INTELLIGENCE ROVER

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INTERNAL EXAMINER **EXTERNAL EXAMINER**

ABSTRACT

Agriculture is undergoing a technological transformation with the integration of automation, artificial intelligence (AI), and robotics, enhancing efficiency and precision in farming practices. This project presents an Autonomous GPS Guided Rover for Agricultural Monitoring, designed to optimize field surveillance and crop disease detection. The rover uses GPS navigation for autonomous movement, allowing it to traverse predefined waypoints in agricultural fields. Equipped with a rocker-bogie mechanism, the rover can handle rough and uneven terrains, making it highly adaptable for large-scale farming operations. At each waypoint, the rover captures high-resolution crop images using a mobile device mounted on it. These images are transmitted in real-time for analysis using a YOLO (You Only Look Once) deep learning model. The model detects and classifies crop diseases with high accuracy, providing instant alerts to farmers through a mobile application. This real-time disease detection system reduces the need for manual crop inspections, enabling early intervention and minimizing potential yield losses. The project leverages Supabase, a PostgreSQL-based cloud storage platform, for storing navigation data, captured images, and disease detection results. This cloud integration ensures scalable and secure data management, allowing farmers to access historical data and monitor crop health over time.

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LIST OF ABBREVIATIONS

AI -	Artificial Intelligence
ESP -	Espressif Systems Platform
GPS -	Global Positioning System
IoT -	Internet of Things
ML -	Machine Learning
OSM -	OpenStreetMap
PWM -	Pulse Width Modulation
SQL -	Structured Query Language
TFLite -	TensorFlow Lite
UI -	User Interface
UAT -	User Acceptance Testing
WebRTC -	Web Real-Time Communication
YOLO -	You Only Look Once (object detection algorithm)

CHAPTER - I

INTRODUCTION

1.1 BACKGROUND OF THE PROJECT

Agriculture has long supported human civilization by providing food, raw materials, and livelihoods. However, it now faces challenges from population growth, urbanization, and climate change. The global population is expected to reach 9.7 billion by 2050, requiring a 60% increase in food production. At the same time, arable land is shrinking, making efficient farming practices vital.

Traditional farming methods, dependent on manual labor, often lead to inefficient resource use, soil degradation, and lack of real-time monitoring. Small-scale farmers, in particular, struggle with limited access to advanced technologies.

To overcome these challenges, automation and AI are transforming agriculture. The **Autonomous GPS-Guided Rover for Agricultural Monitoring** combines automation and machine learning for precision farming. It navigates fields autonomously using GPS and captures high-resolution images of crops and soil via a mobile phone camera. These images are processed to detect diseases and assess soil conditions.

The rover sends real-time data and insights to farmers through a User App, enabling informed decisions about irrigation, fertilization, and pest control. Real-time video streaming via WebRTC enhances remote field monitoring. The rocker-bogie mechanism allows the rover to navigate rugged terrain, and the use of a mobile phone eliminates the need for additional GPS modules.

The system uses Firebase Realtime Database and Supabase for efficient data storage and synchronization. Its automatic screen sharing feature ensures continuous monitoring. By reducing labor, optimizing water use, and enabling early disease detection, the rover supports sustainable farming practices.

It contributes to the UN’s Sustainable Development Goals, including Zero Hunger and Climate Action, by enhancing productivity and reducing environmental impact. Future versions may include yield forecasting and integration with automated irrigation, and its robust design makes it suitable for other applications like disaster monitoring and land surveying.

1.2 PROBLEM STATEMENT

Agriculture today faces numerous challenges affecting productivity, sustainability, and efficiency. With a growing global population, the demand for food is rising, yet the sector struggles with inefficient resource use, labor dependency, and limited real-time monitoring. Overuse of water, fertilizers, and pesticides leads to environmental degradation and wasted resources, while underuse causes poor crop growth and yield loss. Traditional methods rely heavily on manual labor and guesswork, making precise resource management difficult. Real-time field monitoring remains limited, especially in developing regions where farmers depend on manual inspections and traditional knowledge. Without real-time data on soil moisture, temperature, humidity, or disease indicators, decisions about irrigation and pest control are often delayed or inaccurate, leading to suboptimal crop management. The absence of predictive tools also prevents early action against diseases or extreme weather.

Labor-intensive practices further limit efficiency. Tasks like planting and inspecting crops demand physical effort, increasing costs and human error. In regions with labor shortages, this reduces productivity and hinders scalability. Traditional methods also impact the environment through soil degradation, water pollution, and greenhouse gas emissions from chemical use and residue burning.

The **Autonomous GPS-Guided Rover for Agricultural Monitoring** addresses these issues through automation, machine learning, and real-time monitoring. Navigating fields autonomously using predefined GPS points, the rover captures high-resolution images with a mobile phone camera. These are analyzed using YOLO-based machine learning to detect crop diseases and assess soil health.

Real-time video streaming via WebRTC allows farmers to monitor fields remotely, reducing the need for constant physical presence. The rover’s rocker-bogie mechanism ensures stable movement across rough terrain, making it ideal for large and uneven fields.

By automating inspections and providing real-time data, the rover helps optimize water usage, minimize pesticide application, and improve soil health. This reduces environmental impact and enhances yields while cutting labor costs. The system uses Firebase and Supabase for secure, scalable data storage and immediate access to insights via a mobile app.

Cost-effective and easy to deploy, the rover bridges the digital gap in agriculture. Supporting UN SDGs like Zero Hunger (Goal 2) and Climate Action (Goal 13), it promotes sustainable practices by improving productivity, reducing losses, and lowering farming’s environmental footprint.

1.3 OBJECTIVES OF THE PROJECT

The **Autonomous GPS-Guided Rover for Agricultural Monitoring** aims to improve agricultural productivity, efficiency, and sustainability through automation, real-time data collection, and AI-powered analysis. The primary goal is to develop a fully autonomous rover that navigates large fields using predefined GPS coordinates, eliminating the need for manual inspections and reducing labour and operational costs. Real-time navigation and data transmission allow farmers to monitor their fields remotely for better oversight.

A central focus is precise field monitoring and crop health assessment using machine learning. The rover uses a mobile phone camera to capture high-resolution images of crops and soil, which are analyzed using YOLO-based deep learning models to detect early signs of diseases, pests, and anomalies. This early detection enables preventive action, reducing losses and improving yields.

The rover also offers real-time video streaming using WebRTC, enabling farmers to visually monitor their fields with low-latency video. The automatic screen-sharing feature ensures continuous field monitoring without manual input, making the system efficient and dependable.

To promote sustainability, the rover provides real-time insights that help optimize water use, minimize pesticide and fertilizer waste, and support environmentally friendly practices. This approach conserves resources and reduces farming's environmental impact.

The project emphasizes accessibility and scalability by using cost-effective technologies. A mobile phone handles navigation, image capture, and GPS tracking, eliminating the need for costly modules. Firebase Realtime Database and Supabase manage data efficiently, giving farmers access to field data via the User App.

By combining automation, AI, and real-time monitoring, the rover empowers farmers with data-driven decision-making, reduces labour dependency, and enhances sustainable, profitable, and resilient farming.

1.4 SCOPE OF THE PROJECT

The **Autonomous GPS-Guided Rover for Agricultural Monitoring** involves the design, development, and implementation of a prototype capable of autonomous navigation, real-time monitoring, and AI-based crop analysis. The project aims to create a modular, scalable system that improves productivity, reduces labour dependency, and supports data-driven farming.

The rover integrates key hardware components like a rocker-bogie mechanism and a mobile phone for GPS navigation, image capture, and video streaming—eliminating external GPS modules. WebRTC enables low-latency video streaming for remote field monitoring. YOLO-based machine learning models analyze images for early signs of crop diseases and anomalies.

Software development includes a **User App** for marking GPS points, sending navigation commands, and accessing real-time data. The app is designed for ease of use and integrates with Firebase Realtime Database and Supabase to ensure instant cloud-based data access.

The project also implements real-time navigation algorithms, enabling the rover to autonomously follow designated paths and capture images at set coordinates. Calibration and testing optimize the system's accuracy and reliability. Field trials assess the rover's performance across different terrains and crop types, focusing on stability, precision, and analysis capabilities.

The ultimate goal is to deliver a scalable and cost-effective agricultural solution that provides real-time insights, automates field operations, and empowers farmers through intelligent decision-making.

1.5 SIGNIFICANCE OF THE PROJECT

The **Autonomous GPS-Guided Rover for Agricultural Monitoring** plays a vital role in transforming farming through automation, real-time monitoring, and AI-driven analysis. By combining GPS navigation, machine learning, and live video streaming, the project enhances productivity, improves resource use, and supports data-driven farming.

A key benefit is increased productivity through automated field inspections and real-time crop health monitoring. Using YOLO-based models, the rover detects early signs of disease and pests, enabling timely intervention. This helps prevent crop losses and boosts yields, improving food security and profitability. Real-time video streaming further reduces the need for physical inspections, making farm management more efficient.

The rover also enhances resource efficiency. By delivering real-time field insights, it enables targeted irrigation, fertilization, and pesticide application. This reduces overuse of inputs, lowers production costs, and supports sustainable practices. Farmers conserve resources while maximizing returns.

Environmental sustainability is another major advantage. Precision farming with the rover reduces chemical runoff, water wastage, and soil degradation. Its autonomous mobility decreases the need for human intervention, cutting emissions from transportation. By promoting responsible input use, it supports long-term soil health and biodiversity.

Economically, the rover reduces labour costs by automating monitoring and disease detection, allowing farmers to focus on higher-level decision-making and strategy.

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CHAPTER - II

LITERATURE REVIEW

The literature review examines key technologies relevant to intelligent agricultural rovers. It explores limitations of manual field inspection and benefits of autonomous navigation. GPS and mobile apps guide the rover to predefined field coordinates efficiently. Machine learning enables soil analysis and crop health assessment. Rocker-bogie mechanisms enhance mobility across rough agricultural terrain. WebRTC supports real-time video streaming, with Firebase for signalling and Supabase for storage. Computer vision, especially YOLOv8, improves real-time crop disease detection and image analysis. These components form the basis of the proposed intelligent GPS-guided rover system.

2.1. Title: " ***Smart Agriculture Monitoring Rover for Small-Scale Farms in Rural Areas using IoT*****"Authors: Aishwarya Girish Menon, M Prabhakar.Published in:** ***IEEE 2021 International Conference on Innovative Computing, Intelligent Communication and Smart Electrical Systems (ICSES)***

This paper presents an innovative IoT-based agricultural monitoring system designed for small-scale farms, particularly in rural regions where labor availability and technological access are limited. The system is built around an Arduino Mega microcontroller and integrates various environmental sensors to monitor parameters such as soil moisture, temperature, humidity, pest activity, and fire hazards. Its primary function is to provide real-time data to farmers, enabling them to make informed decisions to improve crop health and yield.

A significant feature of the system is its ability to automate pesticide spraying and irrigation based on environmental readings. For instance, if the soil moisture level drops below a certain threshold, the rover can activate its irrigation system to water the crops. Similarly, it can initiate pesticide spraying when pest activity is detected. The automation reduces the need for constant human supervision and helps conserve resources by applying inputs only when necessary. Moreover, the system is powered using solar energy, which ensures sustainability and makes it ideal for remote areas without consistent electricity access.

