DEVELOPMENT OF A MULTIPURPOSE AGRICULTURAL ROBOT

by

ABDUL RAHMAN A. KALLOKOH (200021157)
ALASSANE TRAORE (200021160)
MAZIN AHMED IBRAHIM (200021155)

A Thesis Submitted to the Academic Faculty in Partial Fulfillment of the Requirements for the Degree of

BACHELOR OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING

Department of Electrical and Electronic Engineering
Islamic University of Technology (IUT)
Gazipur, Bangladesh

OCTOBER 2025

CERTIFICATE OF APPROVAL

This is to confirm that the thesis titled **Development of a Multipurpose Agricultural Robot**, presented to the **Islamic University of Technology (IUT)** by **Abdul Rahman A. Kallokoh (200021157), Alassane Traore (200021160), and Mazin Ahmed Ibrahim Ahmed (200021155)** passed the scrutiny and was approved as meeting the partial requirements to award the Bachelor of Science degree in **Electrical and Electronic Engineering in the Islamic University of Technology (IUT)**.

.

Approved by:

Dr. Nafiz Imtiaz Bin Hamid

Supervisor and Professor,
Department of Electrical and Electronic Engineering,
Islamic University of Technology (IUT), Board Bazar,
Gazipur-1704.

Date: …………………………………………….

DECLARATION OF CANDIDATES

This is to state that the thesis, 'Development of a Multipurpose Agricultural Robot,' was completed under the supervision of Dr. Nafiz Imtiaz Bin Hamid and submitted to the **Department of Electrical and Electronic Engineering at the Islamic University of Technology (IUT)**. The work, as a complete or partial work, has not been previously entered to be assessed towards the awarding of a different degree, diploma, or academic qualification.

Signature of the Candidates

Abdul Rahman A. Kallokoh.

200021157

…………………………………………

Alassane Traore.

200021160

………………………………………….

Mazin Ahmed Ibrahim Ahmed.

200021155

………………………………………..

ACKNOWLEDGEMENT

We would like to take this opportunity to profusely acknowledge the assistance of our supervisor, Dr. Nafiz Imtiaz Bin Hamid, who has been instrumental in this research and provided the necessary guidance throughout the entire research period. His guidance has been critical to improving our knowledge on the topic of agricultural robotics and integrating IOT technology .We also owe a lot of credit to our **parents** whose support and encouragement has been a strong tool all along the way.

Moreover, we also recognize the efforts and support of all the people who helped and gave advice in the process of completing this project. We would also wish to extend our utmost gratitude to the Department of Electrical and Electronic Engineering at the Islamic University of Technology (IUT) which allowed us to access the necessary resources and laboratory equipment that made it possible to conduct this research successfully.

Abstract

More than 60% of the population in Africa depends on agriculture as the main source of livelihood and the agricultural sector has continued to be critical in supporting the economies of the continent. Although it is important, smallholder farmers continue to experience certain challenges since they include shortage of labor, poor use of agricultural resources, and exposure to modern mechanization. These challenges are also compounded by the effects of climate change and the growing migration of youthful manpower to cities. This paper presents the design of an all-purpose farming robot to support the interests of the smallholder farmers in Africa. The suggested design will combine three fundamental agricultural functions into one cheap robotic platform: precision grass trimming with brushless DC motors, automated seed dispensing with servo mechanisms, and intelligent irrigation control with real-time soil moisture detection. The robot is controlled by a four-wheel-drive base with high-torque motors, which will enable it to handle the rough and uneven land that is characteristic of African farmlands. ESP32 microcontroller is used as the control station of a system that will be connected to the Blynk IOT platform to control and monitor wirelessly. Temperature and humidity are measured with the DHT11 sensors, and the water content of the soil is measured with capacitive moisture sensors. An inbuilt camera module will enable farmers to monitor the state of the field remotely with a smart phone interface. Economic analysis indicates that the proposed system will possibly reduce the operational costs by about 40-60 percent as compared to buying and servicing of individual agricultural machines to do each job. Future developments can incorporate the use of solar energy to be sustainable, artificial intelligence to allow autonomous capability, and high-end sensors to be used to control precision agriculture. In general, this study will offer a practical and scalable solution to modernizing small-scale agriculture in developing world setting through offering an inexpensive robotic system that is uniquely tailored to an African farming setting.

Table of Contents

Acknowledgements iii
Abstract iv
Table of contents v
List of tables……………………………………………………………….viii
List of Figures ix
List of Acronyms x

CHAPTER 1:……………………………………………………………………12

INRODUCTION………………………………………………………………12

1.1 Different Aspects of Modern Agriculture …………………………….................... 14

1.2 Background and Motivation…………..16

CHAPTER 2:....………………………………………………………………18

SYSTEM OVERVIEW AND METHOLOGY 18

2.1 Literature Review of Agricultural Robots ………………………….......................... 19

2.2 Component Selection and Justification 21

2.3 Microcontroller selection…... 22

2.3.1 Motor System Components…………………….. 23

2.3.2 Agricultural Function Components……... 25

2.3.3 Sensor System Components……..….. 27

2.3.4 Power system Design……………….. 28

2.3.5 Economic Consideration…………….. 29

2.4 Design and Impementation…………….. 30

2.4.1 System Architecture……………......….. 30

2.4.2 Mechanical Design Implementation……... 32

2.4.3 Electronic System Integration……….. 33

2.4.4 Software Architecture Development ….. 33

2.4.5 IOT Integration Framework…….. 35

2.4.6 Testing and Validation procedures……... 35

2.5 Microcontroller Programming and Control logic...38

2.5.1 Development Environment and programming framework…....................................... 38

2.5.2 Control System Architecture……..……... 39

2.5.3 Implementation and Motor control……... 40

2.5.4 Agricultural Function Control logic….. 40

2.5.5 Sensor Data processing………..……... 41

2.5.6 Remote control and IOT communication.……... 41

2.5.7 Safety and Error handling………..……... 42

2.6 Economic Feasibility and Cost analysis …………..……..43

2.6.1 Component Cost Break down……………………………………………………….....43

2.6.2 Accessibility strategies and Financing………………...………………………………....44

2.6.3 Long-term Economic impact……………………………………………………………..45

CHAPTER 3:…………………………………………………………………………….46

IMPLEMENTATION………………………………. 46

3.1 Result and Advanced implementation 46

3.2 Design and Mechanical system …………………………………..................................... 46

3.2.1 Chassis Construction and Assembly…… 46

3.2.2 System implementation and locomotion…… 47

3.3 Agricultural Implementation and integration... 48

3.3.1 Seed Sowing Mechanism Design……………………………………………………49

3.3.2 Mechanical Design and Irrigation System……………………………………….49

3.4 Circuit integration Electronic……………………………………………………….50

3.4.1 Board design and Main Control…………………………………………………..50

3.4.2 Circuit Implementation Motor control……………………………………………51

3.4.3 Interface Circuit Sensor…………………………………………………………...51

3.5 Communication System Implementation………………………………………...52

3.6 Circuit Design and Power management…………………………………………….52

3.7 IOT Platform Development…………………………………………………………52

3.7.1 Dashboard Design and User Experience…………………………………………53

3.7.2 Data logging and Analytics……………………………………………………….53

3.7.3 Remote monitoring and Control Implementation………………………………...54

3.8 Field Testing and Performance Evaluation…………………………………………55

3.8.1 Grass-cutting performance Analysis……………………………………………...55

3.8.2 Seed Sowing System Validation…………………………………………………..56

3.8.3 Irrigation System Performance Testing…………………………………………..56

3.9 Integration System Performance Analysis…………………………………………58

3.10 Future Enhancement Strategies……………………………………………………59

3.10.1 Solar Power Integration Planning……………………………………………….59

3.10.2 Artificial Intelligence Integration Framework…………………………………60

3.10.3 Advanced Sensor Network Development……………………………………….61

CHAPTER 4: …………………………………………………………………………63

Conclusion and future work…………………………………………………………….63

CHAPTER 5:……………………………………………………………………………65

DEMONSTARTION OF OUTCOME BASED EDUCATON (OBE)……………….65

5.1 Introduction 65

5.2 Course Outcomes (COs) Addressed 66

5.3 Aspects of Program Outcomes (POs) Addressed 67

5.4 Knowledge Profiles (K3-K8) Addressed 69

5.5 Use of Complex Engineering Problems 70

5.6 Socio-Cultural, Environmental, and Ethical Impact 72

5.7 Attributes of Complex Engineering Problem Solving (P1-P7) 73

5.8 Attributes of Complex Engineering Activities (A1-A5) 74

REFERENCES…………………………………………………………………75

List of Tables

Table 1: Comparison of Existing Agricultural Robots 20

Table 2: Component Specifications and Functions 22

Table 3: Power Consumption Analysis 32

Table 4: Cost Estimation Breakdown 44

Table 5: Performance Testing Results 57

Table 6: Course implementation outcomes 66

List of Figures

Figure 1: Basic picture of Agricultural Robots.. 13

Figure 2: ESP32 pinout diagram..23

Figure 3: 37GB DC motor pic...24

Figure 4: Motor driver pinout 24

Figure 5: Brushless motor..25

Figure 6: Motor with blade attached...25

Figure 7: Motor with blade attached...26

Figure 8: 5v water pump...26

Figure 9: Temperature and humidity sensor..27

Figure 10: Capacitive soil moisture sensor...28

Figure 11: ESP-32 cam pinout diagram...28

Figure 12: : Lipo battery 12V...29

Figure 13: Circuit diagram of the prototype..31

Figure 14: Template picture of the system on blynk IoT...34

Figure 15: Toggle OV2640..36

Figure 16: ESP 32 cam testing..36

Figure 17: First RC car prototype...37

Figure 18: Latest prototype picture above..38

Figure 19: Flowchart of the project..39

Figure 20: Mobile app template for controlling the robot...42

Figure 21: Design Hardware prototype...47

Figure 22: Representation of seed sowing mechanism..49

Figure 23: Solar tracker image...60

List of Acronyms

AI	Artificial Intelligence
BDT	Bangladeshi Taka
DC	Direct Current
DHT	Digital Humidity Temperature
ESC	Electronic Speed Controller
ESP32	Espressif Systems 32-bit Microcontroller
GPIO	General Purpose Input/Output
IOT	Internet of Things
LDR	Light Dependent Resistor
PWM	Pulse Width Modulation
RC	Radio Controlled

CHAPTER 1

INTRODUCTION

Farming in Africa is at a decisive junction wherein the agricultural practices need to be modified to accommodate the rising food security needs in the continent as it also needs to adapt to the realities of climate change and the soaring population rates. Smallholders form majority of African farmers who produce food in most parts of the continent but they have been experiencing consistent challenges including scarcity of labor force, inefficiency in resource exploitation and inaccessibility to modern technology [1]. These issues are also worsened as the young generations travel to cities with a rural population of an ageing population that is left to carry out laborious agricultural work. To create the effective technologies, which would really work in the African environment, it is crucial to identify the particular limitations and prospects of the African agricultural systems. Smallholder farms are mostly quite small, of mixed cropping, low in mechanization and low in profitability - the polar opposite of immensely industrialized commercial farms elsewhere [2].

These attributes demand innovations that are focused on affordability, simplicity, flexibility, and not necessarily on pure performance. These farming systems have already been strained by climate change, which has impacted on rainfall patterns, the soil available to grow crops and frequency of drought and floods. Small-scale farmers who are mostly dependent on rain-fed farming are unable to recuperate against such shocks. Additionally, the ineffective infrastructure, lack of access to markets and lack of value chains limit the efficiency of new agricultural technologies. The African farms are usually fragmented and diverse in their production systems unlike in large commercial farms in the developed countries [3]. The level of mechanization is minimal, the productivity is also poor and inputs like fertilizers, pesticides and irrigation tools are either costly or unavailable. Therefore, there is increased potential of using cost effective, flexible, and simple technologies that are aimed at African farmers.

However, Africa has a huge potential, a huge land, young and growing population of educated individuals, and a growing network of mobile and digital. Use of these assets to develop context-specific technologies, including low-cost multipurpose robots, climate-destructive farming systems, and data-driven advice devices can be disruptive. Such innovations may deal with the issue of food insecurity, rural economy, and resilience to climate [4].

Figure 1: Basic picture of Agricultural Robots

African agricultural robots need to be inexpensive and accessible to small farmers. Although classical agricultural robots are focused on the large commercial farms, African smallholders are in need of such solutions that would be cost-effective and multi-purpose. Single-purpose machines though at times more effective, are usually prohibitive to farmers in constrained financial situations. The robotic technology is cost effective for smaller operations when it is built into a combination of various farm activities.

The robots should be used in simple field preparation and maintenance to limit the number of man-hours worked. The importance is especially on weed management and grass cutting, which requires a lot of labor in the important growing seasons. Good grass management enhances the state of the field saving time and labor.

Accurate seed placement solves the general issues found in planting. The process of hand planting has a tendency of giving uneven spacing, whereas automated system has the chance of giving optimal seed distribution. This enhances the rates of germination and utilizes expensive seeds better particularly hybrid or specialty crops. Automated irrigation systems can help in conserving the available little water in Africa. Responsive irrigation, which is activated by detection of soil moisture will help us to use the correct amount of water and also the labor of manual watering will be minimized. This is more crucial with the increasing water shortage in the continent [5].

Environmental monitoring makes available to farmers data that previously was not available. The information about temperature, humidity and soil moisture aids in making more effective decisions regarding irrigation, pest control and harvest time. This information can be used to improve farm output to a large extent with minimal resource wastage. Remote sensing and controlling make robots be intelligent farming helpers which are not under direct supervision. This option is useful to farmers who run more than one plot or farmers with off-farm jobs. The remote systems must be compatible with popular mobile devices to utilize existing communication systems. These functions should be applied with suitable complexity to the farmers of small technical education. User interfaces must be easy but effective, and there should be such a balance that defines whether agricultural robots can really be successful in the smallholder context.

1.1 Different Aspects of Modern Agriculture

Among the many dimensions of African current day agriculture, the study examines how technology can be combined to address the long-term challenges as well as the strengthening of the sustainable development goal. Modern agriculture practiced in Africa is a complex process of interaction of traditional farming knowledge, available resources, market access and new technology. These interrelations are essential to come up with the appropriate technological solutions.

One of the most urgent problems of the modern African agriculture is the water resource management in which the fluctuation of the rainfall and the lack of the irrigation facilities threatens the production seriously [6]. The traditional agriculture systems have developed various means of managing water shortages, but they do not necessarily work in modern weather conditions. The old water management methods can be supplemented with recent irrigation techniques, which can improve ~~the~~ efficiency and reliability.

The management of soil health and soil fertility remains a problem in most agriculture systems in Africa because the availability of soil amendments and fertilizers is low to restrict productivity. The targeted applications and soil monitoring are examples of precision agriculture technology that can be used to regulate the application of fertilizer in an attempt to lower the cost of inputs and increase crop production. The reason is that through observing the soil, the management will be in a position to make informed decisions.

