DESIGN AND FABRICATION OF AN AUTOMATED LAWN MOWER

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CERTIFICATION

This is to certify that this project work was carried out and complied by **DAN-ODHOMO JESSICA OGHENETEKOME ENG1905683, EMOMINE ANGEL OGHENEVWEDE ENG1905540, ONUCHUKWU CHIGBOGU DANIEL ENG1904950 AND IMARHIAGBE OWEN VITALIS ENG1805486** of the department of Mechatronics Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria.

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DEDICATION

This project is dedicated to God Almighty for His continuous guidance and protection granted to us throughout the course of this study, to our parents for their unwavering contribution and support during these challenging times and also to everyone who played a part in making this project a success.

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ABSTRACT

An automated lawn mower is a machine designed to cut grass without requiring human guidance or control. With the continuous advancements in technology, automation has become integral to nearly every aspect of modern life. From household appliances to industrial machinery, automation has transformed the way we interact with our environments, reducing manual labour and improving overall efficiency. The emergence of automated lawn mowers follows this trend, replacing the conventional lawn mowing technology that demands significant human effort. This work aims to develop an improved automated lawn mower that is both economically accessible and user-friendly, designed with locally sourced materials to minimize production costs. Unlike the existing robotic lawn mowers technologies, our model emphasizes a simple design making it easy to maintain and repair without specialized tools or skills. It is equipped with advanced sensor technology like the HC-SR04 ultrasonic and infrared sensors for obstacle detection and avoidance within the ranges of 10 to 50cm. When operating at a distance beyond 50cm, the mower consistently moved forward indicating an environment with no obstacles. Within a range of 30 to 50cm, the system effectively slowed the mower, achieving a 150millisecond response time and 98% accuracy. At closer proximities of 10 to 30cm, the mower reversed and turned with a slightly reduced accuracy of 95% and a 180millisecond response time, while obstacles detected at less than 10cm prompted at immediate stop within 120milliseconds at a 97% accuracy rate. It also integrates a 5kHz electromagnetic perimeter wire for systematic navigation and is powered by an 18V DC rechargeable battery, making it both sustainable and eco-friendly.

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ABBREVIATIONS

DC – Direct Current

GPS – Global Positioning System

AI – Artificial Intelligence

STEM – Science, Technology, Engineering, and Mathematics

USB – Universal Serial Bus

AIA – Artificial Intelligence Algorithm

RTK – Real-Time Kinematics

IMU – Inertial Measurement Unit

SLAM – Simultaneous Localization and Mapping

CAD – Computer-Aided Design

CAM – Computer-Aided Manufacturing

CAE – Computer-Aided Engineering

CATIA – Computer Aided Three-Dimensional Application

IDE – Integrated Development Environment

MATLAB – Matrix Laboratory

ROS – Robot Operating System

EAGLE – Easily Applicable Graphical Layout Editor

LiDAR – Light Detection and Ranging

BEME– Bill of Engineering Measurement and Evaluation

3D– 3 Dimensional

PLA – Polylactic Acid

RPM – Revolutions Per Minute

PWM – Pulse Width Modulation

I/O – Input / Output

LCD– Liquid Crystal Display

AC - Alternating Current

NiMH - Nickel-Metal Hydride

MOSFET - Metal-Oxide-Semiconductor Field-Effect Transistor

HC-SR04 - High-Precision Ultrasonic Sensor Module

Ah - Ampere-hour

kHz - Kilohertz

m/s - Meters per second

Nm - Newton meter

V - Volt

mA - Milliampere

A - Ampere

ms - Millisecond

CHAPTER ONE

INTRODUCTION

1.1 Research Background

A lawn mower, also known as a mower or grass cutter, is a machine equipped with one or more blades for cutting grass (Bailey, 2023). The height of the cut grass can either be fixed according to the mower's specifications or adjusted by the user, often through a single master lever or a mechanism on each wheel. The blades can be powered by manually pushing the mower, using an electric motor, or through an internal combustion engine (Bailey, 2023). Different types of mowers are available, each designed for specific scales and uses. Smaller mowers are pushed by hand and are ideal for small residential lawns and gardens. Larger riding mowers are suitable for bigger lawns, while the largest mowers, mounted on tractors, are used for extensive grass areas like golf courses and public parks (Harris Robert, 2020).

The concept of lawn mowers began in the 19th century with the invention of the first mechanical lawn mower by Edwin Budding in 1830. Budding, an engineer from Gloucestershire, England, was inspired by the machinery used to trim the irregular nap from the surface of wool cloth. He adapted this technology to create a device that could cut grass more efficiently and uniformly than the scythe, which was the primary tool used for lawn maintenance at the time (James Hardy, 2024).

Budding's design featured a cylindrical cutting reel or blade assembly that rotated as the mower was pushed forward, cutting the grass against a fixed bottom blade in a scissor-like action (Lawn Starter, 2024). This design became the foundation for most subsequent lawn mowers. The early mowers were made of cast iron and were heavy, but they significantly reduced the labour required to maintain lawns (Lawn Starter, 2024).

Throughout the 19th century, lawn mowers evolved and improved. By the 1850s, lighter and more efficient models became available, making them more accessible to the public. The development of the lawn mower coincided with the popularity of manicured lawns in Europe and North America, driven by the rise of suburban living and public parks (Farrel Evans, 2021).

In the latter part of the 19th century, the introduction of steam-powered and later gas-powered engines further advanced lawn mower technology, leading to the development of more powerful and versatile machines. Electric mowers, both corded and battery-powered, offered a quieter and cleaner alternative, with improvements in battery technology enhancing their runtime and power (Anna Ryan, 2023). These innovations laid the groundwork for the modern lawn mowers we use today, including manual reel mowers, motorized rotary mowers, and, more recently, robotic mowers.

The advent of robotic mowers marked a significant leap in convenience and precision. These mowers use sensors, GPS (Global Positioning System), and boundary wires to autonomously navigate and mow lawns, maintaining consistent cuts. Robotic lawn mowers are a valuable area of research because they offer numerous real-world benefits as a machine that autonomously cuts grass, these include:

i. Providing assistance to elderly users or those with disabilities who may find traditional lawn mowing challenging.

ii. Serving as a convenient option for users with busy schedules who rarely find time to mow.

iii. Allowing a wider working range due to the absence of a constant power supply connection.

iv. Reducing excessive human effort in order to make mowing easier and more efficient.

However, current robotic mowers face challenges such as navigating complex lawn layouts, limited battery life, cutting efficiency, weather resistance, and cost (Consumer Reports, 2024).

To address these challenges, more efficient automated lawn mowers are needed. Enhancing navigation systems with advanced sensors and AI, developing better battery technology, creating more powerful cutting mechanisms, and improving weather resistance are essential steps. Additionally, focusing on sustainability through eco-friendly materials and recycling programs and reducing costs through innovative manufacturing processes can make these mowers more accessible (Popular Mechanics, 2024).

By addressing these issues, we plan to design this next generation automated lawn mower to meet improved specifications and offer greater convenience, efficiency, and environmental benefits, further revolutionizing lawn care.

1.2 Problem Statement

The automated lawn mower has evolved significantly over the years since its inception from early manual reel mowers to modern day robotic mowers. Despite these advancements, several challenges persist in its design and implementation including:

1. Difficulties with navigation and obstacle avoidance.
2. Cost and accessibility.
3. Maintenance and durability.

The problem being faced here is the development of an automated lawn mower that can overcome these challenges resulting in a more economic, environmental and user-friendly mower design.

1.3 Aims and Objectives

1.3.1 Aims

The aim of this project is to design and fabricate an improved version of the modern-day automated lawn mower with low cost, a simple design, easier maintenance and accessibility to be used at home, offices, school lawns, parks, and gardens to efficiently cut grass to a uniform height.

1.3.2 Objectives

The objective of this project is to:

1. Design an improved automated lawn mower.
2. Fabricate a functional prototype.
3. Conduct performance test on the system.

1.4 Research Questions

This study will provide answers to the following research questions:

1. What is the advantage of an automated lawn mower?
2. Does this automated lawn mower overcome the challenges present in the modern-day mower?
3. Is it easier to use an automated lawn mower than a mechanical push mower?

1.5 Scope of Work

This project involves the design and fabrication of a prototype automated lawn mower incorporated with sensors and cost-efficient materials. It consists of a station, and boundary wires to autonomously navigate and mow lawns, maintaining consistent cuts.

1.6 Significance of Work

Building an improved automated lawn mower holds significant potential across multiple dimensions, particularly in addressing local challenges and fostering development. Nigeria struggles with high costs of fuel, making traditional gas-powered lawn mowers financially tasking for many homeowners and businesses. Introducing battery-operated automated mowers can mitigate this challenge by significantly reducing the cost of operation. This also aligns with global environmental goals by reducing carbon emissions and local air pollution, thereby promoting cleaner and healthier communities.

Moreover, low-cost and accessibility are critical factors. Affordable and easier-to-maintain automated mowers will simplify lawn maintenance, making it accessible to a larger population. This can lead to the empowerment of small-scale entrepreneurs in the landscaping sector, potentially creating job opportunities and inspiring local economic activities.

Technologically, developing automated mowers locally will not only meet domestic demand but also spark innovation. It will stimulate local engineering and manufacturing capabilities, promoting a skilled workforce in robotics, electronics, and software development. This technological advancement can place Nigeria as a regional leader in innovative lawn care solutions, attracting investment and bolstering the country's technological ecosystem.

Furthermore, investing in sustainable technologies like automated mowers supports Nigeria's sustainable development goals. Promoting the use of electric mowers reduces reliance on fossil fuels, contributing to environmental conservation efforts and mitigating the impact of climate change. It also promotes educational initiatives in STEM fields, preparing Nigerian youths for future careers in emerging technologies.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In 1830, English engineer Edward Budding invented the first lawn mower. He came up with the idea after observing a machine in a local cloth mill that trimmed fabric for a smooth finish after weaving. Budding realized this same mechanism could be adapted to cut grass (James Hardy, 2024). By the early 1900s, steam-powered mowers with lightweight petrol engines began to emerge. Although steam mowers were effective, petrol-powered mowers quickly became more popular and dominated the market due to their convenience and efficiency (Anna Ryan, 2023). More advancements in the mower technology gave rise to the modern-day automated lawn mower but with some disadvantages which will be resolved with this study.

This chapter discusses the different features of the automated lawn mower. It also contains the existing technologies and the necessary components and materials selected to meet the objectives of this study in order to design an improved automated lawn mower.

2.2 Cutting Mechanism of a Lawn Mower

The lawn mower works on the principle of cutting grass either using rotary blades or cylinder (reel) blades which are central to its function (Steen and Richards, 2021).

Rotary blades are most common in modern mowers, the blades are usually flat or slightly curved and are sharpened along their leading edges. They rotate horizontally beneath the mower's deck at high speeds usually powered by an internal combustion engine or by an electric motor. The rotating blades create a lifting and cutting action in which the centrifugal force lifts the grass upright while the high-speed rotation of the blades also generates a significant airflow that helps lift the grass allowing the blade to cut the grass evenly. This airflow also helps to eject the cut grass either into a collection bag or out of a side discharge chute (Steen and Richards, 2021).

Cylinder (Reel) blades are found in manual push mowers and some powered models as shown in Figure 2.1. These blades are arranged in a cylindrical fashion, with multiple blades (usually 5 to 7) forming a helical pattern around the cylinder. The blades rotate vertically similar to the cutting action of scissors. The rotating cylinder blades push the grass against a fixed horizontal blade (the bed knife), creating a scissor-like cutting action that is very precise and clean (Fink, 2023).

Figure 2.1: Diagram of a Lawn Mower

Source: *rona.ca, 2024.*

2.3 Types of Lawn Mower

There are several types of lawn mowers including:

2.3.1 The Manual Reel Lawn Mower

A manual reel lawn mower (as shown in Figure 2.2) is a type of mower that uses a set of rotating blades in a cylindrical fashion to cut grass. These mowers are human-powered, requiring the user to push the mower to engage the cutting mechanism (Lin Ying, 2024).

2.3.1.1 Modes of Operation

a) Pushing: The primary mode of operation for a manual reel lawn mower is manual pushing. As you push the mower forward, the wheels engage a gear mechanism that spins the reel blades (Lin Ying, 2024).
b) Cutting: The rotating cylinder of blades (reel) works in conjunction with a stationary bed knife. The grass is trapped between the spinning reel blades and the bed knife, resulting in a scissor-like cutting action that is precise and clean (Lin Ying, 2024).

Figure 2.2: Manual Reel Lawn Mower
Source: *Walmart, 2024.*

2.3.1.2 Features

1. Reel and Bed knife: The reel consists of several curved blades arranged in a helical pattern, and the bed knife is a fixed horizontal blade that the grass is pushed against for cutting (National Gardening Association, 2020).
2. Cutting Height Adjustment: Most manual reel mowers offer adjustable cutting levels, allowing users to set their preferred grass length.
3. Lightweight Design: These mowers are typically lightweight making them easy to navigate because they lack an engine or motor (National Gardening Association, 2020).
4. Quiet Operation: Manual reel mowers operate silently, making them ideal for use in noise-sensitive areas or during early morning and late evening hours (National Gardening Association, 2020).
5. Low Maintenance: With fewer mechanical parts, reel mowers require minimal maintenance compared to their gas or electric counterparts (National Gardening Association, 2020).

2.3.1.3 Advantages

1. Manual reel mowers produce no emissions, this makes them an eco-friendly choice for lawn maintenance (Lin Ying, 2024).
2. They are generally less expensive to purchase and maintain, as there is no need for fuel, oil changes, or complex repairs (Lin Ying, 2024).
3. Using a manual reel mower provides physical exercise, contributing to overall health and fitness.
4. The scissor-like action of the blades provides a clean cut, which is healthier for the grass and reduces the likelihood of disease (Lin Ying, 2024).
5. The absence of a motor makes reel mowers extremely quiet, reducing noise pollution and allowing for mowing at any time without disturbing neighbours (Lin Ying, 2024).

2.3.1.4 Disadvantages

1. Manual reel mowers require more physical effort to push, especially on larger lawns or uneven terrain (Lin Ying, 2024).
2. They can struggle with tall grass, thick weeds, or twigs, making them less effective if the lawn is not mowed regularly (Lin Ying, 2024).
3. Mowing with a reel mower can take longer, particularly on larger lawns, due to the need for multiple passes to achieve a uniform cut (Lin Ying, 2024).
4. Reel mowers may have difficulty reaching edges and corners, requiring additional trimming with other tools (Lin Ying, 2024).
5. These mowers work best on small to medium-sized and may not be suitable for rough or hilly terrains (Lin Ying, 2024).

2.3.2 The Gas-Powered Rotary Lawn Mower

A gas-powered lawn mower (as shown in Figure 2.3) is a type of mower that uses a gasoline engine to power the cutting blades. These mowers are commonly used for their power and efficiency, making them suitable for various lawn sizes and conditions (Garden Tool Expert, 2024).

2.3.2.1 Modes of Operation

a) Starting: Gas-powered lawn mowers typically start using a pull cord or, in some models, an electric starter. The engine ignites the gasoline, powering the mower (Garden Tool Expert, 2024).
b) Cutting: The engine drives a horizontal rotary blade located beneath the mower deck. The rapid rotation of the blade creates a lifting and cutting action that efficiently trims the grass (Garden Tool Expert, 2024).
c) Self-Propulsion: Some gas-powered mowers are self-propelled, meaning the engine also powers the wheels. This feature reduces the physical effort required to push the mower, especially useful on larger or sloped lawns (Garden Tool Expert, 2024).

Figure 2.3: Gas-Powered Rotary Lawn Mower
Source: *Craftsman, 2024.*

2.3.2.2 Features

1. Powerful Engine: Gas mowers are equipped with robust engines that provide significant cutting power, making them capable of handling thick, tall grass and tough weeds (National Gardening Association, 2020).
2. Adjustable Cutting Heights: These mowers usually offer multiple height settings, allowing users to customize the grass length (National Gardening Association, 2020).

3. Cutting Width: Gas mowers often have wider cutting decks (usually 20-22 inches), enabling faster mowing by covering more ground in each pass (National Gardening Association, 2020).
4. Grass Management Options: They typically offer options for bagging, mulching, or side discharging grass clippings (National Gardening Association, 2020).
5. Durability: Constructed with sturdy materials, gas-powered mowers are built to withstand rigorous use.

2.3.2.3 Advantages

1. The powerful engine allows for efficient mowing, even in challenging conditions such as thick, tall grass or uneven terrain (Garden Tool Expert, 2024).
2. Suitable for various lawn sizes and types, from small residential yards to large properties (Garden Tool Expert, 2024).
3. The wide cutting deck and powerful engine enable quicker mowing, reducing the time needed to complete the task (Garden Tool Expert, 2024).
4. Many models offer self-propelled functionality, making it easier to operate the mower, especially on slopes and large areas (Garden Tool Expert, 2024).
5. Options for bagging, mulching, or side discharging provide flexibility in handling grass clippings according to preference (Garden Tool Expert, 2024).

2.3.2.4 Disadvantages

1. Gas-powered mowers are significantly louder than electric or manual mowers, contributing to noise pollution (Garden Tool Expert, 2024).
2. These mowers produce exhaust emissions, which can contribute to air pollution and are not environmentally friendly (Garden Tool Expert, 2024).
3. Gas mowers need consistent maintenance, including changing the oil, replacing air filters and spark plug inspection. This adds to the overall cost and effort of upkeep (Garden Tool Expert, 2024).
4. They are heavier than electric or manual mowers, making them more difficult to transport and store (Garden Tool Expert, 2024).
5. The initial purchase price and ongoing costs for fuel and maintenance can be higher compared to electric or manual mowers (Garden Tool Expert, 2024).

2.3.3 The Electric-Powered Rotary Lawn Mower

An electric-powered lawn mower (as shown in Figure 2.4) is a type of mower that uses electricity to power the cutting blades, either through a cord connected to an outlet or a rechargeable battery. These mowers are known for their eco-friendliness, ease of use, and low maintenance requirements (Chen L., 2021).

2.3.3.1 Modes of Operation

a) Starting: Electric mowers start with the push of a button or flip of a switch, eliminating the need for a pull cord (Garden Tool Expert, 2024).
   i. Corded Models: Plug the mower into an electrical outlet using an extension cord (Lin Ying, 2024).
   ii. Cordless Models: Charge the battery, insert it into the mower, and turn it on (Lin Ying, 2024).
b) Cutting: The electric motor drives a horizontal rotary blade beneath the mower deck, which rotates at high speed to cut the grass (Garden Tool Expert, 2024).
c) Self-Propulsion (Optional): Some electric mowers are self-propelled, with the motor also powering the wheels to reduce the physical effort required (Garden Tool Expert, 2024).

Figure 2.4: Electric-Operated Rotary Lawn Mower
Source: *LKM Machinery, 2024.*

2.3.3.2 Features

1. Electric Motor: Electric mowers use a quiet, efficient motor that provides enough power for most residential lawns (National Gardening Association, 2020).
2. Adjustable Cutting Heights: These mowers offer multiple height settings, allowing users to choose the desired grass length (National Gardening Association, 2020).
3. Cutting Width: Electric mowers typically have cutting decks ranging from 14 to 21 inches, suitable for small to medium-sized lawns (National Gardening Association, 2020).
4. Grass Management Options: Many models offer options for bagging, mulching, or side discharging grass clippings (National Gardening Association, 2020).
5. Lightweight Design: Electric mowers are generally lighter than gas-powered mowers, which makes them easier to use and store (National Gardening Association, 2020).

2.3.3.3 Advantages

1. Electric mowers produce no emissions, making them environmentally friendly (Chen L., 2021).
2. These mowers operate much more quietly than gas-powered mowers, reducing noise pollution (Lin Ying, 2024).
3. Electric mowers require minimal maintenance when compared to gas mowers, with no need for oil checks, spark plug inspection and fuel replacements (Chen L., 2021).
4. The push-button start and lighter weight make electric mowers user-friendly and easy to handle (Lin Ying, 2024).
5. While the initial purchase price can be higher than some gas mowers, the lower operating and maintenance costs can result in savings over time (Garden Tool Expert, 2024).