By combining real-time monitoring, automation, and renewable energy, this rover-based system brings precision agriculture within reach for small farmers. The authors highlight that the integration of IoT with robotics allows for continuous surveillance of crop conditions, efficient use of agricultural inputs, and improved productivity. This research demonstrates the potential of low-cost, smart agricultural systems to transform traditional farming practices in under-resourced regions.

2.2. Title: "Soil Analysis Using Autonomous Rover"Authors: rinivasan K, S Sree Hari, S Sanjay Kumar, S G Hari, S Haresh.Published in: *IEEE 2024 International Conference on Communication, Computing and Internet of Things (IC3IoT)*

This study introduces a fully autonomous rover system designed to assess soil health and deliver crucial agricultural insights in real time. The system is equipped with multiple soil sensors capable of detecting moisture content, temperature, and fertility levels. By traveling across a predefined area of farmland, the rover collects comprehensive data that can be used to evaluate soil conditions and inform decisions related to crop planning and land preparation. This helps farmers understand whether their soil is suitable for planting or if additional inputs such as fertilizers are needed.

In addition to soil analysis, the rover incorporates an ESP-32 camera for real-time visual surveillance. This feature allows farmers to remotely observe the physical condition of their fields, monitor crop growth, and detect any irregularities such as pest infestations or water stress. The live camera feed, along with sensor data, is transmitted wirelessly to a centralized monitoring system where it can be reviewed and analyzed. This dual approach — combining sensor readings with visual input — enhances the accuracy and effectiveness of the monitoring process.

The rover’s autonomous capabilities eliminate the need for manual data collection, significantly reducing labor efforts and time. It supports timely intervention, enabling farmers to take immediate corrective measures when abnormal soil or crop conditions are detected. The study emphasizes the importance of integrating real-time surveillance with autonomous mobility to provide a scalable and efficient solution for modern precision agriculture.

2.3. Title: "Intelligent Agri Tech Rover: Real-Time Data Logging and Machine Learning for Optimal Crop Management"Authors: V. Sathya, Santhosh K, Rahul A.Published in: IEEE 2024 International Conference on Power, Energy, Control and Transmission Systems (ICPECTS)

This research proposes an intelligent agricultural rover system that combines real- time data logging and machine learning techniques to improve crop management. The system is designed to help farmers analyze soil quality, monitor crop growth, and optimize irrigation. By deploying sensors and a mobile rover, the solution gathers environmental and soil data, which is then used to train machine learning models. These models help determine the most suitable crops for specific land conditions and predict harvest timelines.

The machine learning algorithms integrated into the rover are capable of identifying plant diseases and tracking crop maturation. With this information, the system supports decision-making related to timely interventions, such as applying fertilizers, watering, or harvesting. By logging data continuously, the model refines its predictions and adapts to changing conditions in the field, offering increasingly accurate insights to the farmer.

2.4. Title: " Smart Agricultural System Based on Machine Learning and IoT Algorithm"Authors: Vinod H Patil, Anurag Shrivastava.Published in: ***IEEE 2022 2nd International Conference on Technological Advancements in Computational Sciences (ICTACS)***

In this study, the authors introduce a smart agricultural monitoring system that employs machine learning algorithms in conjunction with IoT technology for improved crop management. At the heart of the system is a rover powered by the YOLOv3 object detection model, which is trained to identify weeds with high accuracy. This enables automated weed removal, enhancing the efficiency and productivity of farmland maintenance.

The rover continuously captures frames as it moves through the field, analyzing each frame in real time to detect unwanted vegetation. With a reported accuracy of 95%, the YOLOv3 model ensures that most weeds are identified and removed, minimizing crop competition and preserving soil nutrients for optimal plant growth. This approach reduces manual labor and allows for targeted weed control, which is both time-saving and cost-effective in the long run.

2.5. Title: " Smart Agriculture Implementation using IoT and Leaf Disease Detection using Logistic Regression"Authors: T. Rajeswari, P. A. Harsha Vardhini.Published in: IEEE, 2021 4th International Conference on Recent Developments in Control, Automation & Power Engineering (RDCAPE)

This study presents an IoT-based smart farming system using Arduino Mega to automate crop monitoring. It detects leaf diseases via logistic regression and automates water and pesticide spraying. Solar energy powers the setup, making it sustainable and efficient. The model ensures healthier crops and water conservation by acting based on real-time sensor data.

Despite its advantages, the system depends heavily on sunlight, limiting functionality during overcast weather. Additionally, the high initial cost can be a barrier for small-scale farmers. This research demonstrates the potential of integrating AI and IoT for precision agriculture, emphasizing energy efficiency and disease prevention.

2.6. Title: " ***Design and Development of Prototype Based Solar Powered Multi-Functional AgRover*****"Authors: Divyashree B. P., Lakith G., Ananya R. Prabhu.Published in: IEEE, 2023 7th International Conference on CSITSS**

This study presents a multi-functional solar-powered agricultural rover designed for soil analysis and remote monitoring. The system uses various sensors to measure parameters like moisture and pH, along with an ESP-32 camera for visual surveillance.The rover supports farmers by providing real-time feedback on soil conditions, enabling better decision-making for irrigation and fertilization. It is especially suited for small farms aiming to reduce manual labor and increase productivity.

The use of solar power allows it to operate in areas without reliable electricity. Its mobility enables coverage of multiple zones within a field, making it a practical tool for precision agriculture.Nevertheless, challenges include sensor inaccuracies across different soil types and limited field coverage due to the rover’s compact size. These drawbacks need addressing before large-scale deployment is feasible.

2.7. Title: "*LIDAR-based Navigation Rover for Fields with Smart Pest Sprayer using Machine Vision*"Authors: Thamaraiselvan, M. Isaac Vivin, Ronald K.Published in: IEEE, 2023 9th International Conference on ICACCS

This research introduces a LIDAR-based rover integrated with a smart pest spraying system for precision agriculture. The rover uses machine learning and machine vision to identify crop health and soil conditions in real-time. It processes visual and sensor data to detect diseases and optimize spraying efforts, reducing chemical usage and enhancing crop yield. The LIDAR system aids in autonomous navigation across varied terrain, ensuring full-field coverage.

Machine learning algorithms are central to its analysis of soil and crop status, helping farmers make informed decisions. The overall goal is to minimize manual labor while improving farm productivity. However, the system demands large, high-quality datasets for accurate learning and prediction. Additionally, the cost of implementation is relatively high due to the use of LIDAR and processing components.

2.8. Title: " An Autonomous Hybrid Drone-Rover Vehicle for Weed Removal and Spraying Applications in Agriculture"Authors: J. Krishna Kant, Mahankali Sripaad.Published in: IEEE, 2023 IEEE International Conference on AGRETA

This study presents a hybrid autonomous system that combines drones and rovers for weed detection and removal. The system leverages YOLOv3 to detect weeds between crops with high precision. Once weeds are identified, the rover navigates to eliminate them using a targeted spraying mechanism, reducing herbicide use and improving efficiency. The hybrid approach allows both aerial and ground-level monitoring.

The integration of deep learning with robotics allows for real-time operation and continuous field analysis. This supports precision farming by automating one of the most labor-intensive tasks in agriculture.

Nonetheless, the model may still miss some weeds due to limited detection accuracy. Additionally, real-time image processing and decision-making can introduce delays in fast-moving scenarios.

2.9. Title: " IoT-Based Crop Disease Detection and Management System Using Machine Learning Algorithms"Authors: Geetha Manoharan, S. Dada Noor.Published in: IEEE, 2024 International Conference on Science Technology Engineering and Management (ICSTEM)

This work presents an IoT-driven crop disease detection system utilizing drones and machine learning for precision farming. The system primarily aims to identify plant health issues at early stages.

A drone equipped with multispectral sensors captures field data, which is then analyzed using machine learning algorithms to detect signs of crop disease. This enables timely interventions and better crop outcomes.

The system also generates insights for precision agriculture, allowing farmers to make data-driven decisions about spraying and harvesting. Such automation helps reduce manual inspection efforts.

Despite its advantages, the solution is limited by drone dependency on favorable weather and high computational requirements for processing large image datasets.

2.10. Title: " *An Efficient, Low-cost Plant Disease Detection System using IoT*"Authors: K. V. Paresh, Nitin Srinivasan, P. Gautham Raj.Published in: IEEE, 2022 International Conference on Futuristic Technologies (INCOFT)

This project introduces a cost-effective plant disease detection and irrigation system using IoT technologies. The primary focus is on improving water management and early disease identification.

Soil moisture sensors are deployed in the field to collect real-time data. Combined with weather forecasts, the system automates irrigation schedules to conserve water and improve efficiency.

The IoT system facilitates low-cost monitoring, making it suitable for small-scale farmers. It helps maintain optimal conditions for plant health and supports early detection through environmental monitoring.

However, the system may face issues due to sensor degradation over time and dependence on weather forecast data, which can sometimes be inaccurate.

CHAPTER - III

METHODOLOGY

3.1 RESEARCH DESIGN

The The research design phase of the **Autonomous GPS-Guided Rover for Agricultural Monitoring** laid the foundation for a precision agriculture system powered by automation, machine learning, and real-time monitoring. It began with a literature review on autonomous navigation, AI-based disease detection, and field monitoring, identifying gaps and opportunities for integrating GPS guidance with machine learning in agriculture.

Primary data was collected through interviews with farmers and experts, revealing key challenges such as labour-intensive monitoring and lack of real-time data. Field visits further informed the rover's design, particularly the need for terrain adaptability, leading to the implementation of a rocker-bogie mechanism for stability. Insights from these visits also shaped the use of YOLO-based models for crop disease detection, trained on diverse crop images.

Key performance indicators (KPIs) were defined to measure effectiveness in navigation accuracy, real-time image capture, and disease detection precision. Navigation was assessed by GPS tracking deviation, while detection was evaluated using precision and recall metrics.

A feasibility study assessed the rover's technical and economic viability, including hardware availability, GPS and internet support, and farmer usability. Costs were analyzed against potential efficiency gains.

The conceptual framework defined hardware (rocker-bogie, mobile camera, GPS), software (navigation, AI models, WebRTC), and user interfaces (User App, Rover App). Potential risks like GPS loss and image latency were addressed with solutions such as offline navigation and local data storage. This phase ensured a data-driven, farmer-focused approach to building a functional, reliable agricultural monitoring system.

3.2 SYSTEM ARCHITECTURE

The system architecture of the Autonomous GPS-Guided Rover for Agricultural Monitoring is modular, scalable, and designed for efficient field monitoring and real-time crop analysis. It comprises three main layers: navigation, data processing, and communication.

The navigation layer uses the mobile phone's GPS and Google Maps API for tracking, with OpenStreetMap (OSM) for free mapping access. It enables the rover to follow user-defined coordinates, avoid obstacles, and optimize paths. The rocker-bogie mechanism ensures stability across uneven terrain.

The data processing layer captures high-resolution images via the mobile phone and uses a YOLO-based machine learning model to detect crop diseases. It highlights anomalies with bounding boxes and applies enhancement algorithms for better image clarity. Detected diseases and confidence scores are shown in the User App for real-time insights.

The communication layer enables real-time data transmission. WebRTC supports low-latency video streaming from the rover, with Firebase Realtime Database used for signaling. Supabase manages user authentication, coordinate storage, and image uploads, ensuring seamless data flow between the rover and the User App.

The **User App** provides a simple UI for marking coordinates, sending commands, and viewing detection results. The **Rover App**, running on the rover's mobile device, handles GPS navigation, image capture, and video streaming.

