SMART-AG : A PRECISION AGRICULTURE AI-POWERED EDGE COMPUTING SYSTEM

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A PROJECT REPORT SUBMITTED TO THE FACULTY OF ENGINEERING, DESIGN AND TECHNOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF BACHELOR OF SCIENCE IN COMPUTER SCIENCE OF UGANDA CHRISTIAN UNIVERSITY

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UGANDA CHRISTIAN UNIVERSITY
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Declaration:

I, **Tobit Bushenyula Kabuya**, do hereby declare that this project report is my original work and has not been published or submitted for any other degree award at any other university before.

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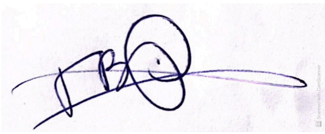
Signature: 

Date: 05/MAY/2025

Approval

This project report has been submitted for examination with the approval of the following supervisor.

Signed: ______________________________

5/5/25

Date: ______________________________

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Dedication

I dedicate this project to the Almighty God, without whom I can do nothing. I also dedicate it to my family and loved ones for their unwavering support, encouragement, and sacrifices throughout my academic journey at Uganda Christian University.

Acknowledgment

I am deeply grateful to my supervisor, **Mr. Ian Raymond Osolo**, for his continuous guidance, invaluable insights, and unwavering support throughout this project. His mentorship has been instrumental in the successful completion of this research.

I extend my heartfelt appreciation to my family and friends for their patience, encouragement, and motivation during the challenging moments of this project. Their belief in me has been a source of strength and determination.

I also thank **Uganda Christian University** for providing me with the platform to undertake this research, equipping me with the necessary knowledge and skills to contribute meaningfully to the field of technology and agriculture.

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CHAPTER ONE: INTRODUCTION

1. Background:

Food insecurity remains one of the most pressing challenges of our time. According to the 2024 edition of the **State of Food Security and Nutrition in the World** report, between **713 and 757 million people** faced hunger in 2023. In Africa alone, **296 million people**—one in every five—suffered from undernourishment. By 2030, projections indicate that **over 582 million people** will be chronically undernourished, with more than half of them residing in Africa. This alarming trend highlights the urgent need for effective and sustainable solutions to improve food production and accessibility. (*The State of Food Security and Nutrition in the World 2024*).

One of the major contributors to food insecurity is **food loss and waste**, which occurs at different stages of the food supply chain. In **high-income countries**, food is mostly wasted at the consumer level, with large amounts of edible food discarded despite being fit for consumption. In contrast, **low-income countries**, including many in Africa, experience food losses primarily during the early and middle stages of production. Inefficient farming techniques, poor post-harvest handling, and inadequate access to modern agricultural tools significantly reduce the quantity of food reaching consumers.

Despite agriculture being a dominant economic sector in Africa—employing **over 42% of the workforce**—the adoption of **technology-driven farming solutions** remains exceptionally low. Many African farmers **lack familiarity with emerging technologies**, making it difficult for them to integrate digital tools into their farming practices. Additionally, most tech-based agricultural solutions require **internet connectivity and expensive infrastructure**, making them inaccessible to rural farmers who rely on traditional methods. As a result, Africa fails to fully harness its agricultural potential, leading to continued food shortages.

To address these challenges, there is a need for **smart, accessible, and internet-independent farming solutions** that empower farmers to make data-driven decisions. **SMART-AG**, an **edge computing system**, is designed to fill this gap. By **analyzing soil health, recommending optimal nutrients, and suggesting the best crops to plant**, SMART-AG equips farmers with actionable insights to improve productivity. Unlike existing solutions, SMART-AG operates **without internet access**, delivering real-time farming recommendations via **SMS**. This ensures that even non-tech-savvy farmers in remote areas can benefit from AI-driven insights, leading to **higher crop yields, reduced food losses, and improved food security** across the continent.

2. Problem statement:

Food insecurity is a critical issue in Africa, with over **296 million people** affected by hunger. Despite efforts to increase food production, **food loss** remains a major contributor to this crisis, particularly in low-income countries where inefficiencies in farming and post-harvest handling are common.

While **42% of Africa's workforce** is employed in agriculture, there is a **low adoption of modern agricultural technologies**, primarily due to **lack of internet access**, **technical skills**, and **high costs**. This results in many farmers continuing to rely on traditional methods, which limits their productivity and exacerbates food insecurity.

Existing solutions to improve farming practices are often **too complex or require constant internet access**, leaving many farmers unable to benefit from them. Therefore, a **practical, affordable, and internet-independent solution** is needed to help farmers increase yields and reduce food losses.

This project proposes **SMART-AG**, an **AI-powered edge computing system** that provides actionable farming advice via **SMS** without requiring internet access. SMART-AG aims to empower farmers with insights on soil health, crop selection, and nutrient management, improving productivity and contributing to food security in Africa.

3. Main Objective:

The main objective of this project is to design and develop an AI-powered edge computing system, SMART-AG, which helps farmers monitor soil health, receive actionable farming advice, and improve crop yields through SMS, all without the need for internet connectivity.

1. **Specific objectives:**

The specific objectives of this project are the following:

- To analyze soil health and provide recommendations for the appropriate crop selection based on soil nutrient levels.

- To assist farmers in improving soil fertility by suggesting the right nutrients or fertilizers to add. This by providing actionable suggestions on what to do based on what is happening in the soil.

- To implement edge computing technology to process and store data locally on the device, ensuring real-time and offline functionality.

- To design an SMS-based communication system that provides actionable farming advice to farmers without requiring internet access.

- To test and evaluate the performance of SMART-AG in real-world agricultural environments and measure its impact on farming productivity.

4. Research Questions:

In this study, I desired to solve the following questions:

- How can I design an inexpensive and straightforward system by which farmers can receive crop advice and manage their soil via SMS?

- What are the difficulties that I would face if I designed a system that uses hardware and software with devices like a Raspberry Pi and soil sensors?

- How can I ensure the system provides some simple suggestions relevant to African agriculture that can be offered?

- How do I make the system scalable, simple, and low-cost to utilize for farmers based in rural communities who have less exposure to technology?

5. Hypotheses:

I worked on the project with the following broad concepts (hypotheses) in my mind:

- Using inexpensive sensors and a Raspberry Pi, one can create an SMS-based system that is affordable but simple to work with.