2.3.3.4 Disadvantages

1. The range is restricted by the length of the extension cord, making them less suitable for large lawns (Lin Ying, 2024).
2. Battery life limits the mowing time, requiring recharges for larger areas (Lin Ying, 2024).
3. Electric mowers generally have less power than gas mowers, which can make them less effective on very tall or thick grass (Garden Tool Expert, 2024).

4. For cordless models, batteries need to be charged and eventually replaced, adding to the long-term cost (Lin Ying, 2024).
5. The upfront cost for a high-quality electric mower, particularly cordless models with high-capacity batteries, can be higher than for some gas mowers (Lin Ying, 2024).
6. Some electric mowers may not be as durable as their gas counterparts, especially in demanding conditions (Garden Tool Expert, 2024).

2.3.4 The Riding Lawn Mower

A riding lawn mower (as shown in Figure 2.5) is a type of mower that allows the operator to sit and drive the mower, similar to driving a small tractor. These mowers are designed for large lawns and provide comfort, efficiency, and powerful cutting capabilities (Knight R., 2019).

2.3.4.1 Modes of Operation

a) Starting: Riding lawn mowers typically start with a key ignition system, similar to a car, which powers up the engine (Garden Tool Expert, 2024).
b) Driving and Steering: The operator sits on the mower and uses a steering wheel or lap bars (in zero-turn mowers) to navigate the mower across the lawn (Garden Tool Expert, 2024).
c) Cutting: The engine drives the blades located underneath the mower deck. The cutting height can be adjusted using levers or buttons, and the mower deck can cover a wide swath of grass in a single pass (Garden Tool Expert, 2024).
d) Self-Propulsion: These mowers are self-propelled by nature, as the engine powers both the cutting blades and the wheels (Garden Tool Expert, 2024).

Figure 2.5: Riding Lawn Mower
Source: *Craftsman, 2024.*

2.3.4.2 Features

1. Powerful Engine: Riding mowers are equipped with powerful gasoline engines, providing substantial cutting power for large lawns (National Gardening Association, 2020).
2. Wide Cutting Deck: The cutting decks are typically much wider (30 to 60 inches), allowing for efficient mowing of large areas (National Gardening Association, 2020).
3. Adjustable Cutting Heights: Multiple height settings allow users to choose the desired grass length.
4. Comfortable Seat and Controls: Ergonomically designed seats and user-friendly controls enhance comfort and ease of operation.
5. Grass Management Options: These mowers offer options for bagging, mulching, or side discharging grass clippings (National Gardening Association, 2020).
6. Attachments and Accessories: Many riding mowers can be equipped with additional attachments, such as snow ploughs, spreaders, and carts, increasing their versatility (National Gardening Association, 2020).

2.3.4.3 Advantages

1. Riding mowers cover large areas quickly, reducing the time and effort needed to mow extensive lawns (Knight R., 2019).

2. The powerful engines and wide cutting decks handle thick, tall grass and uneven terrain with ease (Knight R., 2019).
3. The seated operation with ergonomic controls makes mowing large lawns less physically demanding (Knight R., 2019).
4. The ability to attach various accessories makes riding mowers useful year-round for tasks beyond mowing (Knight R., 2019).
5. Riding mowers are built with robust materials designed to withstand heavy use and challenging conditions (Knight R., 2019).

2.3.4.4 Disadvantages

1. Riding mowers are significantly more expensive to purchase and maintain compared to push mowers or electric mowers (Knight R., 2019).
2. They require more storage space due to their larger size.
3. These mowers consume more fuel and produce more emissions than smaller, electric, or manual mowers, making them less environmentally friendly (Knight R., 2019).
4. Regular maintenance is essential, including oil replacements, air filter checks, blade sharpening, and tire inspections (Knight R., 2019).
5. The larger size and powerful engine pose a higher risk of accidents, particularly on slopes or uneven terrain (Knight R., 2019).

2.3.5 The Robotic Lawn Mower

A robotic lawn mower (as shown in Figure 2.6) is an autonomous device designed to maintain your lawn with minimal human intervention. These mowers are equipped with sensors, motors, and cutting blades, allowing them to navigate and mow the lawn independently (Lopez and Bennet, 2023).

2.3.5.1 Modes of Operation

a) Initial Setup: The initial setup involves installing a boundary wire around the perimeter of the lawn and any obstacles. This wire emits a signal that the mower follows (Garden Tool Expert, 2024).

b) Programming: The user sets the mowing schedule and preferences via a control panel on the mower or through a smartphone application. Some advanced models can connect to smart home systems (Garden Tool Expert, 2024).
c) Autonomous Mowing: Once programmed, the robotic mower automatically leaves its charging station at the scheduled times, navigates the lawn, and cuts the grass within the defined boundaries (Garden Tool Expert, 2024).
d) Docking and Charging: After mowing or when the battery is drained, the mower goes back to its charging station to recharge before the next mowing cycle (Garden Tool Expert, 2024).

Figure 2.6: Robotic Lawn Mower
Source: *Mowbot.com, 2024.*

2.3.5.2 Features

1. Autonomous Operation: The mower uses sensors and programming to navigate the lawn and avoid obstacles (National Gardening Association, 2020).
2. Battery-Powered: Robotic mowers are powered by rechargeable batteries, making them eco-friendly and quiet (National Gardening Association, 2020).
3. Adjustable Cutting Heights: Users can adjust the cutting height to maintain the desired grass length (National Gardening Association, 2020).
4. Rain Sensors: Many models come with rain sensors, allowing the mower to return to the charging station during rain and resume mowing when conditions are dry (National Gardening Association, 2020).

5. Anti-Theft Features: Some mowers are equipped with PIN codes, alarms, and GPS tracking to prevent theft (National Gardening Association, 2020).
6. Smartphone Connectivity: Advanced models can be controlled and monitored via smartphone apps, offering real-time updates and remote programming (National Gardening Association, 2020).

2.3.5.3 Advantages

1. Robotic mowers handle the mowing autonomously, saving time and effort.
2. Regular, scheduled mowing helps maintain a consistently well-manicured lawn (Lopez and Bennet, 2023).
3. Battery operation means no emissions and reduced noise pollution compared to gas-powered mowers (Lopez and Bennet, 2023).
4. Built-in sensors and safety features reduce the risk of accidents and injuries (Lopez and Bennet, 2023).
5. These mowers require minimal maintenance, mainly involving blade replacement and occasional cleaning (Lopez and Bennet, 2023).

2.3.5.4 Disadvantages

1. Robotic mowers are generally more expensive to purchase compared to traditional mowers.
2. The initial setup, including laying boundary wires, can be time-consuming and requires some effort (Lopez and Bennet, 2023).
3. Limited battery life means that large lawns may require multiple charging cycles to complete mowing (Lopez and Bennet, 2023).
4. Robotic mowers may struggle with very complex lawns featuring numerous obstacles, steep (Lopez and Bennet, 2023).
5. The mower relies on boundary wires to navigate, and any breaks or issues with the wire can disrupt operation (Lopez and Bennet, 2023).

2.4 Existing Technology

Several manufacturers dominate the market for robotic lawn mowers, each offering models with unique features and modes of operation. Some of the existing technologies include:

2.4.1 The Husqvarna Robotic Lawn Mower

Models: Automower series (e.g., Automower 315, Automower 450X)

Husqvarna is a prominent manufacturer known for its innovative approach to lawn care with the Automower series of robotic mowers (as shown in Figure 2.7). These mowers use boundary and guide wires to define and navigate the mowing area. They incorporate GPS for precise mapping and tracking of mowed areas and are equipped with sensors to detect rain and adjust mowing schedules accordingly. A special feature of the Automower series is the Automower connect which allows remote control and monitoring via a smartphone app (Husqvarna Group, 2023).

Figure 2.7: Husqvarna Robotic Lawn Mower
Source: *Husqvarna.com, 2024.*

2.4.2 The Robomow Robotic Lawn Mower

Models: Robomow RS, RC, and RX series

Robomow (as shown in Figure 2.8) is another leading brand in the robotic lawn mower market, offering a range of models designed to simplify lawn maintenance with advanced features and user-friendly operation. Its design is quite similar to other robotic lawn mowers incorporating boundary wire navigation, remote control and rain sensors. The special feature of the Robomow is its edge mode which allows the mower mow along the edges of the Lawn for a cleaner finish. The design of the Robomow consists of easy-to-replace parts and blades for user-friendly maintenance (Robomow., 2022).

Figure 2.8: Robomow Robotic Lawn Mower
Source: *Robomow.com, 2024*.

2.4.3 The Worx Robotic Lawn Mower

Models: Landroid series (e.g., Landroid M, Landroid L)

The Worx is a well-known brand offering the landroid series (as shown in Figure 2.9) which standout due to their advanced technology, ease of use and adaptability to various lawn conditions. Its design incorporates the AIA (Artificial Intelligence Algorithm) technology which allows for better navigation and coverage. It is integrated with the Landroid app for scheduling, remote control, and firmware updates. It has customizable options to add accessories like anti-collision systems and GPS modules. The Landroid is designed to automatically return to its charging station, recharge, and then resume mowing without user intervention (Worx, 2023).

Figure 2.9: Worx Robotic Lawn Mower
Source: *Worx.com, 2024.*

2.4.4 The Bosch Robotic Lawn Mower

Models: Indego series (e.g., Indego 350, Indego S+)

Bosch is a respected name in home and garden tools, and their Indego series of robotic lawn mowers (as shown in Figure 2.10) are renowned for their precision, efficiency and smart technology. A standout feature of the Bosch Indego mowers is the LogiCut system (Bosch, 2023). Unlike random mowing patterns used by many other robotic mowers, LogiCut enables systematic mowing by mapping out the lawn and cutting in parallel lines (Bosch, 2023). Another notable feature of the Indego series is its multi-area function giving it the ability to manage and mow multiple separate lawn areas. The Indego mowers come with various safety features such as lift and tilt sensors, which stop the blades if the mower is lifted or tilted. This helps prevent accidents and ensures safe operation (Lee Burkhill, 2018).

Figure 2.10: Bosch Robotic Lawn Mower
Source: *Bosch.com, 2024.*

2.4.5 The Gardena Robotic Lawn Mower

Models: SILENO series (e.g., SILENO City, SILENO Life)

Gardena offers the SILENO series of robotic lawn mowers (as shown in Figure 2.11). These mowers are designed with a SensorCut system which ensures a precise and streak-free cut by navigating in a systematic pattern. They are also equipped with safety features similar to the Bosch mowers and an automatic charging station. Gardena SILENO mowers are built to handle various terrains, including slopes and uneven ground enabling it to cater to various lawn sizes and complexities (Gardena, 2023).

Figure 2.11: Gardena Robotic Lawn Mower
Source: *Gardena.com, 2024.*

2.4.6 The John Deere Robotic Lawn Mower

Models: Tango E5 series

The John Deere Tango E5 series (as shown in Figure 2.12) incorporates intelligent navigation which allows the mower to follow optimized mowing patterns ensuring the entire lawn is evenly cut. A special feature of the Tango E5 mower is its robust and durable design, built to withstand and handle various weather conditions and terrains (Richard and Jackie, 2020).

Figure 2.12: John Deere Robotic Lawn Mower
Source: *Deere.com, 2024.*

2.5 Disadvantages of Existing Technology

While robotic lawn mowers offer numerous advantages, they also come with some potential disadvantages associated with their existing technologies. The current system design has the following disadvantages:

1. Cost and Accessibility

Robotic lawn mowers, especially high-end models, come with a significant initial investment. The cost includes not only the mower itself but also the setup, such as laying boundary wires and potential professional installation. This high cost can be a barrier to entry for many homeowners (Harris R., 2022).

2. Poor Weather Resilience

Many robotic lawn mowers struggle with poor weather resilience. Rain sensors stop mowing during wet conditions to prevent lawn damage, but this can disrupt the mowing schedule and efficiency. Additionally, models without proper waterproofing can suffer from damage or reduced lifespan due to exposure to moisture (Green A., 2022).

3. Difficulties with Navigation and Obstacle Avoidance

Some robotic mowers have difficulties navigating complex lawn layouts and avoiding obstacles. While boundary wires help define the mowing area, they are time-consuming to install and can be inflexible. Additionally, basic models may not efficiently navigate around obstacles, leading to missed spots or collisions (Patterson D., 2023).

4. Maintenance and Durability

Robotic lawn mowers require regular maintenance, such as blade sharpening, sensor cleaning, and part replacement. Models with poor durability may also have a shorter lifespan, leading to higher long-term costs due to frequent repairs or replacements (National Gardening Association, 2022).

2.6 Components of an Automated Lawn Mower

2.6.1 Direct Current (DC) Motor

A DC motor (Direct Current motor) is a device that converts electrical energy into mechanical energy. There are various types of DC motors, including separately excited and self-excited DC motors (Hughes and Drury, 2019). These motors are powered by direct current sources such as batteries, DC power supplies, or solar panels. Common voltage inputs for DC motors range from 3V to 24V. DC motors are known for their ability to operate across a wide range of speeds, offering precise speed control. Additionally, they provide high starting torque, which is essential for applications that require a strong initial force to begin operation (Hughes and Drury, 2019; B. Kumar, 2020).

Figure 2.13: DC Motor
Source: *MowerProject, 2018*.

2.6.2 Ultrasonic Sensor

An ultrasonic sensor measures distance by emitting high-frequency sound waves, which are typically above 20 kHz, beyond the range of human hearing (Kumar B., 2021). This method is based on echolocation, similar to how bats use sound to navigate. The sensor sends out a sound wave that travels through the air until it hits an object, then reflects back to the sensor. The sensor's receiver detects the returning wave and measures the time taken for the sound to make the round trip. By using the speed of sound in air (about 343 meters per second), the sensor calculates the distance to the object based on this time (Kumar B., 2021).

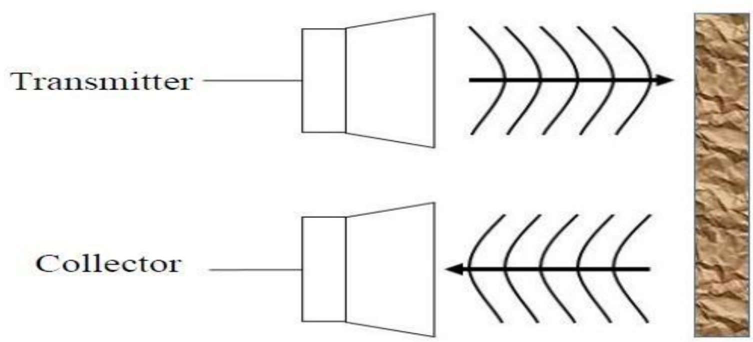


Figure 2.14: Ultrasonic Sensor Concept
Source: *Voltaat.com, 2024*.

Figure 2.15: Ultrasonic Sensor
Source: *Voltaat.com, 2024.*

2.6.3 Arduino UNO

The Arduino UNO is built around the ATmega328P microcontroller, providing a robust platform for electronic projects. It consists of 14 digital input/output pins, six (6) of which can function as PWM outputs, allowing for diverse interfacing capabilities (JavaTpoint, 2024). Additionally, it has six (6) analogue input pins that enable it to read varying sensor signals. The board can be powered via a USB connection or an external power source (JavaTpoint, 2024). A key aspect of its design is the USB interface, which facilitates easy programming and serial communication with a computer. This combination of features makes the Arduino UNO versatile and accessible for various applications. The Arduino UNO operates at 5V and the input power source needs to be a range of 7V to 12V (JavaTpoint, 2024).

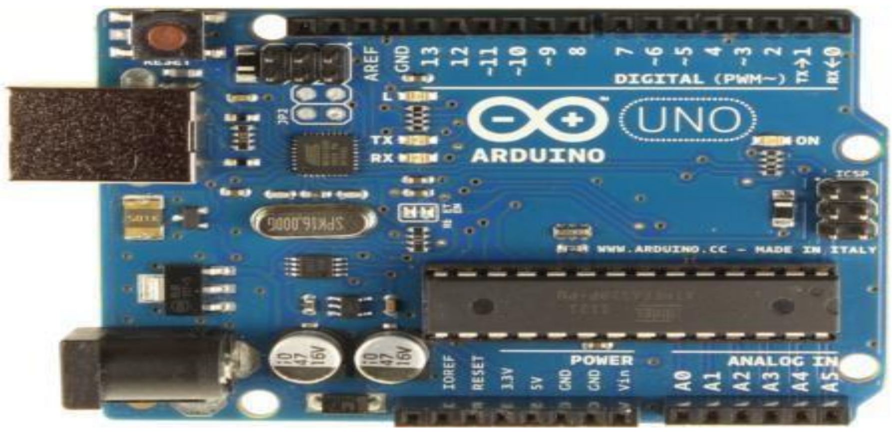


Figure 2.16: Arduino UNO
Source: *JavaTpoint, 2024.*

2.6.4 Cutter

The cutter in a lawnmower is the primary mechanism responsible for cutting the grass. It encompasses several components that work together to ensure efficient and effective mowing. The design and functionality of the cutter vary depending on the type of lawnmower, such as rotary mowers, reel mowers, or robotic mowers (Fink P., 2023). It includes a blade mount used to secure the blades to the mower's motor or engine shaft, ensuring they remain stable during operation. The blades are the primary cutting elements. They are sharp metals with different designs which rotate at high speeds to slice through the grass. The cutter also includes a motor or engine that powers the blades, providing the necessary rotational force for cutting grass. It can be electric (corded or battery-powered) or gas-powered, depending on the lawnmower model (Fink P., 2023).

Figure 2.17: Cutters
Source: *Slideshare, 2022*.

2.6.5 Battery

The battery in a robotic lawn mower is the primary power source, enabling its operation. Similar to two-wheeled vehicles, the battery can be designed to provide sufficient energy for the mower's tasks, or multiple batteries may be utilized to improve performance (Chen L., 2021). Most modern robotic mowers utilize lithium-ion batteries due to their high energy density, lightweight nature, and durability in handling frequent charge-discharge cycles. Battery capacity, typically measured in ampere-hours (Ah), determines the mower's runtime on a single charge, with common capacities ranging from 2.0 Ah to 7.0 Ah or more, depending on the model and manufacturer (Chen L., 2021).

Figure 2.18: Lithium-Ion Battery

Source: *LiTime.com, 2023.*

2.6.6 Wheels

The choice of wheels for a robotic lawn mower is crucial for ensuring effective mobility across various terrains. The wheels must be selected based on factors such as the type of grass, the required ground clearance, and the overall design of the robot. The treads on the tires play a significant role in the mower's performance, influencing traction and stability. Therefore, careful consideration is needed to choose tires that complement the mower's operational needs and the environment it will be used in (Garden Tool Expert, 2024). Additionally, the wheel design must be tailored to handle different types of grass and terrain effectively, ensuring the mower performs optimally across a range of conditions.

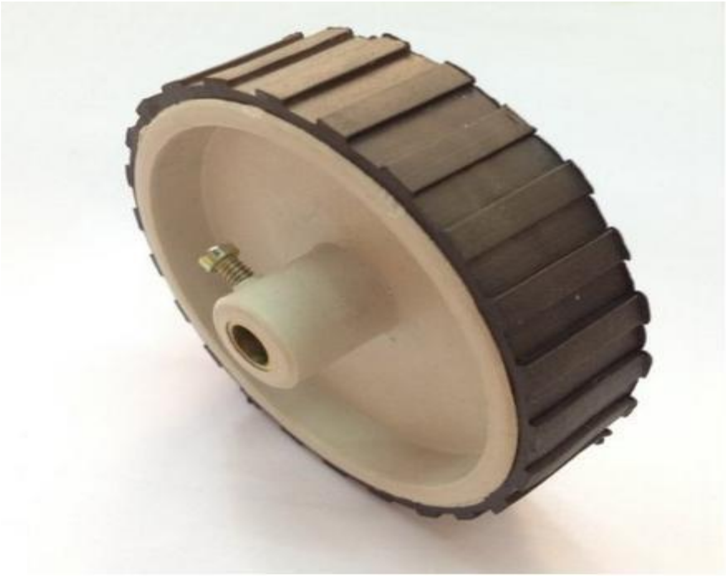


Figure 2.19 Wheel
Source: *Slideshare, 2022*.