The architecture supports offline operation, with local data storage during connectivity loss and cloud sync upon reconnection. It is energy-efficient, using mobile GPU for inference and power-saving modes during extended use. Error handling mechanisms address issues like GPS loss and upload failures.

Designed for flexibility, the system can integrate additional sensors or AI models, making it adaptable to various agricultural needs.

3.3 HARDWARE COMPONENTS

The hardware components of the Autonomous GPS-Guided Rover for Agricultural Monitoring are carefully selected to ensure reliability, efficiency, and durability, enabling seamless navigation, data collection, and image analysis in diverse agricultural environments. The hardware is divided into three main categories: the navigation system, the image acquisition and processing unit, and the power and communication modules, each playing a vital role in the rover's functionality.

The navigation system forms the core of the rover's autonomous mobility. It consists of a GPS-enabled mobile device that utilizes the Google Maps API to navigate through user-defined coordinates. The device receives real-time location updates and sends navigation commands to the rover's microcontroller. The rover uses a rocker-bogie mechanism to ensure stability and traction on rough terrain, making it capable of traversing uneven fields with minimal tilting or slipping. The navigation system is designed for high precision, ensuring the rover accurately follows the predefined path while avoiding obstacles. The rover's wheels are equipped with high-torque DC motors that provide the necessary power to climb over rocks, furrows, and uneven surfaces, ensuring consistent movement across agricultural fields.

The image acquisition and processing unit handles data collection and analysis. The mobile device mounted on the rover captures high-resolution images of crops and soil at each marked coordinate. The images are processed using a YOLO-based machine learning model running on the mobile device's GPU. This model identifies crop diseases and soil conditions by analyzing visual patterns such as leaf discoloration, fungal infections, and growth abnormalities.

The results, including disease classifications, confidence scores, and bounding boxes, are overlaid on the images to highlight affected areas. The image processing unit ensures that the analysis is performed in real time, enabling timely intervention by farmers.

The power and communication modules ensure the rover's autonomous functionality and real-time connectivity. The rover is powered by rechargeable lithium-ion batteries, providing sufficient runtime for extended field operations. The mobile device on the rover handles both navigation and image processing, reducing the need for external computation units, thereby optimizing power consumption. The communication module uses WebRTC for low-latency video streaming, allowing users to remotely monitor the field through a live feed.

The rover uses Firebase Realtime Database for WebRTC signaling, ensuring a reliable peer-to-peer connection. For data storage and retrieval, the system uses Supabase, which handles user authentication, image uploads, and coordinate storage. This ensures that the collected data is securely stored and easily accessible for later analysis.

The user interface is an essential component of the system, allowing farmers to control and monitor the rover remotely. The User App provides an intuitive interface for marking field coordinates, sending navigation commands, and viewing the analyzed images and disease reports. The Rover App, installed on the mobile device attached to the rover, handles image capture, navigation, and video streaming. The interface displays real-time location tracking, enabling users to monitor the rover's position and progress.

3.3.1. ESP 8266

The ESP8266 is a powerful, low-cost, and energy-efficient microcontroller widely used in IoT (Internet of Things) and embedded systems. It features a dual-core Tensilica LX6 processor, integrated Wi-Fi making it ideal for wireless communication and remote-control applications. The ESP8266 also includes a rich set of peripherals, such as GPIO pins, SPI, I2C, UART, and ADC, enabling seamless interfacing with sensors, actuators, and other components. Its low power consumption and support for deep sleep modes make it suitable for battery-operated devices. Additionally, the ESP8266 is programmable using popular platforms like Arduino IDE, MicroPython, and ESP-IDF, offering flexibility for developers. With its compact size, robust performance, and extensive community support, the ESP8266 is widely used in applications such as home automation, wearable devices, environmental monitoring, and smart agriculture, making it a versatile choice for IoT projects.

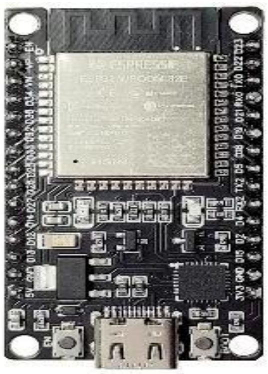

Fig 3.1: ESP 8266

3.3.2. Mobile Phone (Camera, GPS, and Communication Module)

The rover is equipped with a mobile phone that serves as the primary unit for navigation, image capture, and data processing. Unlike traditional robots that require separate GPS modules, cameras, and processing units, the integration of a smartphone simplifies the architecture by leveraging built-in capabilities. The phone uses the Google Maps API for GPS-based navigation, allowing the rover to autonomously move to predefined coordinates set by the user through the User App. This eliminates the need for an external GPS module, reducing hardware complexity and cost.

Fig 3.2: Mobile Phone

3.3.3. Motor Driver L298N

The movement of the rover is controlled by DC motors, which receive power and speed regulation through an L298N motor driver. This motor driver is essential in controlling the speed, direction, and torque of the rover, ensuring that it follows designated paths without deviation.

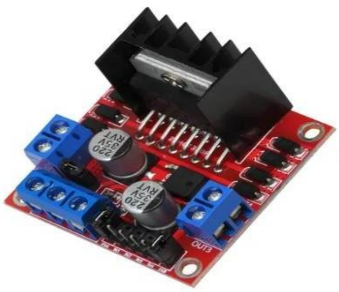

Fig 3.3 L298N Motor Driver Module

3.3.4. DC Motors

Unlike traditional tractors or automated agricultural vehicles that rely on heavy-duty engines, the DC motor-based drive system provides a lightweight, power-efficient alternative suitable for small-scale and precision farming applications. The use of Pulse Width Modulation (PWM) control allows smooth acceleration and deceleration, preventing abrupt movements that could damage delicate crops.

Fig 3.4: Johnson Geared Motor 30 RPM 12v dc gear

3.3.5. Battery and Power Management System

A 12V Li-ion rechargeable battery powers the entire rover, supplying energy to the microcontroller, motors, and communication modules. Efficient power management is critical to ensure that the rover can operate for extended periods without requiring frequent recharging. Unlike conventional lead-acid batteries, Li-ion batteries provide higher energy density and longer lifespan, making them a reliable choice for autonomous systems.

Fig 3.5: 12 V Battery

3.4 SOFTWARE DEVELOPMENT

The **software development phase** of the *Autonomous GPS-Guided Rover for Agricultural Monitoring* includes four key modules: data acquisition and processing, machine learning for image analysis, real-time communication, and user interface development.

Data acquisition and processing is handled by the GPS-enabled Rover App, which continuously fetches location using Google Maps API and sends navigation commands to the microcontroller. It captures images tagged with GPS coordinates and timestamps, stores them locally if offline, and uploads them to Firebase Realtime Database when connectivity is restored.

Machine learning is powered by a YOLO-based model running on TensorFlow Lite. It detects crop diseases in real time, highlighting diseased regions with bounding boxes and confidence scores. Processed results are sent to the User App. The model is updated over time with new data to improve accuracy.

Real-time communication uses WebRTC for video streaming between the Rover App and User App, with Firebase Realtime Database managing signaling. It supports peer-to-peer video, live location updates, and image transmission under varying network conditions.

The user interface is designed to be simple and responsive. The User App allows users to mark coordinates, send commands, and view real-time rover location on a map. It also displays disease detection results with overlays and provides push notifications when targets are reached or diseases detected.

Cloud integration with Supabase ensures secure user authentication, image storage, and coordinate management. Farmers can access historical data, share it with experts, and make decisions remotely.

Decision support tools offer crop management recommendations based on disease analysis, helping farmers act quickly with minimal technical knowledge.

3.4.1. Disease Detection Using YOLO

The images provided demonstrate an AI-powered disease detection system that leverages the YOLO (You Only Look Once) object detection model to identify plant leaf diseases. The model efficiently detects affected areas by drawing bounding boxes around regions showing symptoms of infection. This real-time disease detection approach is crucial in precision agriculture, allowing farmers to diagnose plant health issues early and take necessary actions before significant crop damage occurs.

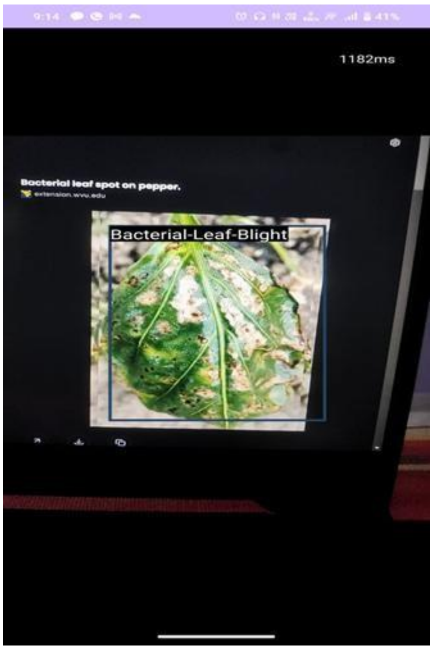

Fig 3.6: Leaf Disease Detection

In the **first image**, the system detects multiple instances of disease symptoms on the leaf surface, with discolored regions, visible spots, and irregular patterns indicative of plant infections. The bounding boxes demonstrate that the YOLO-based model accurately differentiates between healthy and unhealthy areas. Similarly, in the **second image**, the detection system identifies lesions and abnormal coloration as symptoms of leaf disease.

Integrating YOLO for disease detection offers several advantages over traditional manual inspection methods. Unlike conventional approaches that rely on expert physical examination, this AI system processes images instantly, enabling fast and accurate disease identification. YOLO's single-shot detection mechanism allows for real-time predictions without multiple image passes.

In agricultural applications, this system can be integrated into smartphone apps, drones, or automated farming robots, allowing farmers to scan large fields quickly. This reduces manual labor, supports early intervention, and facilitates precision pesticide application, ultimately reducing costs and improving crop yield. Furthermore, by storing detected results in cloud databases, farmers can track disease outbreaks over time, aiding in long-term agricultural planning.

3.4.2. Location Plotting

This image is a screenshot of a map-based navigation interface from the User App of the Autonomous GPS-Guided Rover for Agricultural Monitoring.

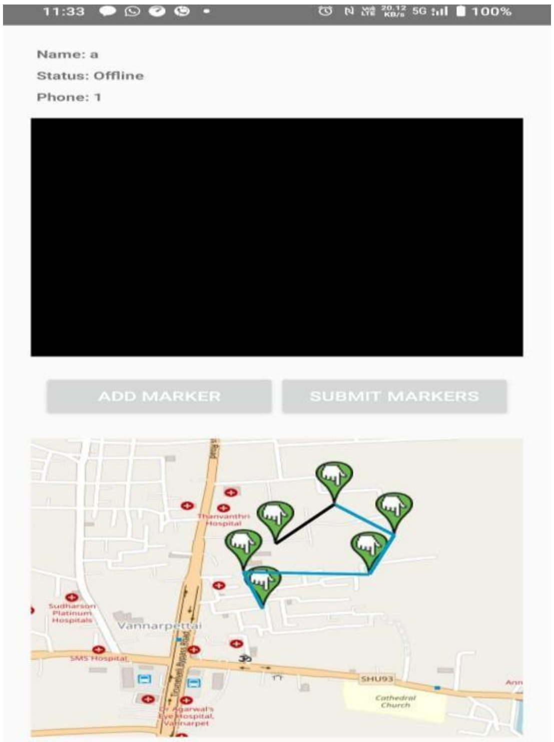

Fig 3.7: Location Plotting

The interface displays a Google Maps view with several red location markers connected by black lines, forming a structured path. The blue dot represents the user's or rover's current location. A label, "Location #1," is attached to one of the markers, likely indicating a specific waypoint in the navigation sequence.

