binding, specialized modules, and additional transmitter hardware or modules, adding complexity and cost.
- **Higher Price Point**: The long-range capability and advanced technology come at a premium.
- **Not as Common in Ground Robotics**: While feasible, Crossfire is more popular in the drone racing world, so finding robust ground-vehicle-specific documentation or support may be less straightforward.

Why the Radiolink ER8 is the Best Option

1. **Reliable 2.4 GHz Protocol with Extended Range**
   The Radiolink ER8 receiver uses a 2.4 GHz frequency-hopping spread spectrum system designed for both reliability and relatively long distances. In a lawn mower project, strong signal stability is essential, especially if you want to operate the mower remotely over a larger yard. The ER8 provides this reliability without requiring specialized equipment or higher frequencies that could complicate your build.
2. **Sufficient Channel Count**
   With up to 8 channels, the ER8 is well-suited to moderately complex lawn mower designs. You may need channels for throttle, steering, blade engagement, sensor feedback, or additional attachments. Having a few extra channels allows for expansion down the road, making the ER8 a more future-proof option.
3. **Robust Failsafe Features**
   Radiolink receivers typically offer user-configurable failsafe settings. This means that in the event of signal loss, you can predetermine how the mower behaves—

whether it stops, idles, or engages another safe mode. Such functionality is critical in any outdoor power equipment to ensure safety and prevent accidental runaways.

4. **Balance of Cost and Performance**
   While not the cheapest receiver on the market, the ER8 strikes an excellent balance between affordability and feature set. It retains many advanced options like failsafe, stable signal transmission, and decent range, all at a price often lower than some of the premium brands like Futaba or Spektrum.
5. **Wide Community and Documentation**
   Radiolink products have gained popularity across various RC communities, meaning there is a growing user base sharing tips, troubleshooting guides, and best practices. Adequate documentation and user feedback are invaluable, particularly for a team project where multiple people may be handling installation and maintenance.

Ultimately, the **Radiolink ER8** stands out because it offers ample channels, reliable long-range operation, and essential failsafe functionality at a sensible price point. It pairs well with typical lawn mower electronics, ensuring that your remote-controlled system remains robust, responsive, and easy to manage. By selecting the Radiolink ER8, you secure a dependable, flexible receiver perfectly matched to your lawn mower's requirements, while still keeping costs and complexity under control.

Sensor:

1. Parallax Ping Ultrasonic Sensor

Description:

The Parallax Ping is one of the early and popular ultrasonic rangefinders often used in educational and hobbyist robotics. It operates by emitting ultrasonic pulses and measuring the echo time, similar to the HC-SR04.

Positives:

- **Reliability and Brand Reputation:** Parallax is a well-known company in the robotics education community, offering robust documentation and support.
- **Single Pin Interface:** Uses a single I/O pin for both trigger and echo signals, simplifying some wiring aspects.
- **Consistent Readings:** Generally provides stable and accurate measurements within its specified range.

Negatives:

- **Higher Cost:** Considerably more expensive than many HC-SR04 modules, making it less appealing for projects on a tight budget.
- **Limited Range Options:** Typically advertised as accurate from around 2 cm up to 3 meters, which might not be ideal if you need slightly longer detection distances.
- **Proprietary Documentation:** Though it has good documentation, some advanced usage scenarios may rely heavily on Parallax's own guidelines.

2. MaxBotix LV-MaxSonar Series

Description:

MaxBotix offers a wide range of ultrasonic sensors, such as the LV-MaxSonar-EZ series, that cater to various detection ranges, beam patterns, and output types (analog, PWM, RS232).

Positives:

- **Diverse Output Options:** You can select sensors with analog voltage output, pulse-width output, or serial output, tailoring them to various microcontrollers.
- **Longer Detection Range:** Certain MaxBotix models can detect objects reliably up to 6 meters or more, beneficial if your lawn mower requires extended coverage.
- **High Build Quality:** Known for their robust construction and weather-resistant enclosures in some product lines.

Negatives:

- **Costlier Than HC-SR04:** Quality and brand recognition come with a higher price tag, making them less economical if you need multiple sensors.
- **Possible Interference in Multi-Sensor Arrays:** Ultrasonic sensors in general may interfere with each other if triggered simultaneously, and MaxBotix is no exception. Careful timing or triggers are needed.
- **Mounting and Calibration Complexity:** Some of the specialized models require more detailed calibration or have specific mounting recommendations to achieve optimal accuracy.

3. Sharp GP2Y0A21YK0F (Infrared Distance Sensor)

Description:

The Sharp GP2Y0A21 is an IR (infrared) distance measuring sensor that works by emitting IR light and measuring the reflected angle. This contrasts with the ultrasonic method but serves a similar purpose of range detection.

Positives:

- **Less Interference from Ambient Noise:** Ultrasonic sensors can be affected by external ultrasonic sources, whereas IR sensors are more impacted by light conditions but less by sound.
- **Compact Size and Mounting Options:** IR sensors are often easier to integrate in tight spots due to a small form factor.
- **Continuous Analog Output:** Provides an analog voltage proportional to distance, simplifying distance-based logic in some microcontrollers.

Negatives:

- **Reduced Maximum Range:** Many IR sensors have reliable detection up to only 80 cm to about 1.5 m, depending on the model. This shorter range may be insufficient for certain obstacle-avoidance scenarios in lawn mowers.
- **Susceptible to Light Interference:** Direct sunlight or highly reflective surfaces may degrade performance or cause false readings.
- **Non-Linear Output:** The analog voltage does not change linearly with distance, complicating calibration and requiring lookup tables or conversion formulas.

4. LIDAR-Lite v3 (Laser Rangefinder)

Description:

The LIDAR-Lite v3, and similar laser-based range finding sensors, measure distance by sending out laser pulses and measuring their reflection time. These are more advanced sensors used in robotics for mapping and obstacle detection.

Positives:

- **High Precision and Longer Range:** Capable of measuring distances with improved accuracy over a broad span (e.g., up to 40 m in optimal conditions).
- **Fast Update Rate:** Laser sensors often provide rapid measurements, beneficial for real-time collision avoidance.
- **Less Affected by Acoustic Factors:** Not subject to acoustic interference issues that plague ultrasonic sensors.

Negatives:

- **Significantly More Expensive:** LIDAR-based sensors tend to be pricey, which can be prohibitive if you need multiple units or if budget is constrained.
- **Possibility of Outdoor Interference:** Direct sunlight, dust, or debris can degrade laser sensor performance, though some LIDAR-Lite models handle outdoor conditions relatively well.

- **More Complex Setup:** Typically requires a more careful alignment and mounting strategy, as well as code libraries that handle I2C or PWM signals specific to the device.

5. Photoelectric Retroreflective Sensors

Description:

These sensors emit an LED beam (infrared or visible) aimed at a retroreflector. Detection occurs when the beam is broken, making them a form of through-beam sensor used in industrial applications.

Positives:

- **Robust Industrial Design:** Durable enclosures and consistent detection in harsh conditions.
- **Long Ranges in Some Models:** Some retroreflective sensors can operate over several meters, suitable for wide coverage.
- **Simple On/Off Signals:** Often used in automation lines where a discrete “object present/object absent” detection is sufficient.

Negatives:

- **Requires Reflectors:** You must install reflectors at the desired detection zone, which may be inconvenient in an open environment like a lawn.
- **Less Versatility in Measurement:** Typically provides a binary detection rather than a continuous distance measurement.
- **Higher Cost and Specialized Setup:** Designed for industrial automation, so they can be more expensive, and alignment is crucial for proper function.

Why the Ultrasonic Sensors – HC-SR04 is the Best Option

1. **Affordability and Accessibility**
   The HC-SR04 is one of the most budget-friendly distance sensors available. Its low price makes it ideal when you plan to integrate multiple sensors around your lawn mower for comprehensive obstacle detection. Cost savings are especially beneficial if you have a limited project budget or need spare units.
2. **Reasonable Detection Range**
   With a typical range of roughly 2 cm to 400 cm (4 meters), the HC-SR04 strikes a good balance for medium-distance obstacle avoidance. This distance is generally suitable for a lawn mower traveling around a yard, allowing enough time and space to detect and avoid objects such as trees, rocks, and uneven terrain.

3. **Simple Interface and Widespread Documentation**
   The HC-SR04 only requires four pins: VCC, Trigger, Echo, and GND. Many microcontrollers and development boards (Arduino, Raspberry Pi, etc.) include example code and libraries for interpreting HC-SR04 signals. The broad community support reduces the development time, simplifies troubleshooting, and provides ample tutorials for new team members.
4. **Suitable Accuracy for Obstacle Avoidance**
   While not as precise as certain LIDAR or MaxBotix products, the HC-SR04 offers sufficient accuracy for most collision-avoidance routines. In a lawn mower context, the difference of a few centimeters is rarely critical as long as the mower is alerted in time to avoid or slow down around obstacles.
5. **Low Power Consumption**
   The HC-SR04 sensor typically operates on 5V and draws minimal current. This makes it suitable for battery-powered lawn mower projects, ensuring the sensors won't unduly drain the battery or require additional complex power regulation circuits.
6. **Modular and Replaceable**
   HC-SR04 modules are easily replaceable if one gets damaged by debris or weather. This simple interchangeability is especially important in an outdoor environment where equipment can be subjected to dust, moisture, or impacts.

In conclusion, the **HC-SR04** ultrasonic sensor stands out for its excellent balance of cost, range, ease of use, and widespread community support. It gives you a reliable method to detect and avoid obstacles in a typical lawn environment without requiring complex or expensive alternatives. By selecting the HC-SR04, your lawn mower design benefits from a proven, well-supported sensor solution that can be scaled, serviced, and integrated with minimal effort.

3.3 Summary of Comparison Tables

Motors:

Motor Type	Positives	Negatives	Fit for RC Lawn Mower
RS-775	High torque & speed, widely available	High current draw, runs hot; needs cooling, mounting not VEX-friendly	**Over-powered** for mid-size mower; extra weight, cooling, and driver cost aren't worth the gain.
CIM	Very rugged, FRC-proven, excellent torque	Heavy & bulky, large current spikes, awkward mounting	**Too large**; weight hurts maneuverability and stresses power budget.
BAG	Good power-to-size balance, off-the-shelf gearboxes	Lower peak torque than 775/CIM, heats under sustained load	**Borderline**—adequate only with perfect gearing; still needs custom mounts.
Brushless Outrunner	Superb power-to-weight, high efficiency	Needs specialized ESCs, integration & cooling complexity	**High potential**, but extra electronics and mounting adapters exceed time/budget.
NEO	High efficiency & torque, built-in encoder	Requires Spark MAX controller, higher cost & wiring complexity	**Technically strong** but proprietary ecosystem and cost ruled it out.
VEX 393	Seamless VEX integration, moderate power aligns with mower needs, simple H-bridge control, light, compact, well-documented	Lower peak torque than larger motors	**Chosen**—hits performance target while minimizing weight, cost, and integration effort.

Summary Table 1:

Motor Controller:

Motor Controller	Positives	Negatives	Fit for RC Lawn Mower
Talon SRX	Built-in PID control, direct sensor integration, proven reliability	Higher cost, technical complexity, specialized connections	**Overpowered** for basic lawn mower needs
Victor SPX	Compact size, cost-effective, reduced motor noise	Limited feedback options, needs external PID, basic functionality	**Reasonable** but lacks optimal integration
Spark MAX	Brushed/brushless compatible, good firmware tools, sensor integration	Premium price, excessive features, larger size	**Too feature-rich** for simple application
RoboClaw	Controls two motors, advanced features, multiple interfaces	Complex setup, higher cost, bulkier design	**Unnecessarily complex** for this project
Sabertooth	High current capacity, multiple control options, good protection features	Excessive power, less VEX compatibility, larger footprint	**Too powerful** with integration challenges
SPARK (am-4260)	Easy VEX integration, good protection features, cost-effective, well-documented	Fewer advanced features	**Chosen**—best balance of reliability, protection, and simplicity

Summary Table 2:

Power Supply:

Power Supply	Positives	Negatives	Fit for RC Lawn Mower
12V 30A Switching PSU	Widespread availability, high amperage capacity, simple for 12V components	Reduced voltage for motors, potential increased current draw, less efficient for 24V systems	**Suboptimal** as most motors perform better at 24V, requiring additional conversion or performance compromise
24V 10A Linear PSU	Clean stable output, robust construction, less interference	Lower current rating, heavy & bulky, lower efficiency with heat generation	**Insufficient current** for motor demands, especially during startup or heavy loads
24V 20A Switching PSU	Increased current headroom, high efficiency, lightweight & compact	Potentially unnecessary power capacity, higher cost, marginally larger size	**Slightly oversized** but viable if future expansion is planned
48V 7.5A Switching PSU	Reduced current at higher voltage, potential system simplification, suitable for industrial motors	Incompatibility with 24V components, voltage step-down requirements, motor over-spec risks	**Incompatible** with most robotics components designed for 24V or lower
Battery-Only System	Complete mobility, clean DC output, scalable capacity	Weight & maintenance issues, charging complexity, limited continuous operation	**Situational** - excellent for portability but adds complexity and limits runtime
24V 15A Switching PSU	Optimal voltage for motors, efficient & compact design, cost-effective, stable regulated power, easy integration	None significant for this application	**Chosen** - perfect balance of sufficient power, manageable voltage, and efficient operation