- Sending farmers customized SMS recommendations based on the soil status, farmers are able to make informed decisions and enhance the yields of the crops.

- While hardware compatibility is not simple, if adequate tweaking and accommodation are permitted, the various parts can be made to harmonize.

- Using data specific to African crops and agriculture will render the system much more useful and beneficial to farmers in the area.

6. Scope of the Study:

This project focuses on the development and implementation of **SMART-AG**, an edge-computing-based system designed to assist farmers in managing soil health and crop planning without the need for internet connectivity.

The system specifically covers:

- **Monitoring soil nutrient levels** (NPK) using sensor-based data collection.
- **Recommending suitable crops** for planting based on current soil nutrient content.
- **Advising on the correct type and quantity of nutrients or fertilizers** to apply in order to improve soil fertility.
- **Delivering this information via SMS**, ensuring accessibility even in areas with no internet or mobile data access.
- **Processing and storing data locally**, using edge computing to eliminate dependence on cloud-based systems.

The study is geographically scoped to smallholder farmers in **rural areas of Africa**, particularly those with limited access to the internet and modern technological tools.

What this study does **not** cover:

- **Post-harvest management**, market access, or distribution chains.
- **Weather forecasting** and pest/disease detection.
- Integration with existing government agricultural systems or third-party platforms.

7. Significance of the Study:

Food insecurity remains a major challenge in Africa, with over **296 million people** suffering from hunger and undernourishment. At the same time, a large portion of the food produced is lost at the early stages of the agricultural process, often due to poor soil management, lack of timely information, and inefficient farming practices.

The significance of this project lies in its potential to **empower farmers with actionable insights** that can boost productivity and reduce food loss—without requiring them to be tech-savvy or connected to the internet.

Key contributions of SMART-AG include:

- **Bridging the technology gap** by offering a simple, affordable solution that delivers AI-powered recommendations via SMS.
- **Encouraging adoption of precision agriculture** among smallholder farmers, even in the most remote areas.
- **Improving decision-making** by offering data-driven crop and nutrient recommendations tailored to the farmer's soil condition.
- **Supporting Sustainable Development Goal 2** (Zero Hunger) by increasing food production and promoting sustainable farming practices.
- **Promoting digital inclusion**, allowing farmers without smartphones or internet access to benefit from modern technology.

This project aims to address a critical need with a locally adaptable and scalable solution, this project has the potential to create a meaningful impact in the fight against food insecurity in Africa.

8. Definition of Terms:

Precision agriculture is technology-driven farm management that monitors, quantifies, and responds to variability in fields to maximize yields and minimize usage of resources.

Edge computing is a type of computer tech where computation of data happens on a device (such as a Raspberry Pi) rather than cloud servers, allowing computation to happen sooner and more offline.

Artificial intelligence (AI) is the imitation of human mental processes using computers, such as robots, as they try to make predictions about soil conditions and choose suitable crops.

Machine learning (ML) is artificial intelligence that enables a system to learn from experience and make predictions or judgments without being directly programmed.

Soil Nutrients (NPK): Three major nutrients for plant growth that are widely used to indicate soil health are nitrogen (N), phosphorus (P), and potassium (K).

Raspberry Pi: An affordable small single-board computer for data acquisition, machine learning, and sending SMS updates in the SMART-AG system.

NPK 7-in-1 Sensor: Seven important soil parameters, namely nitrogen, phosphorus, potassium, soil temperature, pH, conductivity, and humidity, can be sensed through this sensor.

RS485 to TTL Converter: A module used for converting sensor communication signals from the RS485 standard to TTL so that they can be read by the Raspberry Pi.

GSM800L Module: A GSM communication module that allows the SMART-AG system to deliver SMS messages without requiring internet connectivity.

Human-Computer Interaction (HCI): A discipline of study that focuses on building systems that are simple and intuitive for humans to use; used in SMART-AG to make SMS readable to farmers.

Offline Capability: A system's capacity to work without an internet connection, which is crucial for access in low-connectivity or distant areas.

CSV File (Comma-Separated Values) is a simple file format for storing tabular data. SMART-AG records soil data for long-term monitoring. WorldBank.org owns the copyright for this item.

CHAPTER TWO: LITERATURE REVIEW

1. Introduction:

SMART-AG addresses the critical challenge of data-driven decision-making among smallholder farmers in Africa. Numerous studies emphasize the growing importance of digital tools—especially artificial intelligence (AI) and edge computing—in enhancing agricultural productivity, improving soil health monitoring, and reducing post-harvest losses.

According to **Mwangi & Kariuki (2015)**, one of the most significant barriers to technology adoption in African agriculture is the lack of digital literacy and infrastructure among rural farmers, which severely limits their ability to access timely and accurate information. This results in poor crop management decisions, low yields, and persistent food insecurity.

In response, **SMART-AG** is designed to bridge the technological gap by offering a **low-cost, offline-capable, AI-powered system** that delivers real-time insights on soil quality and crop health—right at the edge, without the need for internet connectivity. This project seeks to empower farmers with actionable data to improve their yields and reduce inefficiencies, thereby contributing to broader food security efforts.

By integrating insights from academic journals, case studies, and successful agri-tech implementations, this literature review supports the development of SMART-AG as a **context-aware, farmer-friendly, and sustainable solution** tailored to the realities of small-scale farming in Africa.

2. Current State of Agriculture in Africa:

Agriculture is a cornerstone of Africa's economy and societal structure, playing a pivotal role in employment, economic output, and sustenance. As of 2022, an average of **42% of Africa's total employment** was in the agricultural sector (theglobaleconomy, 2022). This highlighted its significance as a primary livelihood source for a substantial portion of the population. In certain countries, this figure is even more pronounced; for instance, in countries like Burundi and Burkina Faso, around 80% of employment comes from agriculture.

Well, despite this being a proof that food production is well practiced in the continent, there is still a very high level of food insecurity, with around 296 million people who faced hunger in 2023. Well, these are very dramatic statistics, especially because Africa’s population is the most invested in agricultural production.

Reasons for the current crisis:

Africa's population is growing exponentially, with more food demand but very low supply. This highlights the need for innovative solutions that will cater to this emerging challenge.