2.7 Path Planning

Path planning for an automated lawn mower refers to the process of determining an optimal route or trajectory for the mower to navigate and mow a designated lawn area (Thrun *et al*., 2005). This involves utilizing algorithms and sensors to create a path that ensures efficient coverage while avoiding obstacles and adhering to predefined constraints such as battery life and terrain conditions (Thrun *et al*., 2005).

There are several approaches to planning the path of an automated lawn mower:

1. Sensor Integration
2. Path Recording Algorithms
3. Mapping and Localization
4. Data storage and Processing
5. Path planning Algorithms
6. Real time Adjustment

2.7.1 Sensor Integration

This technique involves the use of various sensors to gather real-time data about the environment and the mower’s position to plan the path of the mower for accurate navigation and obstacle avoidance (Lopez and Bennet, 2023). The High-precision GPS or RTK (Real-Time Kinematic) systems are used to record the mower's position accurately within the lawn area. These systems then provide coordinates that are essential for mapping and path planning. Also, the IMU (Inertial Measurement Unit) sensors provide information about the mower's orientation, velocity, and acceleration. This data helps in refining the mower's path and ensuring accurate positioning (Lopez and Bennet, 2023).

2.7.2 Path Recording Algorithms

This involves the process of capturing and documenting the exact route taken by the mower as it navigates its environment (Howard T.M., 2021). Path recording can be done in two (2) ways:

1. Waypoint Recording: Here, the mower is manually guided or programmed to follow specific paths across the lawn while recording waypoints (coordinates) at regular intervals. This method is often used for initial mapping of the lawn (Howard T.M., 2021).
2. Sensor-based Recording: As the mower operates autonomously, onboard sensors (such as GPS and IMU) continuously record its position and movement. This data is used to create a map of the mowed area and adjust path planning algorithms (Howard T.M., 2021).

2.7.3 Mapping and Localization

This technique uses SLAM (Simultaneous Localization and Mapping) algorithms to create a map of the lawn environment based on sensor data (e.g., GPS, IMU) and identify the mower's position relative to this map in real-time (Siciliano and Khatib, 2016). The mower periodically updates its position and adjusts its path based on the SLAM-generated map to ensure accurate navigation and coverage (Siciliano and Khatib, 2016).

2.7.4 Data Storage and Processing

The mower's onboard computer or microcontroller processes data gotten from the sensors in real-time to update its path planning algorithms and ensure efficient navigation. Some advanced systems may store and process path recording data in the cloud, allowing for remote monitoring and management of the mower's operation (Patterson D., 2023).

2.7.5 Path Planning Algorithms

This involves a series of computational methods and techniques used to determine the most efficient route for the mower to navigate while avoiding obstacles (LaValle S.M., 2006).

1. Grid-based Algorithms: Algorithms divide the lawn area into grids or cells and plan paths that cover each cell efficiently (LaValle S.M., 2006).
2. Potential Fields: Algorithms use attractive and repulsive forces to guide the mower towards the goal (complete mowing) while avoiding obstacles (LaValle S.M., 2006).
3. Machine Learning: Advanced algorithms may employ machine learning techniques to optimize path planning based on historical data and environmental conditions (LaValle S.M., 2006).

2.7.6 Real-Time Adjustment

As the mower operates, it continuously evaluates sensor data and adjusts its path planning in real-time to respond to changes in the environment (e.g., new obstacles, variations in terrain) (Howard T.M., 2021).

2.8 Computer Aided Software

The modelling and design of an automated lawn mower requires the use of computer aided software tools to streamline the development process from hardware design, to programming and then simulation (Amit Patel, 2024).

Below are the key software tools used in the design of an automated lawn mower:

2.8.1 CATIA (Computer Aided Three-Dimensional Application)

CATIA is a comprehensive CAD (Computer-Aided Design) software developed by Dassault Systèmes. It is widely used in various industries for product design, engineering, and manufacturing (Amit Patel, 2024).

2.8.1.1 Key Features

1. 3D Modelling: Allows for the creation of detailed 3D models of the lawn mower components, including the chassis, wheels, and cutting mechanisms (Amit Patel, 2024).
2. Simulation: Provides tools for simulating mechanical movements and interactions, helping to optimize the design for performance and durability (Amit Patel, 2024).
3. Assembly Design: Facilitates the assembly of different parts into a complete model, ensuring all components fit and function together properly (Amit Patel, 2024).
4. Drafting and Documentation: Generates detailed technical drawings and documentation needed for manufacturing and assembly (Amit Patel, 2024).

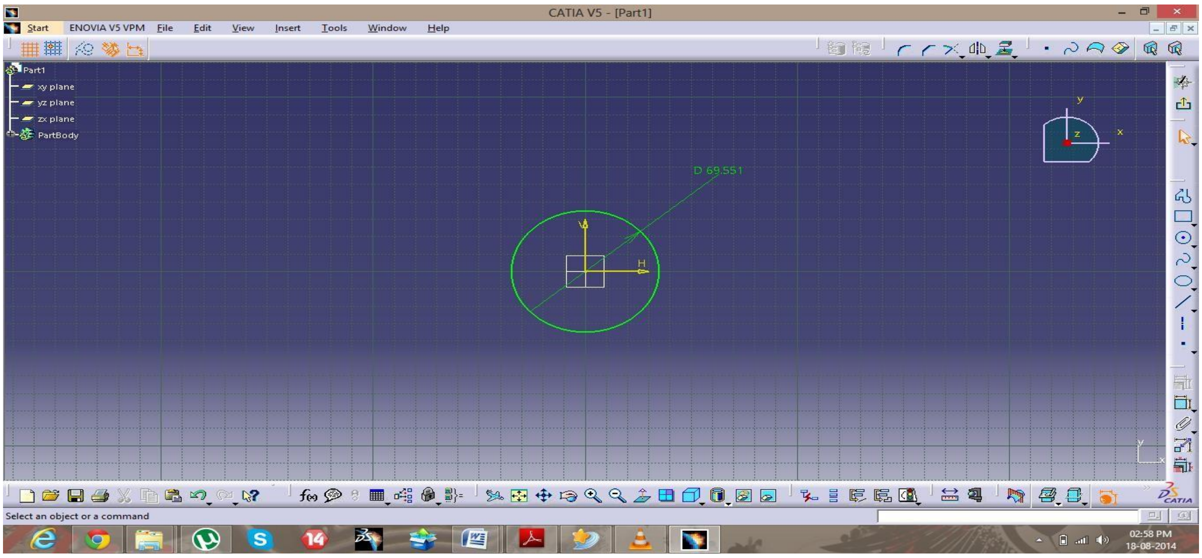


Figure 2.20 CATIA Interface

Source: *TECHNIA, 2014.*

2.8.2 Arduino IDE (Integrated Development Environment)

The Arduino IDE (as shown in Figure 2.21) is a popular software platform used for writing, compiling, and uploading code to Arduino microcontroller boards, which are often used in robotics and automation projects (Monk S., 2022).

2.8.2.1 Key Features

1. Code Editor: A simple, user-friendly code editor that supports C and C++ programming languages (Monk S., 2022).

2. Library Management: Provides access to a vast library of pre-written code (libraries) for various sensors, actuators, and other components, simplifying the development process (Monk S., 2022).
3. Serial Monitor: Allows for real-time communication with the Arduino board, useful for debugging and monitoring sensor data (Monk S., 2022).
4. Board Management: Supports a wide range of Arduino and compatible boards, making it versatile for different hardware configurations (Monk S., 2022).

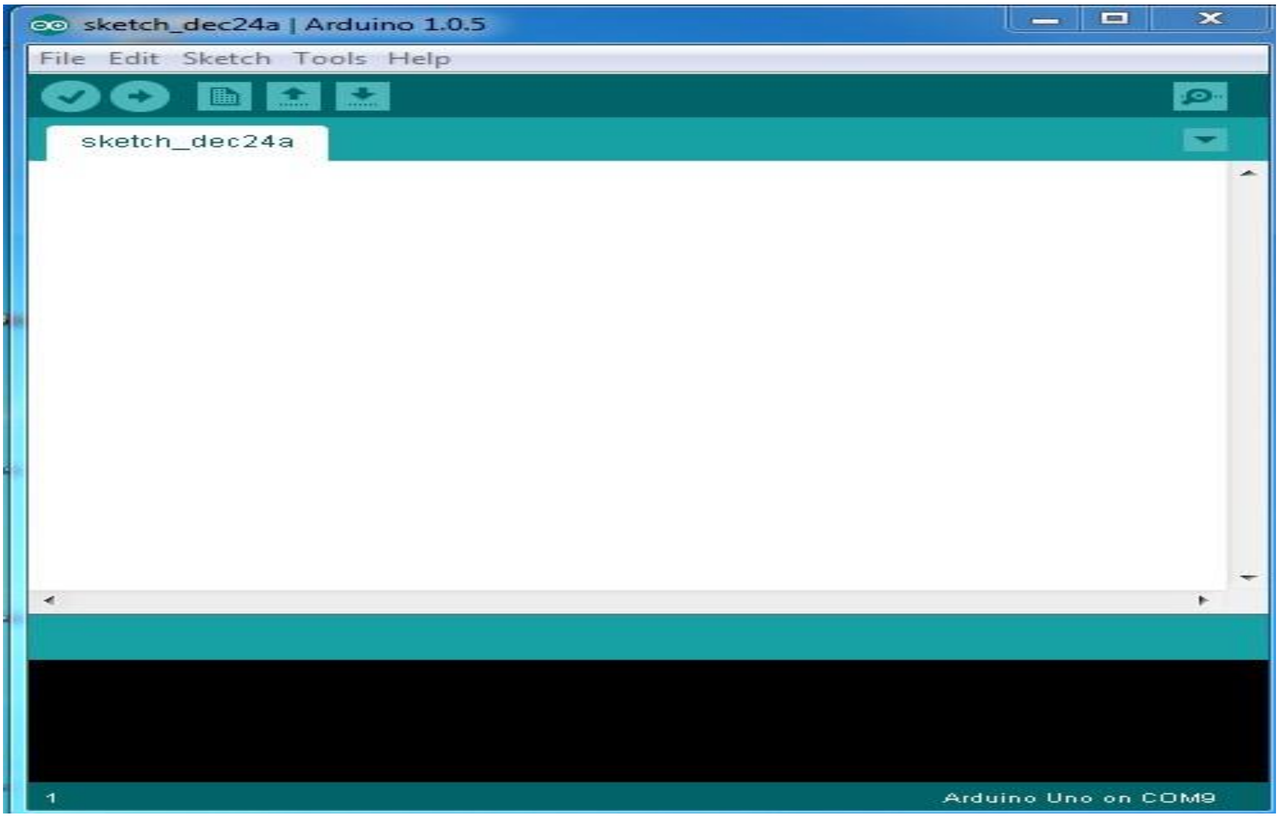


Figure 2.21 User Interface of Arduino 1.0.5 IDE

Source: *Research Gate, 2019.*

2.8.3 Fusion 360

Fusion 360 is a cloud-based CAD/CAM/CAE tool from Autodesk that combines industrial and mechanical design with simulation, collaboration, and machining (Autodesk, 2024). It is ideal for 3D modelling, simulation, and prototyping of lawn mower components. It also supports collaborative workflows, allowing multiple team members to work on the design simultaneously (Autodesk, 2024).

2.8.4 MATLAB/Simulink

MATLAB is a high-level language and interactive environment for numerical computation, visualization, and programming (MathWorks, 2024). Simulink is a MATLAB-based environment for modelling and simulating dynamic systems. It is used for designing and simulating control algorithms for the lawn mower, such as path planning, obstacle avoidance, and battery management systems (MathWorks, 2024).

2.8.5 ROS (Robot Operating System)

ROS is a flexible framework for writing robot software, providing tools and libraries to help build robot applications (Quigley M., 2015). It supports the development and integration of various software components for the automated lawn mower, enabling communication between sensors, controllers, and actuators (Quigley M., 2015).

2.8.6 EAGLE (Easily Applicable Graphical Layout Editor)

EAGLE is a PCB (Printed Circuit Board) design software developed by Autodesk (Autodesk, 2024). It is used for designing custom PCBs for the lawn mower's electronics, such as motor controllers, sensor interfaces, and power management circuits (Autodesk, 2024).

2.8.7 GAZEBO

Gazebo is an open-source 3D robotics simulator that integrates with ROS (Open Robotics, 2024). It allows for the simulation of the lawn mower in a virtual environment, testing its navigation algorithms and sensor interactions before deploying them in the real world (Open Robotics, 2024).

2.9 Different Designs of the Automated Lawn Mower

There are various designs of automatic lawn mowers, influenced by factors such as the energy source, control method, number of cutters, and types of sensors. These factors shape the mower's functionality and efficiency, as discussed below:

1. Energy Source: Two primary energy sources are commonly used in robotic lawn mowers. The first is the conventional battery, where a rechargeable battery powers the mower's motors, enabling wheel movement and blade rotation (Chen L., 2021). The second option uses solar power, where a solar panel converts sunlight into usable energy to operate the mower. However,

this design requires careful consideration of the solar panel's power output, weight, integration, and overall cost (Green A., 2022). The choice between these energy sources depends on factors like power production challenges, weight concerns, and cost considerations.

2. Mode of Control: Robotic mowers can be controlled in different ways. One option is to use sensors such as proximity or ultrasonic sensors to detect obstacles and guide the mower's movement with the help of a microcontroller (Thrun et al., 2005). The second mode involves remote control, where the mower is driven and controlled remotely using a radio control system integrated into the mower's electronics (Patterson D., 2023). The choice of control method is influenced by the ease of integration, radio control range, and cost.

3. Number of Cutters: The mower can either have a single cutter or multiple cutters. Multiple cutters can increase cutting speed and efficiency, allowing more grass to be cut in a shorter time. However, this comes with trade-offs, such as higher costs, greater energy consumption, and the need for a larger physical design to accommodate the extra cutters (Fink P., 2023; Steen and Richards, 2021).

4. Type of Sensors: The design can also vary based on the type of sensors used. A contact-type mower utilizes micro switches that physically engage with obstacles to adjust the mower's path (Harris R., 2022). In contrast, a non-contact-type mower relies on sensors like ultrasonic or proximity sensors to detect obstacles and calculate the mower's route, with a microcontroller handling the adjustments (Kumar B., 2021). The choice of sensor impacts the mower's efficiency in detecting obstacles and adjusting its path.

2.10 Working of the Device

Automated lawn mowers can operate in various modes, each providing different levels of user interaction and control. The three primary modes are remote control mode, teach control mode, and automatic operation mode (Derek Adams, 2024). Remote control mode allows users to manually operate the mower using a remote device such as a smartphone, dedicated remote control, or a tablet. This mode provides direct control over the mower's movements and actions, making it suitable for specific tasks or areas that require precise handling (Derek Adams, 2024). Teach control mode involves manually guiding the mower along a desired path once, which the mower then records and learns. The mower can then repeat this exact path autonomously in subsequent operations. This mode blends manual and automated control, allowing for customized mowing paths (Derek Adams, 2024). Automatic operation mode is the most autonomous mode, where the mower uses built-in sensors, navigation systems, and algorithms to independently navigate and mow the lawn. This mode requires minimal user intervention and is designed for maximum efficiency and convenience (Derek Adams, 2024).

The working of the automated lawn mower is also dependent of the following:

1. Capturing environmental data: This refers to the process of gathering information about the mower's surroundings, including its location, obstacles, and boundaries. Various sensors, such as GPS, ultrasonic, and LiDAR, are used to collect real-time data to assist the mower in navigating its environment (Siciliano and Khatib, 2016).

2. Processing the data: The collected data is processed by microcontrollers, which integrate the sensor inputs to map the lawn and pinpoint the mower's exact location. Using path planning algorithms, the mower calculates an optimal route for mowing. Additionally, real-time decision-making processes allow it to avoid obstacles and adjust its route as necessary (Monk, 2022).

3. Actions: After processing the data, the microcontroller directs the mower's movement and cutting mechanisms. Based on the processed data, it executes the appropriate actions to cut the grass while avoiding any detected obstacles (Howard, 2021).

2.10 Justification of Study

Looking back at previous research, it is evident that there are various existing technologies of the automated lawn mower. However, while each design is unique and built with different special features, there are a number of disadvantages associated with these modern-day designs. This study will help to eliminate these disadvantages by providing the following modified features:

1. Cost Efficiency:

This study introduces an automated lawn mower that is built using locally sourced materials which will provide a more cost-efficient design. Labour costs and fuel expenses associated with traditional gasoline powered mowers (Ruth Olurounbi, 2022) will also be reduced making it a more affordable solution for lawn care in Nigeria.

2. Easy Accessibility:

The current market in Nigeria lacks advanced and affordable lawn maintenance tools, often relying on imported equipment (Opeoluwa Dapo, 2023). This study provides a design with a less complex structure in mind, built with locally sourced materials which will encourage easy accessibility within Nigeria.

3. Easy Maintenance:

Poor maintenance culture is a recurring issue in Nigeria due to a lack of technical knowledge and availability of spare parts (Opeoluwa Dapo, 2023). This project aims to incorporate low-maintenance components and design the mower for easy troubleshooting. With a simplified structure and locally sourced materials, users will encounter fewer operational issues, and repairs can be done quickly and affordably, promoting longer product lifespans.

4. Longer Battery Life

Given the irregular power supply in many parts of Nigeria (Samuel Ayokunle, 2020), having a longer battery life is crucial. This feature ensures that the mower can complete its task even during extended power outages, making it reliable and practical. It also reduces the frequency of charging, which is important for users with limited access to consistent electricity.

5. Weatherproofing with Humidity Sensors

Nigeria's climate, marked by heavy rainfall and high humidity in many regions (Weather Atlas, 2024), makes weatherproofing a necessary feature. By integrating humidity sensors, the mower can detect adverse weather conditions and automatically halt operations, protecting the equipment from damage. This feature also ensures safety, as the system can avoid mowing during unsuitable conditions, such as wet grass, which can clog the mower or cause mechanical failure.

Furthermore, the successfully development of this automated lawn mower can serve as a prototype for local production. This will reduce reliance on imported products and generate employment opportunities within Nigeria's technology and manufacturing sectors (Nwankwo and Okafor, 2022), contributing to the country's economic growth.

Also, this battery-powered lawn mower offers an eco-friendly alternative to gasoline-powered options, reducing carbon emissions and noise pollution. This aligns with Nigeria's ongoing efforts to adopt greener practices and reduce dependence on fossil fuels (World Economic Forum, 2023).

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter outlines the complete development process of the automated lawn mower, covering its design, fabrication, simulation and cost evaluation. The design phase involves selecting the most suitable approach for implementation, defining key parameters, and justifying the choices based on functionality and efficiency. Detailed engineering calculations are presented to support component selection and system performance.

The fabrication phase describes the step-by-step construction process, including chassis assembly, motor and sensor integration, and wiring configurations.

The simulation phase validates the system's expected behaviour before physical implementation. Using Proteus, critical aspects such as navigation, obstacle detection and motor control are tested under simulated conditions.

Finally, the Bill of Engineering Measurement and Evaluation (BEME) provides a detailed cost breakdown of the materials and components used in the project.

This structured approach ensures that the mower is developed with a balance of theoretical analysis, practical execution, and performance verification before real-world deployment.

3.2 Design

3.2.1 Conceptual Design

The conceptual design phase explores different possible methods for implementing the automated lawn mower and selects the most suitable approach based on feasibility, accuracy, and cost-effectiveness. Three distinct navigation methods are considered: GPS-based navigation, vision-based navigation, and perimeter wire navigation. Each approach has its advantages and limitations, but the final selection is based on reliability, ease of implementation, and compatibility with available components.

3.2.1.1 GPS-Based Navigation

A GPS-guided lawn mower relies on satellite positioning to determine its location and autonomously navigate within a predefined area. Advanced systems integrate RTK (Real-Time Kinematic) correction to improve positioning accuracy to centimeters.

Figure 3.1 shows the installation of a GPS system on an autonomous mower tractor, highlighting the components involved in GPS-based navigation.

Figure 3.1 GPS- Based Navigation

i. The GPS receiver on the mower communicates with satellites to determine its precise location.
ii. RTK correction improves accuracy, reducing positioning errors.
iii. The mower follows a pre-programmed path within the mapped boundary.