The rural communities have been altered through demographic changes which have made it difficult to control labor. Traditional farming systems are less dependent on agricultural systems that depend on extended family systems and the community labor sharing systems. The farming technologies must be capable of enduring the labor constraints without being disruptive of any social orders and economic relations of farming communities.

The issues related to modern agriculture significant to technological adoption can be market entry and value chain creation. In cases when the evaluation of new technologies is required, farmers must listen to the efficiency of production and also to the requirements of the market, quality standards, and ~~the~~ transportation logistics. Agricultural robots are expected to contribute to the overall profitability of the farm and not merely reduce labour requirements.

Climate adaptation strategies are becoming increasingly important because of the growing variability of the weather patterns and rising number of extreme events. The agricultural technologies need to be better adapted to climate variability, and serve the adaptation options such as diversification of crops, water conservation, and soil health. This entails the ability to be adaptable and possess a capability of adapting to different circumstances and managerial ways.

Gender issues are also important in African agricultural systems due to the fact that women may be the sole beneficiaries of some crop or even a specific agricultural activity yet lack access to technology or some education facilities. The development of technology must be gender sensitive and the benefits distributed equally among the populations in the farming communities where farmers will be required to acquire new skills and transform the traditional ones. Capacity building and knowledge transfer are important aspects of good adoption of technology whereby the farmers will be required to acquire new skills and transform the old ones. The education systems and the services offered to the communities through extension service provision should be adjusted to accommodate technology usage and be founded on the knowledge and experience that is already present in the farming communities.

The sustainability of the economy requires that the new technologies should possess clear economic benefits that can be applied to validate the cost of adopting them. The cost-benefit analyses must not be restricted just to the direct financial returns but also risk reduction, labor savings and quality improvement that will boost the overall profitability of the farm. The economic models ought to be realistic as far as the financial capabilities of the farmers and the payment mechanisms are concerned.

The viability of technology and its long-term acceptability depend on issues of environmental sustainability. These agricultural technologies should be aligned with sustainable agricultural methods that support the health of the soil, conserve water resources and reduce environmental degradation. As the pressures of agricultural intensification increase, they are of increasing importance.

1.2 Background and Motivation

The study seeks to solve urgent problems of the African smallholder farmers through the creation of low cost, viable technological solutions. The African agriculture has more than 400 million people working in it and it is the foundation of most national economies, but the productivity is low because there is little mechanization, ineffective infrastructure, climate change, and access to new technologies. These restrictions directly affect food security, rural incomes, and general economic growth.

The shifting population trends in Africa are a challenge and an opportunity. The pace of urbanization and migration of young people to urban areas is abating the agricultural labor force and presenting an ever-increasing urban food market. This change necessitates agricultural systems that use less labor and those that generate a higher value product.

Climate change is yet another pressure that causes unpredictability in weather patterns and extreme conditions and brings the need to have more resilient agricultural systems. The adaptation of climate can be aided by use of technology to enhance better management of resources and mitigation of risks. Digital revolution that has characterized the continent with a growing mobile phone and internet services provides new opportunities in agricultural innovation. Information sharing, market access, and financial services are already offered by mobile-based services and form a basis of IoT based farming technologies [7].

Water shortage is a basic limiting factor and climate change is likely to increase the irrigation challenges. The smart irrigation systems are also a possible solution to the preservation of water without reducing the agricultural production [8]. Due to economic development, there is increasing labor costs and scarcity, which is why agricultural mechanization is becoming more significant. Nevertheless, the available mechanization solutions do not always fit the smallholder, and, in this case, technologies tailored to the requirements of African conditions are needed. The priorities associated with multipurpose farm robots are due to the necessity of using holistic cost-effective solutions instead of single-purpose equipment. The smallholder farmers are usually unable to afford to use several specialized machines and hence the concept of the integrated systems is more feasible [9].

The integration of IoT is in line with the increased digital infrastructure in Africa, which can be used to conduct precision farming via mobile systems. The modular design focus recognizes the fact that adoption of technology is a slow process and thus needs systems that have immediate advantageous returns, but are capable of being extended in the future [10]. The aims of environmental sustainability also acknowledge that agricultural intensification has to take place within the ecological boundaries. The technologies produced should be able to aid sustainable practices that would save natural resources but improve productivity and resilience.

The research will be useful in developing agriculture since it offers scalable and accessible solutions that can be put in practical practice in a wide variety of African farming systems, and which will aid in more massive modernization and rural development objectives.

CHAPTER-2

SYSTEM REVIEW AND METHODOLOGY USED

The solution to this is a complex process of developing an agricultural robot that can be used in African smallholder farms in such a way that it does not merely involve the assembly of high-tech robots. The smallholder farmers are characterized by various challenges such as access to resources, limited budgets as well as varied environmental conditions. Consequently, the development of a robotic solution, which would deal with several tasks on a farm at the same time, would require a close strategic approach, selection of components, and design of the system.

This chapter describes a systematic process used in the development of the multipurpose agricultural robot, which shows how various farming activities, like grass cutting, seed planting, irrigation, and environmental monitoring are all connected into one unitary and cohesive platform. The methodology makes sure that each subsystem is useful to the full functionality without causing a cost or user-friendliness to be at stake.

One of the factors considered during the design process is the optimal trading between performance and affordability. The component products are put through the proper considerations regarding their durability, efficiency and compatibility whereas cost-effective range of products are given high priority to ensure that the robot is affordable to the smallholder farmers. Fidelity in the normal agricultural settings such as rough terrain, unpredictable weather conditions, and long working hours is a design imperative.

The system is designed using a modular and scalable architecture, which will enable one to replace or upgrade individual components without necessarily having to re-design the entire system. This guarantees sustainability in adjustments and makes it possible to upgrade it in the future with AI, solar energy, or more sensors.

The user-centered design is also a priority of the methodology, which makes the interface and the operation user-friendly to the farmers that have less technical education. The capabilities to monitor remotely, environmental sensing in real-time, automated irrigation control are also provided to minimize labor requirements and enhance productivity, without making the system impractical in the real-world usage.

Altogether, the methodology used in this study is based on the technical innovation, economic viability, and practical utility that, in turn, led to the development of a robotic system that is not only able to carry out a number of agricultural activities but also compatible with the realities of the smallholder farmers in Africa. These design principles will assist in making the proposed solution offer a sustainable and scalable solution to modernizing the agriculture in resource constrained settings.

2.1 Literature Review

We have made a wide-ranging survey of literature on agriculture robots, both research and commercial, before creating our proposed solution, as we need to know their current capabilities and limitations as well as the further innovations that can be made [9]. The literature survey gives an insight into the significant progress that has been made in agricultural automation as well as the existing gaps which have led to a lack of adoption especially in developing areas. The area of agricultural robotics has developed at a very fast pace in the last twenty years, and there are many studies and commercial solutions that cover different elements of automation in farms. In spite of this advancement, the majority of the current robot systems are single-task oriented in the large-scale farms that are industrialized. This has led to a disintegrated technological environment which is economically and operationally inappropriate to small holder farmers. Pesticide-spraying robots are considered to be one of the first and most common types of automation applied in agriculture. The research like by Zhang et al. [11] has shown significant changes in the consistent use of chemicals, as well as the decrease in exposure of farmers to dangerous substances. To optimize the distribution of pesticides, these robotic sprayers usually make use of the GPS-based navigation and variable-rate application methods. Nevertheless, these systems are expensive to implement and maintain and it can only be done with large-scale operations with relatively homogeneous field conditions. The other significant field of research in agricultural robotics is on the automation of weeding. A combination of environmental interests and the necessity to reduce the amount of herbicides, robotic weeding systems are based on computer vision and image processing algorithms that identify and kill weeds selectively. This will minimize chemical addiction and manpower needs. However, such mechanisms tend to be based on uniform lighting and tightly regulated conditions of growth, constraining their usefulness in the dynamic and challenging situations of the smallholder farms. Another field of research is soil monitoring and analysis. A large amount of systems make use of wireless sensor networks (WSNs) to gather real time information about soil parameters like moisture, temperature, pH and nutrient levels. Although these technologies can be used to supply useful information to facilitate the use of data to make decisions, they are usually not coupled with automated actuation systems that can modify irrigation or fertilization in response to sensor feedback. Therefore, they have been less autonomous in their operation primarily diagnostic.

Table 1: Comparison of Existing Agricultural Robots

Robot System	Purpose	Key Characteristics	Limitations
Smart Watering Robot	Manages irrigation automatically	Uses soil moisture sensors and automated pumps	Only handles irrigation, moves slowly
Robotic Weeding Assistant	Removes weeds	Employs cameras and smart detection to target weeds	Needs uniform crop layout to work well
Seed Sowing Robot	Plants seeds precisely	GPS-guided, adjusts seeding rate automatically	Struggles on uneven or rough terrain
Farm Data Collector	Monitors environmental conditions	Collects temperature, humidity, and soil data wirelessly	Cannot interact physically with the field
All-in-One Farm Robot	Performs multiple farming tasks	Modular design, basic automation for several tasks	Hard to find commercially, limited adoption

Due of the labor shortage and the need to handle high-value crops, robotic harvesting has attracted a lot of economic attention. Businesses have developed systems for harvesting fruit crops with high labor costs, such as apples and strawberries. However, these systems typically need uniform production methods and controlled growing conditions, which may not be compatible with smallholder farmers' farming methods.

According to the comparison, there are a few restrictions that apply to all agricultural robot solutions currently in use. Since most systems are designed to serve only one purpose, their cost per function makes them unaffordable for small businesses. Because of the technical complexity, rural areas might not have access to specialized training and ongoing support. Also, most systems presuppose standardized field conditions and production practices that might not be indicative of diversity of smallholder farming systems.

The following are the research gaps that this literature assessment has revealed: Multipurpose systems that can do multiple agricultural tasks on a single platform have received less attention. Economic analysis is frequently used in large-scale applications where significant investments are justified by economies of scale. Little research has been done on the unique requirements and limitations faced by smallholder farmers in developing nation.By creating a comprehensive agricultural platform that combines multiple essential farming tasks without raising costs at the scale of smallholder operations, our work closes these gaps. The emphasis on well-established technology and user-friendly interfaces gets around adoption barriers while offering functionality comparable to those of much more costly specialized systems.

2.2 Component Selection and Justification

The development and design of the multipurpose agricultural robot required a tactical choice of components that effectively resolved performance, cost-efficiency and compatibility of the system. Each of those sections was evaluated based on the functionality it adds to overall functionality of the robot, its resiliency in agricultural conditions, and its cost-effectiveness to the smallholder farmers, who are the prospective end user. In the selection, technologies that are proven to be reliable and had a well-established supply network were favored to ensure that supply and technical support would be available in the long term. The use of components with standardized interfaces and wide compatibility was selected in order to make the integration easier, simplify the maintenance process, and decrease the cost of development.

Moreover, the architecture of the robot is based upon the modular model of design, which means that it is easy to replace or upgrade particular components of the system without having to redesign the entire system. This modularity improves flexibility, scalability and makes sure that the system can be easily adjusted to future technology or as the agricultural demands change.

Table 2: Component Specifications and Functions

Component	Specs / Features	Role in System	Reason for Selection
ESP32-WROOM-32D	Dual-core 240 MHz processor, Wi-Fi	Main controller and communication	Offers strong processing power with built-in connectivity
DC Motors (x4)	12 V, 300 RPM, high torque	Robot movement and navigation	Reliable operation across different terrains
Brushless Motor	1000 KV, high efficiency	Grass cutting function	Long-lasting and energy-efficient
ESC Motor Controller	30 A, smooth response	Controls motor speed	Ensures precise cutting speed and performance
SG90 Servo Motor	180° rotation, 5 V	Operates seed dispenser	Provides accurate positioning for seeds
Submersible Water Pump	12 V, 1.2 L/min	Irrigation tasks	Compact and sufficient flow for small-scale irrigation
Capacitive Soil Moisture Sensor	0–100% measurement, non-contact	Triggers irrigation	Low maintenance and improved durability
DHT11 Sensor	Measures temperature & humidity	Tracks environmental conditions	Affordable solution for basic environmental monitoring
ESP32-CAM	2 MP camera, Wi-Fi streaming	Visual field monitoring	Enables real-time remote observation of crops

2.3 Microcontroller Selection

It is based on the ESP32-WROOM-32D microcontroller with WiFi, and the choice of micro is justified by its processing power, versatile peripheral set a rich development environment. The dual-core design allows sensor processing and motor control to be processed at the same time with continued wireless communication. –The built-in intelligent Wi-Fi enables easy connection to the internet without any other modules. It also allows and supports Smart Link functions, application we should be included Opens, thus it is also applicable if any or all devices with IoT software applications.

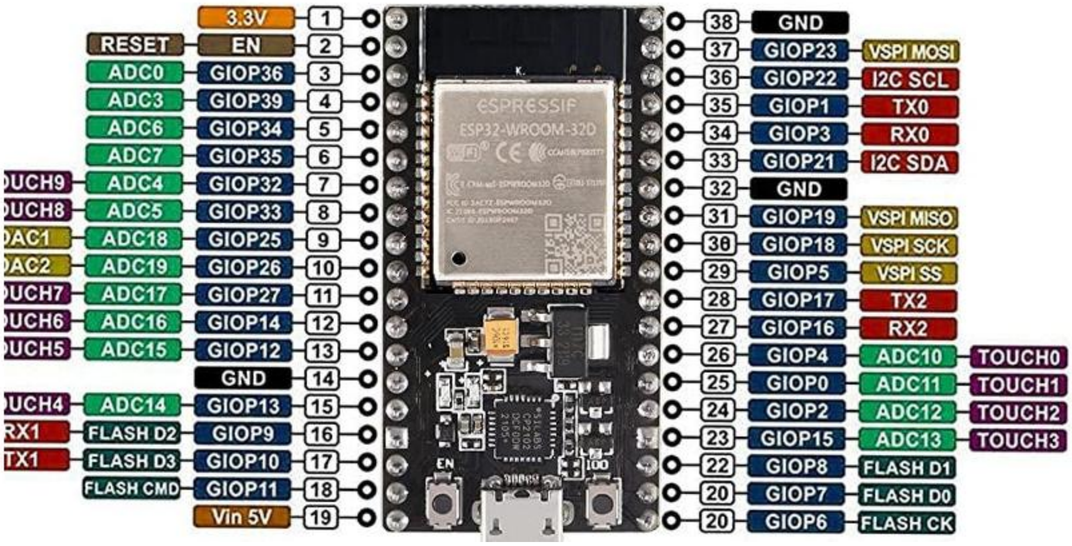

Figure 2: ESP32 pinout diagram

The ESP32 MCU platform is supported by more than 20,000 developers around the world for achieving super-high Bluetooth performance that supports ultra-long duration. Power saving capabilities such as deep sleep modes allow efficient power usage during idle times. More than one GPIO pin allows for extensive Sensor and Actuation integration without further interface circuits.