Potential reasons:

Despite the growing recognition of ICTs as enablers of agricultural transformation in Africa, their adoption among smallholder farmers remains limited due to challenges such as poor internet connectivity, low digital literacy, and affordability barriers (Ayim, Boateng, & Essandoh, 2022). The study highlights that many ICT-based agricultural interventions tend to focus on web- or smartphone-based applications, which often exclude rural farmers who lack access to reliable internet or the technical know-how to navigate such tools. This insight reinforces the need for solutions like SMART-AG, which intentionally bypass these barriers by using offline-capable, mobile-based services that deliver timely, localized information through user-friendly interfaces. By integrating edge computing and AI, SMART-AG can provide real-time support on soil health, crop conditions, and farm decisions—without requiring farmers to have internet access or advanced digital skills. The development of such inclusive systems is essential to closing the technological gap and ensuring that innovation in agriculture is equitable and accessible to the most vulnerable stakeholders in the food production chain.

3. Review of Existing Systems and Approaches

This section evaluates existing digital innovations in agriculture, particularly those relevant to smallholder farming, in order to inform the design and development of the SMART-AG system. The literature reveals a growing trend toward the use of intelligent technologies to bridge information gaps, improve decision-making, and reduce inefficiencies in farming. The following areas are explored in detail:

Mobile Agriculture Applications (mAgri): Mobile-based agricultural platforms have gained prominence for their ability to deliver actionable insights to farmers, such as weather forecasts, planting advice, market prices, and soil management tips. However, many of these platforms rely heavily on internet connectivity and assume a baseline level of digital literacy that many rural farmers lack. Studies, including Ayim et al. (2022), emphasize that limited access to smartphones, poor network infrastructure, and low education levels significantly hinder the adoption of such tools in African agriculture. SMART-AG addresses this gap by offering an offline-capable mobile solution that works on basic devices and delivers AI-powered recommendations tailored to the local context.

Edge Computing and AI-Powered Decision Systems: Edge computing enables real-time data processing directly on local devices, reducing the dependency on cloud infrastructure and internet access. This technology is especially useful in remote areas where connectivity is unreliable. SMART-AG leverages edge computing to analyze sensor data—such as soil nutrient levels—and generate immediate feedback and recommendations. This localized intelligence empowers farmers to make informed decisions without the need for a central server or constant connectivity.

Digital Advisory Systems: Several digital platforms exist to support farmers through SMS or voice-based advisories. While effective in reaching broader populations, these systems often deliver generic information that may not address the unique conditions of each farm. SMART-AG enhances this model by integrating predictive machine learning models trained on local data to offer precise, farm-specific guidance. By doing so, the system improves agricultural productivity and resource use efficiency.

By assessing current digital agriculture solutions, this literature review identifies key limitations in accessibility, personalization, and infrastructure dependency. SMART-AG builds upon these insights to design an inclusive, adaptive, and internet-independent platform tailored to smallholder farmers in Africa. The goal is to ensure that technology works for the farmer—not the other way around.

4. Framework and Methodologies:

The literature review will explore relevant frameworks, methodologies, and conceptual models to guide the development of SMART-AG, a system designed to empower farmers by providing actionable, daily insights and recommendations regarding soil health, crop suggestions, and farming practices. By considering various disciplines, this review aims to inform the design and functionality of the system, ensuring it is practical, accessible, and effective for smallholder farmers with limited digital literacy and without the need for internet connectivity.

Technology Acceptance Model (TAM): The Technology Acceptance Model (TAM) will serve as a critical framework for understanding the factors that influence farmers' willingness to adopt and use SMART-AG. This model posits that perceived ease of use and perceived usefulness are key determinants in technology adoption (Davis, 1989). In the context of SMART-AG, the system must demonstrate its utility in providing tangible benefits such as improved crop yields, soil health monitoring, and tailored farming advice. By ensuring the system is simple and easy to use, even for farmers who are not tech-savvy, the adoption rate of SMART-AG can be optimized.

Behavioral Economics and Decision-Making Models: The decision-making process of farmers is influenced by numerous factors, including psychological biases, economic incentives, and environmental context. By applying behavioral economics, SMART-AG can integrate data-driven nudges that encourage farmers to take beneficial actions, such as optimizing irrigation, applying fertilizers at the right time, or planting more suitable crops. The system will deliver actionable daily insights to farmers, using simple language and practical suggestions, thereby enabling them to make informed decisions and improve farm productivity over time.

Human-Computer Interaction (HCI): Since the SMART-AG system will operate on mobile devices and deliver daily reports on soil health and crop recommendations, it is vital that the interface is intuitive, easy to navigate, and accessible to farmers with limited technological skills. The principles of HCI will guide the design of the user interface, ensuring that it is simple and clear, with features such as easy navigation, visual representations of soil data, and actionable alerts. Additionally, the system's voice-based functionality will make it even more accessible to farmers who may struggle with text-based interfaces, ensuring that it provides a truly inclusive solution.

Edge Computing and Local Data Storage: SMART-AG's reliance on edge computing is central to its operation, as the system will collect and process soil health data locally, without requiring an internet connection. This local processing will enable real-time analysis of soil data, such as pH levels, moisture content, and nutrient deficiencies, and generate tailored reports for farmers every day at 6:30 AM. The system will store this data within the device, allowing for easy access and retrieval during monthly assessments. By leveraging local processing power, SMART-AG reduces the reliance on internet connectivity, a significant barrier in rural Africa, and ensures that farmers can continuously benefit from up-to-date insights.

Participatory Design and User-Centered Development: In the development of SMART-AG, a participatory design approach will be crucial to ensure that the system meets the needs of the farmers. Engaging farmers directly in the design process through interviews, field testing, and feedback loops will ensure that the system is contextually relevant and user-friendly. Since many farmers may not have prior exposure to digital tools; the design will focus on ease of use, with simple interfaces and the ability to deliver valuable insights in a manner that aligns with the farmers' daily routines. This approach ensures that SMART-AG is not just a tool but a practical solution embedded within the agricultural practices of the users.

Mobile Technology and Offline Functionality: Since the SMART-AG system will operate offline, using mobile technology to send farmers daily reports and recommendations, the review will examine the role of mobile applications in agriculture, especially in low-tech environments. The application will provide daily updates on soil health, crops, and actionable farming advice without requiring internet connectivity. By utilizing basic mobile functionalities such as SMS and stored data on the device, SMART-AG will ensure accessibility for farmers who have limited exposure to the internet or advanced technologies. This framework will be informed by the existing literature on mobile agriculture solutions and their success in similar contexts, focusing on how to maximize impact with minimal technological requirements.