Advantages

1. It eliminates the need for physical boundary markers like perimeter wires.
2. It can efficiently map large and complex terrains.
3. It allows for custom mowing patterns and real-time tracking.

Disadvantages

1. Expensive, as it requires RTK-GPS modules for high accuracy.
2. It is prone to signal interference from trees, buildings, or bad weather.
3. It is not ideal for small lawns where GPS errors could lead to boundary violations.

3.2.1.2 Vision- Based Navigation

This approach uses cameras, image processing, and AI algorithms to detect grass boundaries, obstacles, and objects in real-time. The mower identifies the lawn edges and distinguishes between cut and uncut grass using computer vision techniques. Figure 3.2 depicts the overview of a vision based navigation system.

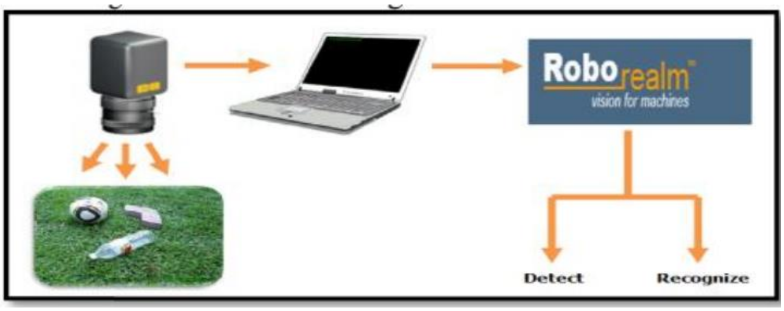


Figure 3.2 Vision based navigation

Figure 3.2 depicts the overview of a vision based navigation system.

i. A camera mounted on the mower captures images of the lawn.
ii. The AI algorithm processes the images, identifying grass, obstacles, and pathways.
iii. The mower adjusts its movement based on detected edges and obstructions.

Advantages

1. No need for GPS or perimeter wires.
2. Can adapt to dynamic environments by recognizing obstacles and adjusting paths.
3. Capable of detecting different grass heights for more efficient cutting.

Disadvantages

1. Requires complex image processing and powerful computing hardware.
2. Affected by lighting conditions (e.g., shadows or low-light environments).

3. More expensive and harder to implement with standard microcontrollers like Arduino Uno.

3.2.1.3 Perimeter wire Navigation

The perimeter wire-based system, which is the selected approach for this project, involves placing a thin wire around the mowing area that emits a low-frequency signal. The mower is equipped with perimeter sensors that detect the wire's electromagnetic field, ensuring it stays within boundaries.

Figure 3.3 and 3.4 depicts the setup of a perimeter wire system for a robotic lawn mower, showing how the wire defines the mowing area.

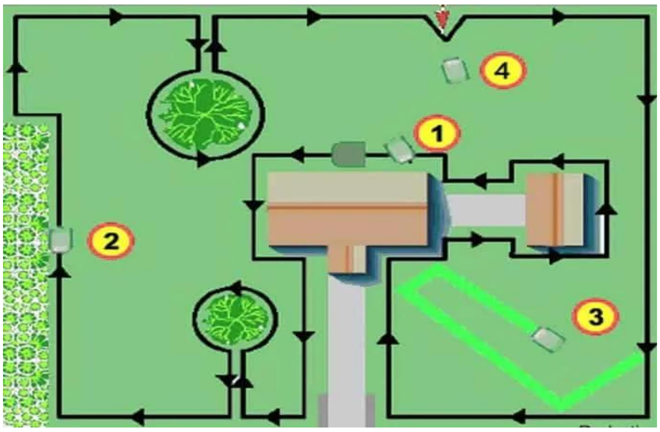


Figure 3.3 A lawn with perimeter wire

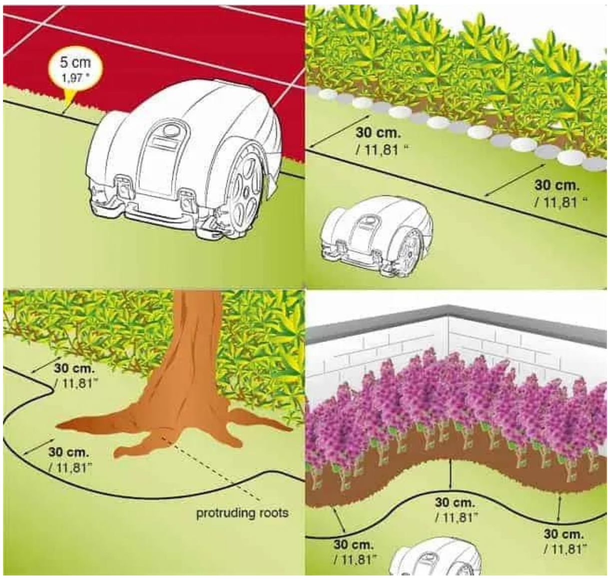


Figure 3.4: Installation of a perimeter wire

A perimeter station is used to generate an electromagnetic field along the wire. The mower's sensors detect the signal and adjust movement accordingly. It changes direction when it reaches the boundary.

Advantages

1. Simple and cost-effective compared to GPS and AI-based methods.
2. Reliable operation regardless of lighting or weather conditions.
3. Easily integrates with an Arduino-controlled system.

Disadvantages

1. Requires manual installation of the perimeter wire.

2. Less adaptable to irregularly shaped lawns.

3.2.1.4 Justification for Selected Design

The perimeter wire-based system was chosen due to its low cost, ease of implementation, and reliability. Unlike GPS or AI-based approaches, it does not rely on expensive hardware or complex computing. Additionally, perimeter detection ensures consistent mowing patterns, making it suitable for small and medium-sized lawns.

Based on these we came up with the CAD model for the project. Figure 3.5, 3.6, 3.7 and 3.8 below represent the model. It depicts the front, side and end views of the automated lawn mower.

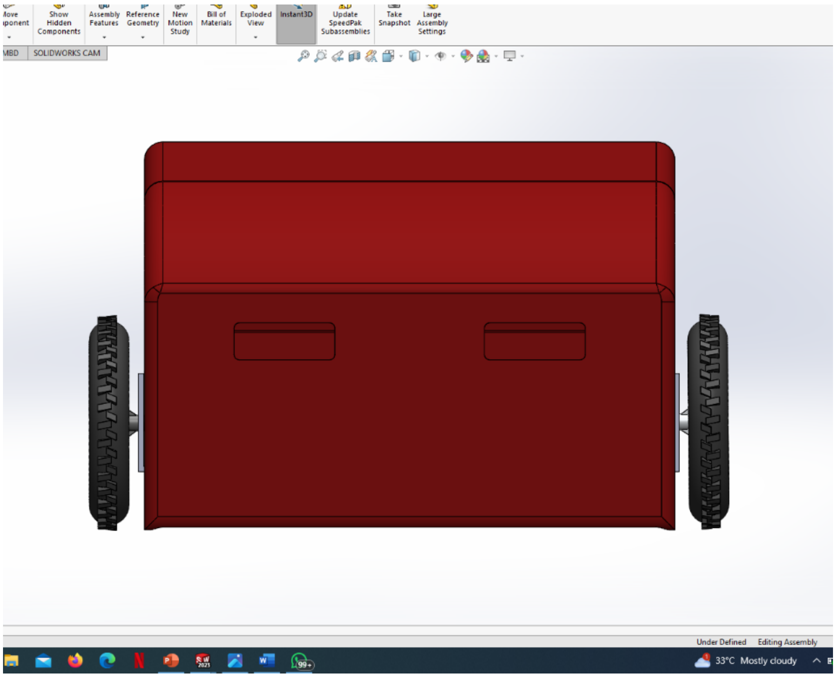


Figure 3.5 Model's front view

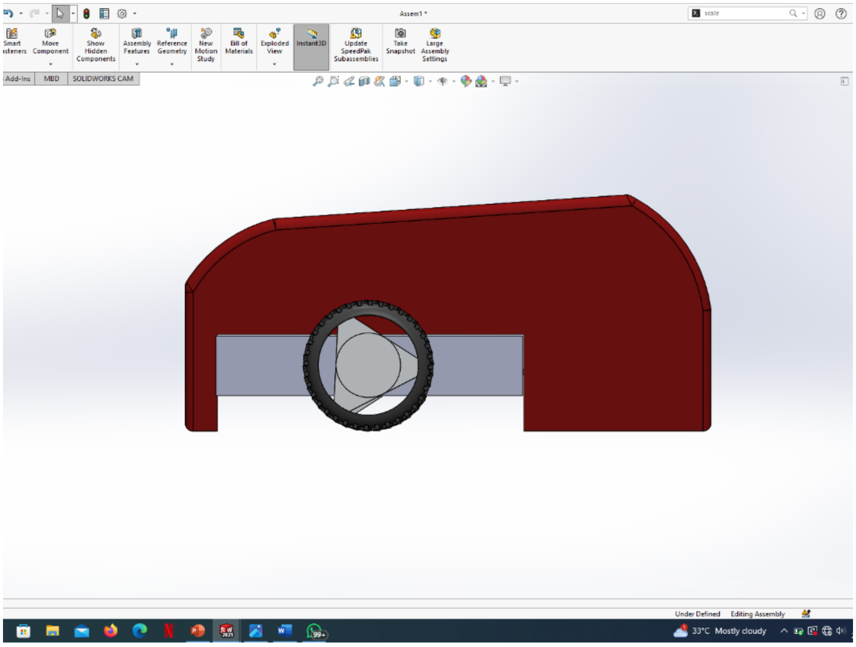


Figure 3.6 Model’s side view

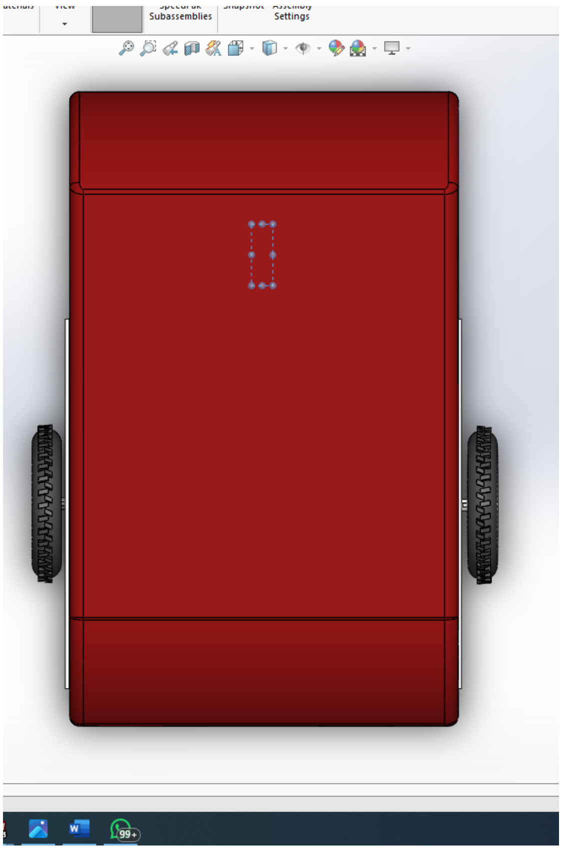


Figure 3.7 Model’s top view

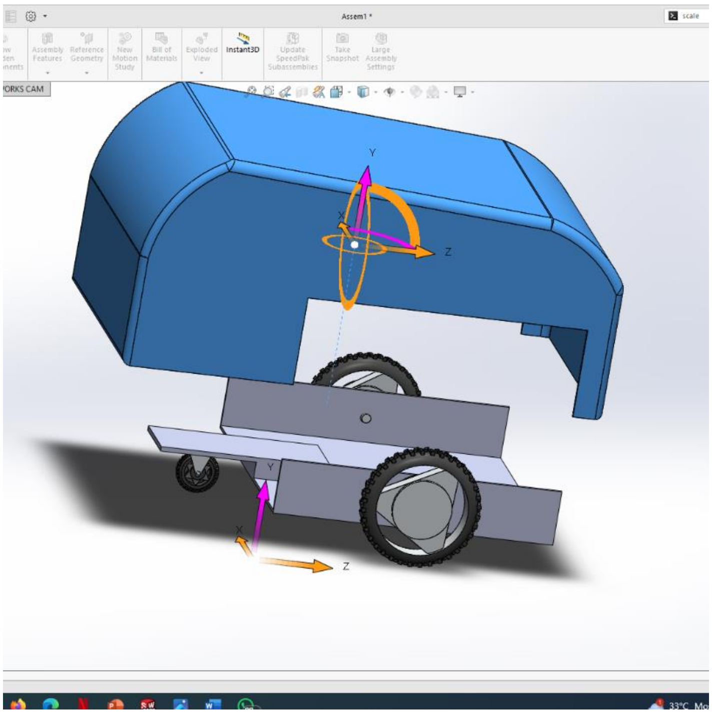


Figure 3.8 Model's exploded view

3.2.2 Design Analysis and Component Selection

This section presents the key components used in the automated lawn mower, detailing their specifications, selection criteria, and relevant calculations. Both hardware and software elements are analyzed to ensure optimal functionality and integration within the system.

3.2.2.1 Hardware Design Analysis

1. Chassis and Frame

The chassis serves as the structural foundation of the automated lawn mower, supporting all major components, including the motors, battery, sensors, and cutting mechanism. The selection of stainless steel (1mm thickness) was based on factors such as durability, resistance to bending under load, and availability.

Material Selection and Justification

Initially, 2mm aluminium was considered due to its lightweight properties, but structural instability under load led to bending issues. 1mm stainless steel was chosen as a more rigid alternative while keeping weight within an acceptable range for the motors. While stainless steel was selected for the chassis due to its strength and durability, a 3D-printed PLA body was integrated to provide an enclosure for electronic components. This material was chosen for its lightweight nature and ease of fabrication, ensuring protection against environmental factors without significantly increasing the mower's weight.

Chassis Dimensions and Weight Estimation

Base Plate Dimensions: 270mm × 190mm

Thickness: 1mm

Material Density (Stainless Steel): 8000 kg/m³

Volume Calculation:

V = Length × Width ×Thickness ....(3.1)

V= 0.270 × 0.190 × 0.001

= $5.13 \times 10^{-5} m^3$

Weight Calculation

W = Density **x** Volume..(3.2)

W= 800 x 5.13 x 10^{-5}

=0.41 kg

This weight estimation accounts for the base plate only. Additional reinforcements and mounted components contribute to the total weight of the mower.

Structural Considerations

Weight Distribution: The placement of the battery, motors, and sensors ensures even weight distribution for balance and stability.

Mounting Provisions: Pre-drilled holes accommodate the wheel motors, cutting motor, and battery compartment. Additionally, mounting points were included for securing the 3D-printed body shell without interfering with other components.

Further Shaping: The chassis undergoes additional bending to achieve the final structure, which is detailed in the Fabrication section.

Corrosion Resistance: Stainless steel offers enhanced resistance to outdoor conditions compared to aluminium.

Protective Enclosure: A 3D-printed PLA body shell was integrated to house and shield electronic components from environmental exposure. The enclosure is lightweight and designed for easy removal, facilitating maintenance and repairs.

Table 3.1 below shows the specifications for the chassis and frame, including the material used, parameters and the dimensions of the material. Justification for the parameters are also stated.

Table 3.1: Specifications for Chassis and Frame

Parameter	**Value**	**Justification**
Material	Stainless Steel (1mm)	Increased rigidity and durability over aluminum
Base Dimensions	270mm × 190mm	Optimized for compact and efficient design
Thickness	1mm	Balances weight and rigidity
Weight Estimate	0.41kg	Ensures stability without excessive load
Corrosion Resistance	High	Suitable for outdoor conditions
Body Enclosure	3D-Printed PLA Shell	Provides lightweight protection for electronic components.
Mounting approach	Secure fasteners	Allows easy removal for maintenance

Figure 3.9, 3.10, 3.11 and 3.12 below illustrates the top, side and front views of the 3D printed body enclosure also showing the isometric plan.

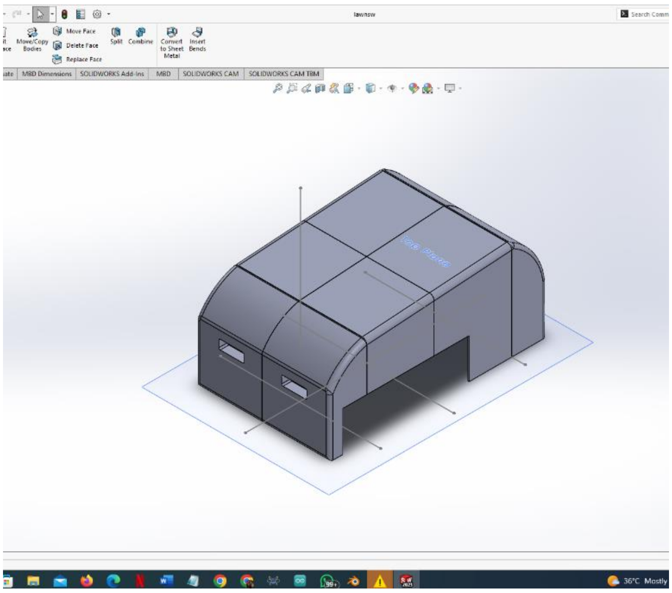


Figure 3.9 Isometric view of 3D body

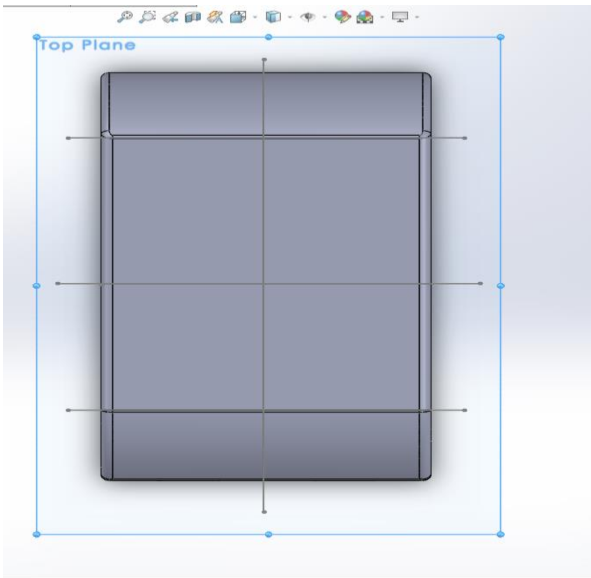


Figure 3.10 Top view of 3D CAD model

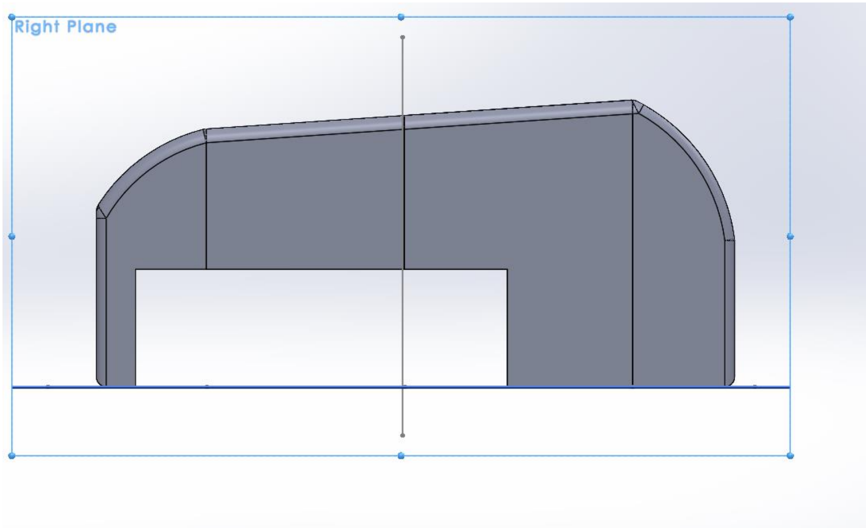


Figure 3.11 Side view of 3D CAD model

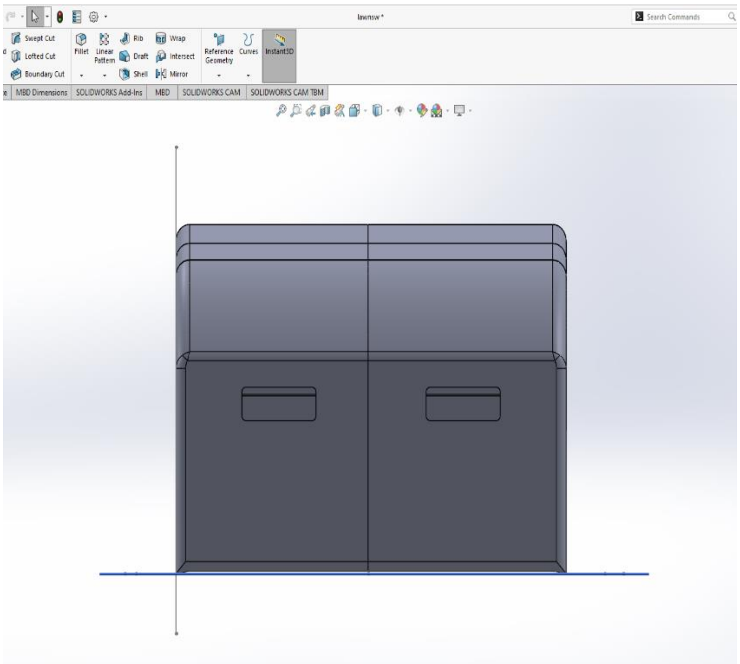


Figure 3.12 Front view of 3D CAD model

2.Wheel motors

The wheel motors are responsible for driving the mower across different terrains while ensuring efficient navigation. Two DC geared motors (755 high-torque motors, 12V DC) were selected for their ability to provide sufficient torque while maintaining reasonable power consumption.