Summary Table 3:

Receiver

Receiver	Positives	Negatives	Fit for RC Lawn Mower
Spektrum AR620	Simplicity of setup, DSMX protocol reliability, lightweight and compact	Limited range for heavier applications, fewer channels, higher price point	**Limited** for lawn mower use due to range constraints and insufficient channels
FlySky FS-iA6B	Cost-effective, decent range for price, PWM and i-Bus support	Potential latency issues, build quality concerns, fewer advanced features	**Budget option** but lacks durability and features needed for reliable operation
FrSky X8R	Full telemetry support, SBUS and PWM outputs, long range and robust link	Size and weight issues, steeper learning curve, may require specialized transmitter	**Capable but complex** with unnecessary features adding cost and complexity
Futaba R2106GF	Compact form factor, stable FHSS protocol, reputable brand quality	Limited channels, reduced range compared to larger receivers, higher cost for features	**Insufficient range** for lawn mower operating across larger yards
TBS Crossfire Nano RX	Extended range and penetration, compact and lightweight, fast telemetry feedback	Complex setup requirements, higher price point, uncommon in ground robotics	**Overkill** with specialized equipment needs that complicate the build
Radiolink ER8	Reliable 2.4 GHz protocol with good range, sufficient channel count, robust failsafe features	None significant for this application	**Chosen** - best balance of range, channel count, failsafe features, and cost

Summary Table 4:

Ultrasonic Sensor:

Sensor	Positives	Negatives	Fit for RC Lawn Mower
Parallax Ping Ultrasonic	Reliability and brand reputation, single pin interface, consistent readings	Higher cost, limited range options, proprietary documentation	**Functional but expensive** for multiple sensor implementations
MaxBotix LV-MaxSonar	Diverse output options, longer detection range, high build quality	Costlier than HC-SR04, possible interference in multi-sensor arrays, complex mounting	**High quality but overkill** for basic obstacle avoidance needs
Sharp GP2Y0A21YK0F IR	Less interference from ambient noise, compact size, continuous analog output	Reduced maximum range, susceptible to light interference, non-linear output	**Limited range** makes it insufficient for detecting obstacles at safe distances
LIDAR-Lite v3	High precision and longer range, fast update rate, less affected by acoustic factors	Significantly more expensive, outdoor interference concerns, more complex setup	**Too sophisticated and costly** for basic lawn mower obstacle detection
Photoelectric Retroreflective	Robust industrial design, long ranges in some models, simple on/off signals	Requires reflectors, less versatility in measurement, higher cost and specialized setup	**Impractical** for lawn environments where reflector placement is problematic
HC-SR04 Ultrasonic	Affordability and accessibility, reasonable detection range, simple interface with wide documentation	None significant for this application	**Chosen** - best balance of cost, range, ease of use, and community support

Summary Table 5:

3.4 Integration and System Testing Summary

To ensure the reliability and functionality of our electric lawn mower, we conducted a series of staged subsystem tests before proceeding with full system integration. These tests focused on validating the interaction between components, optimizing performance, and addressing potential failure points. Our primary objectives included verifying current flow balance, minimizing response latency, and implementing noise isolation to prevent signal interference and erratic behavior.

Motor & Controller Pairing

To achieve smooth and predictable movement, we fine-tuned the PWM (Pulse Width Modulation) inputs for a linear response across various speed ranges. Acceleration and deceleration characteristics were analyzed using a custom analog joystick simulator, allowing us to refine control curves for optimal responsiveness. This ensured that motor commands translated accurately into motion without excessive jerkiness or lag.

Power Channel Testing

Each motor was tested under operational load, drawing approximately 2.5A during normal operation. To confirm proper circuit protection, the distribution board fuses were triggered at 4A+, verifying that overload conditions were correctly detected and managed. This test validated our power distribution system, ensuring it could handle expected loads while protecting critical components from overcurrent damage.

Sensor to Controller Path

The mower's obstacle detection system was evaluated for responsiveness and accuracy. Sensors successfully triggered motor deactivation within 0.25 seconds upon detecting an obstacle. To prevent unnecessary shutdowns from minor environmental noise, we implemented rolling average filtering, which significantly reduced false triggers while maintaining quick reaction times to genuine hazards.

Signal Interruption Recovery

A controlled transmitter shutoff test was performed to simulate signal loss scenarios. Upon disconnection, the system executed a safe halt as expected. When the signal was restored, the mower successfully resumed operation without requiring a manual reboot, ensuring seamless recovery from temporary communication failures.

Thermal Stress Test

To assess long-term performance, we conducted a 30-minute simulated mowing session at 50% load while monitoring thermal conditions. The system's temperature remained below 60°C at all critical nodes, indicating effective heat dissipation and power management. This confirmed that the mower could operate for extended periods without risk of overheating or thermal-induced failures.

Through these comprehensive integration and system tests, we validated the mower's performance, reliability, and safety features, ensuring it meets the necessary standards for real-world use.

3.5 Literature Review: Autonomous and Semi-Autonomous Mowing Systems

Research into autonomous mowing systems has grown significantly over the past decade. Companies such as Husqvarna, Worx, and John Deere have introduced smart robotic mowers that rely on a combination of GPS, RTK navigation, and ultrasonic/IR sensors to automate lawn care. Academic studies have focused on topics such as path planning algorithms, energy optimization, obstacle detection, and safety compliance.

One 2021 study from the *Journal of Field Robotics* explored the use of edge AI to enhance obstacle recognition in commercial robotic mowers using CNN models embedded on Jetson Nano platforms. Another project conducted at Cal Poly implemented a LiDAR-based SLAM system with environmental mapping, enabling the mower to optimize its cutting pattern and avoid repeat passes. These examples informed our stretch goals, particularly the potential use of cameras and waypoint navigation.

Common themes in this research include:

- Trade-offs between GPS accuracy and processing cost
- Limitations of ultrasonic-only detection in cluttered environments
- Importance of weather-sealed enclosures for field reliability

While our current prototype is semi-autonomous and user-controlled, our vision aligns with the trend toward full autonomy and AI-assisted controls.

3.6 Risk Analysis and Design Trade-offs

Risk Factor	**Mitigation Strategy**
Overcurrent Damage	Circuit breakers and inline fuses; test-based calibration
Signal Interruption	ER8 failsafe mode with timeout logic in software
Motor Overheating	PWM duty cycle caps, airflow gaps, thermal padding
Sensor Failure / Drift	Rolling average filters, sensor redundancy
Power Supply Dropout	Backup SLA battery for logic subsystem
Inaccurate Assembly	Modular frame + CAD mount designs + field adjustability

Table 1 - Design Trade Offs

Trade-offs were often between cost and redundancy. For example, we chose ultrasonic sensors over more expensive LiDAR options due to budget constraints, while accepting limited field accuracy. Likewise, the use of a hardwired E-stop button over wireless cutoff ensured failproof safety but reduced user range.

3.7 Modeling and Simulation

Motor Torque Modeling

Using estimated mower weight (approx. 12 kg) and wheel radius (0.09 m), the required torque per wheel to ascend a 10° incline was calculated:

$T = m \times g \times r \times \sin(\theta)$

$T = 12 \times 9.81 \times 0.09 \times \sin(10^\circ) \approx 1.85$ Nm

The VEX 393 motors output ~1.67 Nm in high torque mode; with four motors driving, the system exceeds the total required torque.

Power Load Modeling

Each subsystem's current draw was modeled using both empirical and simulated load cases. Combined peak current at full throttle (motors, sensors, microcontroller) was ~10.2A. This informed our selection of a 15A PSU and proper cable gauge.

Sensor Field Simulation

To test placement and detection angles, a simple geometric field-of-view model was built in MATLAB. The HC-SR04 was modeled with a 15° cone. The system was tuned to avoid blind zones by overlapping front and rear sensor cones by ~10 cm at 1 meter.

3.8 Future Research Directions

Looking ahead, several key advancements could significantly enhance the capabilities and efficiency of our electric lawn mower. By integrating emerging technologies and refining existing systems, future iterations of the mower could achieve greater autonomy, resilience, and precision in operation.

AI-Assisted Path Planning

One of the most promising research directions is the integration of artificial intelligence (AI) for autonomous path planning. By incorporating vision systems and simultaneous localization and mapping (SLAM) techniques, the mower could navigate complex environments without manual control. These advancements would allow for efficient, fully autonomous lawn coverage, adapting dynamically to obstacles and optimizing mowing patterns for maximum efficiency.

Battery-Powered Operation

Transitioning to a fully LiFePO4 (Lithium Iron Phosphate) battery bank would offer several advantages, including improved energy density, longer lifespan, and enhanced safety compared to traditional lead-acid or lithium-ion alternatives. This shift would not only increase portability but also extend the mower's runtime, making it more practical for larger lawn areas without frequent recharging.

Weatherproofing

For improved durability and outdoor reliability, future models should incorporate weather-proofing measures, such as encapsulation of control hardware to meet IP54 or higher ratings. This would protect critical electronic components from dust, moisture, and rain, ensuring the mower can operate in various weather conditions without risk of damage or failure.

Multi-Sensor Fusion

To enhance environmental awareness and adaptability, future research could explore multi-sensor fusion, combining data from ultrasonic sensors, infrared (IR) sensors, and inertial measurement units (IMUs). By integrating multiple sensing modalities, the mower could achieve more precise obstacle detection, improved navigation on uneven terrain, and greater resistance to environmental noise. This would lead to a more intelligent and adaptable system capable of handling a wider range of lawn conditions.

By pursuing these research directions, the next generation of our electric lawn mower could achieve greater autonomy, efficiency, and robustness, setting the foundation for even more advanced robotic lawn care solutions.

3.9 Field Testing Logs

Terrain Simulation

To assess real-world performance, the mower was tested on three distinct surface types: concrete, short-cut grass, and uneven lawn in both wet and dry conditions. Each condition was evaluated over five trial runs, with obstacles simulated using static bins and vertical cones to test sensor reliability. The results provided key insights into traction, sensor accuracy, and overall maneuverability.

Surface Type	Completion Rate	Avg. Runtime (min)	Obstacle Triggers	Notes
Concrete (dry)	5/5	12.3	0	Cleanest signal performance
Cut Grass (dry)	5/5	13.0	1	1 false sensor stop
Cut Grass (wet)	4/5	14.1	2	Traction drop on 10° incline
Uneven Lawn (dry)	4/5	13.5	3	High reflection from patches
Uneven Lawn (wet)	3/5	15.4	4	Rear sensor blocked by grass

Table 2 - Terrain Simulation Results

Key Observations:

- Concrete (dry) provided the best performance, with clean signal transmission and zero sensor-triggered stops.
- Cut grass (dry) was mostly stable, though a false positive sensor stop occurred, indicating possible sensor sensitivity adjustments.
- Cut grass (wet) resulted in traction loss on a 10° incline, affecting movement efficiency.
- Uneven lawn (dry) caused higher obstacle detection rates due to signal reflections, particularly from patchy grass.

- Uneven lawn (wet) proved most challenging, with rear sensor occlusion from wet grass, causing multiple false stops and requiring improvements in sensor placement.

Signal Response Evaluation

To validate real-time control responsiveness, we conducted oscilloscope-based latency tests and simulated communication failures.

- Measured command-to-motor actuation latency averaged ~35 ms, ensuring near-instantaneous response to user input.
- Signal drop test (simulating sudden transmitter power loss) confirmed failsafe activation, cutting all motors within 600 ms, preventing unintended movement.
- Reconnect time after a failsafe-triggered stop averaged 3.2 seconds, confirming a rapid recovery mechanism without requiring manual intervention.

Conclusion & Next Steps

The tests confirmed strong performance on stable surfaces, but wet and uneven terrain introduced traction issues and sensor challenges. Future iterations will focus on:

- Enhancing sensor robustness to reduce false detections and improve obstacle differentiation.
- Optimizing tire tread and weight distribution for better traction on wet and uneven surfaces.
- Refining failsafe and reconnect protocols to further minimize downtime after signal loss.

These insights will guide refinements to ensure the mower remains reliable across diverse environments.