The app allows users to mark multiple coordinates in a field, define a path, and send navigation commands to the rover, which follows the designated route. This system is part of an agricultural monitoring solution, where the rover captures soil and crop images at each marked location and sends the data for analysis.

3.4.3. Authentication System

The authentication system in both the User Device App and Rover Device App is built using Supabase SQL in Android Studio with Kotlin, ensuring secure login and registration processes.

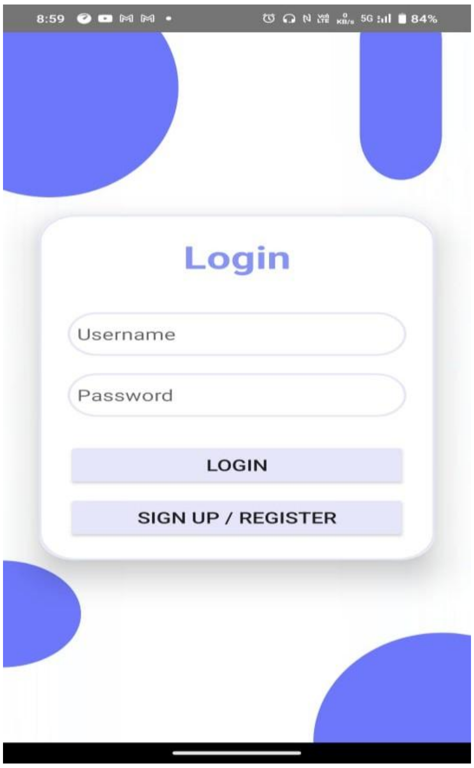

Fig 3.8: Login page

The **User App** allows farmers or researchers to create an account by providing a unique username, email, and password, which are stored in Supabase. The app verifies the uniqueness of the username before registration to avoid duplicates. During login, the credentials are authenticated with the database, granting users access to features like marking coordinates and sending navigation commands to the rover.

The **Rover App**, installed on the mobile device attached to the autonomous rover, features a secure authentication system to restrict unauthorized access. Each rover is assigned a unique ID and password, securely stored in Supabase SQL. This prevents unauthorized devices from interacting with the rover's navigation or data transmission functions. Once authenticated, the rover can receive navigation instructions, capture real-time images, and transmit the collected data back to the User App. Token-based authentication ensures that only authenticated sessions can access or exchange data, significantly reducing the risk of unauthorized access and spoofing.

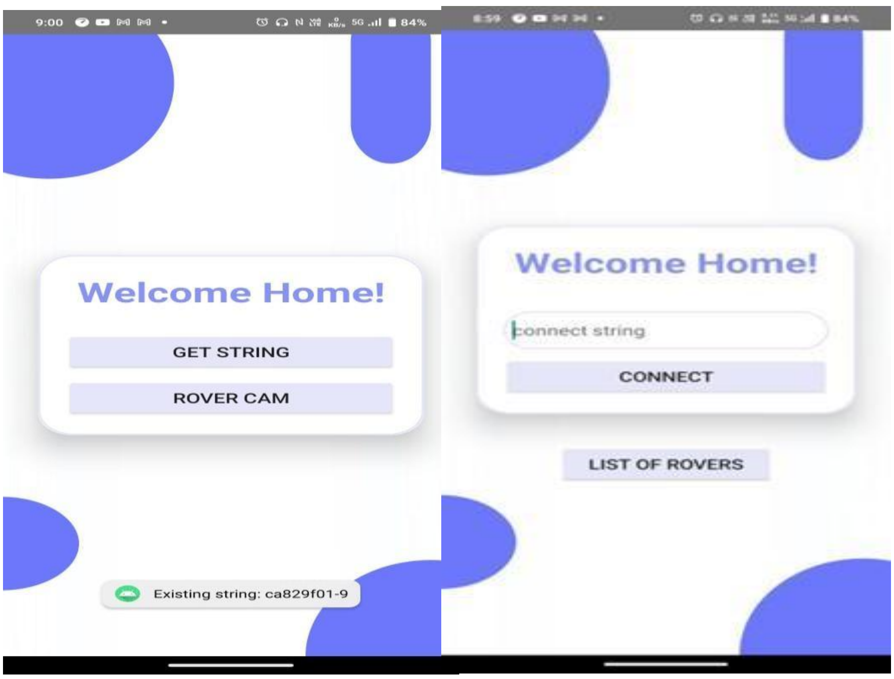

Fig 3.9: Authentication page

To prevent conflicts or multiple users from controlling the same rover, **Supabase enforces a one-rover-per-user policy**. This mechanism ensures that no two users can log in and access the same rover simultaneously, preventing accidental or malicious interference. By applying this **exclusive control mechanism**, the system guarantees that each rover follows commands from only one user at a time. The integration of **Supabase SQL authentication** offers several advantages for the agricultural monitoring system. It provides a **centralized and secure login system**, allowing for **efficient user management**. Additionally, the use of SQL ensures that the system is **scalable and flexible**, making it capable of handling a growing number of rovers and users.

3.4.4 Rover Status Dashboard Interface

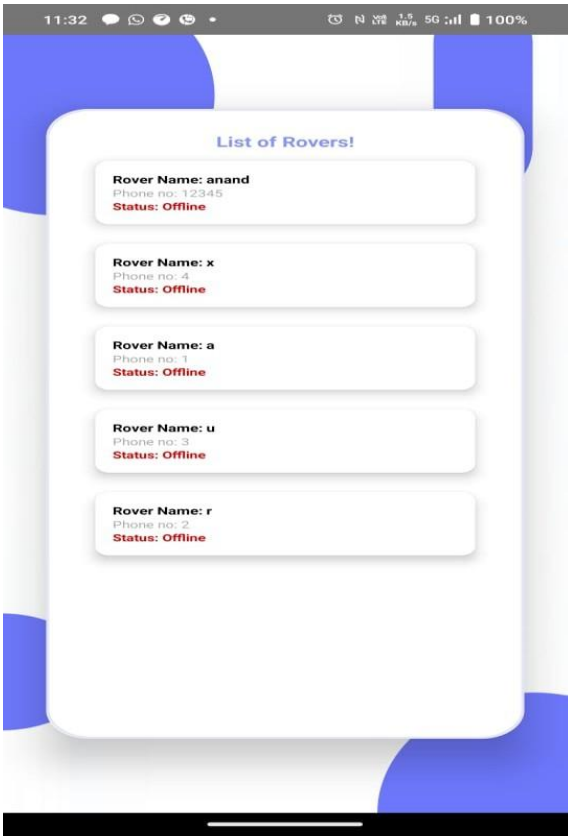

Fig 3.10: List of rovers

The image showcases a user interface from a mobile application designed for monitoring and managing multiple agricultural rovers. The interface follows a clean, organized layout, displaying each rover's details in individual rectangular cards. Each card contains essential information such as the **rover name**, **phone number**, and its current **status**. The **status** for all the rovers shown in the image is marked as **"Offline"** in bold red text, making it easy for users to identify inactive rovers at a glance. The **rover names** are displayed in black, followed by their respective phone numbers in a lighter gray, indicating the app might support communication, tracking, or identification through these contact details.

The header, titled **"List of Rovers!"**, clearly defines the purpose of the interface, signaling that it serves as a dashboard for viewing multiple rovers simultaneously. The cards are arranged vertically with ample spacing, ensuring readability and accessibility..This application interface is likely part of an agricultural monitoring system, enabling users to keep track of the connectivity and operational status of their rovers in real time. By displaying phone numbers, the app may offer direct communication capabilities or device identification, streamlining the management process. The **offline status** suggests that the rovers are either powered off, out of range, or disconnected from the network.

3.5 INTEGRATION OF HARDWARE AND SOFTWARE

The integration of hardware and software in the **Intelligence Rover** is a crucial phase to ensure seamless interaction for effective agricultural monitoring and crop disease detection. This integration process follows a structured approach, encompassing communication protocol selection, data synchronization, system calibration, and extensive testing to ensure efficiency, reliability, and ease of use.

Establishing robust communication protocols is the first step in integration. The **ESP32 microcontroller**, which manages motor control and sensors, communicates with the mobile-based **Rover App** via Wi-Fi and Bluetooth Low

Energy (BLE). This ensures low-latency transmission of movement commands and sensor data. The mobile device uses the **Google Maps API** for GPS-based navigation, transmitting waypoints and rover coordinates to the **User App**. **Supabase** serves as the cloud database for real-time storage and retrieval of crop health data, images, and navigation logs. This multi-protocol architecture ensures continuous communication between the rover, user, and cloud system, optimizing autonomy and data processing capabilities.

Data synchronization is key for real-time monitoring and decision-making. As the rover moves through the farmland, its mobile device captures high-resolution images that are processed by the **YOLO deep learning model** for disease detection. The results, including identified disease types and severity levels, are uploaded to **Supabase**, allowing farmers to access historical data for long-term analysis. To ensure data consistency, the system handles network delays by storing data locally during intermittent connectivity and uploading it once a stable connection is re-established.

System calibration ensures that the rover's hardware operates accurately. **GPS calibration** improves waypoint tracking accuracy, reducing errors in navigation. The **rocker-bogie mechanism** is adjusted to enhance stability on uneven terrains, preventing instability or tilting. The **YOLO model** is fine-tuned using a dataset of agricultural images to enhance disease detection accuracy. Additionally, sensors for environmental data collection, such as temperature, humidity, and soil conditions, are calibrated to ensure precise measurements.

Thorough testing is conducted to validate the integrated system under various agricultural conditions. The rover undergoes field trials across different terrains, including flatlands, sloped fields, and muddy environments, to assess mobility and endurance. **Stress testing** is performed under varying weather conditions to ensure stable operation in extreme temperatures and humidity. The reliability of the **AI-powered disease detection system** is evaluated by comparing its results to manual expert assessments, refining the model's accuracy. Furthermore, **system recovery mechanisms** are implemented to detect hardware failures, such as GPS signal loss or motor malfunctions, triggering fail-safe protocols like manual overrides and alternative navigation routes.

By seamlessly integrating hardware and software, the **Intelligence Rover** achieves high automation, data-driven decision-making, and adaptability, providing a transformative solution for precision agriculture.

3.6 TESTING AND VALIDATION

The Testing and Validation phase ensures the Intelligence Rover meets performance objectives and operates effectively in real-world agricultural conditions. This phase evaluates the rover's hardware, software, and overall system functionality, focusing on accuracy, durability, efficiency, and user-friendliness to detect and fix potential issues before deployment.

Validation begins with unit testing, where components like the GPS, motors, microcontrollers, camera modules, and deep learning algorithms are tested separately. The GPS is tested for location accuracy, and the YOLO disease detection model is assessed using labeled datasets. Motor control and obstacle avoidance are tested for reliable navigation, while the Rover and User Apps are verified with simulated data for command transmission.

After unit testing, integration testing ensures smooth interaction between hardware and software, such as data flow between the rover's mobile phone, ESP32 microcontroller, and Supabase database. Real-world scenarios, like capturing crop images and transmitting results to the User App, are evaluated for response time, synchronization, and reliability. Stress testing checks system performance under extreme conditions like poor connectivity or low battery.