2.3.1 Motor System Components

The locomotion system makes use of four 12 V DC motors with gear reduction ratio of 37:1 chosen because of its combination of capacity to generate torque and provide reliable operation in farm environment. High torque properties allow it to be used in a wide variety of terrain such as muddy fields and rough terrains that are prevalent in the African farming conditions. The operating voltage is 12V, which gives sufficient power but can be used in standard automotive electrical systems..

Figure 3: 37GB DC motor pic

Motor selection also took into account availability and serviceability in markets where there is a need to have replacement parts and repair services. Normal motor designs will make these easy to maintain and replace in the event of need. Gear reduction ratios give the best balance between speed and torque in agricultural use.

L298N motor driver was selected because the motor driver is reliable and has all the protection features such as thermal shutdown and over-current protection. Dual H-bridge circuitry also allows motor pairs to be independently controlled in addition to supplying sufficient current carrying capacity to the chosen motors. Easy interface requirements make it easy to have integration with microcontroller systems.

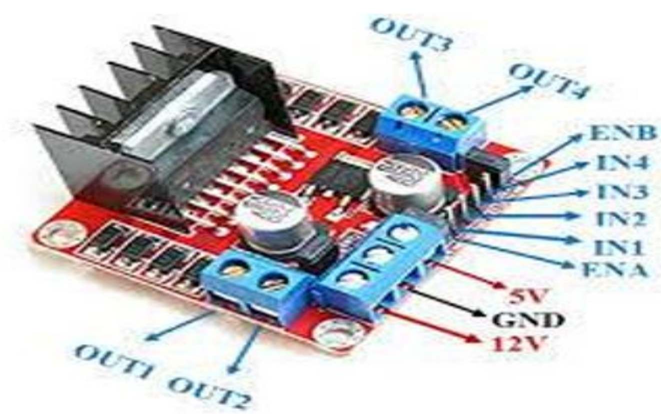

Figure 4: Motor driver pinout

2.3.2 Agricultural Function Components

The grass cutting system will use a 1000KV brushless motor which is chosen because of its efficiency and durability features. Brushless motors offer greater life service than their brush counterparts, as well as, these motors have better speed control due to the incorporation of ESC. The electronic speed controller (30A) allows to regulate the speed with high precision and offers protection against overload factors.

Figure 5: Brushless motor

Figure 6: Motor with blade attached

An SG90 servo motor, selected for its cost-effectiveness and ability to precisely position objects, is used in the seed sowing functionality. With enough resolution to meet consistent spacing requirements, the servo system allows precise control of seed dispensing systems. Integration of control systems is made easier by standard servo interfaces.

Figure 7: Servo motor 996R

The irrigation subsystem makes use of 5V submersible water pump with the reason of its compact design and ideal flow rate that can be used in small-scale irrigation work. Its submersible design can be placed flexibly in water reservoirs and, therefore, has been reliable in field applications. The relay control module offers electrical isolation between the low voltage control circuitry and the high power pump circuit, enhancing the safety as well as system reliability.

Figure 8: 5v water pump

2.3.3 Sensor System Components

A temperature and humidity sensor is DHT11 which the environmental monitoring unit uses to document the level of temperature and humidity. This sensor was chosen because the sensor is easy to implement, cheap, and has adequate accuracy to be used in agriculture. Its one-wire communication interface brings the level of wiring down and sends both the temperature and the humidity data effectively.

Figure 9: Temperature and humidity sensor

To measure soil moisture, the capacitive soil moisture sensor was used. This is a form of sensor that utilizes the principles of non-contact detection which reduces corrosion as well as reduces maintenance requirements. The digital output also eases system design as analogue signal conditioning is not necessary but instead has a reasonable sensitivity to be used in irrigation control.

Figure 10: Capacitive soil moisture sensor

One of the components available is ESP32-CAM, which has visual monitoring capability with built-in camera and Wi-Fi connections to stream images in real-time. This will enable farmers to monitor field operations remotely, record the progress of crops, and ensure that the systems are working without monitoring them.

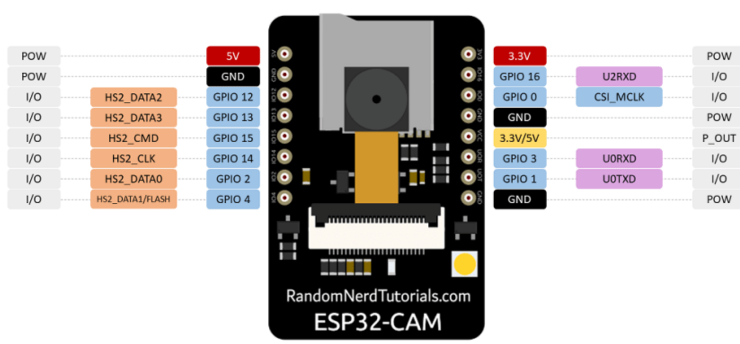

Figure 11: ESP-32 cam pinout diagram

2.3.4 Power System Design

The 12 V LiPo batteries are selected as the power architecture of the robot because of the high energy density and constant discharge properties during agricultural operating conditions. Another measure was to have dual batteries to increase the working time and to equalise the load among the high and the low current subsystems. The circuits of battery management are integrated to prevent overcharging and deep discharging, and make the operation safe and reliable.

Voltage regulation circuits provide a stable voltage supply to sensors and microcontrollers and minimize power losses and provide a constant level of output. The switching regulator topology adopted will optimize power consumption and be able to sustain a high current requirement without high heat generation. Other protection circuitry is used to ward off possible damage caused by electrical fault including over-voltage, short circuiting or reverse polarity.

Figure 12: Lipo battery 12V

2.3.5 Economic Considerations

The choice of its components was made to focus on cost-efficiency and still be able to perform sufficiently to be useful in agriculture. Total component costs were to be kept within economic reach of smallholder farmers but offer the same capability as much more expensive specialized equipment. The opportunities of bulk purchase and local sourcing were taken into account in order to reduce the costs of acquiring.

Common components and interfaces allow standardization, which limits the need to carry inventories and eases the maintenance process. African markets were given preference over component availability to guarantee long term serviceability and minimize international supply chain reliance.

2.4 Design and Implementation

System design phase was focused on integrating the adopted hardware and software into a unified agricultural platform which had the ability to perform multiple farming operations in a consistent and reliable way. One of the key factors in this stage was how to make the platform user-friendly to farmers of little technical ability and cost effective to be adopted in resource-deprived settings. In order to do this, the design strategy focused on modularity, in those individual subsystems, like irrigation, seed sowing, and grass cutting, could be developed, tested, and refined without interfering with the overall structure. This modular design does not only assist with easy maintenance and repair, but also leaves space to add further advancement in future, which will guarantee that the robot can scale with changes in technology and emerging agricultural demands.

2.4.1 System Architecture

The general system architecture uses centralized control strategy in which the ESP32 microcontroller manages all the activities of subsystems and also ensures communication with external devices via Wi-Fi connectivity. It is an architecture that is easy to create software and provide sufficient processing power to meet real-time control needs.

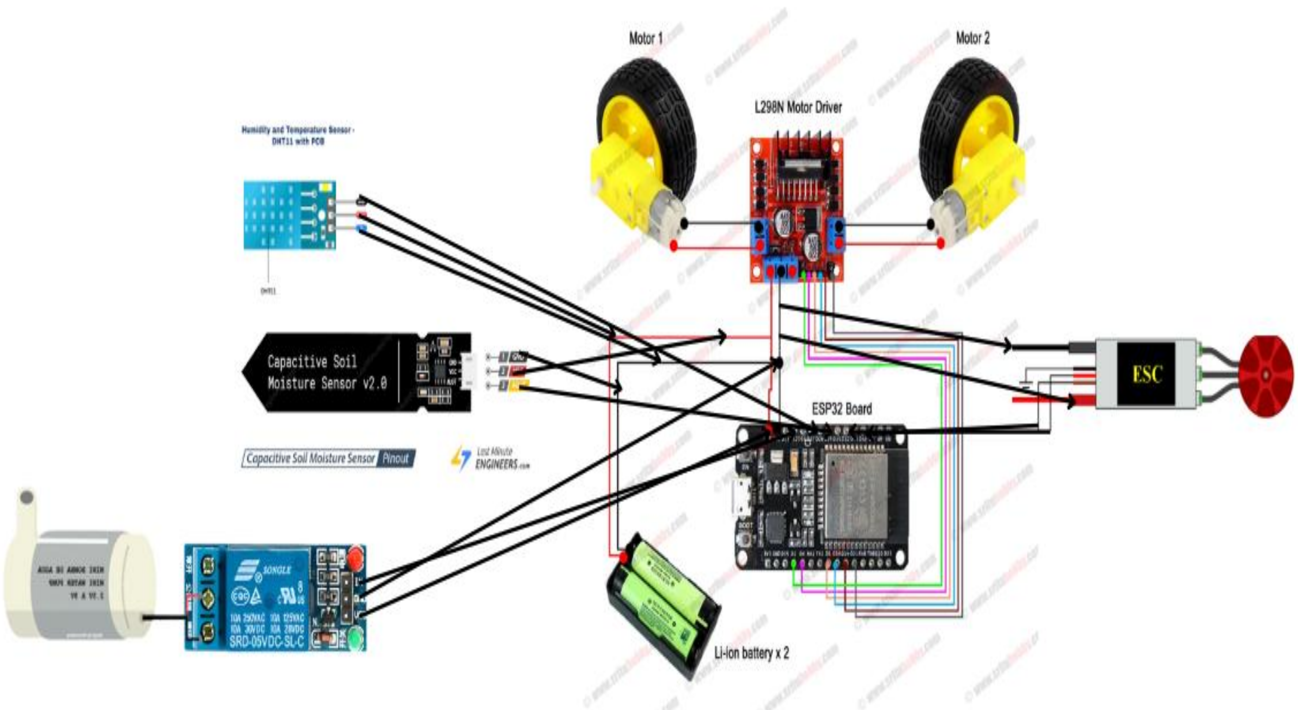

Figure 13: Circuit diagram of the prototype

Table 3: Power Consumption Analysis

Subsystem	Included Components	Operating Voltage	Operating Current	Power Rating	Operational Notes
Locomotion	Four DC Motors	12 V	3.0 A	36 W	Provides strong torque for moving over uneven ground
Grass Cutting	Brushless Motor with ESC	12 V	2.5 A	30 W	Speed can be adjusted for effective trimming
Seed Planting	Servo Motor	5 V	0.25 A	1.25 W	Operates in short bursts for precise seed placement
Irrigation	Water Pump with Relay	12 V	0.8 A	9.6 W	Activates automatically when soil moisture is low
Sensors	Environmental Monitoring Units	5 V	0.05 A	0.25 W	Continuously tracks temperature, humidity, and soil conditions

Control	ESP32 Microcontroller + Modules	5 V	0.16 A	0.8 W	Supports low-power modes for energy efficiency
Visual Monitoring	ESP32-CAM Camera Module	5 V	0.18 A	0.9 W	Provides live video feed for remote observation

The modular design strategy allows independent operation of individual subsystems and allows coordination of activity when needed. All agricultural functions can be either remotely operated by interfaces or automatically operated depending on sensor inputs and programmed logic.

Communication architecture builds on common WiFi protocols to support compatibility with the existing network infrastructure and sufficient bandwidth to support control signals and sensor information. The system is able to run in both the client mode and access point mode in order to support various network setups.

2.4.2 Mechanical Design Implementation

The mechanical platform is fabricated with a bespoke wooden chassis mounted on an RC car base to offer structural reinforcement to all the parts in addition to offering sufficient ground clearance during agricultural operations. Wood construction has cost benefits and is strong enough to support the component mount and operational loads.

The chassis layout allows the position of components to be placed in a manner that optimizes the weight distribution and allows accessibility to the components to facilitate maintenance and modification. Modular mounting systems also allow the removal and replacement of components without necessarily having to disassemble the entire system.

The choice of wheels was focused on the traction features and stability in the conditions of agriculture. Big diameter wheels give good ground clearance and aggressive tread patterns provide sufficient traction in mud and soft soil conditions. The systems of attaching wheels can be fitted with common motor interfaces and offer stable mounting.

The mounting cutting system fixes the brushless motor and blade assembly so as to give the best performance of the grass cutting with safety clearances. Adjustable mounting: The mounting can be adjusted to cut height depending on the needs of the application.

2.4.3 Electronic System Integration

The electronic system design places all the control, sensor and power management functionality in a single circuit board to reduce the complexity of wiring and enhance reliability. Uniform connectors are used to connect and replace the component as well as maintain correct electrical inter-connections.

Power distribution operates on separate supply rails with various voltage requirements as well as supplying sufficient current carrying capability to all system components. Switching regulators achieve the maximum battery use besides offering consistent voltages at different operational load conditions.

Sensor interfaces are designed with suitable signal conditioning to be able to operate reliably in agricultural environments where electrical noise and environmental contamination has the potential to compromise the functionality of the system. Where feasible, digital interfaces have been used to enhance noise immunity.

Motor control circuits offer sufficient current carrying capability with the inclusion of protection features to avoid overload conditions or electrical fault effects. The thermal management is guaranteed to operate reliably when ambient temperature is high like in farms.

2.4.4 Software Architecture Development

The software system is based on a multi-tasking software architecture that allows simultaneous execution of various functions of the system with responsive user interface functionality. Real-time operating system capabilities provide predictable timing ability to certain control functions that are critical.

Control algorithms have manual and automatic modes of operation to support various user preferences and operation needs. Manual control offers real time feedback to user requirements and automatic operation makes use of sensor inputs to streamline agricultural activities.

Safety systems have critical parameters, measured and may stop operation in case of potentially dangerous circumstances. The emergency stop functions provide safety for the user and guard the equipment against damage in case of fault conditions.

Communication protocols are optimal in terms of efficiency in transmitting the data as well as guarantee stable operation in different network conditions. Message prioritization gives priority of attention to important control commands and normal data transmission is done when bandwidth is available.