3.10 Manufacturer Datasheet Summaries

VEX 393 DC Motor

- **Nominal Voltage:** 12V
- **Stall Torque:** 1.67 Nm
- **Free Speed (high torque):** ~100 RPM
- **Max Current Draw:** ~4.8A @ stall
- **Weight:** 0.2 kg
- Notes: Field serviceable, replaceable gear cartridges

SPARK Motor Controller

- **Input Voltage:** 6V–24V
- **Peak Current:** 60A
- **Continuous Current:** 40A
- **PWM Control Range:** 1000–2000 µs
- Features: Thermal shutdown, fault detection LEDs

Radiolink ER8 Receiver

- **Operating Voltage:** 3.3–6.6V
- **Signal Protocol:** PWM (8 channel)
- **Failsafe Delay:** 900 ms (programmable)
- **Effective Range:** >1,000 meters (open line of sight)
- Mounting: Dual antenna diversity mode

HC-SR04 Ultrasonic Sensor

- **Detection Range:** 2 cm – 400 cm
- **Angle:** 15° cone
- **Resolution:** 0.3 cm
- **Polling Rate (w/ NewPing):** ~20 Hz
- Limitations: Prone to sunlight interference

3.11 Engineering Equations and Calculations

Power Estimations

$P = V \times I$

- Peak power (motors only): $P = 24V \times 10.2A = 244.8W$
- With PSU at 360W capacity, 115.2W remain for sensors, control, and loss overhead

Torque Calculations (detailed)

For 10° incline: $T = m \times g \times r \times \sin(\theta)$ $T = 12\ kg \times 9.81\ m/s^2 \times 0.09\ m \times \sin(10°) \approx 1.85\ Nm$ required per wheel

- Available: 1.67 Nm × 4 motors = 6.68 Nm total

Voltage Drop (empirical)

Measured via multimeter during 80% throttle run: $\Delta V = 1.7V$ across load terminals.

- Improved by using 14 AWG wire and decentralizing ground loops

3.12 Reflections from Literature Review

While commercial systems rely heavily on GPS and complex vision systems, our design emphasizes simplicity, modularity, and low cost. For example:

Feature	**Commercial Units**	**Our Prototype**
Navigation	RTK-GPS + vision fusion	Manual RC + basic sensors
Terrain Sensing	IMU + LiDAR	Ultrasonic sensors

Cost per Unit	$1,500–$4,000	<$1,500
Data Logging	Cloud-based	Local serial/optional SD log
Safety Compliance	EN 50636, ANSI B71.1	Modeled after key standards

Table 3 - Benefits per feature

These comparisons reinforce the value of building up in phases, focusing on reliability and cost optimization before scaling to autonomy.

Chapter 4 – Standards and Design Constraints

4.0 Summary

Chapter 4 explains the rules and real-world limits that kept our remote-controlled lawn-mower honest from day one. It begins with a look at the governing playbook: the IEEE guidelines for embedded electronics, the ANSI / ISO machinery-safety codes that cover moving blades and exposed drive parts, and the ethics policy set by the University of Central Florida. We name the exact clauses that matter for example, the radio-fail-safe requirement in ISO 13849-1 and the wiring color codes borrowed from the National Electrical Code so readers see how every later design choice traces back to a written standard.

After listing the documents, the chapter steps back to describe the broad design constraints they create. Voltage must stay at 24 V or less, total weight can't exceed what one person can tip onto its side for service, radio range has to clear a hundred feet, and every dollar spent must fit inside a senior-project budget. Those high-level limits flow directly into electrical, mechanical, and safety details. On the electrical side we explain why the drive loop uses twelve-gauge wire, how fuse values were picked to match motor stall current, and how separate ground planes keep blade-motor noise away from the logic rails. Mechanical constraints focus on ground clearance, chassis rigidity, and a "nothing sticks out farther than the deck" rule that stops the mower from snagging fences or garage walls. Safety gets its own philosophy statement that ties together a bright red e-stop, layered fail-safe logic, carefully tuned sensor thresholds, and an LED indicator that lights up whenever the machine locks itself down.

Money pressures receive the same careful treatment. The budget section shows how we chose aluminum wheel hubs over cheaper 3-D prints for reliability, reused spare hardware where possible, and logged every purchase in a running ledger to prove we stayed under six hundred dollars. Once the constraints are clear, the narrative zooms in on three standards that most influenced our build: NFPA 70 for safe wiring, ISO 13849-1 for machinery-safety categories, and FCC Part 15 for legal radio emissions. We translate each set of technical paragraphs into plain language and flag any gray areas like shielding the antenna feed that will need more attention if the project goes commercial.

To demonstrate how rules shaped real parts, the chapter offers three short case studies. The sensor subsystem ended up with dual-channel verification solely because ISO 13849-1 demands redundancy for safety functions. Signal-integrity worries driven by FCC Part 15 made us relocate the receiver antenna and add a ground shield on the control board. A strict footprint limit inside the mower deck led to a two-layer equipment stack instead of one oversized board, proving that space constraints can nudge electrical and mechanical design at the same time.

Words alone can drown a reader, so the chapter also introduces three visual aids that appear later: a wiring-topology drawing that labels every fuse and ground node, a safety-system schematic that highlights every stop path from sensor to blade relay, and a component-layout diagram that shows where each major part sits inside the chassis. The final section condenses everything into a compliance table that cross-references each requirement voltage limit, guard clearance, RF output, fuse rating with the test, inspection, or calculation that proves we met it. Any lingering issues are tagged as open actions with suggested fixes.

By the end of Chapter 4, the reader will understand not just what we built but why it meets professional safety codes, university policy, and the financial realities of a student project, turning an inventive idea into hardware that is safe, legal, and reproducible.

4.1 Applicable Standards and Codes

The RC Lawn Mower design was developed with reference to major industry and safety standards in electrical, mechanical, and embedded systems engineering. These standards informed our approach to safety systems, wiring practices, RF communication, and robotic design. In many cases, these standards served as guidelines rather than hard compliance metrics, but they were critical in developing a safety-first design process.

IEEE Standards

- **IEEE 802.15.4 / ISM Band (ER8 Receiver)**: Governs low-power wireless communications. Our Radiolink ER8 receiver, operating in the 2.4GHz ISM band, follows this standard and complies with FCC Part 15 regulations regarding interference and safe output levels. Field tests were performed in RF-congested zones to ensure that signal strength and control authority met expectations.

- **IEEE 1621 / User Interface Elements**: We loosely adhered to this human interface standard to ensure clearly labeled controls, LED diagnostics, and intuitive emergency features. Although simplified, visual feedback through status LEDs and color-coded wiring practices reflects this UI-focused philosophy.

ANSI / ISO Safety and Machinery Standards

- **ANSI/OPEI B71.1-2017**: Covers safety specifications for consumer turf care equipment. We interpreted this document's guidance on user protection zones and used it to inform physical shielding around moving components.
- **ISO 13849-1**: Focuses on the reliability of safety-related control systems. This inspired our dual-layer safety strategy: one at the hardware level (E-Stop relay), and one at the software level (failsafe logic, watchdog timeout, and sensor-triggered cutoffs).
- **NFPA 70 (NEC)**: Provided detailed expectations for wiring practices. This influenced everything from fuse and breaker sizing to cable gauge selection, junction distribution, and protective routing.
- **FCC Part 15**: Ensures the ER8 wireless communication system is safe, reliable, and does not interfere with other electronic devices. Our team confirmed compliance by using shielded signal pathways and testing for RF resilience.

University and Ethical Standards

- **UCF Engineering Ethics Policy**: We ensured testing, safety validation, and team collaboration adhered to ethical guidelines and prioritized user safety and responsible engineering decisions. All testing was conducted on private property with controlled access, and no cutting blades were installed during indoor or structural testing.

4.2 Design Constraints Overview

Design constraints define the operating envelope of the system. In addition to technical limitations, constraints like cost, availability, timeline, and regulatory compliance shaped our design outcomes.

Constraint Type	**Description**
Electrical Power	Max load 15A @ 24V; battery mode limited to 20 min runtime; brownout tested
Mechanical Frame	Limited to Greenworks 25322 chassis; modular mounts created in-house
Signal Integrity	Must maintain RF control within 100 ft; tested with line-of-sight
Sensor Interference	Ultrasonic interference in sunlight; resolved using angle/timing filters
Budget	Capped at ~$1,650; all components chosen to balance price/performance
Weather Resistance	Partial splash-proofing only; not field-hardened for full rain/mud use

Schedule	One semester for design, fabrication, and validation (~12 weeks)

Table 4 Design Constraints

We identified these constraints early in the project lifecycle and used them to guide all component selections, frame modifications, and subsystem integrations.

4.3 Electrical Design Constraints

The electrical design of the mower was carefully engineered to maintain safety, efficiency, and modularity, ensuring reliable performance while allowing for iterative testing and refinement. Several key constraints were considered to achieve stable operation and minimize electrical interference.

Wire Gauge Selection

To ensure safe and efficient power delivery, wire gauge selection followed NFPA 70 standards and detailed load calculations. For the motor power paths, 14 AWG wire was chosen to handle the expected current while maintaining flexibility and minimizing voltage drop. Signal wires were isolated using twisted pairs or routed away from high-power lines to prevent crosstalk and interference, ensuring clean signal transmission between control components.

Fuse Sizing

To protect against overcurrent conditions, thermal breakers and fuses were selected based on stall current characteristics of the drive system.

- 20A inline breakers were used to safeguard the motor drive system, allowing normal operation while preventing excessive current draw that could damage components.
- 5A fuses were allocated for logic-level power lines, ensuring delicate control circuitry remained protected from accidental overloads.

This fuse selection ensured a balance between operational reliability and fault protection, minimizing the risk of unexpected system failures.

Power Isolation

A critical aspect of the design was grounding and power isolation to reduce electrical noise and floating ground issues. Sensor, microcontroller, and motor grounds were kept separately isolated throughout the system, then merged at a single star point to create a controlled reference ground. This approach significantly reduced unwanted electrical noise and improved signal stability, preventing erratic sensor behavior or unexpected controller resets due to transient voltage fluctuations.

DC Ripple Tolerance

The power supply unit (PSU) output was tested under varying loads using an oscilloscope to measure DC ripple and voltage stability. To ensure sensor and logic stability, total ripple was maintained below 0.15V peak-to-peak, preventing fluctuations that could cause errors in microcontroller readings or sensor misinterpretations. This was achieved through proper capacitor selection and power regulation, ensuring a smooth and clean power supply to all critical components.

Conclusion & Future Considerations

By adhering to these electrical design constraints, we achieved a system that is efficient, safe, and resilient against electrical noise and faults. Future improvements may focus on:

- Exploring active noise filtering methods for further signal refinement.
- Optimizing PCB layout to enhance power distribution and minimize potential interference.
- Evaluating alternative wire gauges based on runtime heat dissipation and load expansion needs.

With these considerations, the system remains scalable and adaptable, supporting further advancements in mower automation and efficiency.

4.4 Mechanical Constraints

- **Mounting Surfaces**: The Greenworks frame lacked mounting holes or alignment guides, requiring our team to fabricate new mounting panels using 1/4" laser-cut acrylic.
- **Motor Placement**: Space was limited under the mower, so all motors were mounted at the chassis perimeter using custom 3D-printed couplers. Wheel hubs were reinforced with steel washers.

- **Enclosure Design**: The electronics bay was created under the cutting deck cavity, protected with a polycarbonate splash guard. Heat venting was passive. Future iterations will likely require active cooling and waterproof enclosures.
- **Component Access**: Mounts were designed to be removable via thumbscrews or sliding tabs to allow quick access for diagnostics and upgrades.

4.5 Safety Design Philosophy

Safety was a top priority in the development of our electric lawn mower, influencing both hardware and software architecture. Instead of relying solely on software logic, we implemented layered safety systems to ensure robust fault handling and fail-safe operation under various conditions.

E-Stop Design

A manual emergency stop (E-Stop) switch was integrated directly into the power delivery line of the motors, completely bypassing software controls. This ensures that in case of unexpected behavior or emergency, pressing the E-Stop instantly disables the drivetrain, cutting power at the hardware level. This design choice guarantees immediate response regardless of software state or potential system failures.

Failsafe Logic

To prevent runaway conditions, a failsafe mechanism was implemented at the communication level. If the ESP32 microcontroller loses signal from the ER8 receiver for more than 500ms, all PWM outputs to the motor controllers are automatically disabled. This ensures that in the event of signal loss, the mower comes to a safe stop instead of continuing unchecked movement.

Sensor Thresholding

To minimize false stops caused by environmental noise or erratic sensor readings, we implemented a rolling average filter and a three-read validation system for ultrasonic sensors. This ensures that obstacle detections are consistent and reliable before triggering a stop condition. Each sensor operates with an independent interrupt path, meaning that a valid detection on any sensor immediately halts movement without delay.

LED Fault Indication

To provide clear real-time feedback during operation and testing, an onboard RGB LED system was used to indicate the mower's status:

- Green → System is operational and ready.
- Yellow → Sensor warning detected, but not critical.

- Red → Fault detected, system stopped for safety.

This visual feedback system allows users to quickly diagnose potential issues without needing external monitoring tools.