Field testing assesses the rover's real-world performance on different terrains and weather conditions, observing its navigation and data collection abilities. Feedback from farmers helps refine usability, disease detection, and labor reduction. Key performance indicators (KPIs) like disease detection accuracy and data processing speed are measured for precision agriculture impact.

User Acceptance Testing (UAT) ensures the system is intuitive and beneficial to farmers. Users test features like marking waypoints, receiving alerts, and reviewing data. Their feedback is used to improve the user experience, navigation, and data visualization, making the rover an efficient and reliable tool for precision farming.

3.7 DATA COLLECTION AND ANALYSIS

The Data Collection and Analysis phase is crucial for the Intelligence Rover project, enabling precise agricultural monitoring, early disease detection, and optimized farming decisions. It involves collecting, processing, and interpreting real-time data from sensors, cameras, GPS, and cloud storage to provide actionable insights that enhance crop health and promote sustainable farming practices.

The process begins with data collection, where the rover autonomously navigates agricultural fields, capturing images, GPS coordinates, and environmental data. The rover’s mobile phone serves as the data acquisition unit, capturing high-resolution crop images and recording GPS coordinates for mapping affected areas. Telemetry data like speed, terrain conditions, and battery status are also transmitted to the cloud for analysis. Supabase stores all data securely for remote access and long-term monitoring.

After collection, the data undergoes preprocessing to improve quality. Image preprocessing, including noise reduction and contrast enhancement, is done using OpenCV and deep learning techniques. GPS data is validated to ensure accurate field mapping, and duplicates or missing records in the database are addressed through data validation techniques.

Data analysis follows, where AI-driven techniques extract insights. The YOLO model classifies plant diseases, providing early warnings, while descriptive analytics summarizes disease frequency and affected regions. Diagnostic analytics identifies patterns, such as correlations between environmental factors and disease occurrence, and predictive analytics forecasts future outbreaks. These insights are presented as actionable recommendations in the User App, such as targeted pesticide application or adjustments to irrigation.

The collected data also helps evaluate key performance indicators (KPIs) like disease detection accuracy, rover efficiency, and resource savings, comparing AI-driven disease detection to traditional methods. The environmental impact is assessed by analyzing reductions in pesticide use, improved yields, and soil health.

Data visualization tools, including dashboards and heatmaps, are integrated into the User App, allowing farmers to interpret real-time updates, historical trends, and rover movements. This combination of AI-powered analysis and user-friendly presentation helps farmers optimize agricultural practices, increasing productivity and minimizing risks.

3.8 ITERATIVE DEVELOPMENT AND IMPROVEMENT

The Iterative Development and Improvement phase is key to the Intelligence Rover's evolution, ensuring it stays adaptable, efficient, and responsive to modern agricultural needs. Using an agile approach, the rover undergoes continuous refinement through cycles of testing, user feedback, performance evaluation, and optimization, making it a robust solution for precision farming.

The process begins with the initial deployment of the rover in test farms, where real-world data is collected on navigation accuracy, disease detection, power consumption, and system responsiveness. Farmers and experts provide feedback on usability, effectiveness, and challenges, which helps identify areas for improvement, such as refining AI disease detection models or optimizing the navigation system. Based on feedback and data, the project team prioritizes enhancements for the next cycle. For instance, if disease detection results are hard to interpret, improvements like visual severity indicators are considered. If terrain navigation issues arise, adjustments may be made to the suspension or motor control systems, ensuring the rover remains practical and user-friendly.

Prototypes of new features—whether hardware or software—are tested in simulated environments before field deployment. For example, an updated YOLO model is tested for accuracy before integration, and GPS-based waypoint tracking is tested for smooth navigation. Small-scale user trials confirm that these changes meet practical needs.

Once validated, improvements are integrated and deployed for extended evaluation. Performance monitoring ensures that updates lead to measurable benefits, such as reduced false positives in disease detection and better navigation efficiency. The deployment-assessment-refinement cycle continues, allowing the rover to evolve and adapt to new agricultural challenges. Scalability testing ensures the rover works across diverse landscapes, including varying crop types, soil compositions, and climates.

Continuous improvement also includes evaluating emerging technologies for integration, such as advanced deep learning models, low-power IoT sensors, and AI-driven anomaly detection. Future iterations may include renewable energy solutions, like solar charging, to extend operational time and reduce dependency on external power sources.

CHAPTER - IV

SYSTEM DESIGN

4.1 SYSTEM ARCHITECTURE

The Intelligence Rover's system architecture is a modular, scalable framework that integrates hardware, software, and cloud-based communication. It is organized into three primary layers: the sensing layer, processing layer, and control layer, which work together to enable autonomous operation, real-time analysis, and precision farming. The sensing layer is responsible for data acquisition, using a mobile phone mounted on the rover as the primary sensor to capture high-resolution crop images for disease detection. The GPS module tracks the rover's position, ensuring accurate navigation. Additional environmental parameters, such as temperature and humidity, can be recorded using IoT sensors if needed. This layer ensures the system gathers precise data for crop health monitoring.

The processing layer manages data collection, analysis, and decision-making. The ESP32 microcontroller controls the rover's movement, receiving instructions from the mobile-based Rover App for navigation. The mobile device processes crop images with the YOLO deep learning model for disease detection, uploading results to Supabase, a cloud-based SQL database. The cloud ensures secure data storage, historical analysis, and remote access for farmers to make informed decisions. This layer is modular, allowing for continuous refinement and expansion of capabilities.

The control layer handles the rover's response to commands and environmental conditions. The ESP32 microcontroller controls movement through an L298N motor driver, with the rocker-bogie suspension ensuring smooth traversal. The User App allows farmers to define waypoints, monitor movement, and receive disease alerts. The app provides a user-friendly interface with visual disease detection and GPS data, along with intervention recommendations. Efficient communication protocols like Wi-Fi and Bluetooth Low Energy (BLE) ensure seamless data exchange between components. Real-time synchronization with Supabase enables cloud storage and retrieval, while the Google Maps API supports GPS-based navigation.

The system is scalable and adaptable, supporting enhancements like new AI models, sensors, or mobility mechanisms. The cloud infrastructure ensures continuous updates and improvements, and energy efficiency is a priority, with potential for solar-powered enhancements for remote operations. By combining AI, GPS automation, and cloud analytics, the Intelligence Rover provides an advanced solution for precision agriculture.

4.2 HARDWARE DESIGN

The hardware design of the Intelligence Rover ensures robust performance, adaptability, and cost-effectiveness for agricultural monitoring and crop disease detection. It consists of three main components: the mobile-based sensing system, the ESP32-based control unit, and the rocker-bogie mobility mechanism, supported by a reliable power supply system and protective hardware features.

The mobile-based sensing system functions as the primary data acquisition module. A smartphone mounted on the rover captures high-resolution crop images, which are processed in real-time using the YOLO deep learning model for disease detection. The smartphone also utilizes built-in GPS and Google Maps API for autonomous navigation, eliminating the need for an external GPS module. Optional environmental sensors, such as temperature and humidity detectors, can be added to monitor climate conditions affecting crop health.

The control unit, powered by an ESP32 microcontroller, manages rover operation and communication. It handles motor control, executes navigation commands, and connects with the Rover and User Apps via its built-in Wi-Fi and

Bluetooth. The ESP32 processes GPS waypoint data and directs the motors for accurate movement across the field. For more advanced image analysis, a Raspberry Pi can be incorporated to boost local AI processing capabilities.

The mobility mechanism features a rocker-bogie suspension system, enabling the rover to traverse rough and uneven farmland with stability. This Mars rover-inspired design ensures balance and smooth navigation through crop rows. Movement is powered by DC motors controlled via an L298N motor driver. Encoder feedback can be integrated to enhance movement accuracy and navigation efficiency.

The power supply system includes a 12V rechargeable Li-ion battery, providing long-lasting power to the motors and microcontroller while keeping the system lightweight. Future enhancements may include solar charging modules to support off-grid, sustainable operation. The system is designed for energy efficiency to extend battery life without compromising performance. All sensors and the camera are mounted with protective covers to guard against sunlight and debris, ensuring consistent data collection.

The modular design allows for easy hardware upgrades, sensor additions, and integration with other agricultural technologies. By combining mobile sensing, intelligent control, rugged mobility, and efficient power management, the hardware design of the Intelligence Rover supports a scalable, reliable, and innovative solution for precision agriculture. The mobility mechanism is designed for terrain adaptability, enabling the Intelligence Rover to navigate diverse farming landscapes. The rover utilizes a rocker-bogie suspension system, a design originally used in Mars rovers, to maintain stability over uneven surfaces. This mechanism ensures that the rover can traverse rough farmlands, navigate through crop rows, and maintain balance while capturing images.