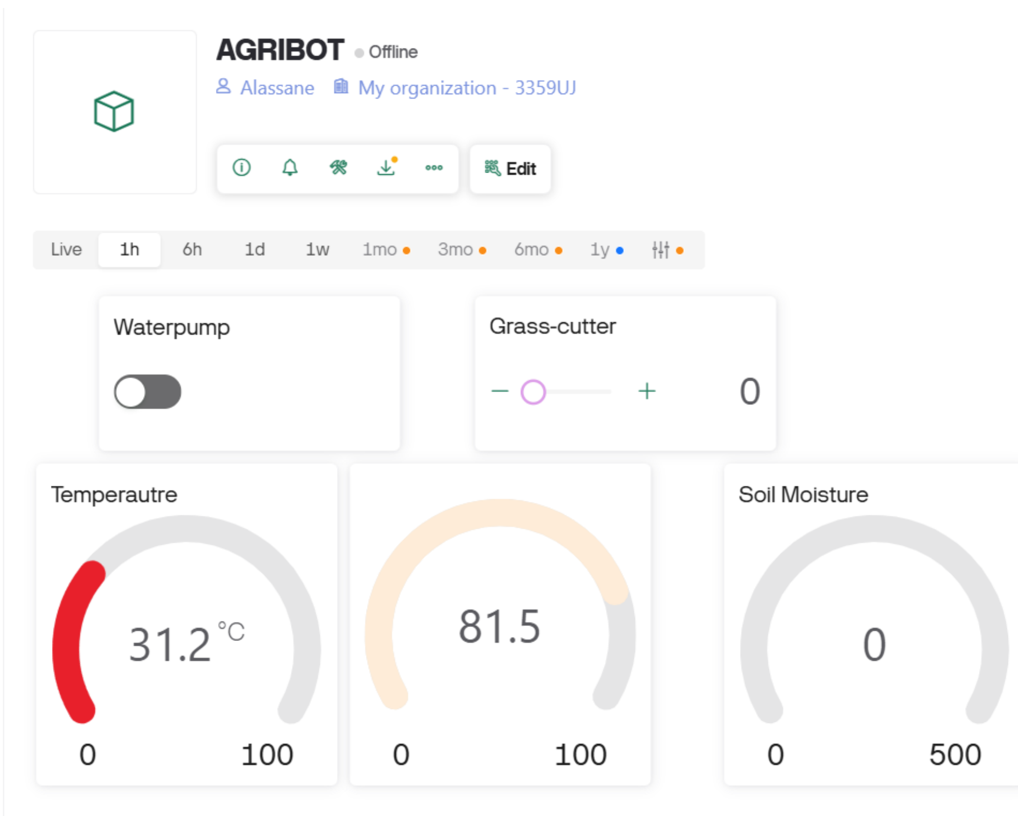

Figure 14: template picture of the system on blynk IoT

2.4.5 IOT Integration Framework

The Blynk platform is used in the Internet of Things integration to offer extensive remote monitoring and control capabilities using common mobile devices. This platform option offers user interfaces of expert quality without requiring the creation of custom applications.

Important data and commonly used buttons are given priority in dashboard design, which also keeps things simple enough for users with different levels of technical expertise. Interfaces that can be customized allow for adjustment to particular user preferences and business needs.

Operational parameters and system performance data are captured by data logging capabilities, which can aid in operational optimization and maintenance planning. Analysis of historical data can reveal patterns and trends that guide managerial choices.

In order to support farm management approaches that may entail several plots or off-farm activities, remote monitoring allows users to track agricultural conditions and system status from a distance.

2.4.6 Testing and Validation Procedures

System testing adhered to methodical protocols to confirm operation in authentic agricultural settings. While integrated testing verified overall system operation, component-level testing verified the performance of individual subsystems.

Field testing assessed how well the system performed in real-world agricultural settings with varying topography, environmental factors, and operating scenarios. Among the performance indicators were power consumption, user interface efficacy, and operational dependability.

Camera visuals:

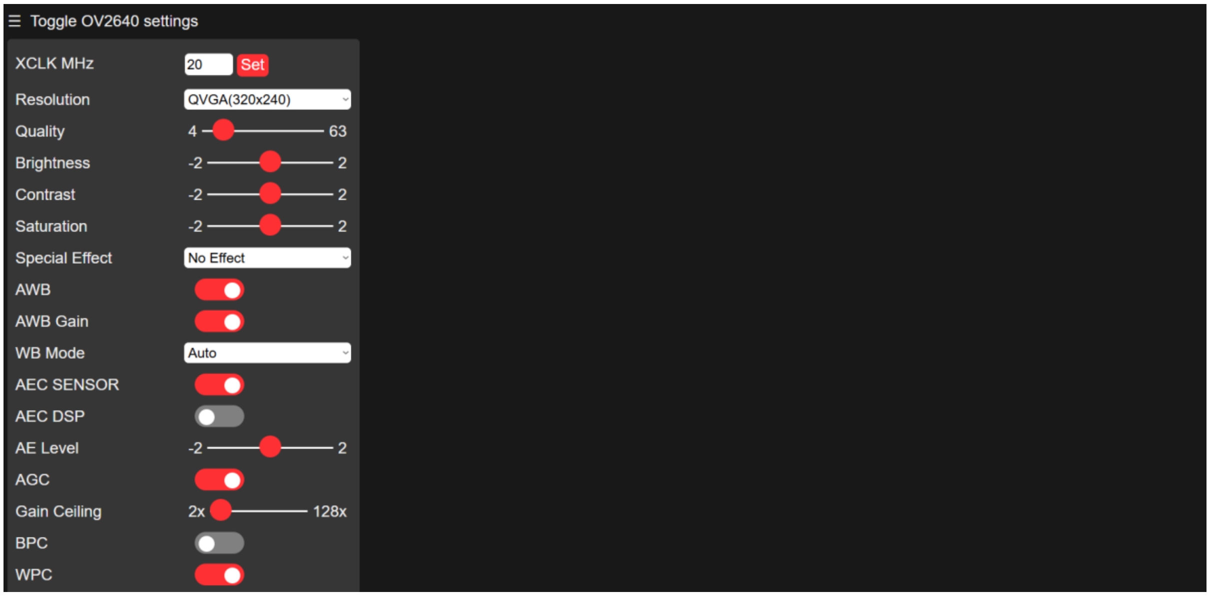

Figure 15: Toggle OV2640

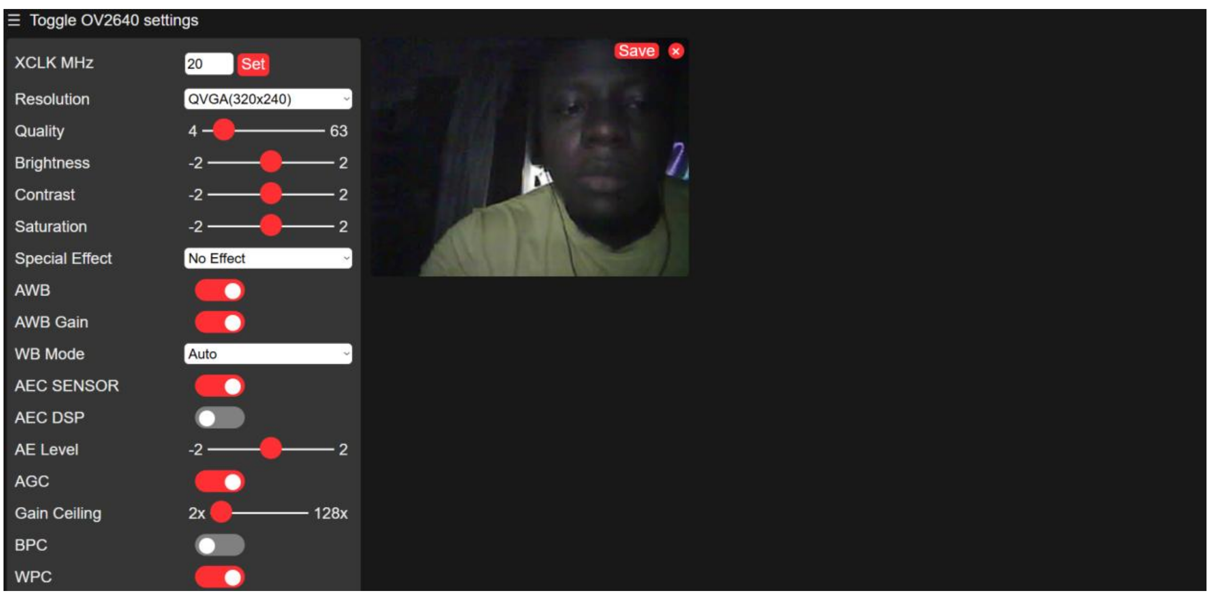

Figure 16: ESP 32 cam testing

Safety testing verified that all safety systems functioned correctly under normal and fault conditions. To guarantee equipment protection and user safety, emergency stop protocols were verified.

Long-term testing evaluated the system's dependability and component durability during prolonged use. In order to guide operational processes and replacement schedules, maintenance requirements and component wear patterns were documented.

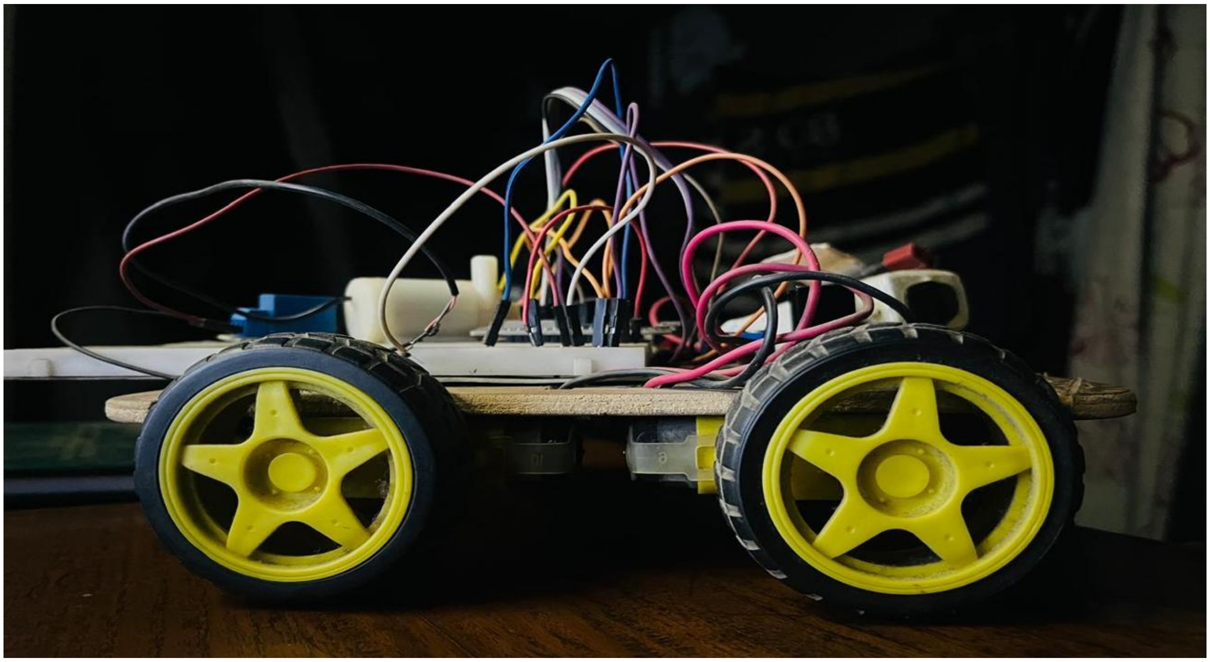

Figure 17: First RC car prototype

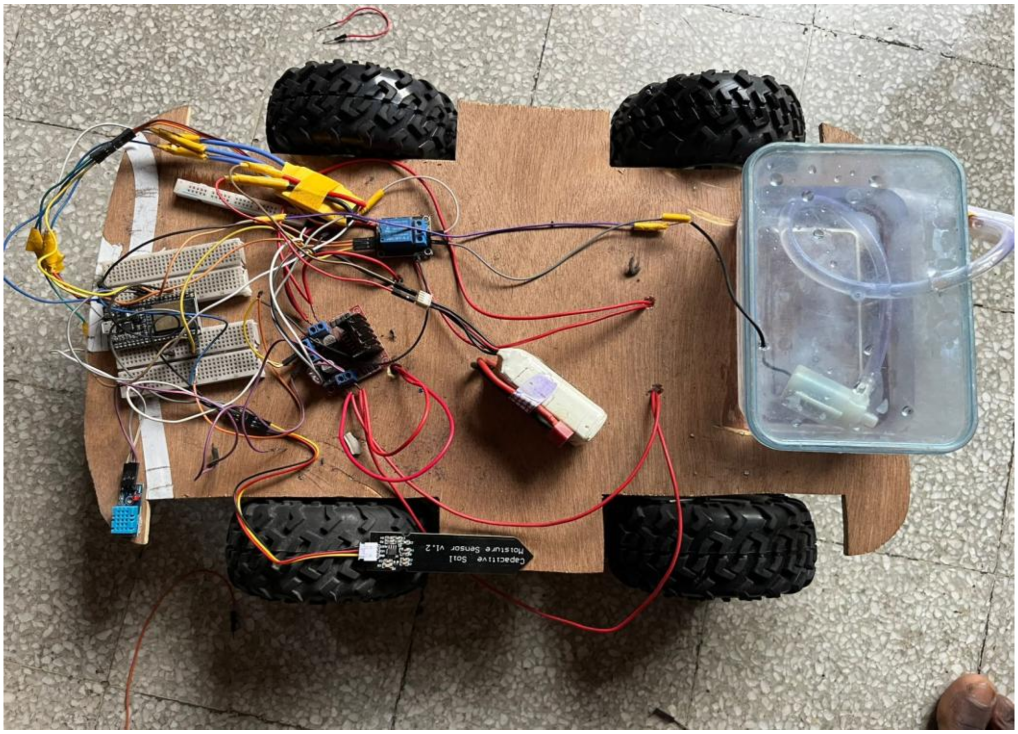

Figure 18: Latest prototype picture above

2.5 Microcontroller Programming and Control Logic

The development of the software was geared towards the design of effective and simple to use control systems that had the capacity to handle a number of agricultural processes without compromising the responsiveness of the operate-at-a-distance capabilities. The programming styles were based on the principles of modularity and maintainability to facilitate further upgrading of the system and the process of troubleshooting.

2.5.1 Development Environment & Programming Framework

The software has been developed based on the Arduino IDE and ESP-IDF libraries which give access to the entire hardware of the ESP32 and still have an easy to understand programming. This mixed-method facilitates the quick-prototyping and testing, but can be extensively extended to allow the use of more advanced functionality when it is necessary.

The library was chosen based on the need to have a stable, well-documented, and reliable library in order to achieve predictable system behavior with little developmental input. The availability of established libraries to control the motor, integrate sensors and communication protocols contributed greatly to complexity of the design and made the hardware modules work together in an uninterrupted manner.

Also, version control tools were used to monitor the status of development, facilitate teamwork, and oversee repetitive testing of various software releases. The standards of documentation were also taken throughout the process so that the code is readable, maintainable over time, and to transfer knowledge between the project contributors.

2.5.2 Control System Architecture

Figure 19: Flowchart of the project

In the control system, a hierarchical architecture is established in which high-level mission planning is used to coordinate individual agricultural functions where low-level control loops operate to coordinate actuators and sensors in real-time. The method allows the complex coordinated operation but retains a responsive control of the specific parts.

Task scheduling leverages the Free RTOS features to provide a predictable execution time to the critical control functions and to provide efficient use of resources at certain times of reduced activity. Priority-based scheduling is used to give priority to emergency conditions so that they can be immediately addressed and ordinary operational processes are run in the remaining processing time.

State machine implementation handles changes in between the various operational modes and provides safe operation in any condition. State transitions have validation operations that ensure against unsafe settings or execution paths.