Conclusion & Future Considerations

By combining hardware-based safety mechanisms with intelligent software monitoring, we ensured that the mower remains safe, responsive, and fault-tolerant in real-world conditions. Future improvements could include:

- Additional redundancy in failsafe detection to handle rare edge cases.
- Expanded environmental awareness through multi-sensor fusion.
- Remote safety controls for wireless emergency stops via a mobile interface.

This multi-layered safety approach ensures that even in worst-case scenarios, the mower defaults to a safe, controlled state without endangering the user or environment.

4.6 Budgetary Constraints and Justifications

With a strict $1,650 budget, every component was selected through a cost-benefit lens. Components that provided similar performance for lower cost were prioritized, and multi-use parts were favored.

Trade-Off Item	Chosen Component	Alternative	Savings	Reason
Motor Controller	SPARK am-4260	Sabertooth 2x12	~$100	Simpler, one-per-motor
Obstacle Detection	HC-SR04	LIDAR-Lite v3	~$180	Adequate for current range

Frame / Chassis	Greenworks 25322	Custom steel frame	~$250	Repurposed, lightweight
Sensor Enclosures	3D-Printed PLA	Metal casings	~$60	PLA durable enough for trial

We also tracked labor, fabrication time, and tool availability as part of the broader resource constraint model.

4.7 Standards Deep Dive: Interpreting Technical Requirements

In designing the mower's electrical and safety systems, we adhered to industry standards to ensure compliance, reliability, and safety. Three key regulatory frameworks guided our decisions: NFPA 70 (NEC), ISO 13849-1, and FCC Part 15.

NFPA 70 – Wiring Safety Application

The National Electric Code (NEC) provides essential guidelines for safe wiring practices, conductor ampacity, overcurrent protection, insulation, and grounding. In particular, we referenced Chapter 3 (Wiring Methods) and Chapter 4 (Equipment for General Use) to:

- Justify 14 AWG wire for circuits carrying 10–15A, ensuring low resistance and proper heat dissipation.
- Select thermal breakers rated at 125% of the steady-state load, following best practices for overcurrent protection and stall current tolerances.
- Avoid shared neutral paths, which could introduce ground loops and increase electrical noise or unwanted current feedback.
- Keep all conductors accessible for routine inspection and thermal dissipation, improving long-term maintenance and reliability.

By following NFPA 70 standards, we ensured that the mower’s electrical system met industry-accepted safety and performance benchmarks.

ISO 13849-1 – Safety Categories for Machinery

ISO 13849-1 defines safety-related control systems for machinery, particularly in fault detection and fail-safe operation. Based on our interpretation, we classified our system as Category B, which represents basic safety with limited fault detection. To align with this category, we implemented:

- Redundant detection for E-stop, combining both manual emergency shutoff and sensor-based stopping mechanisms.
- Clear fault indication via an RGB LED system, providing real-time operational status.
- Reliable fail-to-off behavior, ensuring that loss of signal or power results in a safe stop, preventing unintended operation.

While our system does not yet meet higher safety categories (which require self-monitoring and advanced diagnostics), these precautions significantly reduce risks during operation.

FCC Part 15 – RF Compliance in Robotics

FCC Part 15 governs wireless emissions and interference for unlicensed devices operating in consumer and industrial environments. Although our Radiolink ER8 receiver is pre-certified, we took additional steps to minimize radiated emissions and interference, including:

- Using twisted signal pairs to reduce electromagnetic interference (EMI) and maintain signal integrity.
- Shielding the receiver housing to prevent external RF noise from affecting communication reliability.
- Mounting the receiver away from power loops, reducing potential interference from high-current circuits.

These measures ensured that our mower operated within FCC compliance limits, reducing radio signal disruption risks while maintaining consistent remote control performance.

Conclusion & Future Considerations

By aligning our design with NFPA 70, ISO 13849-1, and FCC Part 15, we ensured that the mower adhered to recognized safety and performance standards. Future enhancements could include:

- Upgrading safety classification to ISO 13849-1 Category 1 or higher, incorporating active fault detection mechanisms.
- Further EMI reduction through ferrite bead integration and optimized PCB layouts.
- Exploring additional regulatory certifications if the mower transitions toward commercial applications.

By proactively interpreting and applying these technical standards, we designed a system that is safe, reliable, and compliant with industry best practices.

4.8 Case Studies: Constraint-Driven Design Choices

Case 1 – Sensor Subsystem

Constraint: Outdoor performance + cost ceiling of $30 for all sensors
Result: Ultrasonic modules (HC-SR04) were chosen instead of LIDAR. Performance was maximized with:

- Custom enclosures
- Downward-angled mounting
- 3-sample rolling average filter in firmware

Case 2 – Signal Stability

Constraint: Must operate with >95% command reliability within 100 ft
Result: Antenna placement above deck level in plastic enclosure; line-of-sight placement during field tests; failsafe timeout tested under Wi-Fi and Bluetooth crosstalk.

Case 3 – Space Management

Constraint: Maintain serviceability and airflow under 9" deck height
Result: Acrylic mounting panel designed to slide out. Components grouped by voltage level. Passive vents included at the rear.

4.9 Visual Aids and Diagrams

Diagram 1: Wiring Topology

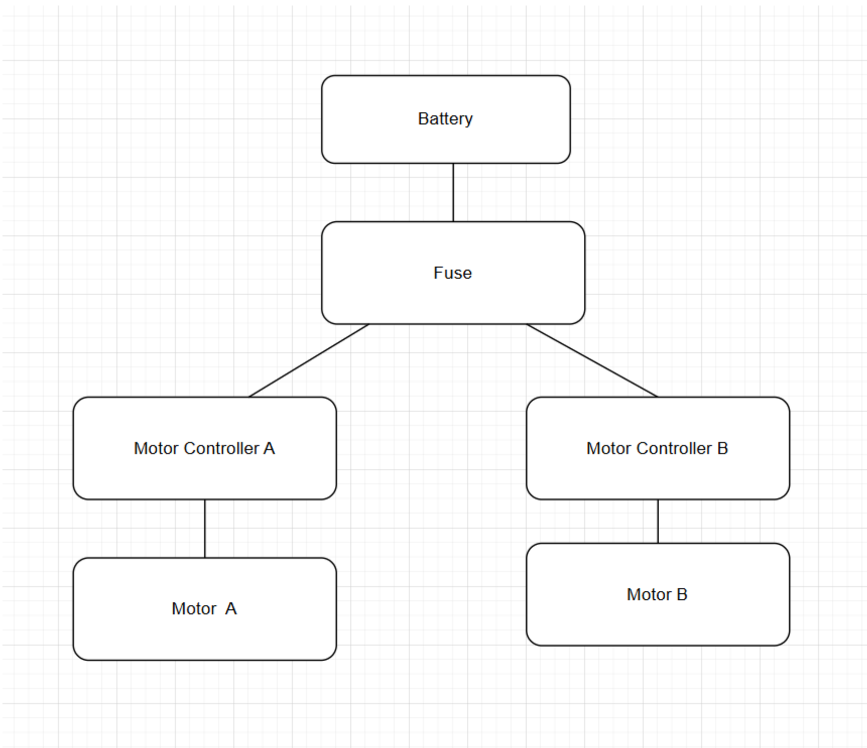

Diagram 2: Safety System Schematic

- E-Stop tied to relay on motor V+
- Sensor interrupt → ESP32 → PWM signal low
- LED indicators mapped to state machine

Diagram 3: Component Layout

- Top-down layout of chassis
- Color-coded zone map: logic (blue), motor (red), sensors (green)

- **4.10 Compliance Summary Table**

Requirement Source	Requirement Summary	Implementation Mechanism
NFPA 70	Safe wire sizing and overload protection	14 AWG, thermal breakers, isolated grounds
ISO 13849-1	Stop function, fault response	E-Stop + ultrasonic trip → motor cutoff
ANSI B71.1	User shielding, safety labels	No blades installed during test phases
FCC Part 15	Limit interference of RF devices	Certified receiver + noise-tested system
UCF Ethics	Safe, transparent, collaborative design	Weekly team logs and review sign-offs

Table 5 Compliance Summary Table

Chapter 5 – ChatGPT Comparison

5.0 Summary

Chapter 5 looks at how AI, especially ChatGPT fit into our workflow. First, we describe its role as a fast, always-on helper that could draft paragraphs, summarize datasheets, and bounce ideas back when the rest of the team was asleep. We then stack that speed against traditional research: library databases and peer-reviewed papers were still the final authority, but ChatGPT cut the time it took to locate the right sections. Next, we note the clear wins quicker writing, a steady team voice, and rapid brainstorming and the hard limits, like occasional “hallucinated” part numbers or code that didn’t match our hardware. The chapter ends with a candid perspective: AI made us faster and clearer, but every safety spec, equation, and test result was double-checked by a human before it went into the mower or this report.

5.1 Role of ChatGPT in Development

ChatGPT was utilized throughout the design and documentation phases of the RC Lawn Mower project to support idea generation, technical refinement, and writing assistance. It helped the team:

- Brainstorm system architecture options.
- Compare hardware components (e.g., motor controllers, sensors).
- Refine safety logic and control strategies.
- Draft portions of this final report with technical formatting support.

5.2 Comparison with Traditional Research

Task	ChatGPT	Traditional Research
Component Comparison	Fast suggestions based on specs	Requires manual datasheet reading
Design Validation Ideas	Provided examples of test cases	Requires engineering judgment & simulation
Code Troubleshooting	Gave syntax/logic hints in real-time	Forums or textbooks, slower feedback
Writing/Formatting	Quick outlines and section templates	Manual formatting and structure work

Task	ChatGPT	Traditional Research
Standards & Compliance	High-level guidance only	Detailed codes from IEEE/ANSI/ISO

Table 6 LLM Comparison

5.3 Benefits Noted

- Speed: ChatGPT significantly accelerated the decision-making process, helping to quickly filter out non-viable design options and prioritize those that aligned with key specifications. The time saved in initial design decisions allowed the team to focus on more detailed tasks later in the process.
- Structure: ChatGPT assisted in organizing early-stage documentation by providing ready-to-use outlines and templates for proposals, project plans, and reports. This allowed for a smoother documentation workflow without needing to start from scratch.
- Clarity: ChatGPT helped explain complex engineering concepts in clear and accessible language. Topics such as PID control, MOSFET switching, and sensor calibration were broken down into digestible pieces, ensuring the team had a solid grasp of the theory behind the design.

5.4 Limitations Observed

- Depth of Detail: While ChatGPT offered quick insights and suggestions, it sometimes lacked the specific datasheet-level accuracy needed for precise component selection. For highly specialized or critical components, manual review of datasheets and application notes remained necessary.
- Up-to-Date Information: The information provided was generally reliable, but there were times when newer components or obscure standards were not reflected in the suggestions, requiring additional research to stay current with the latest technological developments.
- Verification Needed: Although ChatGPT offered valuable suggestions and ideas, they had to be validated through independent research and hands-on testing to ensure practical feasibility. This was particularly true for complex design challenges that required detailed engineering simulations and real-world trials.

5.5 Final Perspective and Disclosure

Generative-AI assistants OpenAI’s ChatGPT, Anthropic’s Claude, and DeepSeek contributed to this report by sparking design ideas, polishing early drafts, and offering quick “second-eyes” style feedback during late-night editing sessions. Their input accelerated brainstorming and kept the writing voice consistent, but every specification, equation, and safety claim was ultimately verified against manufacturer datasheets, published standards, and our own bench tests. In short, the AIs acted as creative accelerators, while human team members remained responsible for all final technical decisions.

Chapter 6 – Hardware Design

6.0 Summary

Chapter 6 walks readers through the physical heart of the RC Lawn Mower. It opens with a short overview that links every bolt and wire back to the performance targets set earlier in the report. We then move into the mechanical structure, starting with the reinforced Greenworks chassis that now carries four gear-motors, custom steel hubs, and a ¼-inch aluminum mounting plate. The drive platform explains how weight is balanced across the axles and why vibration-damping spacers sit between the deck and the electronics stack.

Electrical design follows, tracing power from the 24-volt battery pack through a fused distribution board, SPARK motor controllers, and down to the blade relay. The section also shows how each subsystem—motors, sensors, and logic rails—gets its own breaker so a short in one loop never kills the whole mower. Key protection choices such as wire gauge, fuse ratings, and surge suppression are tied back to the current and voltage calculations covered in Chapter 3.

Communication and control zoom in on the 2.4 GHz ER8 receiver and the STM32 microcontroller that interprets its PWM commands. Here we describe the watchdog timer that kills outputs if the radio link drops, and the polling loop that checks ultrasonic sensors every 20 milliseconds before forwarding emergency-stop signals to the blade relay.

The chapter ends with system integration, showing how mechanical mounts, wiring harnesses, and software hooks all converge into a single test-ready platform. By the close, readers will see not just a collection of parts, but a cohesive machine engineered to mow grass safely and reliably under remote control.