5. Summary of the Literature Review

In this literature review, I discussed the current situation of agriculture in Africa, emphasizing its contribution to employment and food security. Despite its importance, agriculture in most African countries continues to be afflicted by severe problems like low soil fertility, low crop yields, poor access to information, and low adoption of technologies among smallholder farmers.

The review also looked at how digital technologies, including mobile-based solutions and offline systems, are being used to assist farmers. It was evident that, while there is enormous potential in technology, many of the existing solutions are either too complex, too reliant on internet connectivity, or not suitable for farmers with low levels of digital literacy.

Through the exploration of recent research and existing systems, I found that there is a pressing demand for efficient, easy, and local agricultural technologies. These should run offline, feature a user-friendly interface, and provide counsel that is actionable — which matches the design decisions I made for the SMART-AG system directly. Literature also pointed out the importance of fitting solutions to technology appropriate to the situation in Africa by using local data and providing available data that the farmer will be able to believe and understand.

Overall, the review established that SMART-AG addresses tangible, real agricultural needs in rural areas by banking on simplicity, ease of use, and offline capacity.

CHAPTER THREE: METHODOLOGY

Methodology:

This chapter explores the exciting tools and technologies behind the development of SMART-AG, an innovative solution designed to assist farmers with daily insights and actionable recommendations related to soil health and crop management. By leveraging advanced technologies while keeping the system simple and offline, SMART-AG ensures accessibility and practicality for smallholder farmers in rural areas. Below is a breakdown of the methodology used to develop and implement the SMART-AG system:

1. Development Approach: Weekly Tracking of Progress

Since this project was developed by a single person, the approach focuses on tracking progress on a weekly basis. Every week, the development progress was reviewed, challenges faced were noted, and the new features added to the system were tracked. This helped to ensure consistent progress toward the final goal, allowing me to adapt to issues as they arose and refine the features of the system.

Weekly Development Tracking:

- **Feature Identification and Implementation:** Features such as soil health data collection, crop recommendations, data storage, and actionable insights for farmers were identified based on the needs of the target audience. Weekly updates tracked the progress of implementing these features into the system.

- **Challenges and Problem Solving:** Each week, challenges—such as ensuring offline functionality, formatting SMS messages clearly, or managing data storage—were identified and addressed. Regular tracking allowed for timely adjustments.

- **Tracking and Documentation:** Weekly progress was documented to ensure that all steps in the development process were recorded and reviewed. This helped maintain clarity and ensured that no crucial steps were overlooked.

2. Benefits of the Agile Approach

Adopting key principles of Agile development provided significant benefits to the project:

- **Flexibility:** Weekly tracking allowed for flexibility in adapting to changes or new insights, especially regarding farmers' needs and challenges with technology adoption.

- **Continuous Improvement:** The iterative process of reviewing progress each week ensured that SMART-AG was constantly improving. Features were refined and adjusted based on feedback and real-time observations.

- **Risk Mitigation:** Regular tracking of the project allowed potential issues to be identified early and addressed promptly, reducing the risk of delays or functional issues.

- **User-Centric Focus:** By focusing on the practical needs of farmers, such as ensuring SMS-based communication was simple and understandable, the development stayed centered on creating value for the target audience.

3. Tools and Technologies

1. Software Technologies

1. **Python**
   Python was the main programming language used for developing the core logic of the SMART-AG system. It provided the foundation for handling data processing, model training, predictions, and system automation.

2. **Jupyter Notebook**
   Jupyter Notebook was utilized during the experimentation and model development phase. It offered an interactive environment to:

   - Clean and preprocess soil data.
   - Train and evaluate machine learning models.
   - Test the predictive performance of the models.

3. **Machine Learning Models**
   Two machine learning classification models were developed:

- **Crop Prediction Model:** Suggests the most suitable crop based on soil nutrient levels and other environmental parameters.

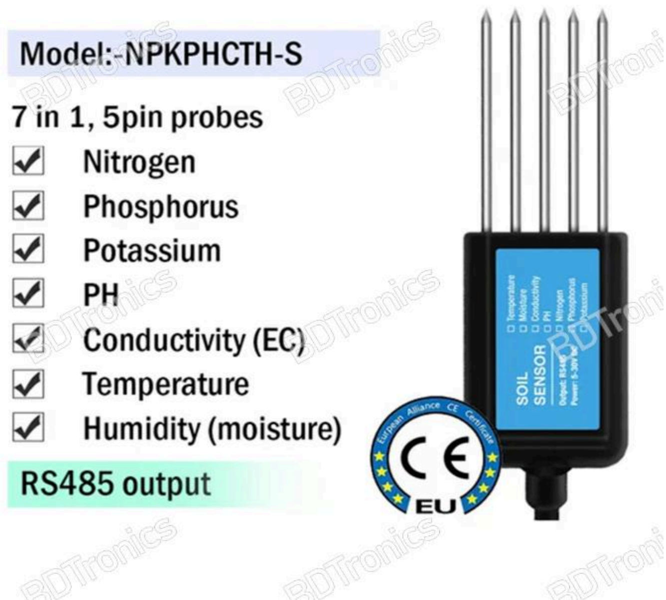
- **Soil Quality Assessment Model:** Classifies soil into **Poor**, **Average**, or **Good** quality based on real-time sensor inputs.

4. **Raspberry Pi OS Integration**
 Once the models were finalized, they were exported and integrated into the Raspberry Pi 4 Model B running Raspberry Pi OS. Python scripts were scheduled to:

   - Automatically read incoming data.
   - Run the ML models.
   - Generate insights.
   - Format and send daily SMS reports to farmers.