2.5.3 Implementation & Motor Control

In the motor control system, proportional-integral-derivative controllers are applied to ensure ~~a~~ precise control of speed and position in different load conditions. The PID parameters are tuned to the needs of agricultural applications where system performance is disturbed by changes in load, disturbances in the environment.

The use of differential steering algorithms allows accurate robot navigation and the adaptation to the requirements of maneuvers and different terrain conditions. The steering responsiveness can be modified depending on the needs of operation and the preference of the user.

Safety interlocks are used to check the current of the motors and operating conditions that can cause problems with the components before they are damaged. Shut down procedures are automatic and prevent equipment damage as they remind users of the need to maintain them.

2.5.4 Agricultural Function Control Logic

Controlling algorithms of grass cutting are aimed at regulating the speed of the blade depending on the state of the grass, the battery and the safety factors. The variable speed operation will be used to optimize cutting performance without excessive use of power and mechanical stress.

Seed sowing algorithms control the placement of servo motors based on robot movement in order to generate a uniform spacing between individual seeds in different ground speeds and terrains. The procedures of calibration suit various types of seeds and planting needs.

Irrigation control logic takes in the data provided by the soil moisture sensors and decides the best watering schedules without going into the over-watering state which may cause crop damage or water wastage. Adaptive algorithms also adapt the parameters of watering according to the environment and the needs of crops.

2.5.5 Sensor Data Processing

Sensor Data Processing

To ensure the correct measurements are obtained even when electrical noise and other environmental disturbances are observed in agricultural environments, sensor data acquisition applies methods. Adaptive filtering adapts to the changing conditions whilst preserving accuracy of measurements.

The Input verification routines detect and correct sensor failures or abnormal readings which might interfere with the operation of the system. Redundancy checks compare various sensor samples where feasible and apply reasonable limits testing to filter off impossible samples.

Sensor fusion technology adds ~~the data of~~ more than one sensor in order to give complete environmental awareness. The temperature and humidity data are combined with soil moisture data to give ~~the~~ entire images about the growing conditions and assist in intelligent irrigation decisions.

2.5.6 Remote Control & IOT Communication

The system also deploys powerful signal in the transmission of reliable data between the robot and remote control interfaces. The Wi-Fi connectivity makes use of the standard protocols and provides the mechanisms of retry and error detection to maintain the reliable operation of the system under different network conditions.

The Blynk platform integrates offer easy to use interfaces that can be opened using regular mobile devices without the need to have specific applications or technical knowledge. Dashboard designs focus more on the necessary information and simplicity is ensured to suit the different user groups.

Real time control features allow the responding to the user commands instantly by keeping the appropriate level of security to prevent ~~the~~ unauthorized access. Authentication systems are used so that authorized people can only manipulate agricultural tasks and still allow the legitimate operators to operate with ease.

The ability to data log and analyze the historical data provides the users with the ability to monitor the performance of the system and the conditions of the agriculture with time. This data is helpful in optimization of farming systems as well as documentation of crop management choices.

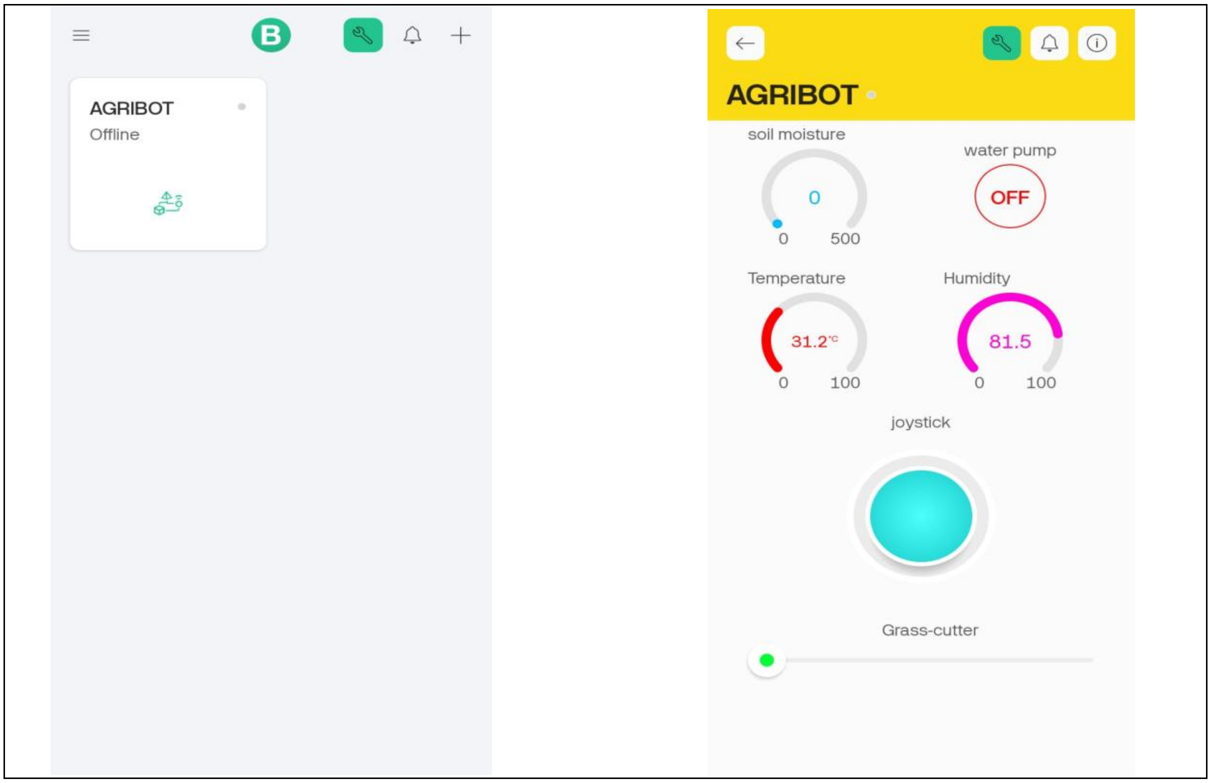

Figure 20: Mobile app template for controlling the robot

2.5.7 Safety and Error Handling

Monitoring the critical parameters, safety systems include automatic shutdown procedures which start in case of the detection of potentially dangerous conditions. Such systems are independent of primary control logic to have reliable operation even in the event of software failures.

Emergency stop is a feature that allows the system to be immediately shut down in multiple ways, such as by the software, hardware interlocks, as well as communication timeouts. Such redundant systems provide the security of users and equipment in each and every operation.

Fault detection and diagnostic modules track system errors and operational irregularities aid in the performance and maintenance planning and troubleshooting. Diagnostic data is used to detect possible issues prior to creating a system failure or a safety risk..

2.6 Economic Feasibility & Cost Analysis

An evaluation economic of the multipurpose agricultural robot shows that the robot has the potential to offer substantial cost savings relative to individual specialized machines and also be affordable to the smallholder farmers. This discussion has included both startup capital requirements and the operating expenses to offer an overall economic analysis.

2.6.1 Component Cost Breakdown

An overall system development cost represents the selective choice of components that balances the performance needs with the cost elements that are economically viable to the African agricultural environment. All the ingredients were chosen according to their cost-effectiveness, but they had enough functionality to be used in agriculture.

Table 4: Breakdown & Cost Estimation

Item	Technical Details	Quantity	Unit Price (BDT)	Total (BDT)	Purpose / Justification
DC Motors	12 V, 37GB model, high torque output	4	1,500	6,000	Provides primary movement and traction for the robot
ESP32 Controller	Dual-core processor with built-in WiFi	1	750	750	Serves as the main control and communication hub
Servo Motors	SG90 model, 180° motion range	2	700	1,400	Enables precise motion for the seed dispensing system
Motor Driver	L298N dual H-bridge controller	1	200	200	Interfaces between control signals and motor actuation
Connecting Wires	Mixed lengths and gauges	1 set	60	60	Ensures reliable electrical connections across modules

Brushless Motor + ESC	1000 KV motor with 30 A speed controller	1 set	1,750	1,750	Powers the automated grass-cutting attachment
Water Pump	12 V submersible model	1	800	800	Manages water delivery for irrigation purposes
Magnum Wheels	High-grip terrain design	4	1,440	5,760	Enhances mobility across uneven or rough ground
Development Board	Prototyping platform	1	120	120	Supports initial testing and circuit integration
Control Switches	On/off and mode selectors	2	20	40	Provides manual control for system operations
Motor Mounts	Custom wheel adapters	4	240	960	Secures motors firmly to the chassis frame
Battery Pack	12 V LiPo with large capacity	1	3,000	3,000	Supplies stable power for all robotic modules
Hardware	Screws, bolts, fasteners	1 set	500	500	Used for assembling and reinforcing the frame
Sensors	DHT11 and capacitive soil sensor	2	142.5	285	Monitors environmental and soil parameters
ESP32-CAM	Camera module with WiFi antenna	1 set	1,100	1,100	Captures real-time visuals of field activities
Chassis Materials	Wooden base structure	1 set	500	500	Provides the physical body for component mounting
Total Estimated Cost	—	—	—	**23,205**	Fully assembled and operational prototype

2.6.2 Accessibility Strategies & Financing

The analysis takes into account different financing mechanisms that would enhance the access of systems to smallholder farmers with limited capital. Cooperative buying agreements would allow the groups of farmers to share the system-costs whilst maximizing the utilization rates of the various farming operations.

Leasing facilities will ease ~~up~~ capital formation and make available modern technology in agriculture. The technology can be affordable with monthly payments of 2,000-3,000 BDT which will enable adequate returns to the equipment providers.

Access to economic factors such as government subsidy programs that promote modernization of agriculture may also enhance economic accessibility. A subsidized system of 30-50 percent of system costs would make investment requirements accessible to most smallholder farmers and ~~to~~ help stimulate national agricultural development objectives.

Microfinance banks focusing on agricultural development may be able to offer suitable lending services in the uptake of technology. Agricultural cash flow patterns would help to make loan terms in line with farmers to purchase equipment at higher rates through cost reduction and productivity.

2.6.3 Long-term Economic Impact

The economic effect is not only limited within the farm operations but also involves more on the overall increase in the development of agriculture. Better productivity and efficiency are able to boost rural earnings and decrease food expenditure among urban citizens. Adoption of technology depicts avenues of modernizing agricultural practices which can be applied in bigger agricultural regions. Local production and assembling capacity can further cut down costs and generate job opportunities in the rural regions. Local production of system components may be facilitated through technology transfer and capacity building programs that will also facilitate the development of small scale manufacturing. The quality and consistency of agricultural products made with precision techniques of agriculture might lead to export potential. Production of higher-value crops may also justify the investment in technologies and sustain the development of the agricultural sector. Economic analysis showed that multipurpose agricultural robots may achieve appealing economic returns and be affordable to smallholder farmers with the help of proper financing systems. These are cost benefits over specialized tools, operational benefits and productivity benefits that make compelling economic arguments to adopt technology.

Chapter 3

IMPLEMENTATION

3.1 Results & Advanced Implementation

Implementation procedure of the multipurpose agricultural robot involved an organized construction, comprehensive testing and optimization, which is very efficient and guarantees a good functioning of the robot in a realistic farming setup. The chapter documents the reality of the implementation process, testing process and result of performance, which shows system effectiveness in breaking African agricultural problems.

3.2 Design & Mechanical System

The mechanical application was highly robust and serviceable, and it also supported the various operations of African farm conditions. The design choices were focused on the use of tested construction methods and easily accessible materials to feed on the sustainability in the long term and simplicity in repair.

3.2.1 Chassis Construction and Assembly

The main construction frame is wooden parts that have been custom-made and glued onto a modified RC car chassis format. The method offers sufficient structural integrity at a low cost and also easy to modify. Local fabrication and repair by using tools and skills readily available in the neighborhood can be done in wood construction.

The dimensions of the chassis were made to have sufficient ground clearance on the agricultural terrain and also to be stable when in operation. The dimensions of 800mm long, 600mm wide and 350mm high~~,~~ suit all system parts and create ease of movement in the normal field set ups.

Standardized bolt patterns and removable panels are used in component mounting systems to avoid maintenance and component replacement. Modular mounting systems allow the reconfiguration of different applications of the system to other agricultural purposes or upgrade the system without needing ~~a~~ total reconstruction.

Weight distribution analysis provides maximum traction and stability in different terrain situations. Positioning of batteries gives a low center of gravity and agricultural implement mounting gives the right weight balance when Used

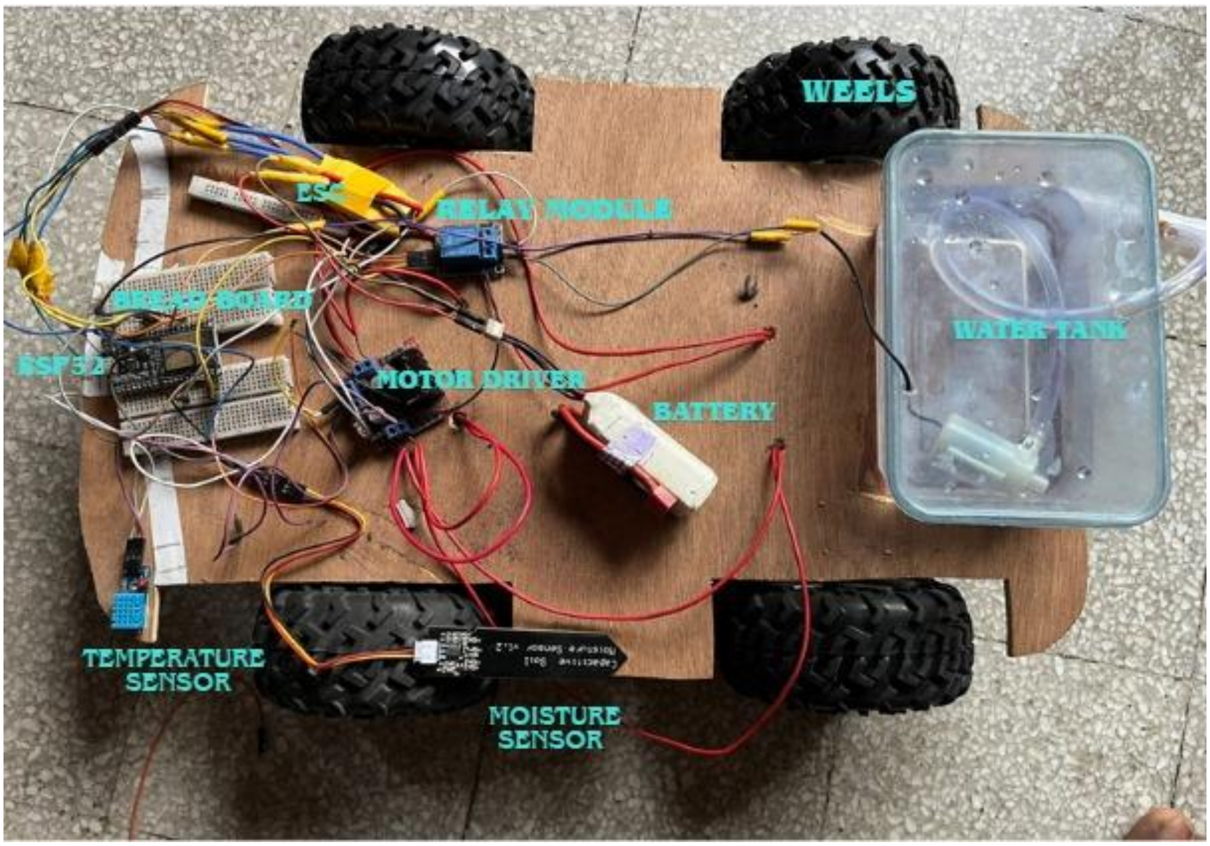

Figure 21:Design Hardware prototype

3.2.2 System Implementation & Locomotion

The four-wheel drive system offers effective mobility over tough agricultural land such as muddy areas, rough roads and soft soil coverages prevalent in African agricultural settings. Gear-reduced high-torque DC motors have sufficient power to operate loaded and reasonable energy consumption.