Motor Selection and Justification

The motors were chosen based on the required torque, speed, and power efficiency to move the mower while carrying the necessary components. The following factors influenced the selection:

1. Torque Requirements: The motors need sufficient torque to overcome rolling resistance and minor inclines.
2. Speed Considerations: A balance between maneuverability and stability was required, ensuring controlled movement.
3. Voltage Compatibility: The motors operate at 12V, aligning with the 18V tool battery using a regulated power supply.

Table 3.2 below shows the specifications for the wheel motors.

Table 3.2: Wheel motor Specifications

Parameter	**Value**
Motor type	DC Gear Motor (Brushed)
Operating Voltage	12V
Speed	4000RPM (at no load)
Torque	1.2 kg.cm
Current draw	1.5A -3A (varies by load)

Torque Calculation

To ensure the motors can move the mower efficiently, we calculate the required torque based on the mower's weight and friction:

Weight of Mower (Estimated Total Load): 7kg

Wheel Radius: 70mm (0.07m)

Coefficient of Rolling Friction (μ): 0.02 (assumed for grass terrain)

Force Required to Move Mower:

$$F = \mu \times W \times g \quad \text{...} (3.3)$$

$$F = 0.02 \times 7 \times 9.81 = 1.37N$$

Torque Required per Wheel:

$$T = F \times R \text{..} (3.4)$$

$$T = 1.37 \times 0.07 = 0.096Nm$$

Since the motor torque is 1.2 kg.cm (0.12 Nm), it is sufficient to drive the mower without excessive strain.

Motor Driver and Control

The motors are powered and controlled via an L298N motor driver, which regulates speed and direction. The Arduino Uno sends control signals to the motor driver based on navigation inputs.

Table 3.3 shows the parameter of the motors with justifications for their choosing.

Table 3.3: Wheel motor Summary

Parameter	Value	Justification
Motor Type	DC Gear Motor (Brushed)	Reliable, efficient, and simple control
Operating Voltage	12V	Compatible with mower's power system
Speed	4000 RPM	Provides necessary movement capability
Torque	1.2 kg.cm	Sufficient for the mower's weight and friction
Control System	L298N Motor Driver	Enables bidirectional speed control

3. **Cutting motor and blade**

The cutting mechanism is powered by a 795 DC motor (12V), which drives a stainless-steel cutting blade to ensure effective grass trimming. This section details the motor selection, blade design, and performance analysis to ensure optimal cutting efficiency.

Motor Selection and Justification

The cutting motor was selected based on its ability to provide sufficient torque and speed to cut grass effectively. Key factors considered include:

1. Torque Output: The motor must generate enough torque to cut through various grass densities without stalling.
2. Speed Requirements: A high enough rotational speed is required to achieve a clean cut.
3. Power Efficiency: The motor must be balance power consumption and cutting efficiency.

Table 3.4 shows the parameters for the cutting motor.

Table 3.4: Cutting Motor Specifications

Parameter	**Value**
Motor type	Brushed DC Motor (795)
Operating voltage	12V
Speed	1000 RPM
Torque	1.5 kg.cm (0.15Nm)
Current Draw	2A -3A(varies by load)

Blade Design and Selection

The cutting blade plays a crucial role in efficiency and durability. Stainless steel was chosen for its sharpness retention, corrosion resistance, and strength.

Table 3.5 shows the parameters for the cutting blade with justifications

Table 3.5: Cutting blade Parameters

Parameter	Value	Justification
Blade Material	Stainless Steel	Corrosion-resistant and durable
Blade Diameter	130mm	Provides sufficient cutting coverage
Blade Mounting	Directly on motor shaft	Ensures stability during operation
Blade Height	Fixed	No need for adjustable cutting heights

Power and Torque Analysis

To validate the motor's capability, we calculate its power output and torque using the motor specifications.

Motor Power Calculation:

$$P = V \times I \quad (3.5)$$

$$P = 12V \times 2.5A = 30W$$

Where:

V =12V (operating voltage of the motor)

I = 2.5A (average current draw)

Torque derived from Motor Power:

$$T = \frac{P \times 60}{2\pi \times N} \quad (3.6)$$

$$T = \frac{30 \times 60}{2\pi \times 1000}$$

$$T = \frac{1800}{6284} = 0.286 \text{ Nm}$$

Since the motor torque is 0.286 Nm, it exceeds the originally assumed torque of 0.15 Nm, meaning the motor should perform better than initially estimated depending on operating conditions.

Motor Control and Power Management

The cutting motor is controlled using an L298N motor driver via PWM signals from the Arduino Uno, allowing for adjustable speed based on load conditions.

Table 3.6 shows the summary of specifications for the cutting motor and the cutting blade with justifications.

Table 3.6: Cutting motor and blade Summary

Component	**Specification**	**Justification**
Cutting motor	795 Brushed DC (12V)	Provides moderate torque and power
Blade Material	Stainless steel	Corrosion- resistant and durable
Blade diameter	130mm	Adequate cutting width
Blade speed	1000 RPM	Ensures clean cuts
Motor torque	0.286 Nm	Meets cutting requirements

4. **Battery and Power System**

The lawn mower is powered by a rechargeable 18V tool battery, supplying energy to the motors, sensors, and control system. The power system is designed to ensure efficient energy distribution and runtime optimization.

Table 3.7 shows the specifications for the battery.

Table 3.7: Battery Specifications

parameter	**Value**
Type	18V tool battery
Voltage	18V
Capacity	1.5 Ah

Charging time	Approx. 1 hour

The single battery pack supplies power to the wheel motors, cutting motor, Arduino, and sensors. A DC-DC converter regulates voltage where necessary to match component requirements.

Battery Runtime Estimation

The estimated runtime of the mower is calculated using the battery energy formula:

$$t = \frac{Battery\ Capacity\ (Ah) \times Battery\ \ voltage\ (V)}{total\ power\ consumption\ (W)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3.7)$$

Where:

Battery specifications: 18V, 1.5Ah

Power consumption breakdown:

Cutting motor (12V, 2.5A avg):

$$P_{cutting} = 12V \times 2.5A = 30W$$

Wheel motors (each 12V, 2A avg, two motors):

$$P_{wheels} = 12V \times 2A \times 2 = 48W$$

Sensors, Arduino and control electronics (estimated):

$$P_{sensors} \approx 5W$$

Total power consumption:

$$P_{total} = 30W + 48W + 5W = 83W$$

Using the battery energy formula:

$$t = \frac{1.5Ah \times 18V}{83W} = \frac{27}{83} = 0.325 \text{ hours}$$

Converting to minutes:

$$t = 0.325 \times 60 = 19.5 \text{ minutes}$$

From the calculations, the estimated operational runtime of the mower on a full charge is approximately 19.5 minutes under normal working conditions. However, this value may vary depending on terrain, load conditions, and battery efficiency over time.

5. Sensor and Navigation System

The mower's autonomous movement relies on boundary detection and obstacle avoidance, ensuring it stays within the mowing area while preventing collisions. The key components include ultrasonic sensors and a perimeter wire system, selected based on range, reliability, and power efficiency.

i. Perimeter Wire System

The perimeter wire system defines the mowing area using a 5kHz signal generated by an L298N motor driver controlled by an Arduino Uno.

Table 3.8 shows the components for the perimeter station.

Table 3.8: Components for Perimeter Station

Component	Specification	Reason for selection
Signal generator	Arduino Uno	Cost -effective, sufficient processing power
Motor driver	L293N	Handles current output for signal transmission
Perimeter wire sensors	Inductive Coils (10mH)	Detects electromagnetic pulses effectively
Amplifier	LM358N	Amplifies weak signals for better detection

Working Principle

The perimeter wire emits a 5kHz signal, creating a virtual boundary that defines the mowing area. As the mower approaches the wire, the Arduino Uno on the mower processes the detected signal from the perimeter sensors, which is amplified by the LM358N operational amplifier.

When the signal strength reaches a predefined threshold, the Arduino triggers a turning maneuver, ensuring the mower remains within the boundary.

ii. Obstacle Detection – Ultrasonic Sensors

The mower uses two front-mounted ultrasonic sensors (HC-SR04) to detect obstacles within 30-50 cm. The sensors work by emitting high-frequency sound waves and measuring the time delay of the echo.

Table 3.9 below shows the specifications for the ultrasonic sensors.

Table 3.9: Specifications for the Ultrasonic sensors

Component	Specification	Reason for selection
Ultrasonic sensor	HC- SR04	Reliable, accurate for short-range detection
Detection range	30-50 cm	Optimized to prevent last-minute collisions
Response mechanism	Stop, reverse, turn	Ensures safe navigation away from obstacles

If an object is detected within 30 cm, the mower stops, reverses slightly, and turns to avoid collision. The detection range can be adjusted via Arduino code, allowing flexibility in different environments.

iii. Navigation Algorithm

The mower navigates autonomously using a predefined pattern, responding dynamically to sensor input.

Movement Logic

The mower moves in a straight line until it detects a boundary or obstacle, then turns away to avoid collisions or boundary crossings. It continuously adjusts its path based on sensor feedback to optimize coverage and ensure efficient mowing.

This navigation system ensures precise movement within the defined area while minimizing collisions and maximizing efficiency. The combination of perimeter wire detection and ultrasonic sensors enables a balance between autonomy, accuracy, and safety.

6. **Motor Driver and Control Electronics**

The L298N motor driver is used to control the wheel motors and cutting motor, providing efficient power distribution and precise speed regulation. It is a dual H-bridge driver, allowing bidirectional motor control, which is essential for the mower's navigation and maneuverability.

Parameters:

Operating Voltage: 5V – 35V

Continuous Current: 2A per channel

Peak Current: 3A per channel

Logic Control Voltage: 5V

PWM Control: Allows speed adjustment

Justification:

The L298N was selected due to its ability to handle the 12V wheel motors and cutting motor, while also being compatible with PWM control for efficient speed regulation. Its built-in heat sink ensures reliable operation under continuous load conditions. Additionally, its ability to drive two independent motors simplifies the design, reducing the need for multiple controllers.

The motor driver receives control signals from the Arduino Uno, which processes inputs from the ultrasonic sensors and perimeter wire sensors to determine movement and obstacle avoidance strategies. The driver then adjusts the PWM duty cycle to regulate motor speed and direction.

3.2.2.2 Software Design Analysis

1. **Microcontroller Programming and Navigation Algorithm**

The microcontroller serves as the central processing unit of the automated lawn mower, coordinating all operations including movement, obstacle detection, and boundary adherence. An Arduino Uno is utilized due to its compatibility with various sensors, ease of programming, and cost-effectiveness. The microcontroller executes the navigation algorithm based on sensor inputs, ensuring efficient coverage of the mowing area while avoiding obstacles and remaining within designated boundaries.

Microcontroller Setup and Implementation

The Arduino Uno is programmed using C++ in the Arduino IDE. The source code governs motor control, obstacle detection, and perimeter adherence by processing sensor data and issuing movement commands. Key components of the microcontroller programming include:

i. Sensor Data Processing – The microcontroller reads inputs from ultrasonic sensors for obstacle detection and perimeter pulse sensors for boundary recognition.
ii. Motor Control via PWM Signals – Speed and direction of the wheel motors and cutting motor are regulated using Pulse Width Modulation (PWM).
iii. Decision-Making Algorithm – Based on sensor feedback, the microcontroller determines appropriate movement actions such as stopping, turning, or reversing.
iv. Failsafe Mechanisms – If an unknown condition is detected (e.g., sensor failure or excessive deviation from the boundary), a predefined emergency stop routine is executed.

Navigation Algorithm

The navigation system is responsible for ensuring optimal lawn coverage while avoiding obstacles and respecting the boundary constraints. The implemented algorithm follows these key steps:

Initial Startup and Boundary Detection:

The mower starts in a predefined position and scans for the perimeter wire signal (5kHz pulse from the perimeter station).

If no boundary is detected, the mower begins forward movement.

Obstacle Detection and Avoidance:

Ultrasonic sensors continuously scan for obstacles within a 30 cm range.

If an obstacle is detected, the mower stops, reverses slightly, then turns left or right (based on obstacle position) before resuming movement.

Boundary Adherence:

The perimeter pulse sensors detect the electromagnetic field generated by the perimeter wire.

If the signal strength exceeds a defined threshold, the mower recognizes proximity to the boundary.

Upon detecting the perimeter, the mower stops, reverses, and turns away to stay within the designated mowing area.

Randomized Coverage Strategy:

The mower moves in a straight line until an obstacle or boundary is detected.

If an obstacle or boundary is encountered, the mower adjusts direction using a randomized turning function to ensure full coverage.

Figure 3.13 below illustrates the navigation logic of the automated lawn mower. The system continuously processes sensor inputs to determine movement. If no obstacle or boundary is detected, the mower moves forward. Upon detecting an obstacle, it reverses slightly and turns to avoid it. If the perimeter signal is detected, the mower turns to stay within the designated area. This ensures efficient and collision-free operation.

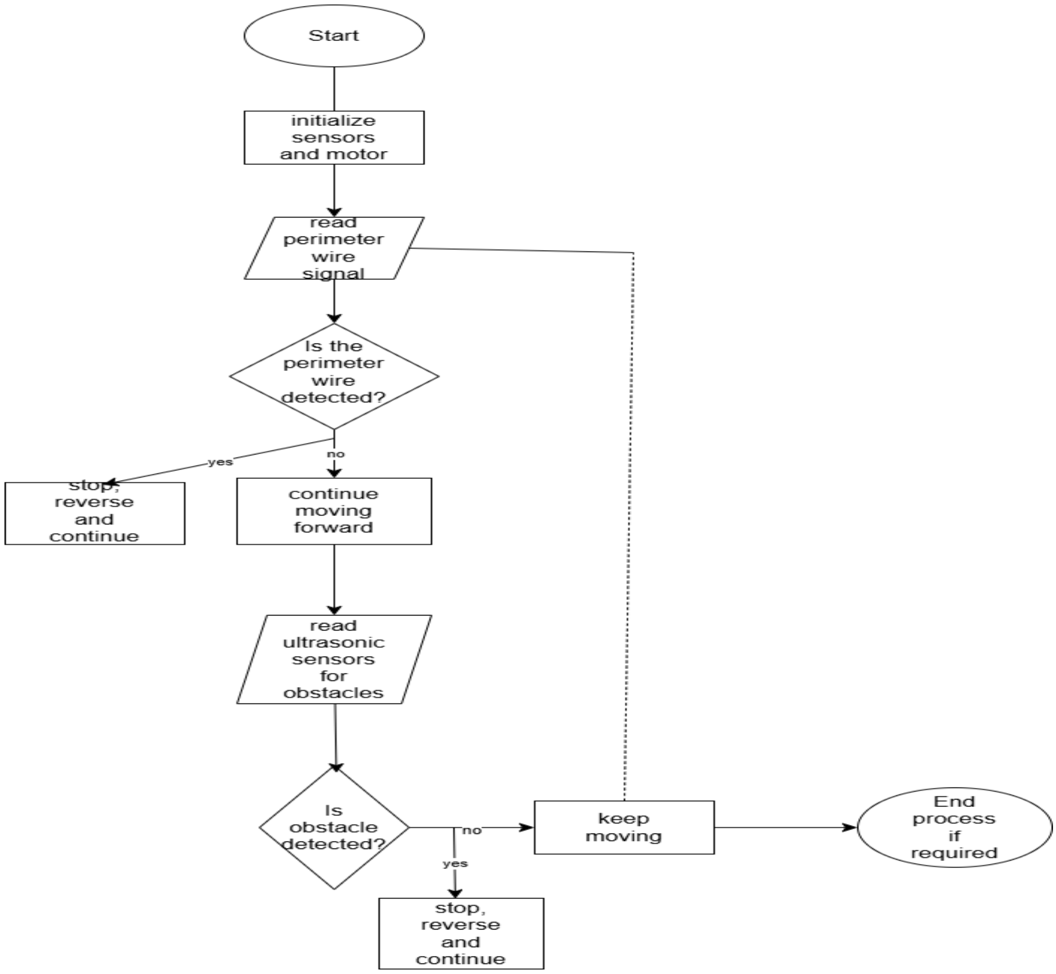


Figure 3.13 Flowchart of navigation algorithm

Motor Driver and Control Implementation

The L298N motor driver is used to control the wheel motors and cutter motor. The Arduino outputs PWM signals to regulate motor speed and direction:

Wheel Motors: Speed controlled via PWM based on terrain and obstacle presence.

Cutting Motor: Runs at a fixed PWM duty cycle for consistent grass cutting performance.

Source Code Implementation

The navigation algorithm and motor control logic are implemented in the Arduino IDE, using C++-based programming. Key functions in the source code include:

Motor control functions: Adjusting PWM duty cycles for speed regulation.

Obstacle detection and avoidance: Interpreting ultrasonic sensor readings and triggering appropriate maneuvers.

Boundary detection logic: Processing perimeter sensor signals to ensure compliance with the mowing area.

Failsafe conditions: Handling unexpected sensor failures or erratic behaviour to prevent malfunction.

Perimeter Station Source Code

```
#include <Arduino.h>
//#define PRINT_OUT
// Pin definitions
int iPinPulse = 3;
// Setup Base station initial state.
void setup()
{
#ifdef PRINT_OUT
Serial.begin(57600);
Serial.println("Begin setup");
#endif
  // Pulse pin setup
 pinMode(iPinPulse, OUTPUT);
#ifdef PRINT_OUT
Serial.println("Return setup");
#endif
}
void loop()
{
// Create a 5KHz pulse for the digital fence
  // Set digital fence high
  analogWrite(iPinPulse, 255);
  delayMicroseconds(100);
// Set digital fence low
 analogWrite(iPinPulse, 0);
  delayMicroseconds(100);
}
```

The perimeter station source code is responsible for generating a 5kHz signal that is transmitted through the perimeter wire, creating a virtual boundary for the mower. The Arduino Uno processes the signal and controls the L298N motor driver to ensure consistent pulse generation. The resistors and capacitors used help shape the signal to be easily detected by the mower's perimeter sensors. This implementation ensures reliable boundary detection, preventing the mower from crossing designated areas.

Justification for Design Choices

Arduino Uno: Chosen for its ease of integration, sufficient I/O pins, and established community support.

PWM Motor Control: Provides smooth acceleration, speed adjustments, and energy efficiency.

Randomized Coverage Strategy: Ensures complete grass coverage without requiring GPS or a predefined mowing pattern.

Ultrasonic Sensors for Obstacle Detection: Reliable in detecting static and dynamic objects within range.

Perimeter Wire for Boundary Detection: Effective for ensuring the mower remains within the designated area.