2. Hardware technologies:

1. NPK 7-in-1 Soil Sensor



This advanced sensor collects seven critical soil parameters:

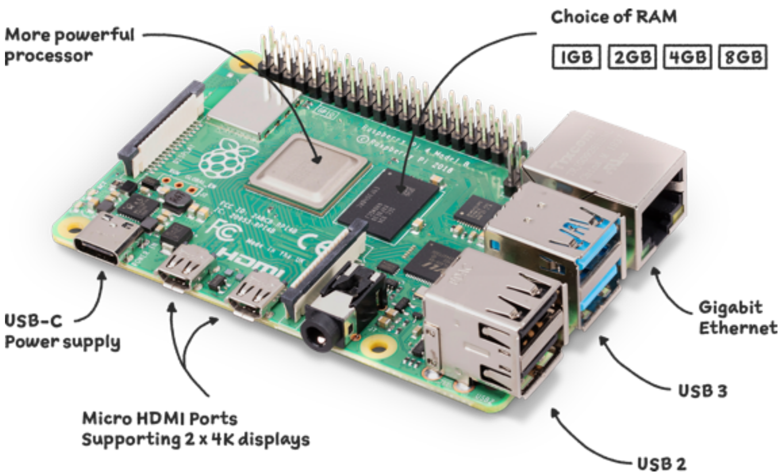
- Nutrient Levels: Nitrogen (N), Phosphorus (P), and Potassium (K)

- Environmental Conditions: Soil Temperature, pH, Conductivity, and Humidity

2. **RS485 to TTL USB Converter**

The sensor transmits data via RS485 protocol, which is not directly readable by the Raspberry Pi. The RS485-to-TTL converter translates this signal into TTL format, making the data accessible to the Pi via USB.

3. **Raspberry Pi 4 Model B**

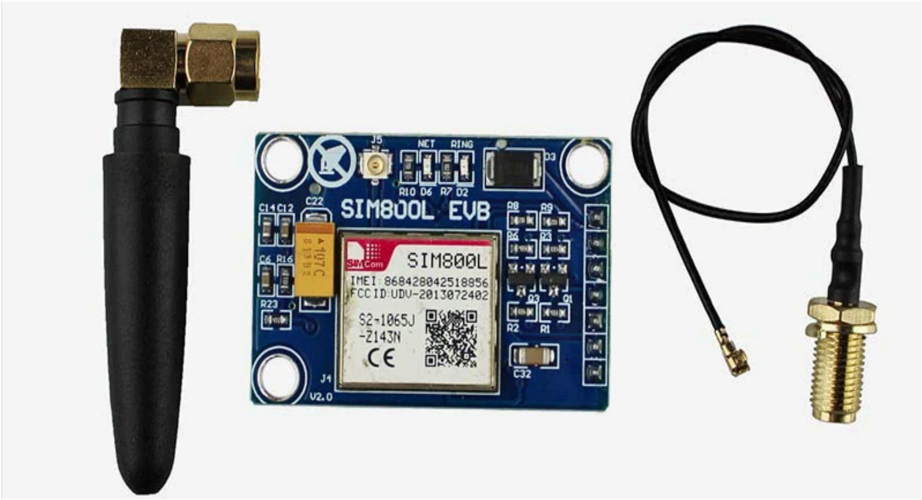


This single-board computer serves as the system's processing unit. Its responsibilities include:

- Reading the sensor data.
- Storing daily readings in a local CSV file (with timestamps).

- Running the ML models on new data to determine soil quality and recommend crops.
- Generating actionable insights (e.g., how to fix nutrient deficiencies).
- Preparing the SMS content.

4. **SIM800L GSM Module with Antenna**



The SIM800L GSM module is responsible for sending daily SMS messages to a predefined farmer's phone number. The SMS includes:

- Personalized greetings.
- Current soil quality assessment.
- Recommended crop (with other similar crop alternatives).
- Tailored and actionable advice on soil improvement or crop planning.

5. **Breadboard:**

All components were integrated onto a breadboard for stable prototyping. This layout includes the power supply connections, data line routing, and component fixing for consistent operation.

6. **Power Supply: 7-12v Lithium rechargeable battery**

To power the entire system in field conditions, a **7–12V rechargeable battery** was considered for supplying power to both the Raspberry Pi and the sensor setup in future iterations.

NB: However, for the **first working prototype**, the Raspberry Pi was powered using its dedicated 5V adapter/charger, ensuring stable performance during development and testing.

FINAL SMART-AG SYSTEM HARDWARE LOOK: SMART-AG BOX

To ensure durability, portability, and environmental resilience, the entire SMART-AG system was housed within a compact enclosure designed specifically for agricultural field deployment. The enclosure was engineered with simplicity and practicality in mind—small enough to be discreet and easy to install, yet robust enough to protect the sensitive electronic components inside.

The design considerations included weather resistance and corrosion prevention. To address these, the enclosure was made waterproof to safeguard the electronics from rain, humidity, and dust. In addition, materials were selected to resist metal corrosion, ensuring long-term reliability even in harsh outdoor conditions.

For the final version of the SMART-AG system, the enclosure is intended to be constructed from **recycled ecological plastic**. This choice aligns with sustainability goals by promoting environmental responsibility while offering lightweight, non-reactive, and corrosion-resistant protection. The ecological plastic casing will not only extend the lifespan of the device but also reduce its environmental footprint, making the SMART-AG system both a smart and sustainable solution for smallholder farmers.

(Below is the **SMART-AG BOX** concept.)

4. Benefits:

Here are the key benefits that come with this system for farmers and anyone who implements the system in his/her garden:

- **Improves Farming Decisions Through Daily Soil Reports:**
Farmers receive automated daily SMS reports with detailed information about soil health and crop suitability, helping them make timely and informed agricultural decisions.

- **Increases Productivity with Tailored Crop Suggestions:**
The system recommends crops that best match the current soil conditions, increasing the likelihood of better yields and sustainable farming practices.

- **Supports nutrient management with actionable insights:**
Farmers are given clear guidance on what actions to take—such as adding specific nutrients or adjusting irrigation—based on data-driven analysis of their soil conditions.

- **Functions Without Internet or Smartphones:**
Initially designed for rural environments, SMART-AG operates offline and delivers insights via basic SMS, making it accessible even to those without internet or advanced mobile phones.

- **Preserves Data for Long-Term Analysis:**
  Soil data is stored locally and updated daily, allowing for monthly performance reviews and helping farmers track progress over time.

- **Reduces Guesswork and Enhances Efficiency:**
  With daily updates and no need for manual soil testing, the system minimizes trial-and-error approaches, saving time, labor, and resources.

- **Rugged, Eco-Friendly Field Deployment:**
  Housed in a durable, recycled plastic SMART-AG Box, the system withstands harsh outdoor conditions, ensuring reliable, year-round functionality in the field.