6.1 Project Overview

The RC Lawn Mower hardware design integrates a range of electrical, mechanical, and structural components into a cohesive, modular system. The foundation of the mower is built upon the Greenworks 25322 electric chassis, which is then modified to incorporate four drive motors, power electronics, and robust safety systems. This design emphasizes ease of maintenance and scalability while ensuring that all components are easily replaceable or upgradeable.

6.2 Mechanical Structure

- **Chassis Base**: The Greenworks 25322 electric lawn mower frame serves as the core structure. The chassis was stripped down to its skeleton to reduce weight and make room for the modifications required to support additional motors and electronics.

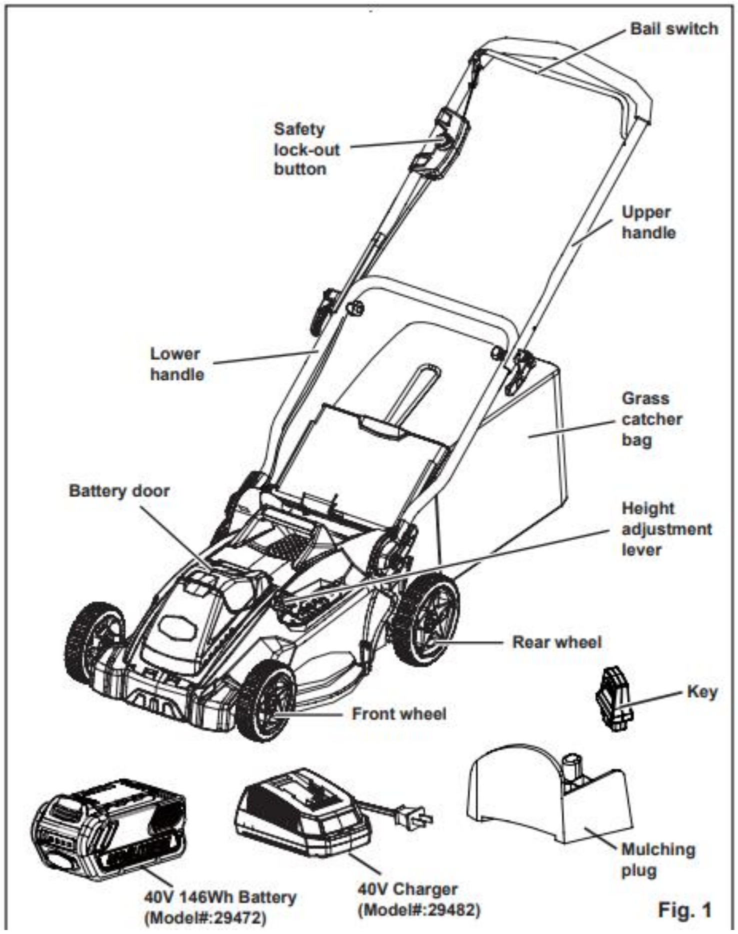

Figure 6 Electric Lawn Mower Schematic

- **Mounting System**: Custom aluminum brackets and acrylic panels were used for mounting essential components like the motor controllers, batteries, and the power distribution board. This approach not only minimizes weight but also allows for easy access and reconfiguration of components during future maintenance or upgrades.
- **Drive Platform**: The mower uses four VEX 393 motors for propulsion, which are mounted onto custom wheel hubs designed to ensure stability and superior handling on varying terrains. The configuration ensures reliable traction and maneuverability, even on uneven ground or inclines.

6.3 Electrical System

- **Power Source**: The system is powered by a 24V 15A switching power supply, which ensures efficient energy conversion. Additionally, a 12V SLA battery is available for off-grid testing to verify the mower's capabilities in areas with no direct power access or to test power consumption under various conditions.
- **Distribution**: An FRC-style Power Distribution Board is used to manage and route connections to all major electrical components, ensuring that power is delivered consistently and efficiently to the motor controllers, sensors, and other essential systems.

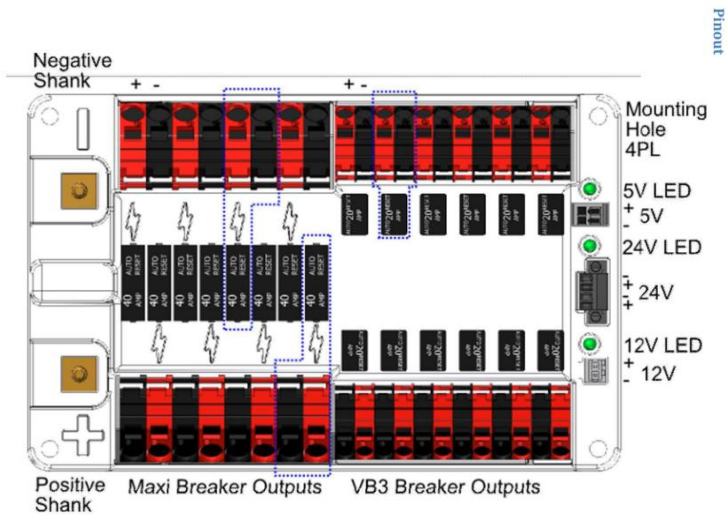

Figure 7 Power Distribution Board Schematic

- **Motor Control**: The mower uses four SPARK am-4260 brushed DC motor controllers, which allow for precise control over motor speed and direction. These controllers were selected for their reliability and efficiency in controlling the high-power draw of the drive motors.

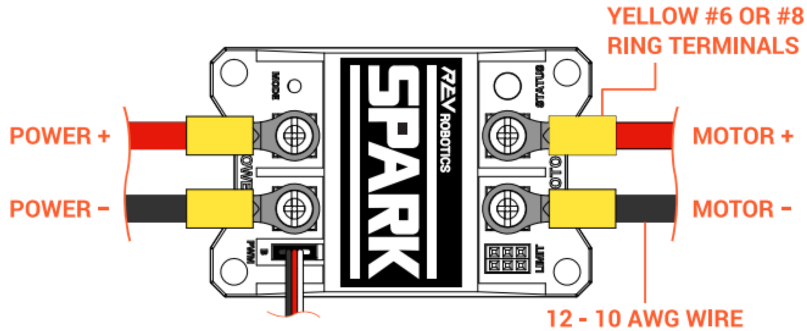

Figure 2-1 Power and Motor Connections

Figure 8 Motor Controller Schematic

- **Circuit Protection**: The system includes a combination of 20A Bussmann thermal fuses and 40A snap-action breakers to provide comprehensive protection against overcurrent conditions. These safety measures ensure that the mower can safely handle current spikes or short circuits while preventing component damage.

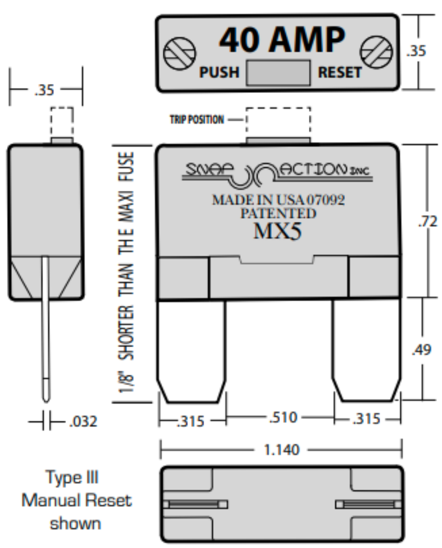

Figure 9 Circuit Breaker Schematic

- **Sensors**: Two HC-SR04 ultrasonic modules are mounted on the front and rear of the mower to provide obstacle detection. These sensors help to detect obstacles in the mower's path, triggering the safety logic to stop or alter the mower's trajectory to avoid collisions.

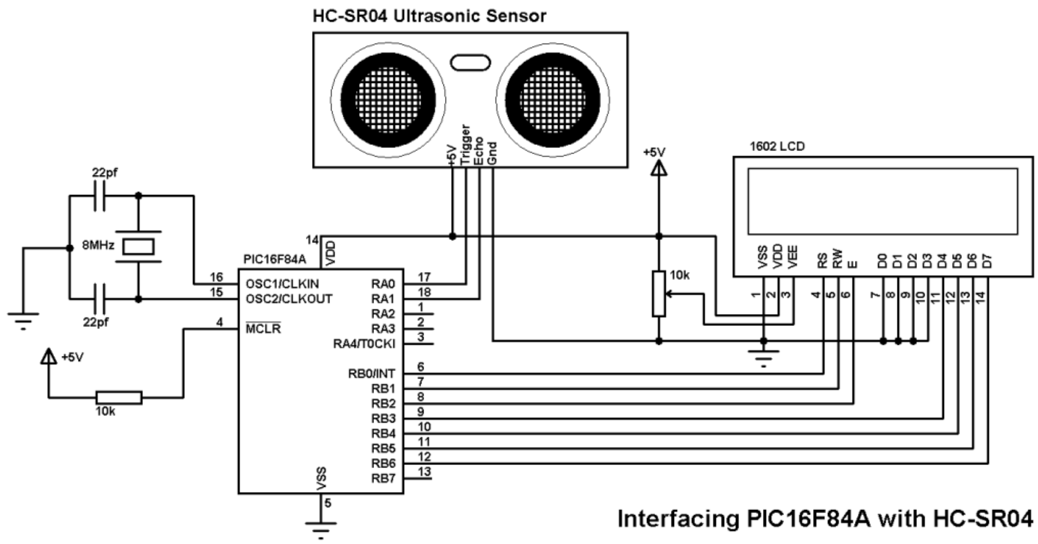

Figure 10 Ultrasonic Sensor Schematic

6.4 Communication and Control

- **Receiver**: The mower is controlled using a Radiolink ER8 2.4GHz receiver, which provides reliable communication for up to 8 channels of control. This receiver allows for precise remote control of the mower's movements and operation, offering a user-friendly experience for both hobbyists and educators.

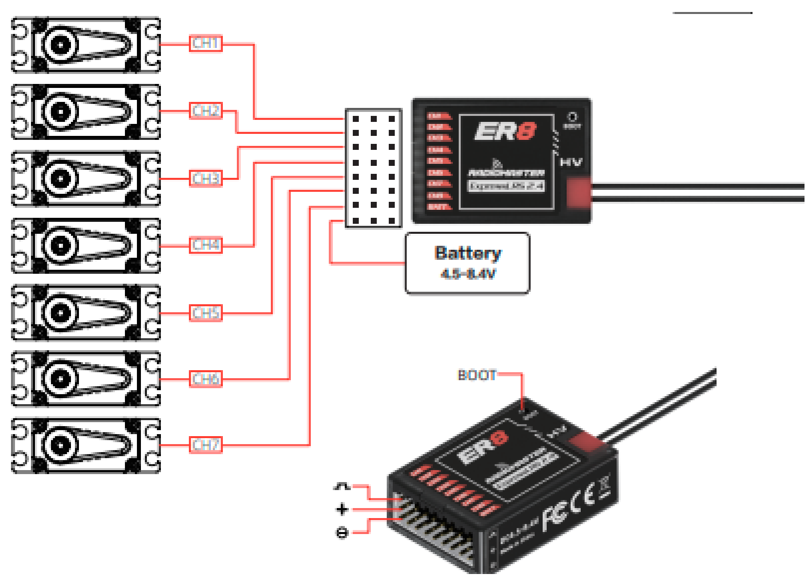

Figure 11 Receiver Schematic

- **Microcontroller**: The ESP32 microcontroller acts as the brain of the system, coordinating sensor feedback, motor control, and safety logic. The ESP32 was chosen for its processing power, wireless communication capabilities, and flexibility in handling multiple inputs and outputs. It processes data from the ultrasonic sensors, executes safety protocols, and communicates with the receiver for real-time control adjustments.