Conclusion

The microcontroller programming and navigation algorithm collectively ensure efficient lawn mowing by enabling obstacle avoidance, systematic coverage, and boundary compliance. With real-time sensor feedback and adaptive movement strategies, the system provides a functional and cost-effective alternative to GPS-based robotic mowers.

2. **User Interface**

The user interface for the automated lawn mower is primarily based on the Arduino IDE and serial communication. Through the Arduino Serial Monitor, system parameters such as battery status, sensor readings, and motor activity can be monitored in real-time. User interaction is minimal, mainly limited to starting and stopping the mower or adjusting certain parameters within the source code. While this prototype relies on basic serial communication for feedback and control, future iterations could incorporate a dedicated interface, such as an LCD display or a mobile/web-based application, to enhance usability and remote monitoring.

3.3 Simulation

The simulation phase was conducted to evaluate key functional aspects of the automated lawn mower before physical implementation. By simulating obstacle detection and motor motion control, potential issues were identified early, allowing for necessary refinements before fabrication.

3.3.1 Simulation Software Used

The Proteus Design Suite was selected for simulation due to its ability to model microcontroller-based circuits, allowing for real-time testing of Arduino-controlled systems. This software provided an effective platform for analyzing sensor response and motor driver behavior and overall navigation logic.

3.3.2 Simulation Scope

The simulations focused on two key functionalities:

1. Obstacle Detection and Avoidance

The simulated response of the ultrasonic sensors (HC-SR04) in detecting obstacles.

The activation of motors based on varying object distances.

2. Motor Driver and Wheel Motion Simulation

How the L298N motor driver controlled the wheel motors for navigation.

Simulated forward motion, obstacle avoidance, and turning maneuvers based on obstacle presence.

3.3.3 Simulation Setup and Execution

The Arduino Uno was programmed with obstacle detection logic, where the ultrasonic sensor continuously monitored distance and adjusted motor behavior accordingly.

Simulation Process

1. **Obstacle Detection Logic**

The HC-SR04 sensor emits ultrasonic pulses and measures the time for the echo to return.

Distance is calculated using the formula:

$$\text{Distance}=\frac{Time\times 0.0342}{2} \text{ ....(3.8)}$$

The ultrasonic sensor sends out a sound pulse and waits for the echo to return. The speed of sound in air is 343 m/s (or 0.034 cm/µs), we can calculate the distance as:

$$\text{Distance=Speed} \times \text{Time ....(3.9)}$$

However, the time measured is for the pulse to travel to the obstacle and back (round trip), so we divide by **2** to get the one-way distance:

The measured distance is displayed on an **LCD screen** within Proteus.

2. **Decision-Making Process**

If an obstacle is detected within 30 cm, the mower moves backward and executes a left turn to avoid the object.

If no obstacle is detected, the mower continues to move forward.

3. **Motor Control Simulation**

The L298N motor driver regulates motor direction. The enable pins (EN1, EN2) were set to HIGH, allowing the motors to operate at full speed.

The motor control logic adjusts wheel movement based on obstacle presence.

4. **Circuit Visualization**

The Proteus oscilloscope tool was used to analyze ultrasonic sensor signal variations. Motor activation was observed in Proteus' virtual environment, validating real-world behavior before hardware implementation.

Figure 3.14 below illustrates the simulation setup, showing the Arduino, ultrasonic sensors, the motor connections and the LCD which shows the distance output result

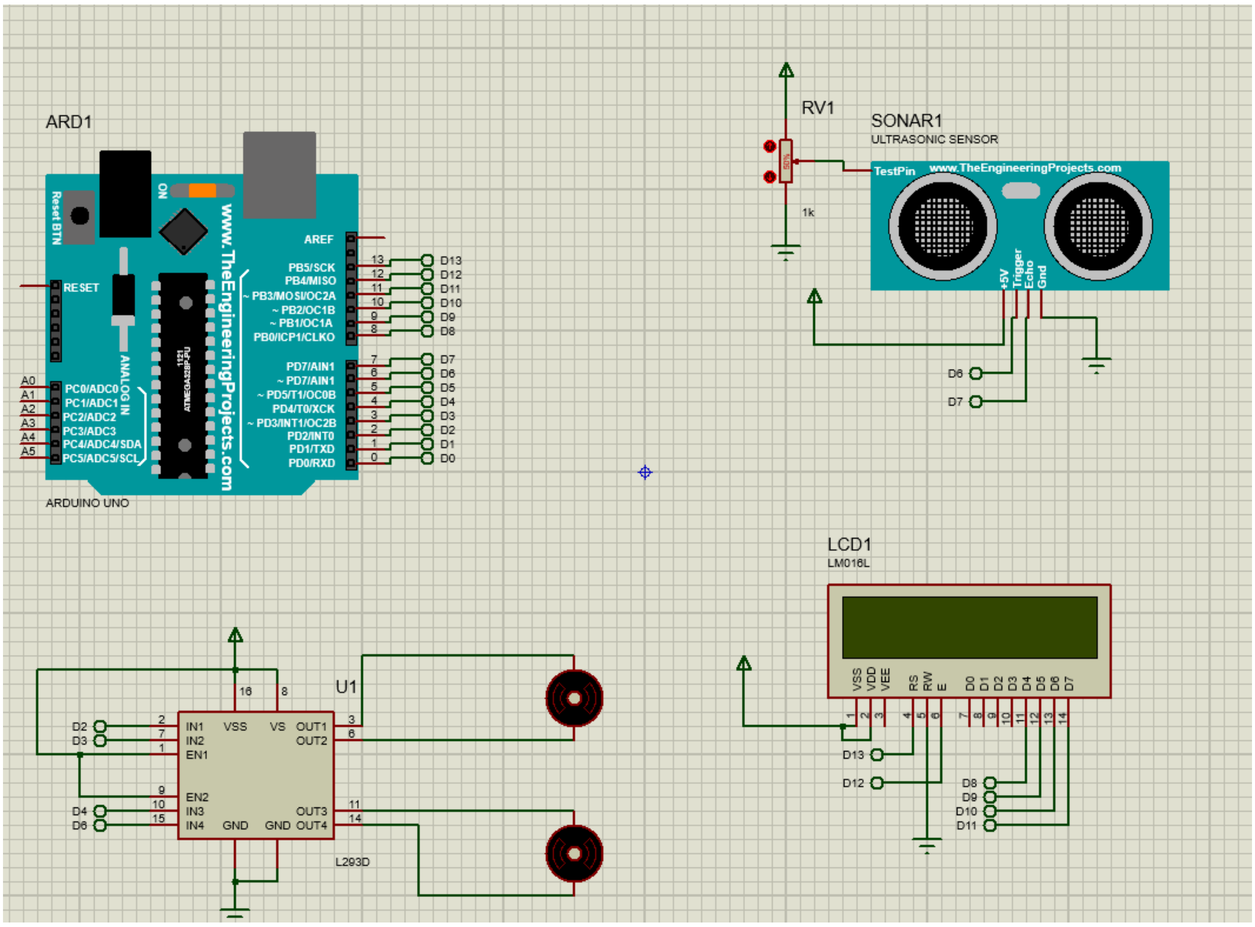


Figure 3.14 Simulation setup

3.4 Fabrication

The fabrication of the automated lawn mower followed a structured process, ensuring precise assembly and integration of all components for optimal performance. This involved constructing the chassis, installing motors and wheels, wiring electrical components, integrating sensors, and assembling the perimeter detection system. Each step was meticulously executed to ensure durability, efficiency, and reliability.

The fabrication process began with the chassis construction, which serves as the structural foundation of the mower. Initially, aluminum was considered due to its lightweight properties, but structural concerns led to the selection of 1mm stainless steel for improved durability. A 270mm x 190mm base plate was cut to shape using precision tools, with additional mounting points drilled to securely attach the motors, battery, and electronic modules. The two 190mm sides of the plate were bent 35mm from the edge, this provided secure mounting positions for the DC motor gearboxes that drive the front wheels.

Figure 3.15 depicts the dimensions of the chassis, after the base plate has been bent. It also shows the drilled holes that will be used as mounting positions for the motors.

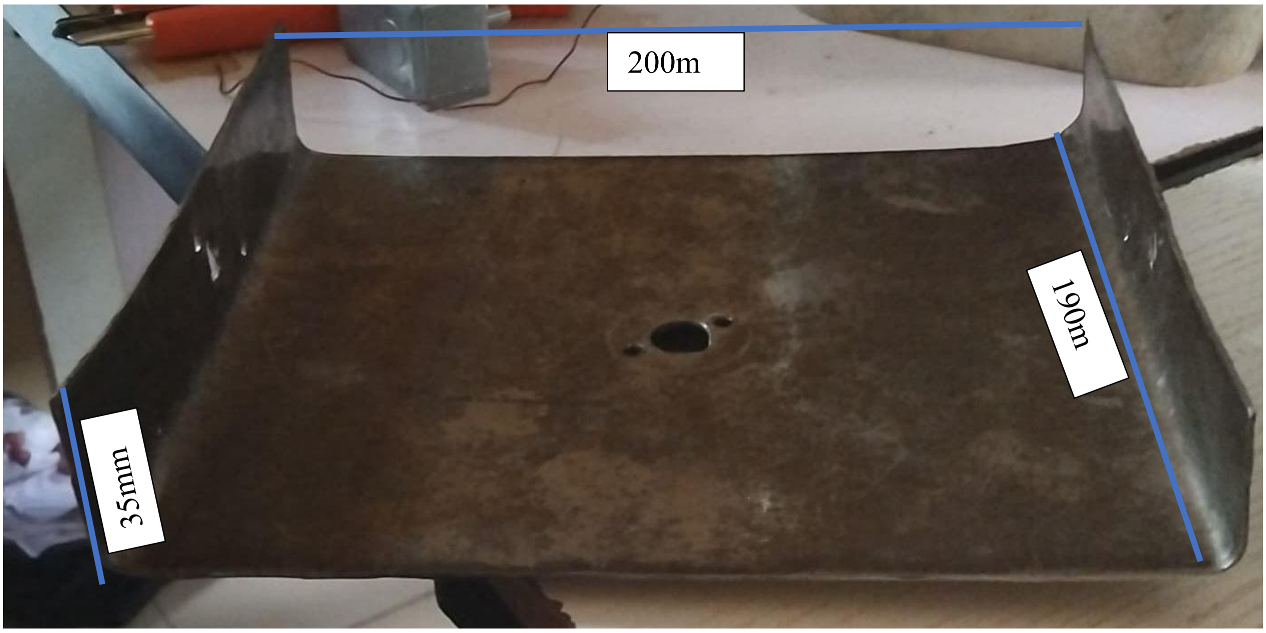
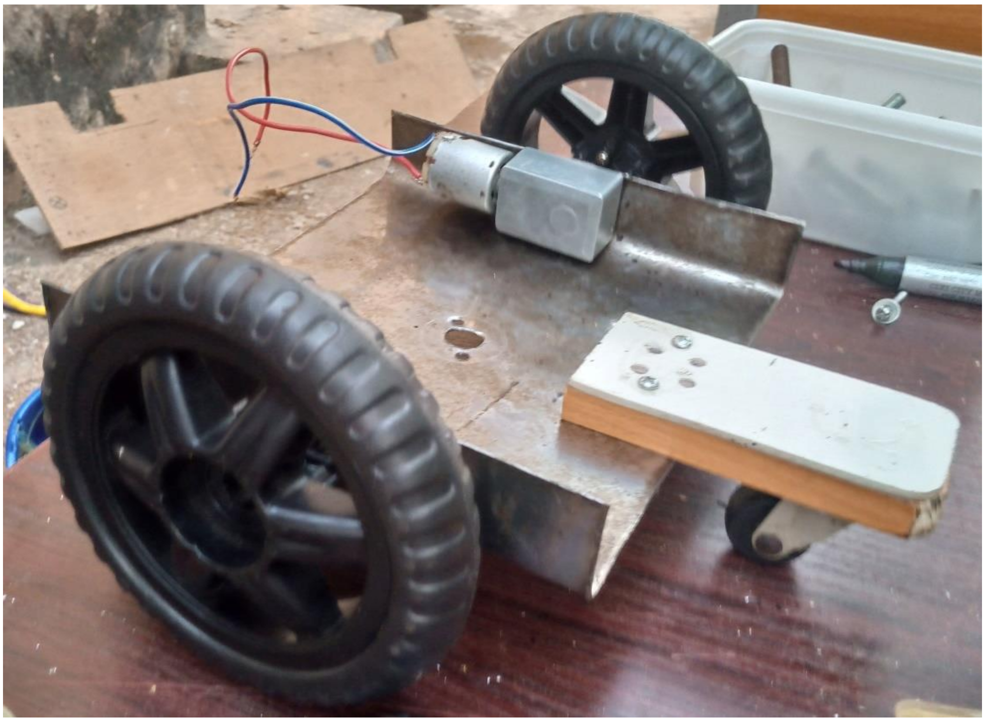


Figure 3.15: Chassis of the Lawnmower

At the rear of the chassis, a caster wheel assembly was installed to enhance maneuverability. The selected caster wheel measures 70mm wide and 65mm high, allowing free rotation for smooth directional adjustments. A wooden spacer was added to ensure that the chassis remained level with the ground. A 115mm x 50mm x 1mm back wheel mounting plate was attached with four screws, securing the caster wheel while allowing full 360-degree rotation without obstruction from the chassis or cutting blade.

Next, the wheel motors were installed. The 12V DC geared motors, known for their high torque and controlled speed, were mounted securely using four mounting screws. The 6mm motor shafts were fitted with screws and lockbolts, which allowed the front wheels to be attached firmly while ensuring smooth traction across lawn surfaces.

Figures 3.16 and 3.17 below shows the implementation of the back caster wheel and the DC motors, it shows the different angles. This is the final assembled chassis of the lawn mower.



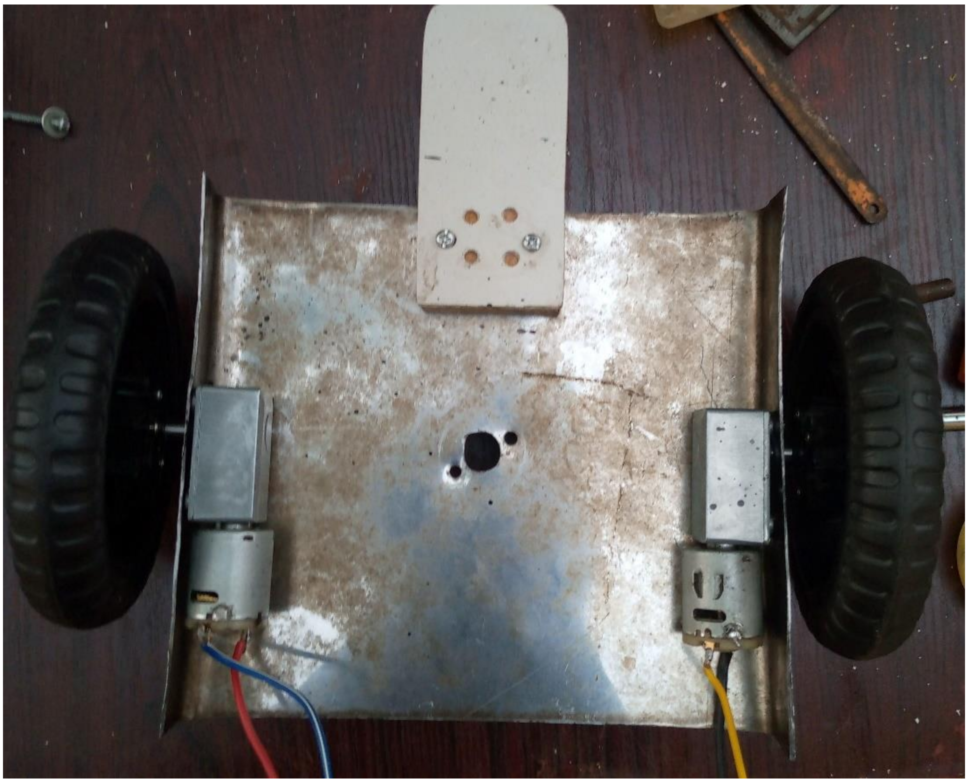


Figure 3.16: Implementation of back wheel caster motor

Figure 3.17: Implementation of wheels and DC motors

The cutting motor and blade assembly followed. The cutter was fabricated using a stainless steel disc and blades. The disc was made from a stainless steel material of thickness 0.5mm, measuring 130mm in diameter. The stainless steel blade was attached to the round disc at 120 degrees from each other. A 795 double shaft DC motor, operating at 12V and 1000RPM, was selected for its efficiency in driving the cutting mechanism. It is placed at the center of the chassis. The cutter was precisely attached to the motor shaft using lock nuts to minimize vibrations. Careful attention was given to balancing the blade to prevent excessive wobbling. The mounting height of the blade was fixed at 35mm from the ground to ensure effective grass cutting while avoiding ground obstructions.

With the mechanical components in place, the wiring and electrical integration were completed. A 18V tool battery was chosen as the primary power source, supplying energy to the Arduino Uno, motor drivers (L298N), sensors, and perimeter system. Electrical connections were systematically routed to ensure a clean, organized layout, minimizing interference and preventing voltage drops. Proper insulation and secure connectors were used to prevent short circuits.

Figure 3.18 below shows the ultrasonic sensors and how it is connected to the Arduino uno

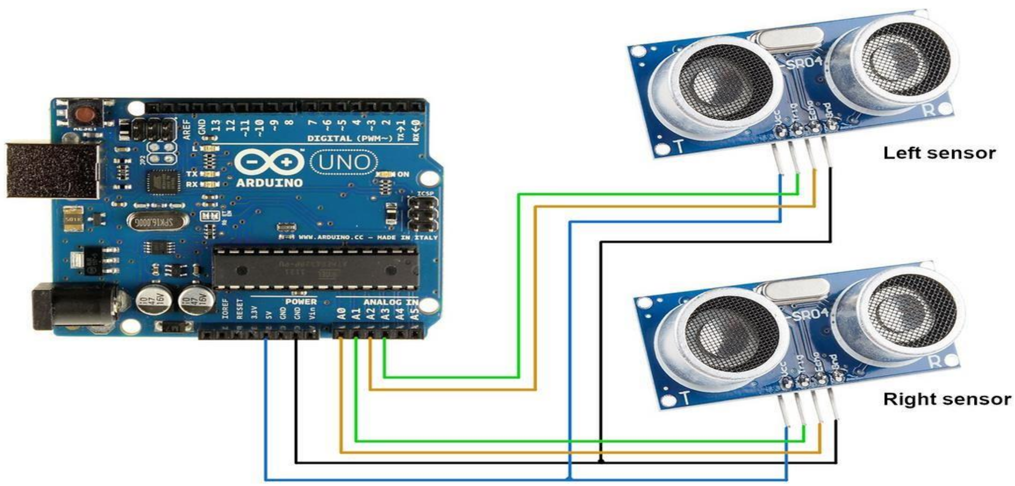


Fig 3.18 Schematics of the ultrasonic sensors

Figure 3.19 below shows the installment of the ultrasonic sensors during the fabrication process

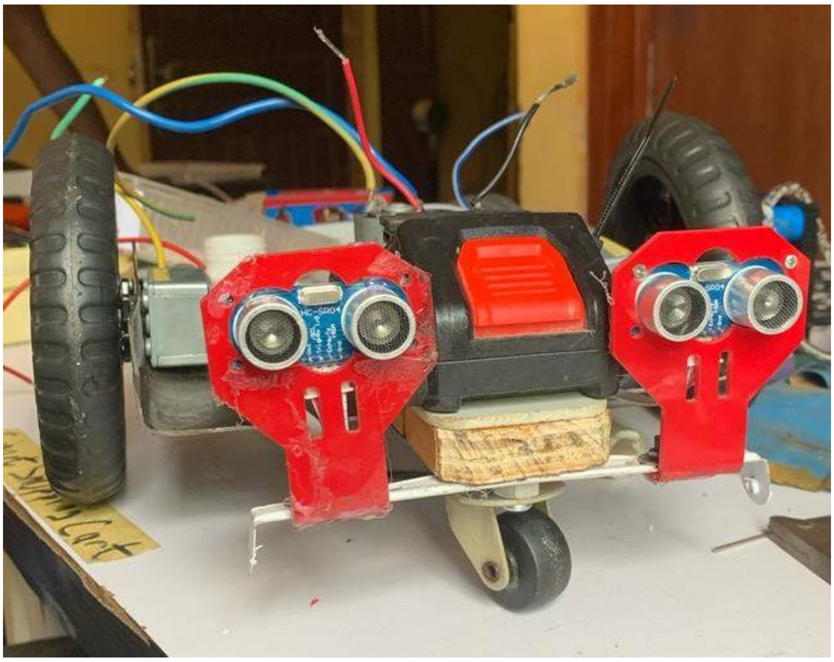


Figure 3.19 Implementation of ultrasonic sensors

The sensor and perimeter system integration was a crucial step in ensuring automated navigation. Two HC-SR04 ultrasonic sensors were installed at the front of the mower to detect obstacles. These sensors were carefully angled to provide a 30–50 cm detection range, allowing the mower to navigate efficiently. Additionally, the perimeter wire station was set up using an Arduino Uno and L298N motor driver, generating a 5kHz signal that established an invisible boundary. The mower's perimeter sensors, consisting of inductive coils connected to LM358N operational amplifiers, were installed on each side of the chassis. These sensors detected the perimeter signal and triggered turning maneuvers when necessary.