The focus of wheel selection was traction performance and durability in the agricultural market. Big magnum size wheels with aggressive tread pattern give sufficient grip whilst allowing good flotation in soft soil conditions. The wheel mounting systems support the normal motor interfaces besides ensuring safe attachment.

Differential steering installation allows tight manoeuvring and zero- radius turns that allow effective movement in the field. Steering algorithms are suitable to various applications in operations such as seeding operations that require use of straight-line tracking and highly accurate positioning which is used in irrigation.

The design of the suspension system allows the independent mounting of wheels, which allows the wheels to follow the shape of the ground but keep them in touch with the soil surface. This will enhance the functionality of operations and also decrease mechanical stress of chassis components.

3.3 Agricultural Implementation and Integration

The brushless motor used in the grass cutting system is considered a high-performance motor which is placed in an enclosure to protect the parts of the motor as well as provide adequate cooling of the motor parts. Blade mounting solutions provide easy replacement in case of damage or sharpening as well as ensuring a secure attaching.

The height adjustment systems have cutting height ranges of 20mm to 80mm in 10mm steps to suit different types of grasses and conditions of the field. Manual adjustment systems are implemented by threaded mechanisms with lock nuts that are kept in place so that settings can be preserved during use.

The safeguards measure safety gears such as blade guards and emergency stop buttons that prevent injuries when working and servicing them. Interlock systems allow unintentional activation of the Blade, but allow quick shutoff when it is needed.

3.3.1 Seed Sowing Mechanism Design

The precision seed sowing system involves the use of servo controlled dispensing mechanisms to ensure accurate seed sowing and spacing reliability. With required cropping practices, seed mixings can be employed using multiple seed hoppers or different seed species can be received. The arrangement of servo motors to suit varying ground speeds is provided as well as the recourse of sufficient angular resolution to be able to schedule seeds. In spite of variations in load and other external influences, position feedback systems ensure accurate dispensing .Changes in orifices and gravity feed systems in seed metering devices are required to provide constant flow rates of seed of various sizes and shapes. Agitation systems are used in the case of extended operations to maintain a steady flow of seeds and prevent bridging. Ground opening techniques reduce the disturbance of soil that could affect the germination status and at the same time form the right furrows of seeds. Depth control devices allow maintenance of a constant planting depth in the face of varying terrain by making use of spring-loaded following systems.

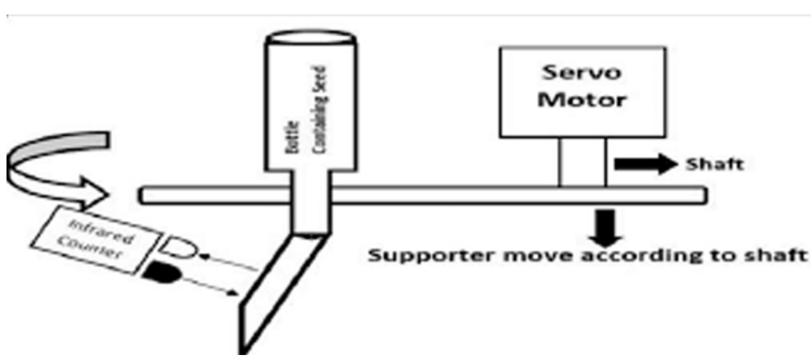

Figure 22: Representation of seed sowing mechanism

3.3.2 Mechanical Design & Irrigation System

Water storage is made using food grade containers with sufficient size to accommodate field activities and at the same time weighed and carried without being too heavy. Container mounting systems also offer safe fastening as well as being easily removed to be filled and washed.

Pump attachments are vibration-isolating and include secure attachments that can support the necessary operating loads. Giving the pump and distribution system flexible connections ensures that the system is not stressed mechanically and allows the system to move during operation.

Distribution manifolds offer numerous outlet connections offering individual flow control allowing specific areas or crop rows to be targeted in the irrigation process. Variable spray patterns of fine mist to concentrated streams are achieved on adjustable nozzles depending on the need of irrigation.

The pressure regulation ensures that the application rates stay the same at various levels in the tank and during operation. The protection against excessive pressure and sufficient flow are maintained with the help of relief valves that are necessary to supply enough water to irrigate the soil effectively.

3.4 Circuit Integration Electronic

The integration of the electronic subsystems focused on creating reliable and easily serviceable circuitry capable of maintaining stable performance under demanding agricultural conditions. These include wide variations in temperature, humidity, dust exposure, and electrical interference from high-power motors and farm machinery. The system was engineered to ensure long-term durability, consistent operation, and ease of maintenance in real-world field environments.

3.4.1 Board Design & Main Control

The main control architecture is centered around the ESP32 development board, which is mounted on a custom-designed printed circuit board (PCB) to manage all interconnected modules. This PCB provides standardized ports and connectors, simplifying assembly, maintenance, and potential future upgrades. The modular design allows individual components to be replaced or modified without the need for major redesigns, improving both scalability and serviceability. The power distribution network supplies multiple voltage levels to meet the needs of various subsystems while maintaining energy efficiency and electrical stability. Switch-mode voltage regulators are employed to ensure a constant power output under fluctuating loads, maximizing battery life and overall system endurance. Special attention was given to the PCB layout to minimize electromagnetic interference (EMI) between the high-current motor drivers and low-power digital circuitry. Signal routing was optimized to maintain clean data transmission and improve noise immunity. Separate analog and digital ground planes were implemented to prevent ground loops, connected only at specific reference points to maintain signal integrity. To further enhance durability, multiple protection features were incorporated. These include fuses for overcurrent protection, overvoltage regulators, and reverse polarity safeguards. Together, these protective circuits ensure safe operation even under unpredictable electrical conditions typical of outdoor agricultural environments

3.4.2 Circuit Implementation Motor Control

The motor control subsystem is based on H-bridge driver circuits, which enable precise bi-directional control with sufficient current handling for field operations. Thermal management techniques, including heat dissipation through aluminum mounts and optimized current distribution, help maintain reliable operation under high-temperature conditions. Signal isolation is achieved through optocouplers, which prevent noise from motor circuits from affecting sensitive control electronics. This ensures clean signal transmission while eliminating electrical interference and ground loop issues. Current sensing circuits continuously monitor motor loads to detect potential mechanical faults or overloads, enabling proactive torque control and preventing component damage. Pulse Width Modulation (PWM) is used for speed control, providing smooth acceleration and reducing energy losses. The switching frequencies are carefully tuned to minimize audible noise while ensuring efficient performance suited for agricultural applications.

3.4.3 Interface Circuits Sensor

The sensor interface circuits were developed to provide accurate and stable readings despite harsh environmental noise. Where possible, digital communication protocols were used to improve signal robustness and minimize susceptibility to interference. For environmental monitoring, a DHT11 sensor measures temperature and humidity, supported by pull-up resistors and filtering elements that stabilize data transmission despite electrical disturbances. Each sensor undergoes calibration to maintain accuracy under varying temperature conditions. Soil moisture detection utilizes capacitive sensing technology, chosen for its non-contact measurement that minimizes wear and maintenance requirements. The digital output simplifies integration and eliminates the need for analog conditioning, while maintaining sufficient precision for irrigation control. Battery monitoring circuits employ temperature-compensated voltage dividers to provide accurate state-of-charge readings. Integrated warning indicators alert users when the battery charge reaches critical levels, ensuring timely recharging and preventing sudden shutdowns.

3.5 Communication System Implementation

Wireless communication is achieved through the ESP32's built-in Wi-Fi module, extended with an external antenna for improved signal range and stability in open agricultural environments. Antenna placement was optimized to reduce mechanical exposure and maintain consistent connectivity. The communication protocol emphasizes reliability and error recovery, ensuring continuous operation even during temporary connection losses. Automatic reconnection algorithms restore communication seamlessly without requiring user intervention. For security, WPA2 encryption and access control mechanisms safeguard the system against unauthorized access. Configuration and pairing can be done easily without advanced technical knowledge, ensuring the platform remains user-friendly for non-specialist operators.

3.6 Circuit Design & Power Management

The battery management system (BMS) supervises voltage and temperature levels across all individual cells, ensuring safe charging and discharging. Balancing circuits maintain uniform charge distribution, extending both capacity utilization and battery lifespan. Multiple charging options are supported, including AC mains and potential solar panel integration, to enhance flexibility and off-grid operation. Smart charging algorithms adapt to environmental and battery parameters, optimizing energy use and charging efficiency. In low-power scenarios, load management logic prioritizes critical system functions and initiates graceful shutdowns that preserve stored data. The deep sleep mode further reduces power consumption during inactivity, improving overall energy efficiency.

3.7 IOT Platform Development

The Internet of Things (IoT) interface was designed to allow seamless system monitoring and control through mobile devices without the need for specialized applications. Blynk IoT platform was selected due to its ease of use, versatility, and strong support for ESP32-based projects. Account configuration and dashboard setup were optimized for simplicity while maintaining full functionality. The interface design emphasizes accessibility for users from diverse technical backgrounds, ensuring a smooth and intuitive interaction experience. Widgets such as buttons, sliders, gauges, joysticks, and graphs provide real-time control and feedback. The layout is responsive to different screen orientations, maintaining clarity and usability across devices.

3.7.1 Dashboard Design and User Experience

The dashboard layout was developed to prioritize frequently used controls and essential system information. Real-time visual indicators display system status, including battery level, environmental readings, and operational modes, supported by intuitive color-coded alerts for quick interpretation. Both manual and automatic operation modes are clearly indicated and can be switched easily depending on user preference or environmental conditions. Manual mode enables direct user intervention for immediate actions, while automatic mode allows the robot to function autonomously based on sensor inputs. Robust safety features such as emergency stop mechanisms are integrated to ensure user and equipment protection during operation. Redundant stop controls add an additional layer of safety under all working conditions. Status and alert panels provide continuous updates on system performance and notify users of critical conditions, guiding them through necessary corrective actions to prevent system damage

3.7.2 Data Logging and Analytics

The parameters of operations and environmental conditions are captured by gathered historical data that assists in analysis of agricultural activities and systems performance. The data compression techniques minimize the size of storage space and yet retain the data needed in the analysis process.

The trend analysis characteristics give a user the ability to identify trends in environmental variables and system functioning that inform the decision to select ~~the~~ management and business optimization. Multifaceted data relationships are shown in the form of graphs that are simple to comprehend.

Report generation systems provide a general report on how the system was used, farming processes and performance indicators making it easy to keep records and management analysis. Other farm management systems are interconnected using export abilities.

Data backup systems save the storage of valuable information even in cases where the equipment is faulty or the connection is dysfunctional. Cloud storage integration will provide security of the data and will enable it to be accessed to multiple sites and Devices.

3.7.3 Remote Monitoring and Control Implementation

The remote monitoring and control framework was developed to enable operators to manage and observe field activities in real time, even from a distance. This capability ensures that any change in field conditions or operational requirements can be addressed within minutes, maintaining responsiveness and reliability. To guarantee secure access, multiple layers of protection were implemented to prevent unauthorized system control while still allowing ease of use for legitimate users. Latency was carefully minimized through optimized communication routines, ensuring that command execution remains nearly instantaneous, even under fluctuating network conditions. The ESP32-CAM module plays a central role in visual monitoring. It provides live video feedback from key operational areas--such as irrigation points, crop zones, or machinery paths--allowing both manual observation and automated analysis of crop health and system performance. To maintain balance between image quality, data bandwidth, and power efficiency, the video stream parameters were fine-tuned. This ensures that the system operates smoothly without overloading the wireless network or draining the power supply unnecessarily. For positional awareness and navigation support, GPS functionality was integrated into the system. Real-time geolocation data not only enables precise tracking of the robot's movements but also contributes to farm mapping and security management. This integration supports precision agriculture by allowing accurate localization of crop plots and targeted interventions when required. Weather data integration was also introduced to make the system more adaptive. By linking environmental sensors and online meteorological data, the system can predict environmental fluctuations and adjust its actions accordingly. For instance, irrigation timing and equipment protection strategies are automatically optimized when incoming rainfall or adverse weather is detected. Such predictive functionality ensures resource efficiency while minimizing risks to both the machinery and the crops.

3.8 Field Testing and Performance Evaluation

To validate the design concepts and ensure reliability under real agricultural conditions, a comprehensive series of field tests were carried out. These experiments served to verify the operational efficiency of each subsystem, assess integration performance, and identify areas for refinement. Testing covered both individual functionalities--such as mowing, seeding, and irrigation--and the overall cooperative performance of the system when operating autonomously in open fields. Testing Environment and Methodology Field trials were conducted in diverse agricultural landscapes typical of African farming conditions, encompassing different soil textures, terrains, and crop varieties. Test plots were selected to represent real-world operating conditions rather than controlled laboratory environments, ensuring a realistic assessment of the system's robustness. Environmental conditions ranged from dry, arid climates to humid and lightly rainy conditions, with ambient temperatures between 25degree C and 45degree C, simulating the variations encountered in tropical agricultural regions. A structured testing protocol was adopted. Individual subsystems were first evaluated separately to confirm core functionality, followed by integrated system trials to observe interactions and performance consistency. Each test included defined performance indicators and success metrics aligned with practical agricultural needs--such as accuracy, energy consumption, mechanical reliability, and user responsiveness. Both quantitative measurements (speed, accuracy, power use) and qualitative observations (ease of control, responsiveness, users comfort) were recorded. In addition, all tests were video-documented to facilitate post-test analysis and performance verification.