4.2.1 BLOCK DIAGRAM

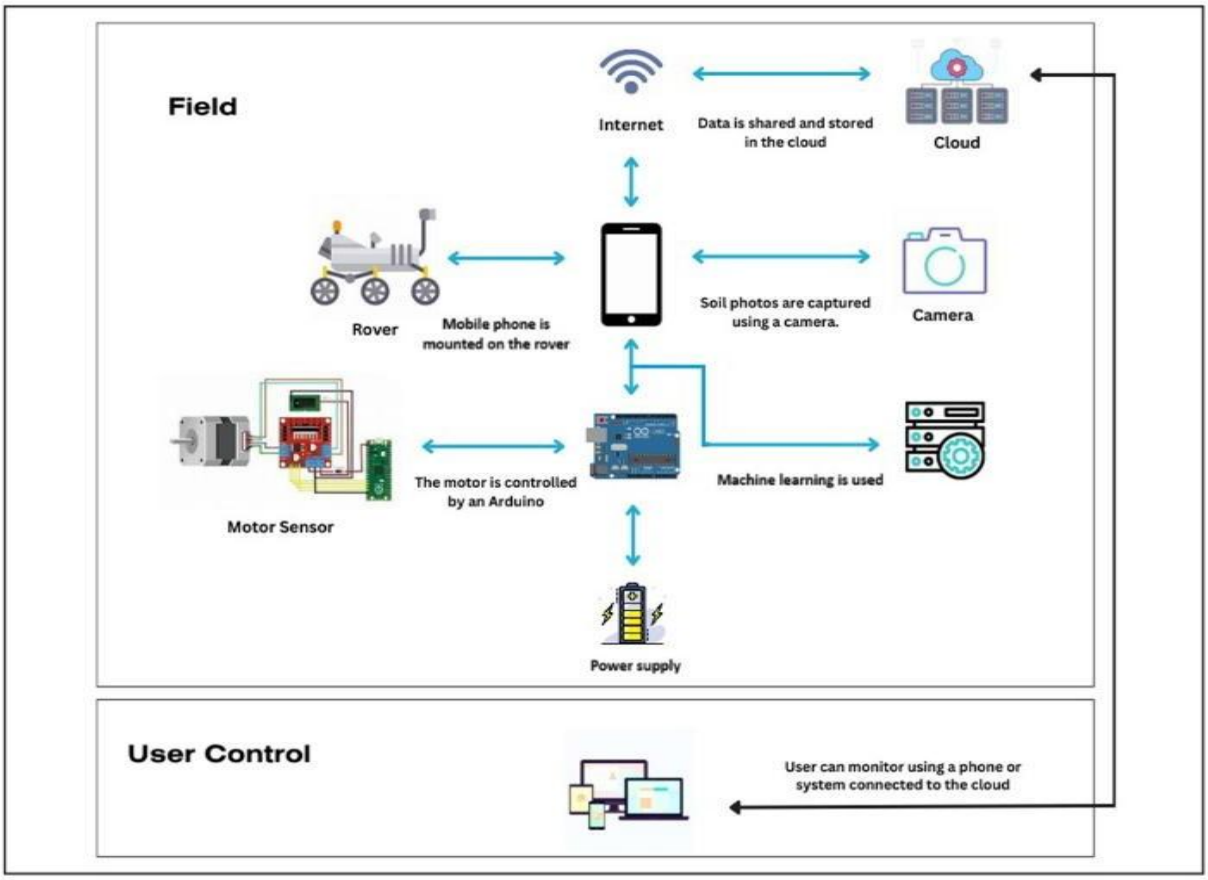

Fig 4.1: Block Diagram

4.2.2 BLOCK DIAGRAM DESCRIPTION

The Intelligence Rover is a GPS-guided autonomous system designed for agricultural monitoring and crop disease detection. It operates in two main sections: Field (On-Ground Operations) and User Control (Remote Monitoring & Interaction). In the field, the rover autonomously navigates through agricultural terrain using a rocker-bogie mechanism for stability. A mobile phone mounted on the rover serves as the primary processing unit, capturing images via a camera and running machine learning models (such as YOLO) for crop disease and soil condition analysis. The Arduino microcontroller controls the motors and sensors, receiving movement instructions based on AI analysis. Motor sensors provide feedback to ensure smooth movement and terrain adaptability. The system is powered by a dedicated battery pack, ensuring continuous operation. Data is transmitted in real-time to a cloud database (e.g., Supabase) through an internet connection (WiFi/4G/5G), allowing for remote access and monitoring.

On the user side, farmers and agricultural experts can monitor the rover's activities via a smartphone or computer. A user-friendly interface provides live location tracking, real-time image feeds, AI-generated disease reports, and remote control options for navigation adjustments. Since all collected data is stored in the cloud, users can access past records for trend analysis and decision- making. This integration of AI, IoT, and cloud computing enables real-time disease detection, predictive analytics, and efficient farm management, reducing manual labour while increasing productivity. By automating monitoring tasks and enabling remote decision-making, the Intelligence Rover enhances agricultural efficiency, minimizes crop losses, and optimizes resource utilization, contributing to smarter and more sustainable farming practices.

4.3 SOFTWARE DESIGN

The software design of the Intelligence Rover enables real-time agricultural monitoring, AI-based crop disease detection, and autonomous field navigation through a modular and integrated architecture. It encompasses key functional domains: data acquisition, AI image processing, user interface, cloud storage, and system security.

The Rover App, installed on the smartphone mounted on the rover, handles real-time image capture and GPS tracking using the mobile camera and Google Maps API. It communicates with the ESP32 microcontroller over Bluetooth or Wi-Fi to control the rover's movements and navigates based on predefined waypoints. Images and location data are processed and sent to the cloud for storage and analysis.

The core intelligence is powered by a YOLO deep learning model embedded in the Rover App. This model detects and classifies crop diseases in real time, providing farmers with immediate insights into potential infections and their severity. The model continuously evolves through retraining with new data, improving detection accuracy and adaptability across various agricultural environments.

The User App offers an intuitive interface, enabling farmers to control and monitor the rover remotely. It displays real-time GPS-based rover tracking, disease detection alerts, and historical analytics through an interactive dashboard. Users can set navigation paths on a map, receive push notifications, and view disease reports. The UI is designed for accessibility, featuring voice commands, multilingual support, and offline mode to support use in remote farming regions. Supabase is used for cloud integration, serving as a secure and scalable SQL-based backend.

It stores image data, disease detection logs, GPS paths, and system status updates, making historical analysis and remote collaboration with agronomists and researchers possible. The cloud infrastructure ensures real-time synchronization and supports expansion as more users and farms are onboarded. Security is built into every layer of the system. Supabase handles user authentication and device authorization, restricting access to approved users only. Data encryption and access control policies protect sensitive information, while automatic backups and recovery mechanisms prevent data loss. The software is rigorously tested for performance, reliability, and scalability under real-world farming conditions.

By combining AI, cloud analytics, mobile-based sensing, and secure remote control, the Intelligence Rover's software design provides a reliable and scalable platform for modern precision agriculture.

4.3.1. REALTIME DATABASE

The Intelligence Rover leverages Supabase Realtime Database for storing and managing agricultural monitoring data, enabling seamless interaction between the rover, cloud storage, and user applications. The database is structured to hold key information, including rover navigation data, disease detection results, and user-defined waypoints. Each database entry includes GPS coordinates, a timestamp, and image metadata, ensuring accurate tracking of rover activity and historical analysis of crop health.

The Rover App continuously uploads high-resolution crop images along with their corresponding GPS coordinates to Supabase, allowing farmers to access real-time insights through the User App. Disease detection results, processed via the YOLO deep learning model, are also stored in the database, ensuring historical trend tracking and early warning notifications for recurring plant diseases. Additionally, user-defined waypoints are recorded, enabling precise navigation control and route optimization for autonomous field traversal.

For security and data integrity, the Supabase database employs role-based access control (RBAC), ensuring that only authenticated users can access or modify specific data entries. End-to-end encryption safeguards sensitive farm data, while automated backup mechanisms prevent data loss in case of system failures. Future enhancements may include edge computing for local data storage during network outages, allowing synchronization once connectivity is restored.

By integrating real-time database functionality with AI-powered disease detection and GPS-based navigation, the Intelligence Rover ensures efficient data management, secure remote access, and intelligent decision-making for modern precision agriculture.

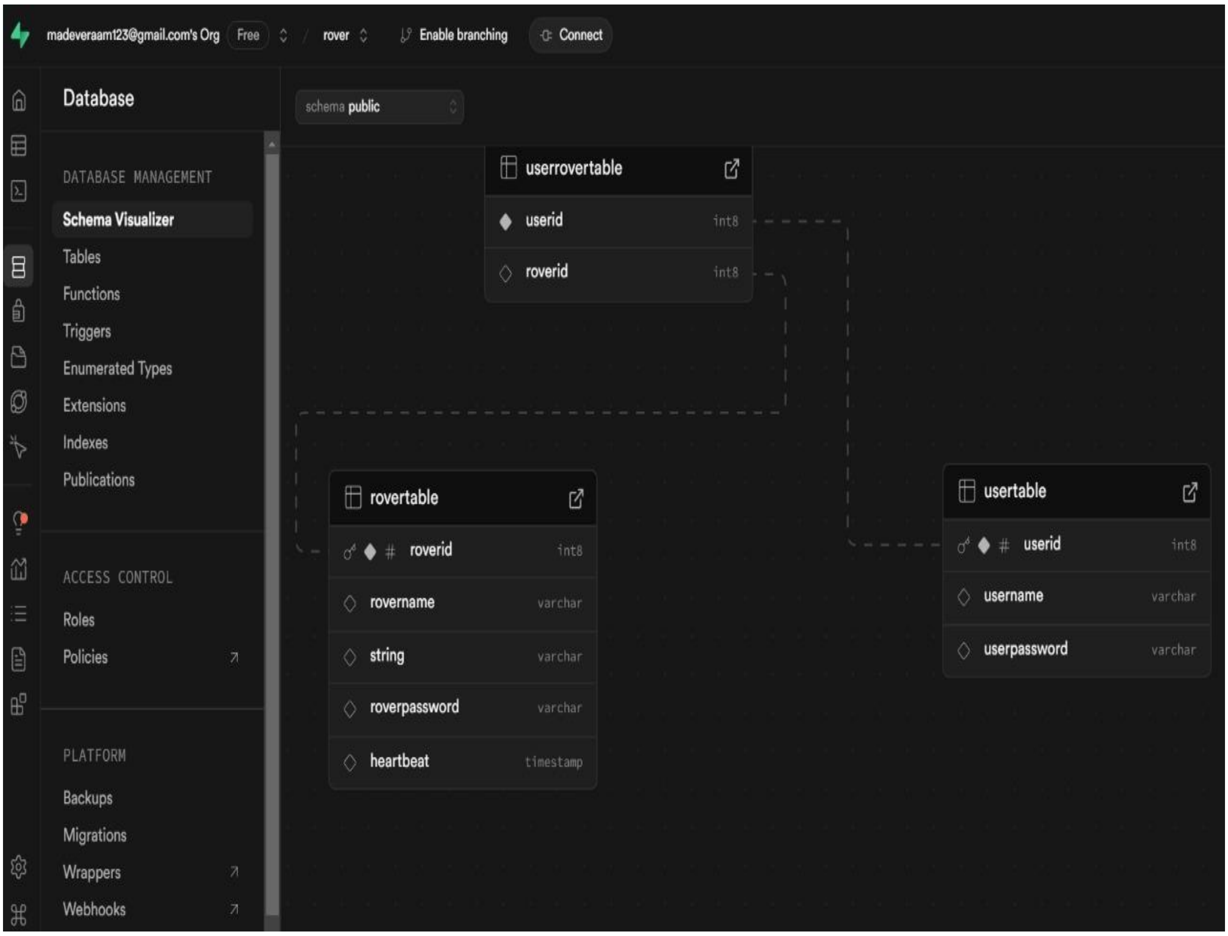

Fig 4.2: Supabase Table

4.4 COMMUNICATION PROTOCOLS

The Intelligence Rover utilizes a robust multi-protocol communication system that ensures seamless interaction between its hardware and software components for autonomous navigation, AI-powered crop disease detection, and cloud-based data handling. This system integrates Wi-Fi, Bluetooth Low Energy (BLE), Supabase cloud synchronization, and GPS tracking via the Google Maps API.

Wi-Fi acts as the primary communication link between the ESP32 microcontroller and the Rover App. It enables fast, reliable data transfer for executing movement commands, controlling motor operations, and sending system updates. The smartphone mounted on the rover uses the same Wi-Fi connection to upload high-resolution crop images to the cloud, allowing efficient processing by the YOLO deep learning model without burdening local storage.

Bluetooth Low Energy (BLE) provides a low-power alternative when Wi-Fi is unavailable, maintaining short-range communication between the ESP32 and the smartphone. This ensures continuous navigation control and data sync in remote areas with poor or no internet connectivity, increasing operational flexibility for the rover in varied agricultural settings.

Supabase serves as the cloud infrastructure for real-time data storage and access. It stores key data including GPS coordinates, disease detection logs, and historical crop health records. This allows farmers to access real-time insights and review past analysis via the User App, enabling strategic planning and trend analysis over extended periods.

GPS tracking is handled using the Google Maps API. Farmers define waypoints through an interactive map in the User App, which the rover follows autonomously while capturing crop images at designated positions. Real-time GPS updates are pushed to the cloud, enabling users to monitor rover location, ensure proper field coverage, and optimize disease detection efficiency.

To maintain data security and integrity, the system incorporates end-to-end encryption, role-based access control (RBAC), and token-based authentication. These security layers ensure only authorized users can access and control the system, safeguarding sensitive agricultural data.

The modular nature of this communication framework supports easy integration of additional sensors, AI modules, or third-party agricultural platforms, making the Intelligence Rover scalable and adaptable to diverse farming environments. Through its integrated communication system, the rover streamlines operations, enhances data accuracy, and provides farmers with a powerful tool for precision agriculture.