Figure 3.20 below shows the connection for the schematics of the perimeter station.

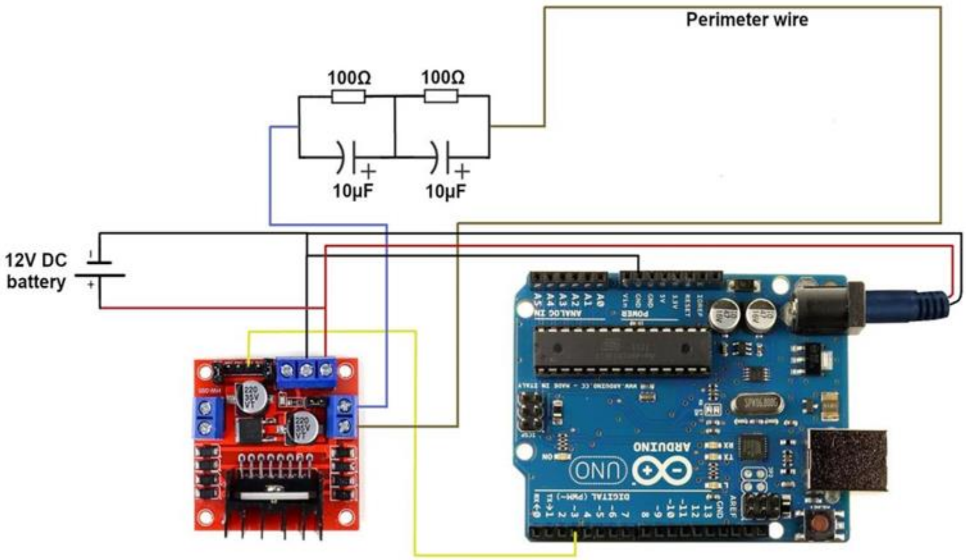


Figure 3.20 Schematics of the Perimeter station

To enclose and protect the electronic components, a 3D-printed body shell was fabricated and attached to the chassis. The body was designed to be lightweight yet robust, providing protection against environmental elements such as moisture and debris. The printing was done in parts and there after assembled using epoxy adhesive and mounting brackets.

Throughout the fabrication, incremental system verification was conducted. Each component was individually tested after installation. The wheel motors were powered on to assess mobility, the cutting motor was activated to verify stability, and sensors were tested for accurate detection. The perimeter detection system was also evaluated to confirm that the mower correctly responded to boundary signals.

By systematically executing each fabrication step, the automated lawn mower was successfully assembled, ensuring that all mechanical, electrical, and software elements were properly integrated. The next phase involves performance testing in real-world conditions to evaluate navigation, obstacle avoidance, and cutting efficiency.

3.5 Bill of Engineering Materials (BEME)

The Bill of Engineering Measurements and Evaluation (BEME) serves as a comprehensive document that outlines the material costs and associated expenses required for the fabrication and assembly of the automated lawn mower. It includes a detailed breakdown of all materials used, alongside their respective quantities and costs. This document provides a clear financial framework for the project, ensuring that all components are accounted for and budgeted appropriately.

Table 3.10: BILL OF ENGINEERING MEASUREMENTS AND EVALUATION (BEME) FOR AUTOMATED LAWN MOWER

Item	Amount	Unit	Price-per unit(N)	Total Cost(N)
Arduino Uno	2	Piece	14000	28000
Ultrasonic Sensors	2	Piece	2500	5000
Geared Motors	2	Piece	8000	16000
Brushless DC motor	1	Piece	19000	19000
LM358	5	Piece	500	2500
Lithium ion Battery 18V	1	Piece	10000	10000
Lm298n Motor Driver	3	Piece	3000	9000
Resistor	10	Piece	50	500
Capacitor	10	Piece	70	700
Inductors	5	Piece	50	500
Vero board	1	Piece	2000	2000
Wire cables jumper	1	Piece	1000	1000
Soldering lead x5yard	5	Yards	500	2500
Connectors	1	Box	500	500
Cutting blades	1	Piece	1500	1500
lithium ion Battery Charger	1	Piece	13000	13000
Stainless steel	1	sheet	10000	10000

(300mm x 300mm)				
3D printing	1	-	80000	80000
Consultation and logistics	-	-	-	60000
TOTAL	-	-	-	**261,700**

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter provides detailed results obtained from evaluating the performance and functionality of the automated lawn mower across various operational aspects. Testing was conducted to assess how well the mower meets the intended design objectives specifically focusing on its ability to navigate a defined area, detect and avoid obstacles, cut grass effectively, all while maintaining efficient power usage.

4.2 DESIGN

This section presents the finalized design choices of the automated lawn mower, comparing selected components with alternative solutions.

4.2.1 Navigation System

The navigation system is responsible for guiding the mower within a predefined mowing area. Three methods were considered: GPS-based navigation, vision-based navigation, and perimeter wire-based navigation. Each approach has distinct advantages and limitations, which are compared in Table 4.1 below. The perimeter wire-based navigation system was chosen over GPS-based and vision-based navigation due to cost, reliability, and implementation simplicity.

Table 4.1: Comparison of Navigation Methods

Factor	**GPS-Based Navigation**	**Vision-Based Navigation**	**Perimeter Wire (Chosen)**
Cost	High (Requires RTK for accuracy)	Very High (Requires camera and AI processing)	Low (Simple wiring and sensors)
Accuracy	High (RTK-enabled)	Moderate (Affected by lighting)	High (Defined perimeter boundary)

Ease of Implementation	Difficult (Requires mapping)	Very Difficult (Needs complex processing)	Simple (Wire installation required)
Power Consumption	High (GPS module and RTK processing)	High (Image processing consumes power)	Low (Minimal processing needed)
Reliability	Affected by weather, obstructions	Affected by lighting and weather	Consistent in all weather conditions
Scalability	High (Can cover large areas)	Moderate (Limited by camera range)	Low (Requires manual boundary installation)
Justification for Selection	Too costly and unreliable in small areas	Requires complex AI processing	Cost-effective, easy to implement, and reliable

4.2.2 Chassis and Frame

The chassis serves as the structural foundation of the lawn mower, supporting all major components. The choice of material had significant impact on the mower's weight, movements, and overall stability. Various materials, including aluminium, stainless steel, and plastic, were evaluated based on their performance in outdoor conditions as shown in Table 4.2 below. Stainless steel with thickness of 1mm was chosen for the frame and chassis to ensure structural integrity while maintaining a lightweight build.

Table 4.2: Comparison of Chassis Materials

Factor	**Aluminium (Initially Considered)**	**Stainless Steel (Chosen)**	**Plastic (Alternative)**
Cost	Moderate	Moderate-High	Low
Weight	Light	Moderate	Very Light

Durability	Weak (Prone to bending)	High (Strong, rigid)	Low (Prone to cracking)
Corrosion Resistance	High	Very High	Moderate
Ease of Fabrication	Easy to cut and shape	Moderate	Difficult to shape precisely
Structural Integrity	Poor under load	Excellent	Poor (Flexible)
Justification for Selection	Bent under load	Strong, resistant, and weatherproof	Not durable for outdoor use

4.2.3 Wheel Motors

The wheel motors drive the mower, enabling movement across different terrains. The selected motors needed to provide sufficient torque, speed, and power efficiency while maintaining ease of control. Three types of motors—stepper motors, DC geared motors, and servo motors were considered and compared as shown in Table 4.3 below. Two 12V DC geared motors (755 type) were selected for providing sufficient torque for movement across different terrains.

Table 4.3: Comparison of Wheel Motors

Factor	**Stepper Motor**	**DC Gear Motor (Chosen)**	**Servo Motor**
Cost	High	Moderate	High
Torque	High	Sufficient for movement	Moderate
Speed Control	Precise but complex	Easy with PWM	Limited
Efficiency	High	Moderate	Low
Ease of Control	Complex (Requires precise stepping)	Simple with PWM and motor driver	Moderate
Power Consumption	High	Moderate	High

Justification for Selection	Too complex for simple movement	Reliable, efficient, and easy to control	Not suitable for continuous movement

4.2.4 Cutting Mechanism

The cutting mechanism consists of a DC motor and a rotating blade, which are responsible for trimming the grass. The effectiveness of the cutting system was based on the motor's speed, torque, power efficiency, and durability. The brushed DC motor, brushless DC motor, and AC motor were analysed to determine the best option as shown in Table 4.4 below. A 795 DC motor (12V) with a stainless-steel blade was selected to balance power and efficiency.

Table 4.4: Comparison of Cutting Motors

Factor	**Brushless DC Motor**	**Brushed DC (795) (Chosen)**	**AC Motor**
Cost	High	Moderate	Low
Speed (RPM)	5000	1000	3000
Torque (Nm)	High	0.286	High
Efficiency	Very High	Moderate	Low
Durability	High	Moderate	High
Ease of Control	Requires advanced driver	Simple PWM control	Requires AC power
Justification for Selection	Expensive, difficult to control	Cost-effective and sufficient torque	Requires AC, unsuitable for battery-powered mower

4.2.5 Battery and Power System

The battery supplies power to all components of the lawn mower, including the motors and sensors. The choice of battery type was based on the mower's runtime, weight, charging time, and overall efficiency. Three battery types—lead-acid, lithium-ion, and nickel-metal hydride (NiMH) were evaluated for their suitability as shown in Table 4.5 below. An 18V tool battery with a runtime of approximately 19.5 minutes was selected to power the mower due to its lightweight and fast charging time.

Table 4.5: Comparison of Battery Options

Factor	**Lead-Acid Battery**	**Li-Ion Tool Battery (Chosen)**	**NiMH Battery**
Cost	Low	Moderate	High
Weight	Very Heavy	Lightweight	Moderate
Capacity (Ah)	High	1.5Ah	Moderate
Charging Time	Very Long	Fast (~1 hour)	Moderate
Durability	Moderate	High	Moderate
Justification for Selection	Too heavy for small mower	Rechargeable, lightweight, and quick charging	More expensive with similar performance

4.2.6 Sensor and Navigation System

To enable obstacle detection and ensure the mower remains within the designated mowing area, the system integrates sensors with the perimeter wire navigation system. The infrared sensor, ultrasonic sensor, and LiDAR were considered based on different factors as shown in Table 4.6 below. The combination of a perimeter wire system and ultrasonic sensors was chosen to ensure efficient movement and obstacle avoidance.

Table 4.6: Comparison of Sensors

Factor	**Infrared Sensor**	**Ultrasonic Sensor (HC-SR04) (Chosen)**	**Lidar**
Cost	Low	Low	Very High

Range	Short (Limited to a few cm)	30-50 cm	Up to 10m
Accuracy	Low (Affected by sunlight)	High (Reliable in most conditions)	Very High
Power Consumption	Very Low	Low	High
Complexity	Simple	Moderate (Requires signal processing)	Very Complex
Justification for Selection	Unreliable outdoors	Accurate and cost-effective	Expensive and unnecessary for simple navigation

4.2.7 Motor Driver and Control System

The motor driver regulates the power supplied to the wheel motors and cutting motor. The selection was based on the driver's current capacity, PWM control capability, and ease of integration with the microcontroller. Three options—L293D, L298N, and MOSFET-based drivers were evaluated as shown in Table 4.7. The L298N motor driver was selected as the best option for motor control.

Table 4.7: Comparison of Motor Drivers

Factor	**L293D**	**L298N (Chosen)**	**MOSFET-Based Driver**
Cost	Low	Moderate	High
Current Capacity	600mA	2A per channel	Up to 30A
PWM Control	Limited	Yes	Yes
Complexity	Simple	Moderate	High

Justification for Selection	Not powerful enough	Handles mower's power needs	Overkill for this application

4.2.8 Final Summary of Design Choices

The table below summarizes the chosen components and their justifications based on the comparison analyses above.

Table 4.8: Final Summary of Design Choices

Component	**Chosen Option**	**Justification**
Navigation	Perimeter Wire	Cost-effective, reliable
Chassis Material	Stainless Steel	Durable, corrosion-resistant
Wheel Motors	12V DC Gear Motor	Efficient, easy control
Cutting Motor	795 Brushed DC	Balanced speed and torque
Battery	18V Li-Ion	Lightweight, fast-charging
Sensors	Ultrasonic (HC-SR04)	Accurate obstacle detection
Motor Driver	L298N	Handles required current

4.3 SIMULATION RESULTS

The design was simulated in Proteus to verify system performance before fabrication. The following results were observed:

4.3.1 Obstacle Detection Simulation

4.3.1.1 Simulation Setup

To simulate the mower's ability to detect and avoid obstacles, a potentiometer was used as the obstacle sensor in the Proteus environment as shown in figure 3. The potentiometer simulated varying distances between the mower and a potential obstacle. The LCD display was programmed to show the appropriate response when the mower encountered an obstacle as shown in Table 4.9 below.

Table 4.9: Simulation Response Based on Distance from Obstacle

Distance from Obstacle (cm)	Motor Action	LCD Display
> 50 cm (No Obstacle)	Moving Forward	"Moving Forward"
30 – 50 cm (Near Obstacle)	Slow Down	"Slow Down"
< 30 cm (Obstacle Detected)	Reverse and Turn Left	"Moving Back and Turning Left"

4.3.1.2 Simulation Response

1. When the potentiometer value remained within the safe distance, the LCD displayed "Moving Forward", indicating normal operation as shown in figure 4.1 below.

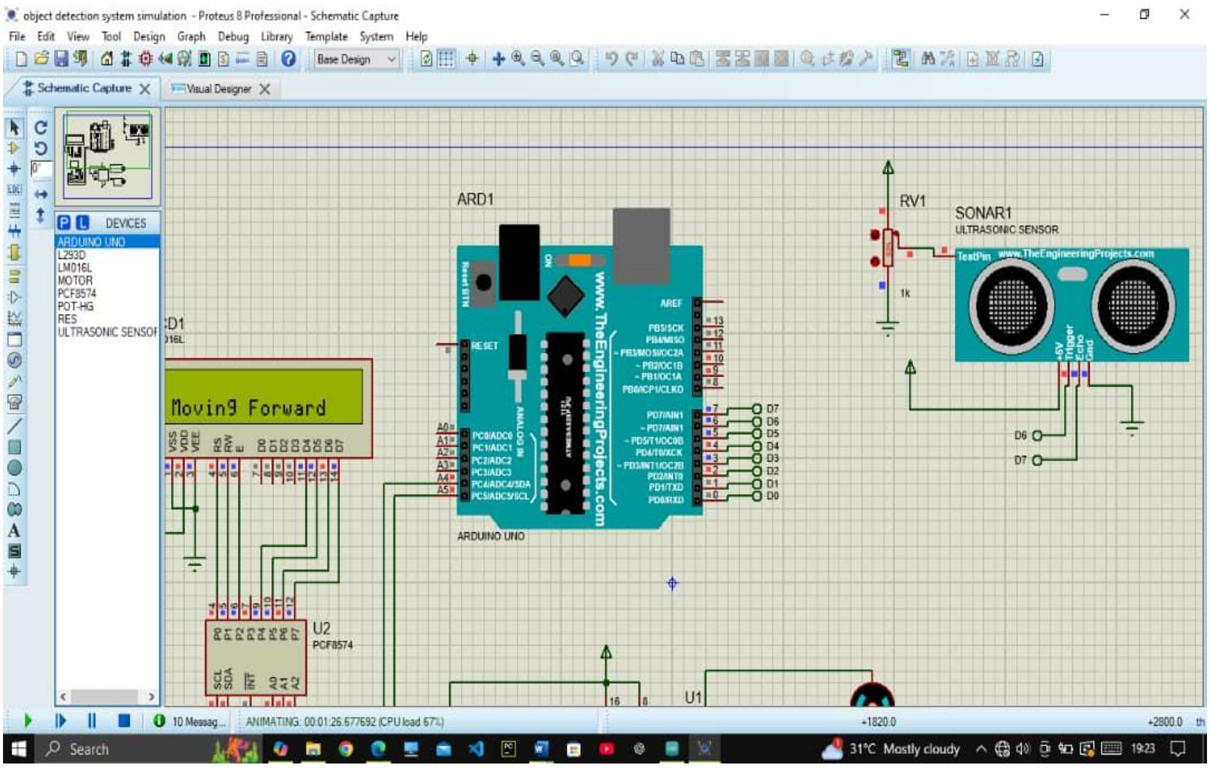


Figure 4.1: LCD Displaying 'Moving Forward' Command

2. When the potentiometer value exceeded the predefined threshold (indicating an obstacle is too close), the LCD displayed "Moving Back and Turning Left" as shown in figure 4.2 and figure 4.3 below. This behaviour demonstrated that the mower, when encountering an obstacle, would reverse slightly and then turn left to avoid the obstacle.