5. Requirements

1. User Requirements:

- **Simplicity and Understandability:**
  The SMS content sent to farmers must be **clear, concise, and written in simple language**, ensuring that even users with minimal education or technical knowledge can understand and act on the information provided.

- **Offline Accessibility:**
  The system must work **without the need for internet access**, relying solely on basic mobile networks to deliver SMS updates, making it suitable for remote rural environments.

- **Timely and Reliable Updates:**
  Farmers expect **daily reports at a consistent time (6:30 AM)**. The system must ensure timely SMS delivery to support daily planning and decision-making.

- **Actionable Information:**
  The messages must contain **not just raw data**, but **recommendations and actionable steps**, helping users address nutrient deficiencies and choose appropriate crops based on real-time soil conditions.

- **Low Maintenance and Autonomy:**
  Once installed, the system should operate **autonomously** with minimal user intervention, ensuring convenience and consistent functionality.

System Requirements

Performance Requirements:

- **Efficient Processing:**
  The system must efficiently handle **daily soil readings**, perform **real-time ML predictions** (soil quality and crop suggestions), and **generate SMS content** without performance lag on the Raspberry Pi 4.

- **Data Storage and Logging:**
  The system should **log and store soil data locally** in CSV format, with **timestamped entries updated daily**, allowing for monthly data collection and analysis.

- **Reliable Operation:**
  The system must function **autonomously** and **consistently**, even in harsh field conditions, without requiring constant human intervention.

2. System requirement:

1. Performance Requirements:

- **Efficient Processing:**
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2. Scalability:

- **Modular Design:**

  The SMART-AG system should be easily replicated or scaled to support **multiple farms or expanded deployment**, allowing new sensor units to be integrated using the same configuration.

3. Security and Data Protection:

- **Data Integrity:**
  Locally stored soil data must be protected from corruption or loss during unexpected power outages by using **safe write protocols** and **periodic backups**.

- **Restricted Access:**
  Only authorized individuals should have **physical or terminal access** to the system's stored data and configuration files.

4. Functional Requirement:

- **SMS Delivery System:**
  The system must send **well-formatted SMS reports every day at 6:30 AM** using the GSM800L module to the farmer's mobile number. The message includes:
  - Soil condition summary (e.g., poor, average, good)
  - Recommended crops
  - Actionable insights based on deficiencies

- **Sensor Data Acquisition:**
  It must continuously gather accurate soil metrics (NPK, temperature, pH, humidity, conductivity) via the NPK sensor, processed through the RS485 to TTL interface.

- **Machine Learning Integration:**
  Embedded ML models must accurately **classify soil quality** and **suggest suitable crops** based on the real-time data received.

5. System design:

Data Flow Diagram:

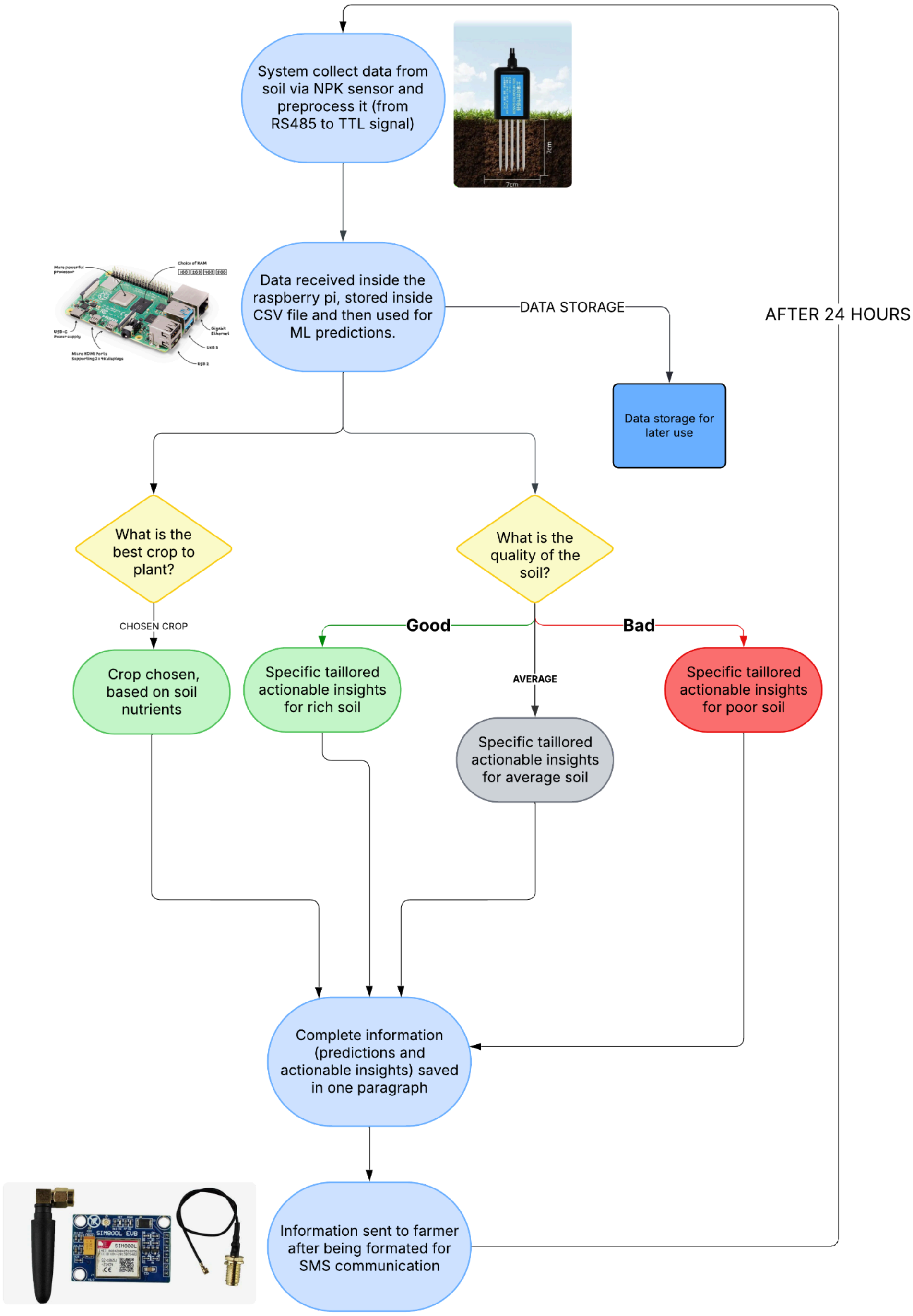


Figure 1: SMART-AG Data Flow Diagram

6. Human Interface Design

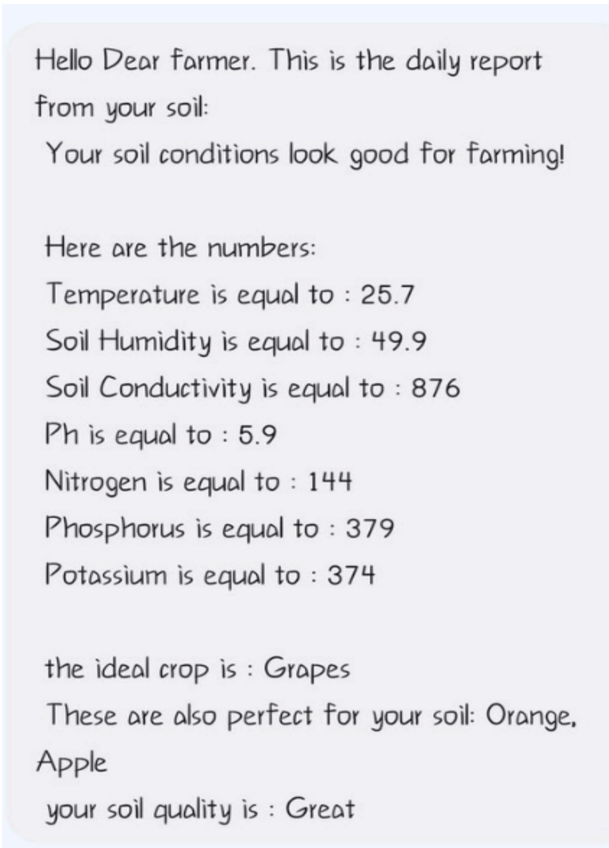
The SMART-AG system adopts a **human-centered approach** to ensure that even **non-tech-conversant farmers** can understand and benefit from the information sent via SMS. Since there is **no app or graphical interface**, the design priority is placed on the **clarity, structure, and simplicity** of the SMS messages.

User-Friendly SMS Format

The system sends a **daily SMS at 6:30 AM** that includes:

- **Soil health status** (e.g., Good, Average, Poor)
- **Recommended crop** based on current soil conditions
- **Actionable insights** (e.g., “Add compost to improve nitrogen levels”)
- **Date and time** of the reading for clear tracking

Each message is written using **simple language** in a structured format that follows Human-Computer Interaction (HCI) principles for text-based communication - Here is the example of the Message sent:



(Just one of the messages sent to the farmer.)

3. Testing and Evaluation

To ensure the reliability, accuracy, and practicality of the SMART-AG system in real-world farming environments, a variety of testing phases were conducted throughout development:

• Unit Testing

Each individual hardware and software component was tested separately:

- **Sensor Unit**: The NPK 7-in-1 sensor was tested to confirm accurate reading of soil parameters (N, P, K, pH, temp, etc.).

- **ML Models**: The crop prediction and soil quality classification models were tested independently in Jupyter Notebook using test datasets to validate prediction accuracy.

- **Soil Quality Model:**

```
[48]: LGBMClassifier
      LGBMClassifier()

[ ]:  # SOIL QUALITY ASSESSMENT MODEL

[49]: soil_qual_model.score(X_test, y_test)

[49]: 1.0

[50]: soil_qual_model.score(X_train, y_train)

[50]: 1.0
```

- **Crop Reccomandation Model:**

```
[ ]:  # CROP RECCOMANDATION MODEL

[26]: model_1.score(X_train, y_train)

[26]: 0.9987012987012988

[27]: model_1.score(X_test, y_test)

[27]: 0.990909090909091
```

- **GSM Module (SIM800L)**: The SMS module was tested by sending sample messages to different phone numbers to ensure delivery and network reliability, This went down to a back and forth trouble shooting due to initial component incompatibility issues.

4. **Integrated Component Testing**

After verifying individual components, integrated testing was done to ensure that connected parts work together smoothly:

- Sensor → Raspberry Pi → ML Models → SMS Output
  This tested the full data flow: from data collection to prediction to SMS generation.

5. **System Testing**

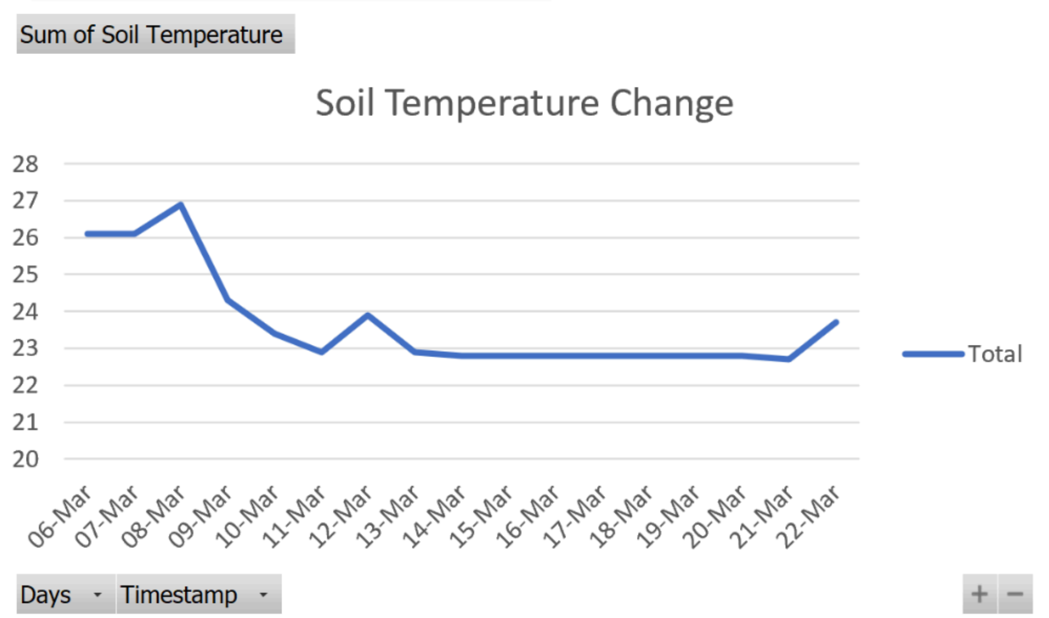
An end-to-end test of the full SMART-AG system was performed:

- The entire system was powered on and left running to simulate daily operation for at least 2 weeks.
- Real-time soil readings were collected.
- The system processed the data, generated predictions, formatted them into an SMS, and sent it at 6:30 AM.
- The CSV storage feature was also monitored to ensure it logged daily readings correctly.