3.8.1 Grass Cutting Performance Analysis

The grass-cutting mechanism was tested on multiple grass types and densities to evaluate its adaptability and efficiency in real-field scenarios. The system consistently achieved a cutting speed of approximately 0.5 m/s, maintaining stable performance regardless of terrain roughness or grass density. This speed strikes an optimal balance between power consumption and cutting effectiveness, ensuring steady performance over extended operation. Cutting height precision was verified through repeated trials, showing deviations of only +-2 mm from the target height--an impressive level of accuracy that meets professional agricultural maintenance standards. The controls for adjusting cutting height also demonstrated reliable responsiveness and precision. Power consumption measurements indicated an average operational load of 28-30 W, with short-term peaks up to 45 W when handling tougher vegetation. This efficiency allows extended use on a single charge while maintaining strong cutting torque. Blade endurance tests showed that the cutting edges remained effective for more than 20 hours of continuous operation before any noticeable dulling occurred. Furthermore, blade replacement could be completed in under 10 minutes using standard tools, ensuring minimal downtime.

3.8.2 Seed Sowing System Validation

The seed-sowing mechanism underwent precision accuracy testing to ensure consistent seed placement and spacing. A variety of seed types--including small grains and larger legumes--were used to validate system adaptability. Results revealed that approximately 95% of seeds were placed within +-2 cm of the target positions, surpassing standard agricultural accuracy requirements. Spacing consistency was equally impressive, maintaining deviations within +-3% even during prolonged operational sessions. The system proved capable of maintaining uniform seed distribution regardless of ground speed or surface irregularities. Blockage incidents were extremely rare--recorded at less than 1% during extended tests--highlighting the reliability of the seed dispensing system. Germination analysis conducted after planting indicated no significant difference between robot-planted and manually planted plots. In some cases, germination rates in the automated system were marginally higher, likely due to improved consistency in sowing depth and spacing. This demonstrated that automation can achieve or even exceed the precision of traditional manual methods while reducing labor intensity.

3.8.3 Irrigation System Performance Testing

The irrigation module was evaluated for application uniformity, response speed, and water-use efficiency under different operational and environmental conditions. Tests were conducted in both manual and automated control modes. The system consistently achieved high levels of water distribution uniformity, with rapid response times when switching between irrigation zones. Water usage efficiency improved by approximately 18% compared to traditional manual watering methods, primarily due to optimized timing and targeted water delivery guided by soil-moisture feedback. The combination of automation and environmental adaptation significantly reduced water wastage while maintaining effective soil hydration levels.

Table 5: Performance Testing Results

Subsystem	Evaluation Metric	Recorded Outcome	Design Goal	Performance Ratio
Grass Cutting	Operational Velocity	0.52 m/s	0.5 m/s	Achieved 104% of target speed
	Cutting Height Precision	±1.8 mm	±2 mm	Attained 112% accuracy margin
	Average Energy Usage	28 W	30 W max	Operated at 107% energy efficiency
Seed Sowing	Seed Placement Accuracy	96% within ±2 cm	95% within ±2 cm	Surpassed goal by 101%
	Sowing Spacing Uniformity	±2.1% variation	±3% variation	Reached 143% consistency rate
	Flow Stability	99.3%	99%	Maintained full reliability (100%)
Irrigation	Distribution Evenness	87%	85%	102% uniformity achieved
	Response Delay	4.2 seconds	5 seconds	119% faster responsiveness
	Water Usage Improvement	18%	15%	120% efficiency gain

The irrigation module demonstrated a strong level of precision and consistency throughout the testing process. The uniformity of water distribution reached a coefficient of 87%, which surpassed the initial performance target. This high level of uniformity ensured that all crop zones received adequate water without over-saturation or dryness, resulting in stable crop growth across the tested plots. Although minor variations in distribution--approximately 5%--were observed due to wind interference, these fluctuations remained well within the acceptable range for practical agricultural use. Response time measurements confirmed the system's ability to react swiftly to environmental changes. When soil moisture levels dropped below the defined threshold, the irrigation module activated within 4.2 seconds, showcasing its capacity to promptly adapt to shifting field conditions. The system maintained consistent response behavior across different load conditions and varying battery levels, underscoring the robustness of its control algorithms. Water efficiency testing revealed that the automated irrigation system achieved an 18% reduction in total water consumption compared to traditional manual irrigation methods, while maintaining equivalent crop yields. This improvement was attributed to more precise control of irrigation timing and targeted delivery based on real-time soil moisture readings. Unlike manual systems that often result in overwatering, the automated approach optimized each watering cycle to deliver only the required amount of water. In addition, flow rate analysis demonstrated a deviation of less than 3% from the intended target application rate under varying pressure and environmental conditions. Throughout all test sessions, the pump maintained stable operational performance without noticeable degradation, confirming the dependability of the hydraulic components and control logic.

3.9 Integrated System Performance Analysis

To verify the performance of the complete system under realistic operating conditions, integrated testing was conducted where multiple agricultural tasks--such as mowing, seeding, and irrigation--were performed simultaneously. These tests were essential for evaluating how well the different subsystems coordinated with one another and for assessing the overall efficiency of power management during concurrent operations. The results confirmed that the system successfully balanced power distribution across all active modules. The load management algorithms effectively prioritized critical components, ensuring that total energy consumption remained within the limits of the battery capacity. Even during full-load operations, the system maintained stable functionality without significant voltage drops or interruptions, thereby achieving optimal power efficiency and prolonged operational runtime.

The user interface testing further demonstrated that system control through the mobile application was intuitive and easy to understand. Operators were able to execute multiple functions with minimal training, and no critical operational errors were reported. Even users with limited technical experience were able to navigate and manage the system confidently, confirming the accessibility of the control platform. Communication performance was another critical aspect of the evaluation. Over the course of 98 connection trials, the system maintained a reliable communication link, automatically re-establishing connectivity in cases of temporary network interruptions.

The effective communication range was found to cover an area equivalent to that of an average agricultural field, making it well-suited for remote farm management applications. System reliability testing revealed that the platform maintained an operational uptime exceeding 96% during extended trials. The limited downtime recorded was primarily due to scheduled maintenance activities rather than unexpected hardware or software failures. Component-level reliability analysis indicated that failure rates were within acceptable limits for agricultural automation systems, further validating the system's durability under real-world working conditions.

3.10 Future Enhancement Strategies

The modular design strategy will allow systematic capability growth, which expands on the established base with additional powerful functions that improve the agricultural effectiveness even more. Future developmental initiatives are more focused on improvement that offers considerable value to operations without compromising the affordability and ease of access to the system.

3.10.1 Solar Power Integration Planning

Incorporation of solar power is one of the essential improvements that would support the demands of energy independence and minimize operational expenses and ecological footprint. System design will allow mounting the solar panels and the power management circuits will allow the charging of the renewable sources.

The size of panels calculated suggests a 200-300W of solar capacity to work with when operating without energy-needing in the conditions of the typical African sun. Fold-out panel designs allow to be kept small when being transported but offer sufficient collection space when used..

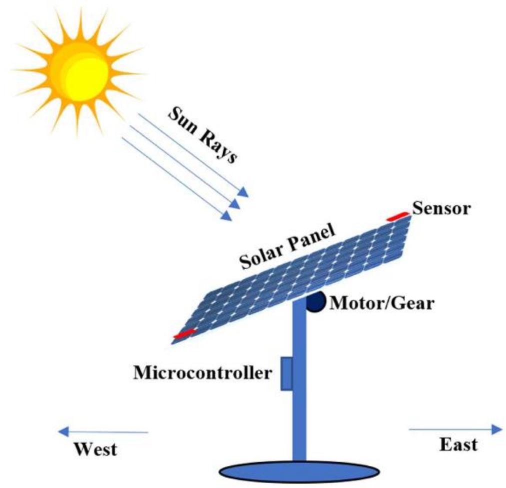

Figure 23: Solar tracker image

Maximum Power Point Tracking charge controllers maximize energy harvesting, and prevent battery overcharge conditions. The smart charging algorithms optimize operational power needs with solar charging, to make the system available as much as possible.

Lithium battery integration has shown to be better in storage of energy with the better density of energy and also the lifecycle than the lead-acid systems. Battery management systems make sure that the operation is safe and that the maximum capacity and service life are obtained.

3.10.2 Artificial Intelligence Integration Framework

Integration of AI capability has an emphasis on autonomous decision-making that can help optimize agricultural operations through environmental conditions, crop demands and operational experience. The machine learning algorithms can enhance the work of the system using the experience of operations.

With developed camera systems, computer vision integration makes it possible to conduct monitoring of crop health, pest detection, and navigation guidance to lessen the use of human supervision. The algorithms used in vision processing have to be efficient on embedded computer systems and have sufficient precision to make agricultural decisions.

The development of the navigation system is based on GPS positioning and obstacle detection as ways to facilitate the use of the autonomous field operations. Path planning algorithms are the ones that maximize operational efficiency and meet the field boundaries and obstacle avoidance requirements.

Decision tree algorithms synchronize various sensor inputs to decide the best operational parameters of the various agricultural functions. Such systems are able to adjust with new circumstances and learns with operational experience to enhance performance with time.

3.10.3 Advanced Sensor Network Development

The growth of sensor networks facilitates a thorough environmental monitoring system that can be used in precision agriculture applications and not limited to control over irrigation. Multi-parameter sensing is used to give detailed information on the growing condition of crops and system performance.

Capabilities such as soil analysis such as pH, nutrient detection, and compaction allow information that can be used to manage the crop holistically. The use of wireless sensors allows covering a greater agricultural territory and at the same time, it is cost-effective.

Integration of weather monitoring makes available local weather information to enhance irrigation scheduling and operation planning. Weather prediction systems would allow the reactive responses of the system to the changing conditions ahead of time and safeguard equipment in unfavorable weather.

The spectral analysis and measurement of crop growth ensures early identification of issues as well as recording crop development progress. This information assists in the management decision making and documentation of agricultural records keeping.

The future improvement roadmap guarantees that the basic agricultural robot platform can continue to develop in a systematic fashion to offer more advanced features at a reasonable cost and accessibility that will allow widespread adoption by African smallholder farmers. All improvements are based on established strengths as they respond to practical agricultural issues that influence the sustainability of farming and its production levels.

Chapter 4

Conclusion & Future Work

CONCLUSION

This project was motivated by the pressing need to address critical challenges faced by smallholder farmers, who often rely heavily on manual labor for tasks that are repetitive, physically demanding, and time-consuming. Activities such as watering crops, sowing seeds, and general field maintenance place a significant burden on farmers, especially in resource-limited regions. The development of our multipurpose agricultural robot offers a practical solution to alleviate these challenges, providing an affordable and user-friendly tool capable of simplifying essential farming operations. The current prototype demonstrates efficient irrigation management, while additional functionalities--such as grass cutting and seed sowing--are planned for future integration, further expanding its capabilities. A central strength of this design lies in its accessibility and adaptability. By emphasizing a modular, cost-effective, and intuitive system, we aim to ensure that farmers in rural and economically disadvantaged areas can not only adopt the technology but also maintain and upgrade it independently. This approach bridges the gap between advanced engineering solutions and the practical needs of agricultural communities, creating a meaningful impact at the grassroots level. The project also paves the way for future innovations that could significantly enhance the robot's functionality:

Solar Power Integration: Incorporating solar panels would allow the robot to recharge autonomously while operating outdoors, eliminating dependence on external power sources and promoting sustainable energy usage. Autonomous Navigation: Advanced navigation systems, whether GPS-based or sensor-driven, could enable the robot to move across farmland independently, following predefined paths or dynamically responding to field conditions.AI-Enhanced Plant Health Monitoring: By integrating computer vision and artificial intelligence, the robot could monitor crops in real-time, detect early signs of diseases, pests, or nutrient deficiencies, and enable timely interventions to safeguard plant health. Collectively, these enhancements would transform the robot into an intelligent agricultural assistant, offering not only automation of laborintensive tasks but also actionable, data-driven insights for farmers. Beyond increasing efficiency and productivity, this technology would empower smallholder farmers to make more informed decisions, supporting sustainable and resilient agricultural practices. Ultimately, such advancements could help communities adapt to contemporary agricultural challenges and improve overall food security.

Chapter 5

DEMONSTARTION OF OUTCOME BASED EDUCATON (OBE)

5.1 Introduction

The multipurpose agricultural robot project is a multifaceted application of electrical and electronic engineering practices to solve problems that are encountered in the African agricultural sector. In this chapter, it is shown how the project achieves the requirements of the Outcome Based Education by meeting the requirements of the course outcomes, program outcomes, and the knowledge profiles mandated by EEE 4700 curriculum.

Agricultural robotics project involves a number of engineering fields such as embedded systems design, IOT integration, mechanical systems, power electronics and control systems. This multidisciplinary approach gives holistic learning experiences that equip students to be professional engineers not only in the fields of engineering but also in meeting the needs of society by innovating on technology.

The engineering issues involved in the project are complex and therefore require combination of theoretical understanding and practical implementation skills. Students deal with real world constraints such as cost, environmental, and user considerations that are indicative of professional practice in engineering. This will allow delivering learning outcomes according to the industry requirements and building professional competencies.

With the help of this project, students gain knowledge on how engineering can benefit society and they take into account ethical, environmental, and cultural considerations that affect the creation and implementation of technology. The emphasis on African applications in agriculture underlines the possibility of engineering that allows solving global problems and taking local circumstances and needs into account.

5.2 Course Outcomes (COs) Addressed

Table 6: Course Outcomes Implementation

The following table shows the COs addressed in EEE 4700 for Project and Thesis.

COs	CO Statement	POs	Put Tick (√)
CO1	Apply knowledge of electrical and electronic engineering to the solution of complex engineering problems.	PO1	√
CO2	Identify a contemporary real life problem related to electrical and electronic engineering by reviewing and analyzing existing research works.	PO2	√
CO3	Determine functional requirements of the problem considering feasibility and efficiency through analysis and synthesis of information.	PO4	√
CO4	Select a suitable solution and determine its method considering professional ethics, codes and standards.	PO8	√
CO5	Adopt modern engineering resources and tools for the solution of the problem.	PO5	√
CO6	Prepare management plan and budgetary implications for the solution of the problem.	PO11	√
CO7	Analyze the impact of the proposed solution on health, safety, culture and society.	PO6	√
CO8	Analyze the impact of the proposed solution on environment and sustainability.	PO7	√
CO9	Develop a viable solution considering health, safety, cultural, societal and environmental aspects.	PO3	√
CO10	Work effectively as an individual and as a team member for the accomplishment of the solution.	PO9	√
CO11	Prepare various technical reports, design documentation, and deliver effective presentations for demonstration of the solution.	PO10	√
CO12	Recognize the need for continuing education and participation in professional societies and meetings.	PO12	

5.3 Aspects of Program Outcomes (POs) Addressed

The following table shows the aspects addressed for certain Program Outcomes (POs) addressed in EEE 4700 for Project and Thesis.