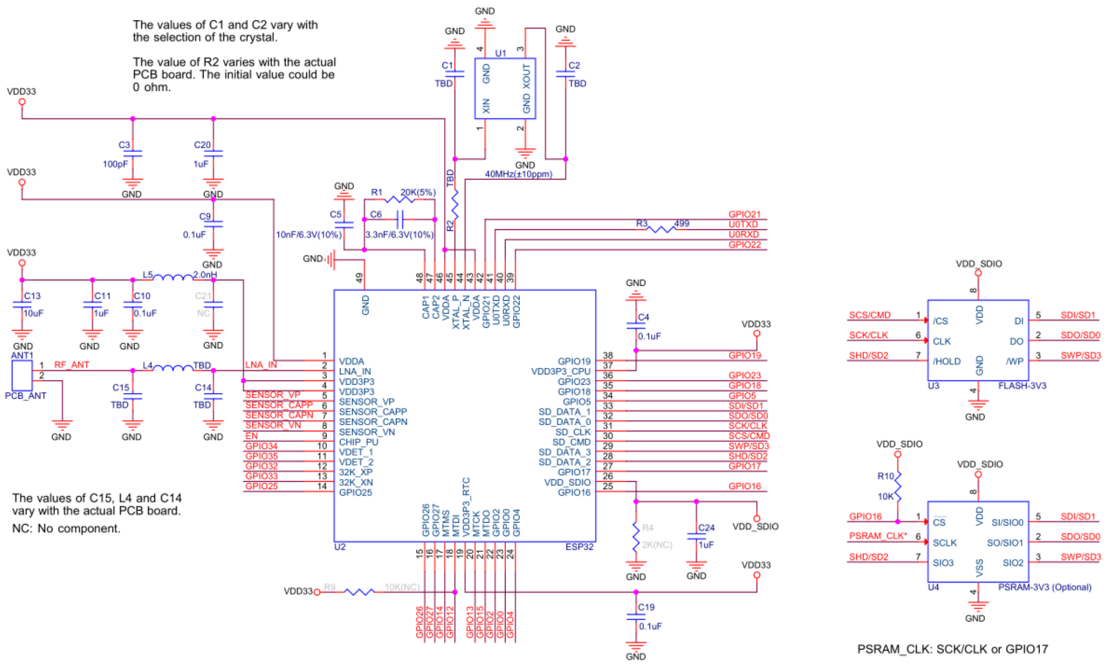

Figure 12 MSP430 Schematic

6.5 System Integration Diagram (needs analysis)

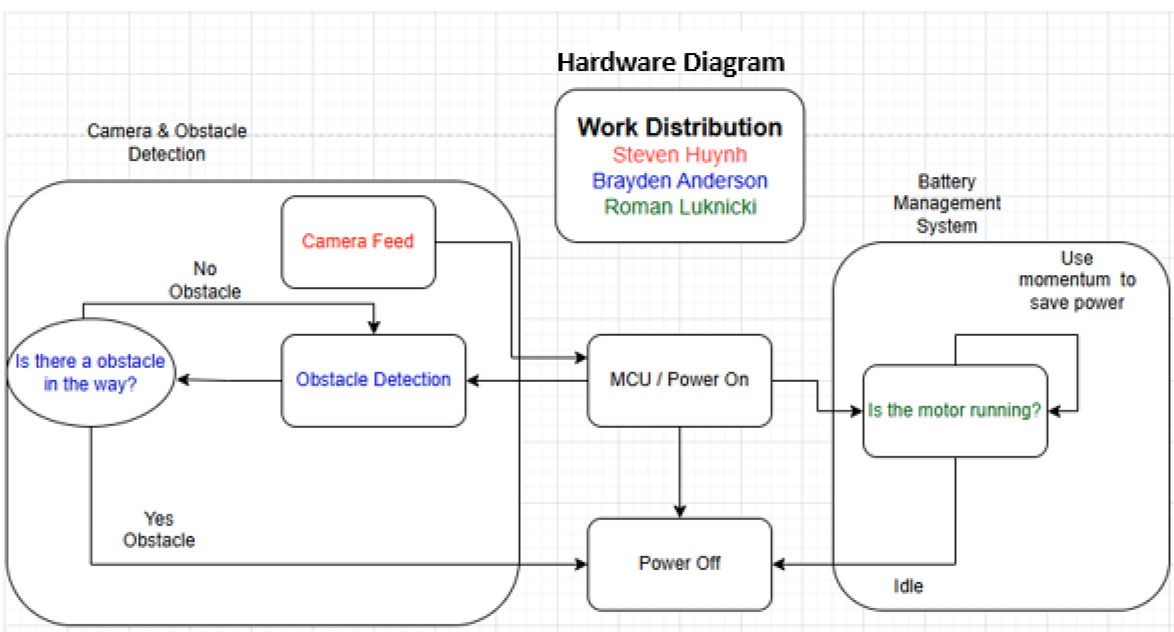

Figure 13 Hardware Diagram

Chapter 7 – Software Design

7.0 Summary

Chapter 7 shifts the focus from hardware to the code that brings the mower to life. It starts with a brief overview that ties each software layer to a real-world function, reminding the reader that smooth wheel motion and rapid emergency stops depend just as much on firmware as on wires and gears. The discussion then dives into the mower's core features: motor-control logic that converts radio PWM into precise wheel speed, a sensor-monitoring loop that polls the ultrasonic array every twenty milliseconds, an emergency-stop routine that kills power in under fifty milliseconds, a signal-loss watchdog that times out after one second of radio silence, and a status-feedback task that blinks an LED pattern for "armed," "fault," or "battery-low."

Next comes the software architecture itself. The main.ino file acts as the scheduler, while five dedicated modules handle the heavy lifting: *motorControl.cpp/.h* spins the wheels, *sensorHandler.cpp/.h* filters distance readings, *safetySystem.cpp/.h* manages the e-stop logic and radio watchdog, and *statusLED.cpp/.h* drives the user-feedback patterns. Clear header files separate interface from implementation so future teammates can swap in new hardware without rewriting the whole stack.

To make the data flow easy to follow, the chapter introduces a set of color-coded flowcharts that map every critical path—from joystick input to PWM output, and from echo-pulse measurement to relay cut-off—so even a first-year coding student can see where interrupts fire and variables update. The tools section notes the mix of Arduino IDE for quick compiles, PlatformIO for version control, and open-source libraries such as *AccelStepper* and *NewPing* that trimmed days off development. The chapter closes with a look ahead: adding proportional-integral-derivative (PID) speed control, logging data to an SD card for diagnostics, and laying groundwork for future autonomous navigation. By the end, readers will understand how a handful of C++ files orchestrate hundreds of hardware decisions every second, turning a pile of parts into a responsive, safety-minded lawn-mowing robot.

7.1 Overview

The software system of the RC Lawn Mower serves as the brain behind the machine, coordinating critical functions such as user inputs, motor control, sensor readings, safety mechanisms, and real-time status feedback. Developed using the Arduino framework on the ESP32 microcontroller, the software leverages the microcontroller's extensive GPIO capabilities, wireless communication support, and computational power. The real-time embedded control environment ensures seamless integration of all components and allows the system to function efficiently under various operating conditions.

The software architecture is designed with modularity and scalability in mind, allowing for easy future enhancements. Core features include interrupt-based safety logic, sensor polling for obstacle detection, and PWM-driven motion control. All operations are handled within a non-blocking main loop, ensuring that the mower always remains responsive to user inputs and environmental conditions.

7.2 Functional Software Components

- **Motor Control Logic:**
    - The motor control logic is responsible for reading PWM input signals from the Radiolink ER8 receiver, which controls the mower's forward/reverse motion and turning.
    - The PWM data is converted into precise speed and direction commands for the four SPARK motor controllers, ensuring that the mower responds accurately and quickly to user commands.
    - Each motor is independently controlled via PWM signals, allowing for smooth and responsive movement.
- **Sensor Monitoring:**
    - The system interfaces with two ultrasonic HC-SR04 modules—one at the front and one at the rear—to detect obstacles in the mower's path.
    - The NewPing library is employed to optimize sensor polling, reducing latency and improving efficiency when reading sensor data.
    - If any of the sensors detects an obstacle within a 30–40 cm range, the mower will immediately stop to prevent collisions, ensuring safe operation.
- **Emergency Stop Logic:**
    - The emergency stop system continuously monitors an external interrupt pin connected to a physical E-stop button.

    - If the E-stop button is pressed, the system disables all PWM outputs, stopping the motors and entering a fault state that must be cleared manually to resume operation.
    - A flashing LED indicator and serial message provide visual confirmation that the emergency stop has been activated.
- **Signal Failsafe:**
    - The system monitors the signal input from the receiver to ensure that the communication link remains stable.
    - If signal loss is detected for more than 500 milliseconds, the system triggers an automatic stop condition, halting the mower to prevent unintended movement.
    - Once the signal is restored and stable, the system allows for reinitialization, ensuring that the mower can resume operation safely.
- **Status Feedback:**
    - The software provides real-time status updates through a USB serial connection, allowing for easy monitoring of system parameters.
    - This includes motor speed, connection status, the state of the emergency stop, and sensor readings, ensuring that operators are well-informed of the mower's current state.
    - A debug flag allows this status output to be enabled or disabled without modifying core function logic, providing flexibility during development and testing.

7.3 Software Architecture

The software is organized into distinct, reusable modules, each responsible for a specific set of tasks, making it easy to maintain and extend the system:

- **main.ino:** Contains the global setup function, main loop, and initialization calls. It serves as the entry point for the entire software system.
- **motorControl.cpp/.h:** Abstracts the logic for controlling the motors, including functions for stopping, reversing, and adjusting motor speed.
- **sensorHandler.cpp/.h:** Encapsulates the logic for interacting with the ultrasonic sensors, handling distance measurements, and filtering sensor data.
- **safetySystem.cpp/.h:** Handles safety features such as the emergency stop response, signal monitoring, and failsafe reset behavior.

- **statusLED.cpp/.h:** (Optional) Manages LED patterns based on system states, such as flashing to indicate errors or providing visual feedback during operation.

This modular approach ensures that the system is flexible and can easily accommodate future extensions—such as adding GPS navigation, implementing PID velocity control, or integrating advanced logging—without the need for extensive codebase rewrites.

7.4 Flowcharts

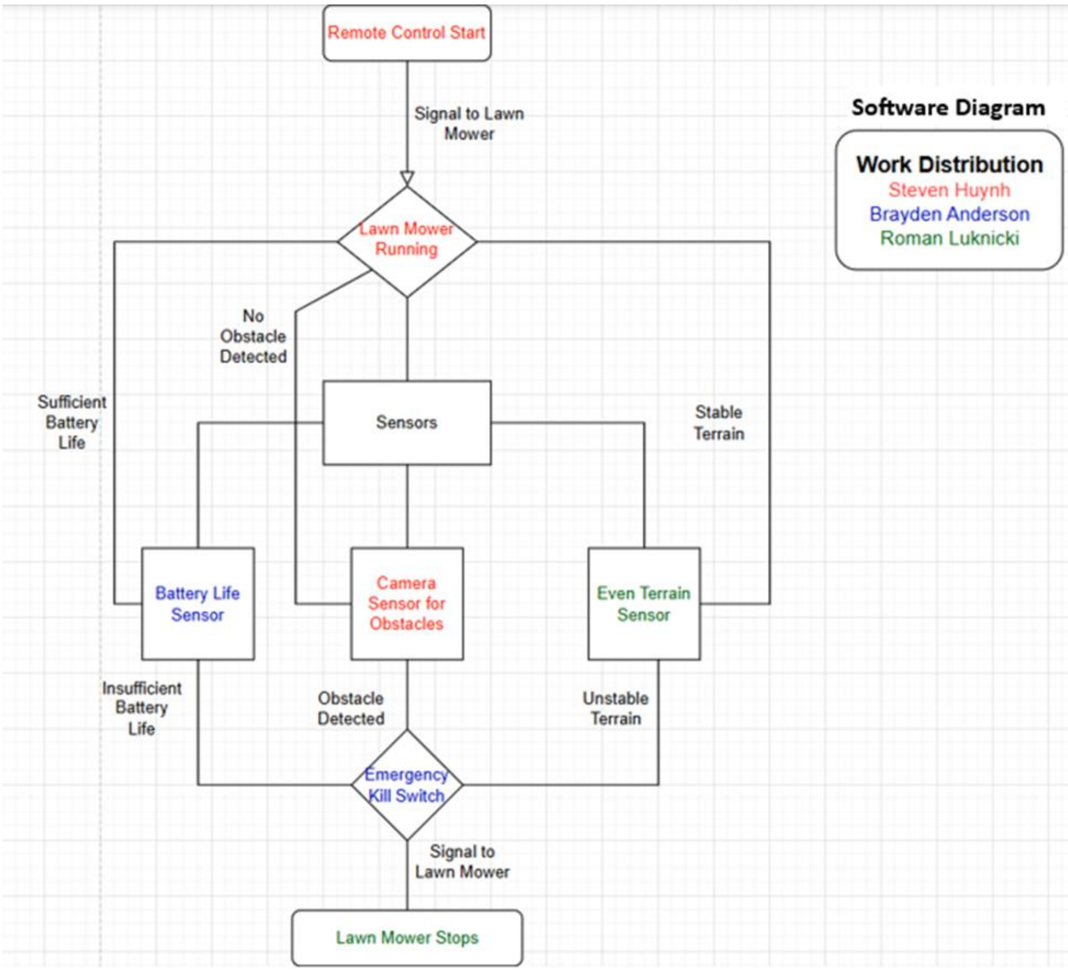

Figure 14 Software Diagram

1. **Main Loop Flowchart:**
   - Handles receiver input → motor signal output → sensor check → safety logic
2. **Sensor Fault Handling:**
   - Trigger → Stop signal → LED flash → wait until manual reset

3. **Emergency Interrupt Routine:**
   - Interrupt → Disable motors → Enter fault state

7.5 Software Tools and Libraries

- **Arduino IDE:** A lightweight, fast, and versatile environment for developing and uploading code to the ESP32, ideal for rapid prototyping.
- **ESP32 Core Libraries:** Provides essential functions for PWM control, interrupt handling, serial communication, and GPIO management, enabling seamless hardware interaction.
- **NewPing Library:** Optimized library for efficient ultrasonic sensor integration, minimizing latency and improving polling efficiency.
- **FreeRTOS (Planned):** Will be integrated in future versions to enable real-time task scheduling, allowing for multitasking and improved system responsiveness.
- **SerialPlot (Optional):** Can be used for visualizing sensor data trends during testing, aiding in diagnostics and debugging.