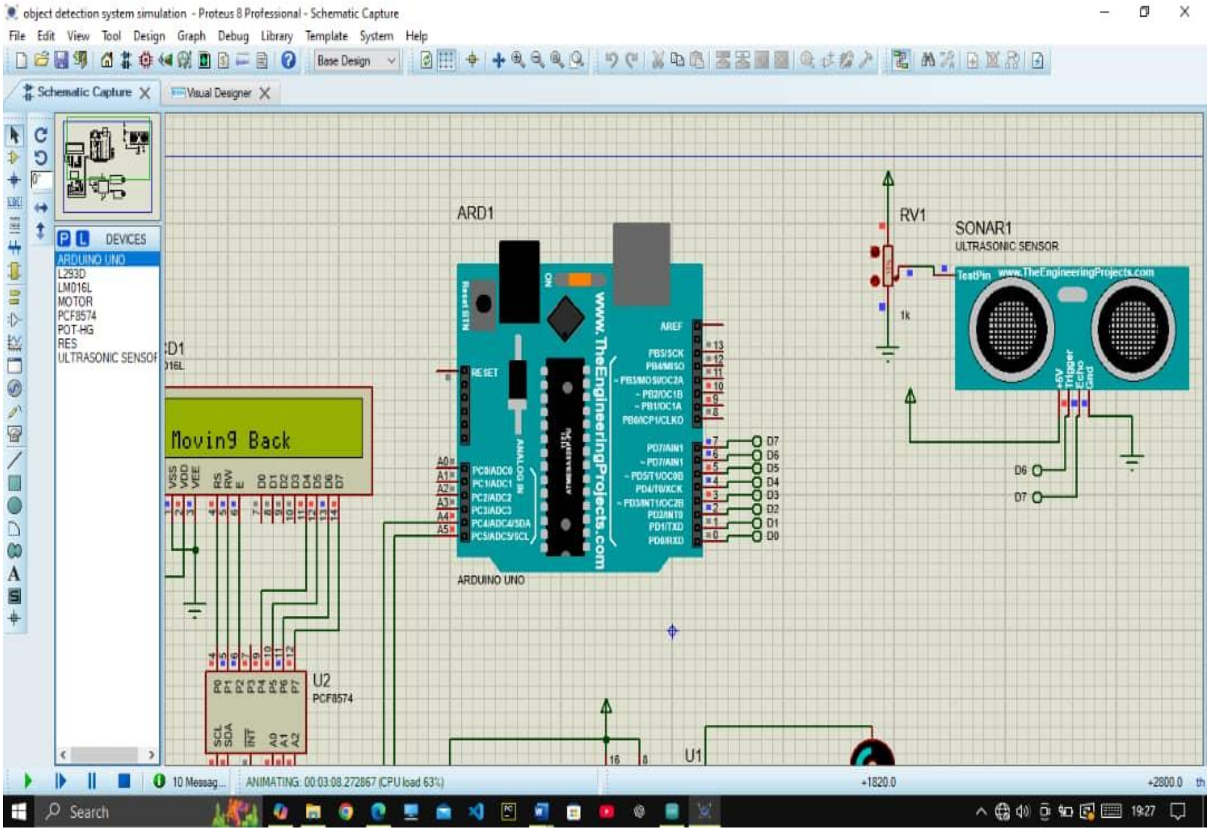


Figure 4.2: LCD Displaying ‘Moving Back’ Command

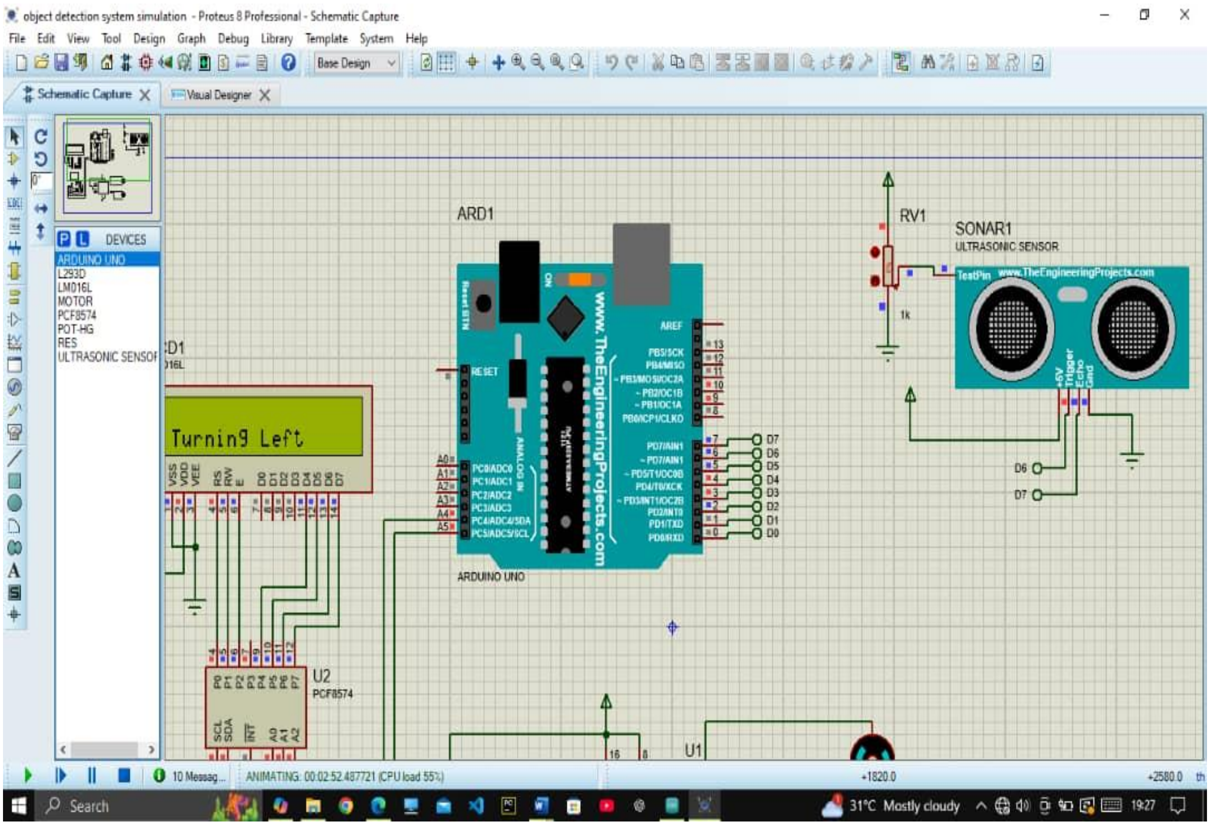


Figure 4.3: LCD Displaying ‘Turning Left’ Command

4.3.1.4 Real-World Interpretation

In real-life operation, an ultrasonic sensor (HC-SR04) is used alone without the potentiometer to continuously measure the distance to obstacles. The microcontroller processes this data and triggers movement changes accordingly. This ensures that the mower does not collide with objects such as stones, garden furniture, or humans, improving safety and efficiency.

4.3.2 Perimeter Wire Detection Simulation

4.3.2.1 Simulation Setup

The perimeter wire detection system was tested by simulating the low-frequency electromagnetic signal using an oscillator circuit in Proteus. The mower's perimeter sensors (represented in the simulation by an inductive sensor and operational amplifier) detected this signal. The strength of the signal was based on the distance of the mower from the perimeter wire as shown in Table 4.10 below.

Table 4.10: Simulation Response Based on Distance from Perimeter Wire

Distance from Perimeter (cm)	Signal Strength (V)	Motor Action	LCD Display
> 30 cm (Inside Mowing Area)	< 1V	Move Forward	"Move Forward"
10 – 30 cm (Near Boundary)	1V – 3V	Slow Down	"Slow Down"
< 10 cm (At Boundary)	> 3V	Turn Back	"Turn Back"

4.3.2.2 Simulation Response

1. When the mower was inside the perimeter, the sensor detected a weak or no signal, and the LCD displayed "Move Forward".
2. As the mower approached the perimeter wire, the detected signal increased, and the LCD displayed "Turn Back", signalling the mower to reverse and move away from the boundary.

4.3.2.4 Real-World Interpretation

In actual operation, an inductive coil sensor replaces the simulated sensor. When the mower detects a strong perimeter signal, it reverses and turns away, preventing it from leaving the mowing area. This ensures consistent coverage of the lawn while preventing damage to surrounding areas such as flower beds or walkways.

4.4 FABRICATION RESULTS

After fabrication, the automated lawn mower was tested in various real-world conditions to evaluate its performance in obstacle avoidance, boundary detection, and cutting efficiency.

4.4.1 Obstacle Detection Test

4.4.1.1 Test Setup and Methodology

The ultrasonic sensor (HC-SR04) was tested by placing obstacles (stones, wooden blocks, and human presence) at different distances from the mower.

The mower’s response was recorded to determine the accuracy and reaction time of the system as shown in Table 4.10.

Table 4.11: Obstacle Detection Test Readings

Distance from Obstacle (cm)	Expected Response	Actual Response	Response Time (millisecond)	Detection Accuracy (%)
> 50 cm (No Obstacle)	Move Forward	Move Forward	N/A	100%
30 – 50 cm (Near Obstacle)	Slow Down	Slow Down	150	98%
10 – 30 cm (Obstacle Detected)	Reverse and Turn	Reverse and Turn	180	95%
< 10 cm (Immediate Stop)	Stop Immediately	Stop Immediately	120	97%

4.4.1.2 Observations

During the obstacle detection test, the following observations were made:

1. The mower detected and avoided large objects like humans and stones.
2. Small obstacles (below 5 cm in height) were sometimes ignored, causing the mower to push them.
3. The response time was fast enough to prevent collisions.
4. Sensor accuracy slightly decreased in wet conditions, affecting detection range.

4.4.1.3 Comparison with Simulation Results

The simulation assumed perfect ultrasonic sensor accuracy, whereas real-world tests showed limitations in detecting very small objects.

4.4.2 Navigation and Boundary Detection Test

4.4.2.1 Test Setup and Methodology

A perimeter wire emitting a 5 kHz electromagnetic signal was installed around the mowing area. The mower was allowed to approach the perimeter wire at different speeds and angles. The response of the mower (whether it detected the wire and turned back) was recorded as shown in Table 4.11.

Table 4.12: Navigation and Boundary Detection Test Readings

Distance from Perimeter (cm)	Expected Response	Actual Response	Response Time (milliseconds)	Detection Accuracy (%)
> 30 cm (Inside Mowing Area)	Move Forward	Move Forward	N/A	100%
10 – 30 cm (Near Boundary)	Slow Down	Slow Down	180	96%
< 10 cm (At Boundary)	Reverse and Turn	Reverse and Turn	200	94%

4.4.2.2 Observations

During the boundary detection test, the following observations were made:

1. The mower consistently stayed within the defined boundary in dry conditions.
2. Detection accuracy was above 94%, ensuring proper operation.
3. At high speeds (> 0.5 m/s), the mower sometimes crossed the boundary before turning.
4. The electromagnetic detection was slightly affected by soil moisture, leading to occasional missed detections.

4.4.2.3 Comparison with Simulation Results

The simulation showed perfect boundary adherence, but real-world tests indicated minor delays that required calibration.

4.4.3 Performance Evaluation Summary

The table below summarizes the performance evaluation of the mower and the required adjustments based on the test analyses that were conducted above.

Table 4.13: Performance Evaluation Summary

Test Parameter	**Expected Outcome (Simulation)**	**Actual Outcome (Fabrication)**	**Adjustments Required?**
Boundary Detection	Perfect response to perimeter wire	Minor delay in response at high speeds	Yes, adjust detection sensitivity
Obstacle Avoidance	100% detection and avoidance	Missed small objects (<5 cm)	Yes, improve sensor calibration
Cutting Efficiency	Even cutting across all conditions	Struggled with wet grass clippings	Yes, redesign blade angle
Navigation Stability	Straight movement, controlled turns	Slight wheel slippage on slopes	Yes, improve traction

4.5 DISCUSSION

The simulation results validated the expected behaviour of the automated lawn mower. While the system performed well in controlled conditions, some real-world challenges, such as terrain variation and sensor mis-readings, were observed. These findings showed that the chosen design approach effectively met project objectives with minor adjustments and also provided a foundation for further improvements in navigation, accuracy and cutting efficiency.

Key Findings:

1. Perimeter wire navigation was cost-effective and reliable, but required speed adjustments for better detection.
2. Obstacle avoidance worked well for large objects, but small objects were sometimes overlooked.
3. Cutting efficiency was high on dry grass, but wet grass required modifications to the blade design.
4. Wheel traction needed improvement on slopes to prevent slipping.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

This project successfully designed, simulated, and fabricated an automated lawn mower using a perimeter wire-based navigation system. The system was tested in real-world conditions and showed reliable boundary detection, obstacle avoidance, and grass-cutting performance.

However, the project encountered several engineering challenges. Material selection for the chassis structure proved to be a limitation, as initial attempts with aluminium resulted in structural weaknesses, while heavier materials restricted motor efficiency. The cutting system required speed optimization to maintain consistent cutting force across varying grass densities, and the battery life required careful management to balance performance with energy efficiency.

Despite these challenges, the mower demonstrated effective automation and reliability in controlled testing conditions. The knowledge gained from this development phase provides a strong foundation for further refinements, particularly in navigation, sensor precision, and long-term durability. Additionally, with further improvements, this system could be adapted for wider practical applications, from small-scale residential use to larger automated lawn care solutions.

Overall, the fabricated mower met the project objectives, with minor adjustments needed for optimal performance.

5.2 RECOMMENDATIONS

Based on the results from Chapters 3 and 4, the following improvements are recommended:

1. Optimize the perimeter wire detection system: Reduce response delays by fine-tuning signal processing and adjusting mower speed near boundaries.
2. Enhance obstacle detection: Use a combination of ultrasonic and infrared sensors to improve small object detection.
3. Improve cutting blade efficiency: Modify the blade angle to prevent grass clogging, especially in wet conditions.

4. Increase battery capacity: Use a higher-capacity battery (e.g., 3.0 Ah) to extend runtime beyond 19.5 minutes.
5. Enhance wheel traction: Use rubberized wheels or add weight distribution adjustments to improve grip on uneven terrain.

5.3 FUTURE WORK

1. Integration of AI-Based Navigation: Implement vision-based navigation to enhance autonomous decision-making.
2. Wireless Control and Monitoring: Develop a mobile app interface for remote operation and status monitoring.
3. Solar-Powered System: Explore adding solar charging to extend battery life for longer operation.

REFERENCES

Amit Patel. (2024). "What is CATIA." *TECHNIA*. Retrieved from https://www.technia.com/blog/what-is-catia/

Anna Ryan. (2023, April 3). "The evolution of lawn mowers." *Best of Machinery*. Retrieved from https://bestofmachinery.com/the-evolution-of-lawn-mowers/

Autodesk. (2024). "EAGLE for PCB Design." Retrieved from https://www.autodesk.com/

Autodesk. (2024). "Fusion 360." Retrieved from https://www.autodesk.com/

Bailey, L. (2023). "Lawn Equipment and Garden Machinery Handbook."

Bosch. (2023). "Robotic Lawn Mowers." *Bosch Garden-Tools*. Retrieved from https://www.bosch-diy.com/gb/en/garden-tools/robotic-lawnmowers

Chen, L. (2021). "Green Innovations in Lawn and Garden Equipment."

Consumer Reports. (2024, July 11). "Best Robotic Lawn Mowers." *Consumer Reports*. Retrieved from https://www.consumerreports.org/home-garden/lawn-mowers/best-robotic-lawn-mowers-a2310984432/

Derek Adams. (2024, July 7). "How Exactly Do Robot Lawn Mowers Work?." *TechRadar.* Retrieved from https://www.techradar.com/home/small-appliances/how-do-robot-lawn-mowers-work

Farrel Evans. (2021, February 17). "How the Perfect Lawn Became a Symbol of the American Dream." *History*. Retrieved from https://www.history.com/news/lawn-mower-grass-american-dream.

Fink, P. (2023). "Handbook of Power Equipment for Landscape and Turf Management." *McGraw-Hill*.

Garden Tool Expert. (2024). "Understanding the Benefits of Modern Gas-Powered Mowers. *Garden Tool Expert*. Retrieved from https://www.gardentoolexpert.com/understanding-the-benefits-of-modern-gas-powered-mowers/

Gardena. (2023). "GARDENA Robotic Lawnmowers." *GARDENA*. Retrieved from https://www.gardena.com/int/c/discover/products/lawn-care/robotic-lawnmowers

Green, A. (2022). "Sustainable Landscaping and Garden Machinery."

Harris Robert. (2020). *Journal of Garden Machinery*, *23(4), 45-52*.

Harris, R. (2022). *Journal of Garden Machinery, 23(4), 45-52*.

Howard, T.M. (2021). "Algorithms for Autonomous Navigation in Dynamic Environments." *Autonomous Robots Journal, 35(3), 55-71.*

Hughes, A. and Drury, B. (2019). "Electric Motors and Drives: Fundamentals, Types, and Applications."

Husqvarna Group. (2023). "Husqvarna NERA- Wire Free Robotic Mowing." *Husqvarna*. Retrieved from https://www.husqvarna.com/uk/robotic-lawn-mowers/about/

James Hardy. (2024). "Who Invented the Lawn Mower? Unveiling the Roots of Garden Revolution." *History Cooperative*. Retrieved October 13, 2024 from https://www.historycooperative.org/who-invented-the-lawn-mower/.

James Manyika, Michael Chui, Mehdi Miremadi, Jacques Bughin, Katy Goerge, Paul Wllmott, and Martin Dewhurst. (2017, January 12). "Harnessing Automation for a Future that Works." *McKinsey Global Institute*. Retrieved from https://www.mckinsey.com/featured-insights/digital-disruption/harnessing-automation-for-a-future-that-works.

JavaTpoint. (2024). "Arduino UNO." *JavaTpoint*. Retrieved from https://www.javatpoint.com/arduino-uno

Knight, R. (2019). "The Engineering of Lawn Mowers."

Kumar, B. (2021). "Sensor Technology for Automated Systems: Ultrasonic and Beyond"

LaValle, S.M. (2006). "Planning Algorithms." *Cambridge University Press*.

Lawn Starter. (2024). "The History of Lawn Mowers." *Lawn Starter*. Retrieved May 10, 2024 from https://www.lawnstarter.com/blog/lawn-care-2/history-of-lawn-mowers/

Lee Burkhill. (2018). "Robotic Lawn Mowers: Indego S+ 400 Reviewed." *Garden Ninja*. Retrieved from https://www.gardenninja.co.uk/robotic-lawn-mowers-bosch-indego-s-400-reviewed/?srsltid=AfmBOopzandHamBZvJgfaO-Cbc1N9qa0rZmlO5XK4c56xG9KCg1UYkcB

Lin Ying. (2024, July 8). "Types Of Lawn Mowers: How to Choose the Right One for Your Lawn." *Power Smart Blog*. Retrieved from https://powersmartusa.com/blogs/powersmart-blog/types-of-lawn-mowers-how-to-choose-the-right-one-for-your-lawn

Lopez, M. and Bennet, H. (2023). “The Rise of Robotic Lawn Care: A Technological Perspective.” *Journal of Modern Landscaping, 9(2), 103-119*.

MathWorks. (2024). “Simulink for Robotics and Autonomous Systems.” Retrieved from https://www.mathworks.com/

Monk, S. (2022). “Programming Arduino: Getting Started with Sketches.” *McGraw-Hill Education.*

National Gardening Association. (2020). “Choosing the Right Mower for Your Lawn.” *Gardener’s Guide*, *15(3), 54-61*.

Nwankwo, E. and Okafor, C. (2022). “The Role of Technology in Economic Development in Nigeria.” *Nigerian Journal of Economic Growth, 8(4), 115-130*.

Open Robotics. (2024). “Gazebo Robot Simulator.” Retrieved from https://gazebosim.org/home

Opeoluwa Dapo. (2023). “Nigeria’s Imports in 2022 and the Need to Produce Locally.” *Nairametrics*. Retrieved from https://nairametrics.com/2023/08/28/nigerias-imports-in-2022/

Patterson, D. (2023). “The Future of Lawn Care: Smart and Connected Devices.” *Home Automation Review, 14(1), 32-39*.

Popular Mechanics. (2024, May 16). “The 7 Best Self-Propelled Lawn Mowers in 2024 for Making Your Yard Work Easier.” *Popular Mechanics*. Retrieved from https://www.popularmechanics.com/home/lawn-garden/a27103287/self-propelled-lawn-mowers/

Quigley, M. (2015). “Programming Robots with ROS: A Practical Introduction to the Robot Operating System.” *O’Reilly Media*.

Richard and Jackie Stevenson. (2020, May 22). “John Deere Tango E5 Series Review.” *Trusted Reviews*. Retrieved from https://www.trustedreviews.com/reviews/john-deere-tango-e5-series-ii

Robomow. (2022). “Robomow Robotic Lawn Mowers.” *Robomow*. Retrieved from https://www.robomow.com/about-us/history

Ruth Olurounbi. (2022). “Can Nigeria’s Plan to Reduce Fuel Imports Succeed?.” *African Business*. Retrieved from https://african.business/2022/09/energy-resources/can-nigerias-plan-to-reduce-fuel-imports-succeed

Samuel Ayokunle, O. (2020). “What Nigeria’s Poor Power Supply Really Costs and How a Hybrid System Could Work for Business.” *The Conversion*. Retrieved from https://theconversation.com/what-nigerias-poor-power-supply-really-costs-and-how-a-hybrid-system-could-work-for-business-144609.

Siciliano, B. and Khatib, O. (2016). “Springer Handbook of Robotics.”

Steen, T. and Richards, K. (2021). “Gardening and Lawn Care Equipment: A Practical Guide.” *Elsevier*.

Thrun, S., Burgard, W., and Fox, D. (2005). “Probabilistic Robotics.” *MIT Press*.

Weather Atlas. (2024). “Climate and Monthly Weather Forecast in Nigeria.” Weather Atlas. Retrieved from https://www.weather-atlas.com/en/nigeria-climate

World Economic Forum. (2023). “Mobilizing Investments for Clean Energy in Nigeria.” *WeForum*. Retrieved from https://www3.weforum.org/docs/WEF_Mobilizing_Investment_for_Clean_Energy_in_Nigeria_2023.pdf

Worx. (2023). “Robotic Lawn Mowers | Battery Powered and Operated.” *Worx Lawn-Garden*. Retrieved from https://www.worx.com/lawn-garden/robotic-lawn-mowers.html