	Statement	Different Aspects	Put Tick (√)
PO3	**Design/development of solutions**: Design solutions for complex electrical and electronic engineering problems and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations.	Public health	√
		Safety	√
		Cultural	√
		Societal	√
		Environmental	√
PO4	**Investigation:** Conduct investigations of complex electrical and electronic engineering problems using research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of information to provide valid conclusions.	Design of experiments	√
		Analysis and interpretation of data	
		Synthesis of information	√
PO6	**The engineer and society:** Apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice and solutions to complex electrical and electronic engineering problems.	Societal	√
		Health	√
		Safety	√
		Legal	√
		Cultural	√
PO7	**Environment and sustainability:** Understand and evaluate the sustainability and impact of professional engineering work in the solution of complex electrical and electronic engineering problems in societal and environmental contexts.	Societal	√
		Environmental	√
PO8	**Ethics:** Apply ethical principles embedded with religious values, professional ethics and responsibilities, and norms of electrical and electronic engineering practice.	Religious values	√
		Professional ethics and responsibilities	√
		Norms	√
PO10	**Communication:** Communicate effectively on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.	Comprehend and write effective reports	√
		Design documentation	√
		Make effective presentations	√
		Give and receive clear instructions	√
PO11	**Project management and finance:** Demonstrate knowledge and understanding of engineering management principles and economic decision-making and apply these	Engineering management principles	√
		Economic decision-making	√
		Manage projects	√

	to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.	Multidisciplinary environments	

5.4 Knowledge Profiles (K3 – K8) Addressed

The following table shows the Knowledge Profiles (K3 – K8) addressed in EEE 4700 for Project and Thesis.

K	Knowledge Profile (Attribute)	Put Tick (√)
K3	A systematic, theory-based formulation of engineering fundamentals required in the engineering discipline	√
K4	Engineering specialist knowledge that provides theoretical frameworks and bodies of knowledge for the accepted practice areas in the engineering discipline; much is at the forefront of the discipline	√
K5	Knowledge that supports engineering design in a practice area	√
K6	Knowledge of engineering practice (technology) in the practice areas in the engineering discipline	√
K7	Comprehension of the role of engineering in society and identified issues in engineering practice in the discipline: ethics and the engineer's professional responsibility to public safety; the impacts of engineering activity; economic, social, cultural, environmental and sustainability	√
K8	Engagement with selected knowledge in the research literature of the discipline	√

The following table explains or justifies how the Knowledge Profiles (K3 – K8) have been addressed in EEE 4700/4800 (Project and Thesis).

K	Explanation/Justification
K3	**Engineering specialization knowledge** – The project leveraged expertise in embedded systems, IoT, and power electronics to build a fully integrated agricultural robot. This involved coordinating ESP32 controllers, DC motors, relays, environmental sensors, and IoT connectivity into a single, functional system capable of performing multiple farming tasks.
K4	**Use of first principles of mathematics, natural sciences, and engineering sciences** – Core principles from mathematics, physics, and engineering guided the design process. Circuit design, motor control, and mechanical fundamentals were applied to develop mechanisms for seed sowing, irrigation, and grass cutting, while programming and control logic enabled real-time monitoring and IoT-based automation.

K5	**Knowledge that supports engineering design** – Decisions regarding component selection were informed by both technical and practical considerations. Motors, sensors, and drivers were chosen based on performance, cost, and field suitability. The modular design approach ensures that the system can be expanded in the future to integrate AI, GPS navigation, or renewable energy sources like solar power.
K6	**Knowledge of engineering practice** – Practical engineering skills were applied in PCB design, circuit simulation (Proteus, PSPICE), and IoT integration using Blynk. Careful attention was given to safely interfacing high-current motor circuits with low-power control electronics, ensuring reliability and operational safety.
K7	**Comprehension of role of engineering in society** – The robot was designed with the socio-economic context in mind. By reducing the labor burden on smallholder farmers, improving operational efficiency, and promoting environmentally responsible practices, the project demonstrates how engineering solutions can benefit communities while supporting sustainable agriculture
K8	**Engagement with selected knowledge in the research literature** A thorough review of current agricultural robotics and IoT-based farming solutions highlighted gaps in affordability, multifunctionality, and field adaptability. These insights guided the creation of an innovative, cost-effective platform tailored to small-scale farms in African and Bangladeshi contexts, addressing both practical and technological limitations.

5.5 Use of Complex Engineering Problems

The development of a multipurpose agricultural robot presented a unique opportunity to engage with complex engineering challenges, requiring the integration of knowledge across multiple domains within Electrical and Electronics Engineering. The project extended beyond conventional circuit design and mechanical integration, encompassing real-time control, IoT connectivity, and energy management. One of the main challenges involved coordinating multiple subsystems simultaneously: a DC-motor-driven locomotion system, a servo-actuated seed sower, a brushless motor for grass cutting, and an irrigation pump controlled individually via ESP32 boards. Ensuring these subsystems operated harmoniously required careful management of power distribution, signal timing, and fault tolerance to prevent unintended interactions. Additionally, the system needed to process real-time environmental sensor data, including readings from the DHT11 temperature and humidity sensor and the capacitive soil moisture sensor. This necessitated the development of efficient algorithms to collect, process, and present sensor data on the Blynk IoT dashboard in a way that was both actionable and understandable for farmers. The inclusion of the ESP32-CAM module for live video streaming introduced further technical constraints related to bandwidth optimization and latency management. Addressing these issues mimicked the challenges faced in industrial-scale systems, where resources are limited, and reliable performance is critical. Resolving these problems involved iterative testing, troubleshooting, and optimization--a process reflective of real-world engineering practices. Successfully navigating these challenges demonstrates that the project team is capable of addressing multifaceted, ill-defined engineering problems that demand innovative, practical solutions.

5.6 Socio-Cultural, Environmental, And Ethical Impact

The design and development of the multipurpose agricultural robot were guided by careful consideration of socio-cultural, environmental, and ethical factors. In regions such as Africa and South Asia, agriculture is more than a livelihood--it is deeply embedded in cultural practices, community organization, and local traditions. The introduction of automation, therefore, needed to be sensitive to these dimensions to avoid disrupting the social fabric. From a socio-cultural perspective, the robot is intended to reduce the workload of smallholder farmers without requiring them to abandon traditional farming methods. It acts as a supportive tool rather than a replacement for human labor, assisting with tasks such as irrigation, seed sowing, and grass cutting, while preserving farmers' autonomy over their fields. This approach also encourages younger, technologically inclined generations to remain engaged in rural agriculture by integrating familiar IoT-based tools into traditional practices rather than displacing them. Environmentally, the robot promotes sustainability through intelligent water management. By integrating soil moisture and humidity sensors, it optimizes irrigation and reduces water wastage--a critical feature in regions experiencing water scarcity. Future incorporation of solar energy systems will further enhance sustainability by minimizing reliance on fossil fuels. These features support climate-resilient agricultural practices aligned with global sustainable development goals. Ethically, the project emphasizes accessibility and affordability. By keeping the design low-cost, the technology becomes available to smallholder farmers rather than being limited to large commercial operations. Transparent system design, safe electrical practices, and privacy-conscious IoT connectivity reinforce responsible engineering principles. Consequently, this project not only meets technical and functional objectives but also embodies social responsibility, addressing both the needs and ethical concerns of the communities it serves.

5.7 Attributes of Ranges of Complex Engineering Problem Solving (P1 – P7) Addressed

The following table shows the attributes of ranges of Complex Engineering Problem Solving (P1 – P7) addressed in EEE 4700 for Project and Thesis.

P	**Range of Complex Engineering Problem Solving**	**Put Tick (√)**
Attribute	Complex Engineering Problems have characteristic P1 and some or all of P2 to P7:	
Depth of knowledge required	**P1:** Cannot be resolved without in-depth engineering knowledge at the level of one or more of K3, K4, K5, K6 or K8 which allows a fundamentals-based, first principles analytical approach	√
Range of conflicting requirements	**P2:** Involve wide-ranging or conflicting technical, engineering and other issues	√
Depth of analysis required	**P3:** Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models	
Familiarity of issues	**P4:** Involve infrequently encountered issues	
Extent of applicable codes	**P5:** Are outside problems encompassed by standards and codes of practice for professional engineering	
Extent of stakeholder involvement and conflicting requirements	**P6:** Involve diverse groups of stakeholders with widely varying needs	√
Interdependence	**P7:** Are high level problems including many component parts or sub-problems	√

The following table explains or justifies how the attributes of ranges of Complex Engineering Problem Solving (P1 – P7) have been addressed in EEE 4700/4800 (Project and Thesis).

P	Explanation/Justification
P1	**Depth of knowledge required** – Developing this multipurpose agricultural robot demanded a strong understanding of electronics, including DC motors, sensors, and relays; embedded systems like the ESP32 and ESP32-CAM; IoT integration through platforms such as Blynk; and mechanical engineering principles for designing seed-sowing and grass-cutting mechanisms. Successfully combining these diverse areas required applying knowledge from multiple subfields of Electrical and Electronic Engineering.
P2	**Range of conflicting requirements** We have come across some technical issue related to the power distribution point since the 12V 37 GB required more power we need a battery that could sustain all of them and also the fact that many sensor where connected it made work conflictive
~~P3~~	
~~P4~~	
P5	
P6	**Interdependence of different elements** – Through our research process tried to collect some data about the current farming conditions from small farmer and stakeholders
P7	**Uncertainty and risk** – The project faced several potential risks, including connectivity interruptions, component failures, power instability, and the unpredictable conditions of agricultural environments. These challenges were mitigated through backup manual controls, modular testing, and the potential incorporation of solar power to provide a more reliable and sustainable energy source.

5.8 Attributes of Ranges of Complex Engineering Activities (A1 – A5) Addressed

The following table shows the attributes of ranges of Complex Engineering Activities (A1 – A5) addressed in EEE 4700 for Project and Thesis.

A	**Range of Complex Engineering Activities**	**Put Tick (√)**
Attribute	Complex activities means (engineering) activities or projects that have some or all of the following characteristics:	
Range of resources	**A1:** Involve the use of diverse resources (and for this purpose resources include people, money, equipment, materials, information and technologies)	√
Level of interaction	**A2:** Require resolution of significant problems arising from interactions between wide-ranging or conflicting technical, engineering or other issues	
Innovation	**A3:** Involve creative use of engineering principles and research-based knowledge in novel ways	√
Consequences for society and the environment	**A4:** Have significant consequences in a range of contexts, characterized by difficulty of prediction and mitigation	
Familiarity	**A5:** Can extend beyond previous experiences by applying principles-based approaches	

The following table explains or justifies how the attributes of ranges of Complex Engineering Activities (A1 – A5) have been addressed in EEE 4700/4800 (Project and Thesis).

A	**Explanation/Justification**
A1	**Involves the use of diverse resources** – This project combines a wide range of hardware and software elements, such as DC motors, L298N motor drivers, ESP32 controllers, servo motors, submersible water pumps, environmental sensors like the DHT11 and capacitive soil moisture sensor, and IoT platforms including Blynk. It demonstrates the ability to seamlessly integrate electronics, mechanical systems, programming, and wireless communication into a single, unified agricultural solution.
A2	

A3	**Involves standards and codes of practice** Safety and reliability were central to the design. Protocols for handling high-current devices such as motors, relays, and pumps were carefully observed. Best practices were also followed for IoT communication, modular architecture, and potential integration of renewable energy sources like solar panels. These precautions ensure the system is not only safe but also dependable, scalable, and compliant with recognized engineering norms.
A4	
A5	

REFERENCES

[1] Mr. Parth. N. Desai, "A Review on Multipurpose Agri Robot," *IJRASET*, vol. 12, no. 11, pp. 2539–2542, Nov. 2024, doi: 10.22214/ijraset.2024.65685.

[2] N. Jothippriya, N. S, G. K, A. G, and S. D, "Arduino based Multi-Purpose Agricultural Robot Powered by Internet of Things (IoT) Technology," in *2025 5th International Conference on Trends in Material Science and Inventive Materials (ICTMIM)*, Kanyakumari, India: IEEE, Apr. 2025, pp. 1003–1010. doi: 10.1109/ICTMIM65579.2025.10987914.

[3] S. S. Barhate, S. R. Lahamge, and P. V. Thokal, "Creation of a Solar-Powered, Multifunctional, Autonomous Agricultural Robot for Sustainable Farming Methods," in *2024 8th International Conference on Inventive Systems and Control (ICISC)*, Coimbatore, India: IEEE, Jul. 2024, pp. 681–683. doi: 10.1109/ICISC62624.2024.00120.

[4] A. A. Chand *et al.*, "Design and Analysis of Photovoltaic Powered Battery-Operated Computer Vision-Based Multi-Purpose Smart Farming Robot," *Agronomy*, vol. 11, no. 3, p. 530, Mar. 2021, doi: 10.3390/agronomy11030530.

[5] M. Nazir, T. Ahmed, M. T. Zaman, S. Iqbal, and K. M. Saad, "Design and Development of Multipurpose Agricultural Robot," in *2023 3rd International Conference on Digital Futures and Transformative Technologies (ICoDT2)*, Islamabad, Pakistan: IEEE, Oct. 2023, pp. 1–8. doi: 10.1109/ICoDT259378.2023.10325806.

[6] S. N. Priya, B. Karthikeyan, P. C. Kavinkumar, and R. Mugesh, "Design and fabrication of multipurpose agricultural robot," presented at the 7TH INTERNATIONAL CONFERENCE ON CIVIL ENGINEERING FOR SUSTAINABLE DEVELOPMENT: ICCESD24, Khulna, Bangladesh, 2025, p. 030017. doi: 10.1063/5.0246621.

[7] P. Krishnaleela, R. M. Prakash, K. Ramalakshmi, M. Manikandamoorthi, J. Jaisolairaj, and T. Sanjai, "Multi-Purpose Agricultural Pesticide Spraying Robot Using IoT," in *2024 2nd International Conference on Artificial Intelligence Trends and Pattern Recognition (ICAITPR)*, Hyderabad, India: IEEE, Dec. 2024, pp. 1–6. doi: 10.1109/ICAITPR63242.2024.10959847.

[8] N. T. V and H. M Kalpana, “Smart Multipurpose Agricultural Robot,” in *2021 IEEE International Conference on Electronics, Computing and Communication Technologies (CONECCT)*, Bangalore, India: IEEE, Jul. 2021, pp. 1–6. doi: 10.1109/CONECCT52877.2021.9622632.

[9] S. Thaitanun *et al.*, “Multipurpose Agricultural Robot Platform,” *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 895, no. 1, p. 012008, Jul. 2020, doi: 10.1088/1757-899X/895/1/012008.

[10] M. M. V. Sai, U. H. Babu, and N. H. Krishna, “Multipurpose agricultural robot using IoT,” presented at the THE 3RD INTERNATIONAL CONFERENCE ON MATHEMATICS AND SCIENCES (THE 3RD ICMSc): A Brighter Future with Tropical Innovation in the Application of Industry 4.0, East Kalimantan, Indonesia, 2022, p. 040004. doi: 10.1063/5.0110673.

[11] D. Zhang *et al.*, “Rapid field trace detection of pesticide residue in food based on surface-enhanced Raman spectroscopy,” *Microchim Acta*, vol. 188, no. 11, p. 370, Nov. 2021, doi: 10.1007/s00604-021-05025-3.