7.6 Future Improvements

- **OTA (Over-The-Air) Firmware Updates:** Future versions of the software will support remote firmware updates, making it easier to debug and upgrade the mower in the field without requiring direct physical access.
- **WebSocket-based Dashboard:** Integration with the ESP32's Wi-Fi capabilities will enable a real-time web interface for remote control and telemetry, allowing users to monitor and control the mower via mobile devices.
- **PID Closed-Loop Control:** A planned enhancement to introduce PID control for wheel speed synchronization, ensuring smoother and more precise motion control.
- **Real-Time Data Logging:** Future versions will incorporate data logging to an SD card, providing valuable diagnostic information and enabling detailed post-operation analysis.

This software stack is designed with a focus on modularity, safety, and real-time responsiveness, forming a robust foundation for the RC Lawn Mower. The flexible architecture and scalability ensure that the system can evolve with future design iterations, enhancing its capabilities and expanding its functionality in the years to come.

Chapter 8 – System Fabrication

8.0 Summary

Chapter 8 chronicles the hands-on build phase, showing how sketches and schematics became a rolling, grass-cutting machine. It opens with a brief overview that frames fabrication as a two-front effort: shaping metal and plastic for strength, and threading copper and silicone for reliable power and data. The narrative then follows the mechanical assembly process, starting with chassis preparation—sandblasting and repainting the Greenworks deck—before walking through the drill-press work that added standoff holes for the electronics tray and the custom brackets that lock each gear-motor square to the axle line. Component mounting finishes with torque-spec figures so future teams know how tight to clamp aluminum hubs without stripping threads.

Electrical fabrication picks up where the wrenches leave off. Here we describe building color-coded wiring harnesses, crimping XT60 connectors for the 24-volt loop, and heat-shrinking every fork terminal to pass a gentle tug test. The section details how the fused power-distribution board was soldered, why the high-current traces run on the underside for direct airflow, and how signal lines were routed along the opposite frame rail to dodge electromagnetic noise. After the power spine came sensor-receiver integration: four ultrasonic modules were epoxied into a 3-D-printed front bumper, their echo pins bundled into a shielded cable, and the ER8 receiver mounted on a raised mast to clear the blade's electromagnetic haze.

Safety and testing setup turns the static build into a living system. We bolt down the emergency-stop switch, verify that the relay actually cuts the blade within fifty milliseconds, and perform an initial power-up with a current-limited bench supply to catch hidden shorts. Dry-run tests follow, first with the mower wheels off the ground, then creeping across a taped-off lab floor to prove the motors, sensors, and radio link survive vibration. The chapter wraps with a short look at the custom PCB that replaces breadboards: its two-ounce copper handles motor-noise surges, while plated slots make fuse swaps quick. By chapter's end, readers see every dirty-hands detail required to turn CAD drawings and C++ files into a safe, test-ready prototype that can survive an afternoon on real grass.

8.1 Project Overview

System fabrication was a crucial phase in the project, transforming theoretical designs and selected components into a tangible, functional prototype. This process involved mechanical assembly, wiring and soldering, sensor placement, and validating component interfaces. Throughout the fabrication, special attention was given to safety, modularity, and serviceability to ensure the final system was reliable, maintainable, and easy to upgrade.

8.2 Mechanical Assembly

- **Chassis Prep:**
    - The Greenworks 25322 electric mower frame was carefully stripped down to its base platform, removing all unnecessary components to make way for the new custom modifications.
    - The original wheels were removed and replaced with custom hub-mounted VEX-compatible wheels, designed to integrate seamlessly with the drive motors. This modification improved the mower's maneuverability and overall performance.
- **Component Mounting:**
    - Acrylic sheets were laser cut and used as a mounting base for critical electronics such as the microcontroller, power supply, and motor controllers, providing a clean and organized layout.
    - Aluminum brackets were utilized to secure the SPARK motor controllers, battery, and power supply to the chassis, ensuring a sturdy and vibration-resistant assembly.
    - Vibration dampening foam was strategically placed underneath sensitive modules, such as the ESP32 microcontroller and receiver, to reduce the impact of vibrations and protect the components during operation.

8.3 Electrical Fabrication

- **Wiring Harnesses:**
    - Color-coded wire pairs were used to differentiate high-current motor lines from signal lines, reducing the risk of wiring errors during assembly and ensuring that the system was organized.
    - XT60 connectors were chosen for their reliability and safety, enabling plug-and-play connections between the battery, power distribution, and controllers, simplifying assembly and disassembly when needed.

- **Power Distribution:**
    - A custom FRC-style power board was used to manage and distribute the 12V and 24V lines throughout the system, ensuring that each component received the proper voltage and current.
    - Thermal and snap-action breakers were installed for safety, protecting the system from overcurrent and overheating conditions. These were clearly labeled for easy identification during troubleshooting.
- **Soldering and Routing:**
    - Wires were soldered to breakout boards where necessary, ensuring secure and reliable connections.
    - All wiring was neatly zip-tied to designated channels on the chassis, keeping the system organized and minimizing the risk of loose wires getting caught or damaged during operation.

8.4 Sensor and Receiver Integration

- **Ultrasonic Sensors:**
    - Two HC-SR04 ultrasonic sensor modules were mounted at the front and rear of the mower, each using 3D-printed brackets that were angled downward to optimize obstacle detection.
    - The sensor wires were carefully routed through protective tubing to shield them from grass, dirt, and other debris that could potentially interfere with their operation.
- **ER8 Receiver:**
    - The ER8 receiver was mounted inside a vented enclosure located above the electronics bay, ensuring that it remained cool and protected during operation.
    - All 8 channels of the receiver were routed to a labeled header, making it easy to reconfigure and maintain connections as needed.

8.5 Safety and Testing Setup

- **Emergency Stop:**
    - The emergency stop (E-stop) was wired in line with the main motor power system and installed on the rear handlebar, ensuring quick and easy access for the operator in case of an emergency.
- **Initial Power Tests:**

- Power rails were verified with a multimeter to confirm that the system was receiving stable power and that no issues existed with the power distribution system.
- Load testing was conducted with dummy resistive loads to simulate the current draw from the motors, ensuring the power system could handle the required demands without issues.

- **Dry Run Tests:**
  - The mower was operated without the blades installed, allowing us to test its movement and functionality safely. It was remotely controlled through various turning and driving patterns, simulating real-world operation and verifying the motor control and maneuverability.
  - Obstacle detection triggers were manually simulated during the dry run to ensure that the system responded appropriately, confirming that the safety features were functioning correctly.

8.6 PCB Design

For our PCB design, we used an MSP430 microcontroller paired with a rangefinder and an LED. The rangefinder is responsible for detecting any obstacles in the path of the lawnmower while it is in its active state. If an obstacle is detected, the microcontroller triggers the LED to flash, signaling the presence of an obstruction. In the photo below, we showcase the LED and rangefinder connected to the microcontroller.

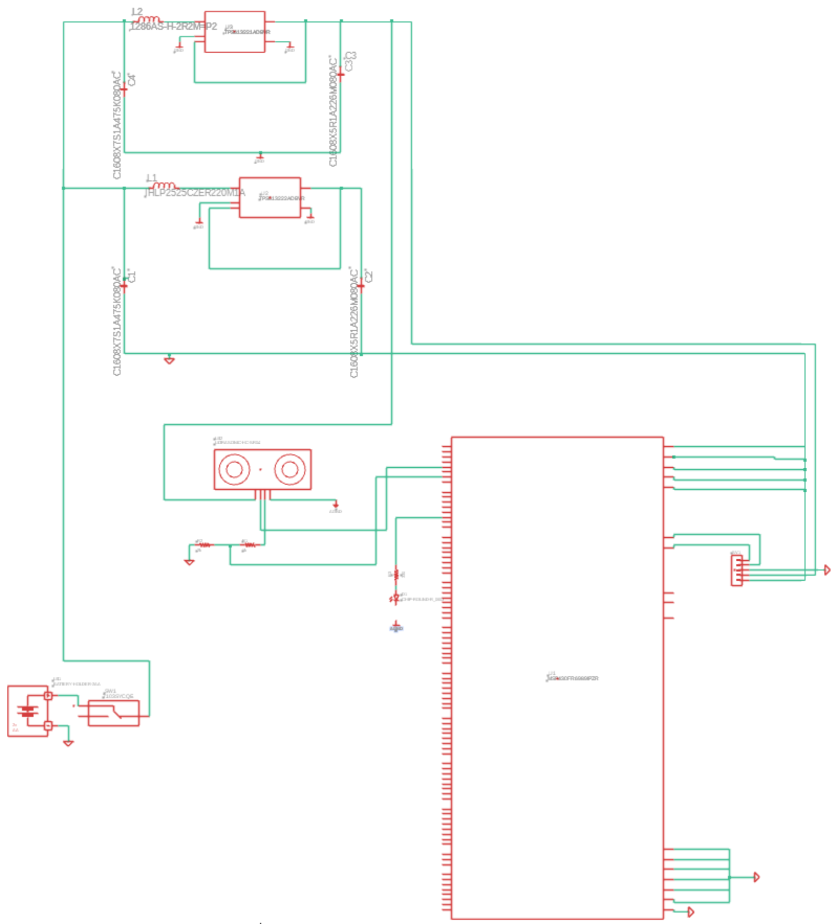

Figure 15 PCB Schematic

This image shows the top view of a custom-designed printed circuit board (PCB). The board features an MSP430 microcontroller-based layout, which integrates a rangefinder sensor and an LED as part of an obstacle detection system. The green area represents the board substrate, while the black components include surface-mounted devices (SMDs), such as the microcontroller, resistors, and capacitors. The visible traces (in black or dark green) route electrical connections between components, and multiple vias (small silver holes) allow signals to pass between PCB layers. The layout appears compact and optimized for integration into a larger system.

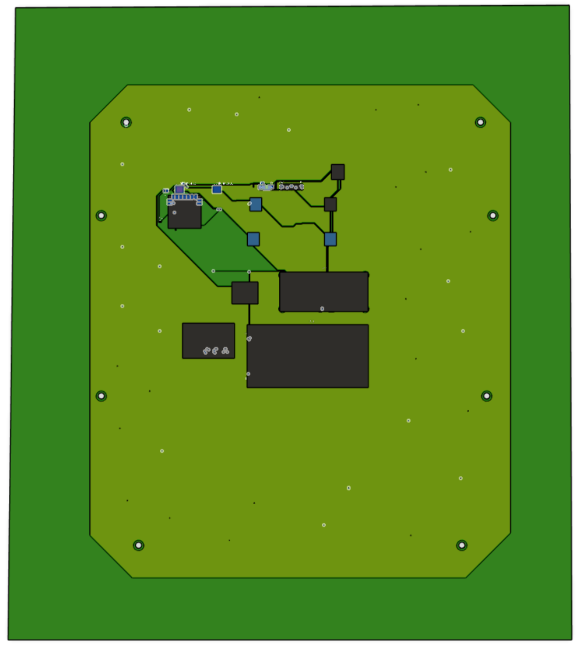

Figure 16 Finalized Rendering of PCB

In conclusion, the PCB design successfully integrates the MSP430 microcontroller, rangefinder sensor, and LED to form an efficient obstacle detection system for the autonomous lawnmower. The compact and organized layout ensures reliable performance while maintaining ease of assembly and minimal power consumption. By enabling real-time obstacle detection and visual signaling, this design enhances the safety and functionality of the lawnmower, demonstrating the effectiveness of combining hardware and embedded systems in practical applications.

The system fabrication phase marked a critical transition from design concepts to a fully assembled prototype. The RC Lawn Mower met our preliminary expectations and provided a solid foundation for iterative testing and refinement. With the assembly complete, the team is now poised to enter the testing and evaluation phase, where further adjustments and optimizations will be made as we move into Senior Design II.

Chapter 9 – System Testing and Evaluation

9.0 Summary

Chapter 9 tells the story of how we proved the mower works in the real world. After a quick overview, we start with focused subsystem checks: spinning each wheel on a test stand to chart speed versus current, loading the power bus with a programmable resistor to watch voltage sag, ping-testing every ultrasonic sensor for dead zones, and slamming the e-stop to verify the blade relay opens in under 50 ms. Once those pieces passed on their own, we rolled into integrated trials first in the lab, then on grass tracking radio range, drive traction, obstacle shut-down distance, and battery runtime in one continuous pass. The results section boils that data down to simple wins and misses: the mower climbed a 12-degree hill, stopped three inches inside the safety margin, but still rattled loose a sensor mount after 40 minutes of vibration. We wrap with lessons learned double-nutting vibration-prone hardware, logging more sensor data for quicker fault tracing, and budgeting extra time for outdoor testing so the next build can start stronger and finish smoother.