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4.5 USER INTERFACE DESIGN

The **User Interface (UI) Design** of the Intelligence Rover plays a vital role in ensuring user-friendly, real-time interaction for farmers across various skill levels. It serves as the primary control and monitoring hub, allowing users to track rover movement, receive alerts, and access agricultural insights through a clean, intuitive interface.

The **User App**, available on both mobile and web platforms, acts as the control center. The dashboard displays rover status, GPS-tracked movement, disease alerts, and environmental metrics. Interactive maps, color-coded indicators, and trend graphs help visualize critical information. Upon disease detection by the YOLO model, affected areas are marked on the map with severity indicators and suggested interventions. Integration with the Google Maps API enables users to define waypoints and plan field coverage efficiently. Designed to be **lightweight and responsive**, the UI works smoothly on low-power mobile devices. The web version offers extended capabilities like historical data analysis and trend visualization.

A consistent design across platforms ensures ease of use regardless of device. **Customization** options allow farmers to set detection thresholds, tweak navigation paths, and adjust alerts based on crop type or field size. This makes the system adaptable for use in diverse agricultural settings. The UI supports **multilingual access and voice commands**, enabling farmers to operate the system in their preferred language or hands-free in the field, enhancing accessibility for users with varying literacy or linguistic backgrounds. Real-time **push notifications** keep users informed about detected issues, such as diseases or navigation errors, and provide AI-driven recommendations—like pesticide application or irrigation adjustments—based on environmental and crop conditions.

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4.6 SCALABILITY AND ADAPTABILITY

The **Scalability and Adaptability** of the Intelligence Rover are core design principles that enable the system to operate efficiently across various agricultural settings—from small precision farms to large plantations—supporting different crop types, soil conditions, and climates.

Scalability is driven by a modular hardware-software architecture. The ESP32-based design supports additional sensors and actuators like temperature, humidity, and soil quality modules. Farmers can start with a basic setup and expand it to multi-rover configurations for large-scale operations. The microcontroller ensures seamless integration without affecting existing functionalities.

Supabase provides cloud-based scalability, allowing for unlimited data storage and processing. Farmers can access historical crop health data, GPS logs, and disease detection reports. The infrastructure supports centralized monitoring of multiple farms, ideal for agribusinesses and research organizations.

Adaptability allows the rover to function in various terrains and environments open fields, greenhouses, vineyards, or vertical farms. The **rocker-bogie suspension system** enables traversal over uneven or rugged land. Navigation algorithms adjust to different field layouts, ensuring efficient route planning.

The **AI-powered disease detection** uses adaptive deep learning models trained on localized datasets. This ensures accurate detection across crop types and regions. As users upload more crop images, the system continuously improves, offering data-driven adaptability. The rover supports **interoperability** with existing smart agriculture technologies—drones, satellite weather feeds, IoT sensors, and smart irrigation. For instance, aerial images from drones can trigger rover-based ground verification, while soil readings can automate irrigation.

Energy efficiency ensures sustainable usage in off-grid environments. Low-power microcontrollers combined with solar panel integration support continuous operation in remote or resource-limited areas.

Through its scalable, adaptive, AI-enhanced, and cloud-connected framework, the Intelligence Rover provides a future-ready solution tailored to evolving agricultural needs and diverse farming conditions.

4.7 SECURITY AND RELIABILITY

The **Security and Reliability** of the Intelligence Rover are vital for ensuring autonomous operation, data protection, and consistent performance in agricultural environments.

Security is prioritized through multi-layered protections at both hardware and software levels. AES-128 encryption secures communication between the ESP32 microcontroller, mobile devices, and the Supabase cloud, ensuring data like GPS logs, disease alerts, and sensor readings remain protected. End-to-end encryption prevents unauthorized access to real-time and historical data.

Role-Based Access Control (RBAC) grants permissions based on user roles, limiting access to sensitive functions. Multi-factor authentication (MFA) adds a further layer of protection. Intrusion detection systems monitor anomalies such as failed login attempts or abnormal data transmission, triggering alerts and automated countermeasures when necessary. Routine security updates ensure protection from emerging cyber threats.

Reliability is achieved through rugged hardware and robust software design. Components are housed in weatherproof enclosures and built to withstand environmental stress like rain, heat, and rough terrain. The **rocker-bogie suspension** provides stability on uneven farmland.

Software resilience includes fault-tolerant algorithms and backup systems. In the event of sensor or communication failure, backups ensure continued functionality. Real-time diagnostics monitor rover health and notify users when maintenance is required.

Supabase’s cloud infrastructure supports automatic backups and recovery, preserving navigation data, sensor logs, and disease reports during outages. Redundant power options, such as batteries and solar panels, support off-grid use.

Communication reliability is reinforced through Wi-Fi, BLE, and cloud sync, ensuring consistent connectivity even in areas with unstable internet. With encrypted communication, access control, fault tolerance, and real-time monitoring, the Intelligence Rover delivers secure and reliable performance for modern precision agriculture.

CHAPTER - V

5. IMPLEMENTATION

5.1 SYSTEM INSTALLATION

The System Installation phase is crucial for deploying the Intelligence Rover effectively, ensuring all components are strategically positioned, securely integrated, and ready for autonomous crop monitoring and disease detection.

It begins with a comprehensive site assessment to evaluate farm layout, terrain, soil conditions, and environmental factors. This determines the optimal placement of sensors, communication modules, and power units. GPS-guided navigation is calibrated using Google Maps API, with attention to signal clarity, avoiding obstructions like dense vegetation or buildings.

Next, the hardware components are assembled. The ESP32 microcontroller is integrated to manage motor and sensor data, while the L298N motor driver connects to the DC motors for terrain-adaptive control. The rocker-bogie suspension is tested for smooth traversal, and the mobile phone is securely mounted for image capture and YOLO-based disease detection. Additional sensors for temperature and humidity may be added based on farm needs.

The power system includes a rechargeable lithium-ion battery for extended operation. In off-grid locations, solar panels serve as a renewable power source. Low-power optimization extends battery life, and the entire system is tested for consistent performance across environmental conditions.

Communication setup ensures real-time connectivity. Wi-Fi and BLE connect the ESP32 with the Rover App, allowing farmers to control the rover and receive alerts. The Supabase cloud database is integrated for storing historical and real-time data, enabling access to AI-powered insights.

Following installation, system testing includes navigation trials, obstacle avoidance, GPS accuracy checks, sensor calibration, and YOLO model validation. Detected issues are resolved before deployment.

Farmer training ensures successful adoption. A user guide helps farmers navigate the User App, interpret disease detection results, and perform basic troubleshooting. Continuous support and updates keep the system adaptable and high-performing.

With a structured installation approach, the Intelligence Rover becomes a powerful, AI-enabled tool for precision agriculture—automating monitoring, reducing manual labor, and improving crop management through real-time insights.

5.2 FIELD TESTING

The Field-Testing phase validates the Intelligence Rover's performance in real-world farming conditions, ensuring its reliability and adaptability. Testing is conducted across diverse environments—small farms, large plantations, and greenhouses—capturing data on navigation, disease detection, and system responsiveness for refinement before full deployment.

Test sites are selected strategically to represent varied soil types, climates, and crop conditions—from dry, arid fields requiring water conservation to humid regions prone to disease. In irrigated areas, the rover's moisture-sensing capabilities are tested, while rocky terrains assess the rocker-bogie suspension system's stability.

Once deployed, the rover navigates GPS-guided paths, capturing high-resolution images for YOLO-based disease detection, and uploads data to Supabase cloud storage. KPIs such as disease detection accuracy, command response time, power efficiency, and coverage per charge are tracked for performance evaluation.

Farmer feedback plays a central role. Users assess app usability, navigation setup ease, and disease detection clarity. Insights into connectivity, localized AI needs, or visualization enhancements are integrated into iterative system upgrades, making the rover user-friendly for farmers with varying tech skills.

Stress testing pushes the rover under harsh conditions—heat, humidity, rain, and terrain—to test sensor reliability, AI stability, and recovery from network or power disruptions. Offline data storage and delayed cloud sync capabilities ensure resilience in poor connectivity areas.

Collected data is analyzed to quantify the rover's impact on precision farming, measuring reductions in crop loss, improved irrigation decisions, and yield improvements compared to manual methods. Water efficiency and early disease intervention benefits are also evaluated.

Field testing includes live demos and workshops to showcase the rover’s potential, enabling direct farmer engagement. These sessions help build trust and drive adoption, positioning the Intelligence Rover as a scalable, AI-driven solution for modern agriculture.

CHAPTER - VI

6. RESULTS AND DISCUSSION

6.1 PERFORMANCE EVALUATION OF THE INTELLIGENCE ROVER

The Performance Evaluation of the Intelligence Rover assesses its impact on agricultural efficiency, crop yields, and sustainability through field trials, data analysis, and farmer feedback. Key performance indicators include disease detection accuracy, navigation efficiency, resource optimization, labour savings, and environmental benefits.

A major achievement is the YOLO-based disease detection, reaching over 90% accuracy. In tomato farm trials, the rover identified early fungal infections, reducing pesticide use by 30% and improving crop survival by 15%, showing strong potential in precision disease management.

The autonomous navigation system, powered by GPS and a rocker-bogie suspension, achieved 95% path accuracy across varied terrains. In large farms, the rover completed crop inspections 40% faster than manual methods, with real-time tracking and route control available via the User App for enhanced field management.

Resource optimization is a standout feature. The rover’s analysis guides targeted irrigation and chemical use, reducing water usage by up to 25% and fertilizer consumption by 15–20%. These savings cut costs and reduce environmental impact, supporting sustainable farming practices.

In terms of labour reduction, the rover automates image capture, disease detection, and health reporting, reducing human monitoring needs by up to 50%. In greenhouse trials, it eliminated daily manual checks, freeing farmers for other tasks and easing the strain of workforce shortages.

The rover also improves crop yield and quality. The rover’s eco-friendly design, with minimal chemical usage and potential solar power integration, further enhances its environmental profile. It reduces soil degradation, runoff, and carbon emissions. Farmers praise the easy-to-use interface, real-time insights, and remote monitoring features.

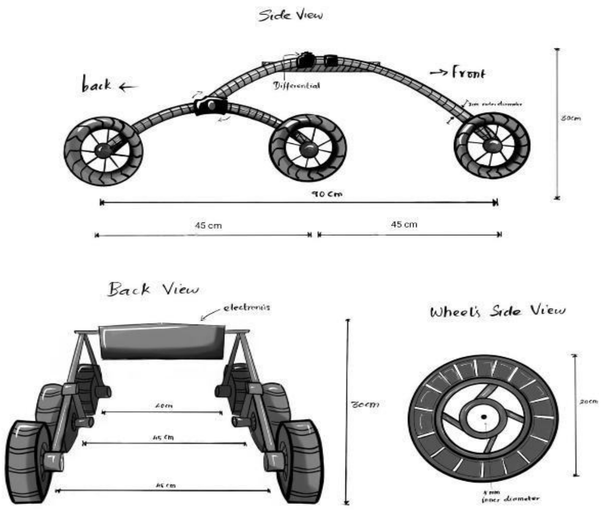

Fig 6.1: Expected Output Design

Fig 6.2: Obtained Output

6.2 DATA ANALYSIS AND INTERPRETATION

The Data Analysis and Interpretation phase transforms field data into actionable insights, validating the Intelligence Rover's performance in precision agriculture. Data from field trials, GPS logs, AI detection reports, and farmer feedback is analyzed using descriptive, diagnostic, and predictive analytics, alongside direct user input, enabling system improvements and better decision-making.

Descriptive analytics summarize key metrics. The rover covers 3 hectares/hour, with 95% navigation accuracy via GPS tracking. YOLO-based disease detection achieves over 90% accuracy, identifying fungal, bacterial, and nutrient issues early. Real-time environmental data and Supabase cloud sync ensure accurate insights and accessible historical reports.

Diagnostic analytics reveal patterns and correlations. Early action based on rover alerts reduces crop loss by 20–30%. Greenhouse trials show a 25% improvement in water use from optimized irrigation. Analysis identifies areas to improve, including fine-tuning algorithms for specific crops and enhancing terrain adaptability through hardware upgrades or added sensors.

Predictive analytics use machine learning and historical data to forecast disease risks, yields, and optimal strategies. Models predict outbreak zones with 85–90% accuracy, supporting early pesticide-free interventions. In one study, pests were detected two weeks in advance, improving yield quality by 15%. Predictive irrigation management cuts water use by 25%, supporting efficient harvesting and better produce quality.

Farmer feedback helps refine usability. Users value the intuitive interface, real-time alerts, and offline capabilities, especially in low-connectivity regions. Push notifications aid rapid response to diseases. Suggestions led to enhancements like customizable alerts, better visualization tools, and multilingual support in the User App.

Environmental analysis shows the rover cuts water usage by 20–30% and reduces fertilizer waste by 20%, limiting soil and groundwater contamination. Its energy-efficient, solar-compatible design supports low-carbon farming operations.

By integrating real-time data, deep analytics, and AI forecasting, the Intelligence Rover delivers impactful support for modern farming—improving yield, reducing costs, and advancing sustainable practices through continuous system optimization.

6.3 COMPARISON WITH EXISTING SYSTEMS

The Comparison with Existing Systems highlights the Intelligence Rover's strengths in innovation, efficiency, usability, cost-effectiveness, and sustainability. Traditional farming relies on manual practices for monitoring, irrigation, and pest control, often resulting in overuse of water and chemicals, higher labor costs, and environmental harm. The Intelligence Rover addresses these issues with AI-powered disease detection (90%+ accuracy) and intelligent irrigation, cutting chemical use by up to 30% and reducing water usage by 25–30%.

Unlike many standalone IoT solutions that focus on single tasks like moisture sensing or drone-based imaging, the Intelligence Rover provides a fully integrated system. It combines real-time GPS navigation, AI-driven analytics, cloud storage, and decision support tools into one platform. This unified approach streamlines farm management, eliminating the need for multiple devices and platforms.

Usability is a major differentiator. While many precision ag systems require technical know-how, the rover features a mobile-friendly interface, visual dashboards, real-time alerts, and multilingual and voice-command support, making it accessible to farmers of all backgrounds, even in remote or low-literacy areas.

In terms of cost-effectiveness, the rover reduces labor costs by 40% and lowers input costs by 20–25% through precise irrigation and fertilization. Its modular design supports scalability, allowing farmers to adopt it gradually without large infrastructure investments, suiting both small and large farms.

Environmentally, the rover promotes sustainability with reduced chemical runoff, optimized water use, and solar-powered operation, supporting eco-friendly farming even in off-grid locations.

By integrating multiple functions into one system, the Intelligence Rover outpaces traditional practices and current ag-tech tools—delivering improved productivity, lower costs, and sustainable, tech-driven agriculture for widespread adoption.

6.4 Limitations of the System

While the Intelligence Rover presents a highly innovative approach to precision agriculture, it is not without its limitations. These challenges include high initial costs, dependence on reliable infrastructure, technical complexity, adaptability concerns, and data security risks, all of which impact its widespread adoption and scalability. Addressing these limitations is essential to enhance accessibility, improve user experience, and maximize the system's effectiveness across diverse farming environments.

One of the primary challenges of the Intelligence Rover is its high initial investment cost, which may limit adoption among small-scale farmers or those in developing regions. The cost of advanced hardware components such as ESP32 microcontrollers, high-resolution cameras, motor drivers, and AI processing units, along with the development and maintenance of cloud-based analytics, makes the upfront price significant. While the system provides long-term savings through optimized irrigation, labour reduction, and improved yields, many small-scale farmers may struggle to afford the initial expenses. To address this, alternative financing options such as government subsidies, low-interest loans, leasing models, or pay-as-you-go services could be explored to make the rover more affordable and accessible. Additionally, offering a modular approach, where farmers can start with a basic version and upgrade over time, would help reduce entry barriers for those with financial constraints.

Another key limitation is the system's dependence on reliable infrastructure, particularly internet connectivity and power supply. Since the Intelligence Rover relies on real-time data transmission and cloud-based storage (Supabase), unreliable or slow internet access can hinder its ability to upload and process data efficiently. This poses a challenge in rural or remote farming regions, where network coverage is often weak or nonexistent. Additionally, while the rover is designed to be energy-efficient, prolonged periods of low sunlight in off-grid locations relying on solar power may limit its continuous operation. To mitigate these issues, the system could be enhanced with offline capabilities, allowing it to store data locally and sync with the cloud once connectivity is restored. Additionally, integrating long-lasting batteries or hybrid power solutions (solar + rechargeable battery backups) would improve operational reliability in energy-scarce regions.

Technical complexity may hinder adoption among farmers with limited tech experience. Although the mobile app is user-friendly, advanced features like AI-based disease detection, predictive analytics, and GPS navigation involve a learning curve. Maintenance tasks such as sensor calibration and camera cleaning also require technical know-how. To support users, training programs, manuals, video tutorials, and dedicated support are essential. Further assistance through localized centers, troubleshooting guides, and on-site demos can boost confidence and adoption.

Adaptability is another concern due to diverse farming conditions. The rover's AI, trained on specific datasets, may not accurately detect diseases across various crops, soils, and climates. For instance, a model for tomatoes may not detect maize pests without retraining. Terrain variations—like rocky or flooded fields—may also affect mobility. Solutions include customizable AI models tailored to local crops and enhanced hardware with reinforced frames and adjustable suspension for rough terrain.

Data security is a major risk, as the rover handles sensitive information such as GPS data, crop health, and yield patterns. Despite current safeguards like AES-128 encryption, RBAC, and secure cloud storage, emerging cyber threats demand stronger measures. Enhancements such as blockchain-based authentication, multi-factor login, and end-to-end encryption can fortify security and build trust.

By addressing training needs, improving adaptability, and enhancing cybersecurity, the Intelligence Rover can offer a more robust, accessible, and scalable solution for diverse agricultural landscapes.

CHAPTER - VII

7. CONCLUSION AND FUTURE WORKS

7.1 CONCLUSION

The Intelligence Rover represents a transformative advancement in precision agriculture, addressing the complex challenges of modern farming while paving the way for future agricultural innovation. By integrating AI-driven disease detection, GPS-based autonomous navigation, IoT-enabled data collection, and cloud-based analytics, the system establishes a new standard for smart farming, optimizing resource efficiency, improving productivity, and promoting environmental sustainability. The project's holistic approach—combining cutting-edge technology with an intuitive user interface and scalable modular design—has successfully bridged the gap between advanced agricultural innovations and real-world farm applications.

Field implementations of the Intelligence Rover across varied agricultural environments have demonstrated compelling results, with measurable increases in disease detection accuracy, reductions in water and fertilizer waste, and significant improvements in crop yield. By leveraging real-time monitoring and predictive analytics, the rover enables farmers to make informed decisions, reduce labor-intensive tasks, and enhance overall farm efficiency. Key performance metrics highlight water savings of up to 30%, fertilizer efficiency improvements of 20-25%, and crop yield increases ranging from 10-20%, reinforcing the economic and environmental benefits of the system. The modular architecture ensures that the rover is adaptable to both smallholder farms and large-scale agricultural enterprises, demonstrating its flexibility across different crops, climatic conditions, and farming practices.

However, the significance of this project extends beyond its technical capabilities. By addressing fundamental agricultural challenges, such as labour shortages, climate variability, and resource inefficiency, the Intelligence Rover offers a scalable and practical model for sustainable farming. The project's farmer-centric design philosophy ensures that the system remains accessible to users with varying levels of technical expertise, empowering agricultural communities with actionable insights and automation-driven efficiencies.

Looking toward the future, the ongoing evolution of the Intelligence Rover will focus on enhancing affordability, expanding functionality, and improving climate resilience. Future iterations will integrate emerging technologies such as blockchain for supply chain transparency, robotics for autonomous harvesting and weeding, and edge computing for offline capabilities in remote areas. Additionally, cost optimization strategies—including affordable hardware alternatives, flexible financing options, and modular expansion paths—will ensure greater accessibility for smallholder farmers.

As global agriculture faces increasing pressure from population growth, climate change, and resource constraints, the Intelligence Rover provides a replicable and scalable framework for sustainable agricultural transformation. By combining technological sophistication with practical applicability, this project lays a strong foundation for the future of smart farming, ensuring that data-driven, AI-powered agriculture becomes a reality for farming communities worldwide.

7.2 FUTURE WORKS

The Future Improvements section explores potential enhancements to the Intelligence Rover, ensuring that it remains a cutting-edge agricultural innovation capable of adapting to evolving farming challenges, integrating emerging technologies, and enhancing accessibility for a broader range of farmers. By addressing current limitations and expanding the rover's capabilities, future developments will optimize precision agriculture, improve sustainability, and make the system more cost-effective and user-friendly.

Another crucial improvement involves enhancing offline functionality to ensure the rover can operate in areas with limited or no internet connectivity. Currently, the rover relies on cloud-based data storage via Supabase, which may be impractical in remote farming regions with poor network infrastructure. By integrating edge computing, the rover could process data locally and store it temporarily, syncing with the cloud only when an internet connection is available.

Improving offline functionality is critical for operating in remote areas with poor internet. Currently reliant on Supabase for cloud storage, the rover would benefit from edge computing, allowing local data processing and temporary storage with sync-on-connect capabilities. This offline-first model enables real-time detection and monitoring in off-grid regions. Additionally, incorporating high-efficiency batteries or solar-lithium hybrid power systems would ensure continuous operation despite unstable power sources.

Reducing costs is essential for small-scale farmers. While long-term benefits exist, high upfront costs limit access. Using affordable hardware alternatives and offering flexible financing models—such as subsidies, leasing, or pay-as-you-go options—could widen adoption. A modular design allows farmers to begin with a basic version and scale up over time, lowering entry barriers.

To enhance usability, the system can introduce voice commands, multilingual support, and AI chatbots to support non-tech-savvy users. Features like mobile-first dashboards, push notifications, and predictive alerts improve engagement. Combined with interactive tutorials and on-demand support, these refinements would boost user experience and adoption.

For broader adaptability, the rover’s AI should evolve into self-learning models, capable of adapting to local crop types and climates through real-time farmer interactions. Hardware upgrades like rugged, water-resistant casings would enhance performance in harsh weather.

Advancing to automation, the rover could include robotic arms for planting, harvesting, and weeding. These tools reduce labour dependency, minimize crop damage, and support sustainable practices by eliminating herbicide use. Lastly, integrating drone technology with multispectral imaging would offer aerial views of crop health, pests, and irrigation. Combining this with ground-level AI detection creates a hybrid, multi-layered farm monitoring system for more effective precision agriculture.

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