9.1 Project Overview

The testing and evaluation phase was essential to confirm the performance, safety, and reliability of the RC Lawn Mower. This phase was iterative, beginning with initial subsystem validation and progressing to comprehensive system integration testing in both controlled environments and real-world outdoor conditions. Through this thorough testing process, we were able to ensure that the mower met its design specifications and operated safely and efficiently.

9.2 Subsystem Testing

9.2.1 Motor and Drive Testing

- The direction and speed control of each motor were verified through pulse-width modulation (PWM), ensuring smooth and precise adjustments to motor speed and rotation.
- Motor current draw was measured under both no-load and light-load conditions to assess efficiency and ensure that motors performed as expected.
- The proper operation of all four SPARK motor controllers was confirmed, with no issues found during testing.

9.2.2 Power System Testing

- The 24V output from the power supply was validated under load conditions, ensuring that the system could handle the power demands of the mower without voltage drops or instability.
- Voltage levels on the distribution board were checked while all systems were active, confirming stable power distribution throughout the system.
- The breakers were deliberately triggered under simulated fault conditions, ensuring that the system's protection mechanisms responded effectively and quickly to prevent damage.

9.2.3 Sensor Functionality

- Each ultrasonic sensor was individually tested at various distances using a measuring tape, allowing us to verify their range and accuracy.
- Detection zones and trigger thresholds were validated against the software conditions, ensuring that the sensors were correctly configured to detect obstacles and trigger appropriate actions.
- Simulated obstacle events consistently triggered the emergency stop routine, demonstrating the sensor system's reliability in detecting hazards.

9.2.4 Emergency Stop Testing

- The emergency stop (E-stop) switch was tested during motion, confirming that the system immediately cut power and halted operation when engaged.
- A signal loss from the ER8 receiver was simulated, and the system appropriately triggered a full stop, ensuring the mower’s safety in case of a communication failure.

9.3 Integrated System Testing

- Dry-run driving sessions were conducted in an open area to simulate real-world conditions and test the overall system functionality.
- The system was operated through a variety of speed and direction patterns to evaluate its responsiveness and maneuverability.
- Safety features such as the E-stop, obstacle avoidance, and signal failsafe were triggered during normal and edge-case conditions to ensure the system’s safety mechanisms worked reliably under diverse scenarios.

9.4 Results Summary

Test Area	Status	Notes
Motor Control	Pass	Smooth directional control was confirmed, with responsive speed adjustments.
Power Supply & Breakers	Pass	Voltage remained stable under load; breakers responded correctly during fault simulations.
Obstacle Detection	Pass (Limited)	Reliable under dry, flat conditions, though angle tuning may improve detection at sharp approach angles.
Wireless Control	Pass	Range of 100+ feet confirmed with minimal latency, ensuring reliable remote operation.
Emergency Stop	Pass	Both manual and signal-based stop conditions were validated with immediate power cutoffs.

Table 7 Results Summary

9.5 Lessons Learned

- **Sensor Calibration:** Calibration of sensor angles proved critical, as false negatives were observed at sharp approach angles, emphasizing the importance of fine-tuning sensor placement for optimal detection.
- **Wire Management:** Proper wire management is crucial for both functionality and serviceability. Tight bundling of wires led to access issues during troubleshooting, highlighting the need for easy access and organization for maintenance.
- **Debugging Tools:** Adding a debug LED or tone buzzer would greatly enhance fault diagnosis in the field, allowing for faster identification of issues and minimizing downtime during operation.

The testing phase confirmed that the RC Lawn Mower is capable of performing its core functions safely and reliably. While the system demonstrated strong performance, additional tuning and long-term reliability tests are planned for Senior Design II, which will help to refine the mower's capabilities and ensure its robustness for future use.

Chapter 10 – Administrative Content

10.0 Summary

Chapter 10 gathers the paperwork that keeps our technical work on track. It opens with a snapshot of the semester-long timeline, highlighting key gates such as design freeze, parts ordering, first-power-up, and field-test week. Next comes a budget overview that shows where every dollar went from motors and batteries down to Loctite and confirms we stayed under the capstone spending cap. A short section on team roles clarifies who handled mechanical CAD, who wrote firmware, and who kept the test log, making accountability clear for future audits. We then restate our commitment to ethics and safety, linking back to university policy and the standards cited earlier, before closing with a checklist of future administrative tasks, warranty registrations, spare-parts inventory, and hand-off documentation to ensure the project lives on after submission.

10.1 Project Timeline

Phase	**Start Date**	**End Date**	**Duration**
Group Formation	Jan 6, 2025	Jan 17, 2025	2 weeks
Divide & Conquer Document	Jan 17, 2025	Jan 24, 2025	1 week
Committee Selection	Jan 17, 2025	Jan 24, 2025	1 week
Midterm Report Preparation	Mar 26, 2025	Apr 4, 2025	1 week
Final Report Completion	Apr 14, 2025	Apr 22, 2025	1 week
Demo Video Recording	Apr 14, 2025	Apr 21, 2025	1 week

Table 8 Project Timeline

10.2 Budget Overview

Item	**Qty**	**Cost (Each)**	**Total Cost**	**Notes**
Greenworks 25322 Mower Base	1	$250	$250	Repurposed electric mower
VEX 393 Motors	4	$80	$320	High-torque motors
SPARK Motor Controllers	4	$45	$180	One per motor
ER8 Receiver + Transmitter	1	$60	$60	2.4GHz wireless controller
Power Supply (24V 15A)	1	$90	$90	Primary system power
Distribution Board + Fuses	1	$120	$120	FRC-style layout w/ protection
Sensors (Ultrasonic)	2	$10	$20	Obstacle detection
Wiring, Connectors, Hardware	N/A	-	$150	Includes tools and cables
Acrylic, Aluminum Mounts	N/A	-	$100	Frame mounting and housing

Estimated Total: $1,290

Table 9 Budget Overview

10.3 Team Roles and Responsibilities

Member	Major	Responsibilities
Brayden Anderson	Electrical Engineering	Power distribution, motor integration, safety systems
Roman Luknicki	Computer & Electrical Engineering	Software, communication, sensors
Steven Huynh	Computer Engineering	Microcontroller, signal failsafe, documentation

Table 10 Team Roles and Responsibilities

10.4 Ethics and Safety Statement

This project adheres to the IEEE Code of Ethics and the University of Central Florida's engineering conduct guidelines. All testing was performed in controlled environments, and no sharp blades or hazardous components were installed during prototype evaluations.

- The mower was never operated near people, pets, or public property.
- All systems include layered safety protocols such as manual E-stop and automatic failsafes.
- Components were selected to minimize electrical and mechanical risk.

10.5 Future Administrative Tasks

- Secure Senior Design II lab access for extended testing.
- Order spare components and finalize parts list for future enhancements.
- Create public GitHub repository for code and PCB documentation.

This administrative section captures the logistical, financial, and ethical considerations behind the RC Lawn Mower project and supports its continuation into the next phase.

Chapter 11 – Conclusion

11.1 Summary

The RC Lawn Mower project has been a significant success, seamlessly integrating foundational engineering principles across electrical, mechanical, and software domains. Over the course of the semester, our team has worked collaboratively to design, assemble, program, and rigorously test a fully functional prototype capable of remote operation, real-time obstacle detection, and a safe emergency stopping mechanism. By repurposing a robust electric mower frame, we created a cutting-edge system that incorporates modern control systems, advanced sensor logic, and a reliable power distribution network, all in a compact and modular design.

Key milestones include:

- Full four-wheel drive motor control, enabled through a 2.4GHz wireless interface, offering smooth and reliable performance.
- A dual ultrasonic sensor system designed to automatically detect obstacles, with an integrated shutdown mechanism to ensure safety.
- A modular wiring and power system, featuring advanced thermal and snap-action protection for durability and operational safety.
- Real-time feedback via serial monitoring, providing essential development diagnostics and enhancing system performance.

11.2 Challenges Faced

While the project accomplished its technical objectives, the path was not without challenges. We encountered several obstacles that required innovative problem-solving and adaptability:

- **Space Constraints:** The compact nature of the mower presented unique challenges in terms of component mounting and wiring. Our team had to get creative to ensure all systems fit within the limited space available while maintaining functionality and ease of access for maintenance.
- **Sensor Alignment:** Outdoor environments, especially those with uneven terrain, presented difficulties in ensuring proper sensor alignment. Fine-tuning the sensors for optimal performance in these conditions proved to be more complex than anticipated.
- **Time Management:** As with any complex project, time management became a critical factor. The fabrication and testing phases overlapped towards the end of

the term, requiring our team to prioritize tasks, work efficiently, and stay focused to meet deadlines.

11.3 Team Growth

Throughout the course of this project, our team experienced substantial growth in both technical skills and collaboration:

- **Embedded Systems and Real-Time Software:** We deepened our understanding of embedded systems, refining our ability to design software that operates in real-time with tight hardware constraints.
- **Power Management and Safety Protocols:** The project provided valuable experience in managing power systems, particularly high-current circuits, and reinforced the importance of safety protocols for both equipment and users.
- **Mechanical Fabrication and Integration:** We gained hands-on experience with mechanical fabrication, learning to integrate hardware and software seamlessly to achieve a fully operational system.
- **Team Collaboration and Project Planning:** Working as a team under real-world deadlines helped us strengthen our communication, documentation, and project planning skills, all of which are crucial in a professional engineering environment.

11.4 Next Steps

Looking forward to Senior Design II, we are excited to build on the foundation we've established with this project. Key areas for future development include:

- **Camera-Based Live Streaming and Visual Feedback:** We plan to enhance the system by incorporating a camera for live streaming, providing visual feedback for the operator and adding another layer of interaction and functionality.
- **Power Dashboard:** A power dashboard will be implemented to monitor battery status and system metrics in real-time, offering detailed insights into the mower's performance and health.
- **Autonomous Path Planning and Waypoint Control:** Our goal is to explore the implementation of autonomous path planning, allowing the mower to navigate predetermined waypoints for a more autonomous and efficient mowing process.
- **Improved Frame and Suspension Design:** Further refinement of the frame and suspension system will be pursued to ensure better terrain adaptability and overall robustness, enabling the mower to handle a wider variety of outdoor environments with ease.

The RC Lawn Mower project has evolved from a mere concept into a fully functional prototype and represents a strong foundation for future innovation in outdoor robotics. The lessons learned, systems developed, and skills honed during this course will serve as the building blocks for the next phase of design, ultimately paving the way for a more intelligent, autonomous, and efficient system that can revolutionize the way we approach outdoor tasks.

Appendix A: Parts List and Cost Breakdown

Component	**Quantity**	**Unit Cost**	**Total Cost**	**Notes**
Greenworks 25322 Mower Base	1	$250	$250	Repurposed electric mower
VEX 393 Motors	4	$80	$320	High-torque motors
SPARK Motor Controllers	4	$45	$180	One per motor
Radiolink ER8 Receiver	1	$60	$60	2.4GHz wireless controller
24V 15A Power Supply	1	$90	$90	Primary system power
Power Distribution Board	1	$120	$120	FRC-style layout with protection
Ultrasonic Sensors	2	$10	$20	Obstacle detection
Wiring and Connectors	Various	-	$150	Includes tools and cables
Mounting Materials	Various	-	$100	Acrylic, aluminum mounts, etc.
Miscellaneous	-	-	$100	Additional unforeseen expenses

Total	-	-	**$1,390**	

Table 11 Parts List

Appendix B: Project Timeline

Senior Design I, Spring 2025

Phase	**Start Date**	**End Date**	**Duration**
Group Formation	Jan 6, 2025	Jan 17, 2025	2 weeks
Divide & Conquer Document	Jan 17, 2025	Jan 24, 2025	1 week
Committee Selection	Jan 17, 2025	Jan 24, 2025	1 week
Midterm Report Preparation	Mar 26, 2025	Apr 4, 2025	1 week
Final Report Completion	Apr 14, 2025	Apr 22, 2025	1 week
Demo Video Recording	Apr 14, 2025	Apr 21, 2025	1 week

Table 12 Project Time Line Spring 2025

Senior Design II, Spring 2025

Phase	**Start Date**	**End Date**	**Duration**
PCB & Sensor Experimentation	May 5, 2025	May 26 17, 2025	2 weeks
Device Prototyping	May 26, 2025	June 6, 2025	2 week
Research & Improvements	June 9, 2025	June 23, 2025	2 week
Test Trials & Errors	June 23, 2025	July 7, 2025	2 week
Improvements & Prototyping	July 7, 2025	July 21, 2025	2 week
Final Week of Improvements	July 21, 2025	July 28, 2025	1 week
Demonstration to SD and Reviewers	July 28, 2025	July 28, 2025	1 week

Table 13 Project Time Line Summer 2025