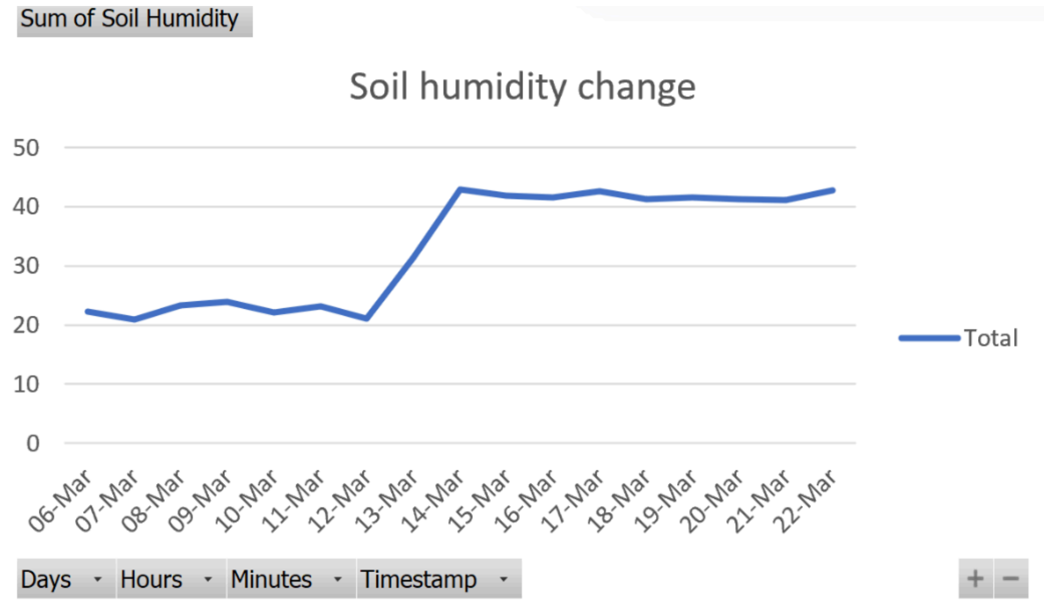
Quick Notice:

During the two weeks of the full system testing, the SMART-AG system was able to detect the climate change that occurred around the 16th of March, 2025, with rain increasing while heat decreased, and then the system went ahead by giving recommendations that were tailored to the climate change, and these recommendations were meant to help farmers not drought their crops by adding more water since the weather was already humid, impacting the increase in soil humidity and decrease in soil temperature.

(Below is the small analysis does on the insights gathered by the SMART-AG system around March 16th, 2025.) Notice that we are only seeing the **soil temperature** and **soil humidity**—–this is because these are the two parameters, out of the 7, that are mainly impacted or influenced by climate change.



(A very considerable drop in the soil temperature)



(A very considerable drop in the soil Humidity)

6. User Acceptance Testing

Though not tested on a wide commercial scale, the system was shared with a small group of agriculture students who received daily SMS messages and gave feedback on them.

- **Ease of understanding the messages**
- **Helpfulness of the advice**

- **Timeliness of the SMS**

Their feedback was used to improve message clarity, formatting, and system reliability to tailor it specifically to the end users available, but this needed more polishing since we need the system to be effective also for non-tech-conversant farmers.

7. Evaluation of the system:

The SMART-AG system successfully accomplished its primary goal of providing rural farmers with real-time soil health monitoring and personalized, actionable advice in the form of daily SMS alerts. The system is purely offline and was engineered to be field-deployable, allowing continuous, unmanned operation without the need for internet connectivity or operator intervention.

All the main functionalities—proper identification of soil parameters, local data storage, ML predictions, actionable suggestion generation, and immediate SMS notification—were successfully implemented, and the system was made reliable and pragmatic enough for non-technical users. The SMS format was generated based on HCI principles to make it readable and understandable by farmers with varying literacy levels.

Despite these improvements, there is still space for development in the SMART-AG system. One of these is the lifespan of power supplies. Although a rechargeable battery was investigated, the first prototype had a direct power supply, which made it difficult to install for long periods in isolated areas. Subsequent versions need to include solar power or a reliable off-grid storage system.

Scalability is another feature that can be improved. Currently, the system handles one user (one phone number) at a time. It can be scaled to handle multiple users and community-level deployment with future development.

The biggest development challenge was having a low budget, which limited the quality and durability of the housing materials and the possibility of testing the system in numerous real-life situations over extended periods of time.

Overall, the SMART-AG project provides a functional, innovative solution to improve farming outcomes through precision agriculture and edge AI. It demonstrates strong potential for wider adoption with further iterations and improvements.

CHAPTER FOUR: RESULTS AND DISCUSSION

Results and Discussions:

1. Results:

The SMART-AG project presentation by the stakeholders was brief and well articulated, with system goals clearly stated and solutions proposed.
The research was viewed as a valuable reference guide for agricultural enterprise. Stakeholder feedback was authentic and was specifically taken down to act as a guide during future realignments. Here they are:

- **Tailor SMS Based on Farmer Progress:**
  Stakeholders pointed out that the system must give contextualized messages depending on the farmer's stage or circumstance. For example, once a crop is planted, the system should stop giving crop recommendations and instead give maintenance and care tips. This renders communications relevant and avoids duplication.

- **Focus on Actionable Insights Over Raw Data:**
  It was advised that SMS messages must be kept simple by avoiding technical jargon and excessive sensor data. Instead, messages need to be straightforward, actionable recommendations that farmers can quickly grasp and use right away.

- **Evaluate System Usability and Affordability:**
  The stakeholders supported more research on how available the technology is to the average farmer, not only in application but also in affordability. There is a need to make sure that the solution is not only technically feasible but also feasible in reality for smallholder farmers.

- **Use Locally Relevant (African) Data:**
  They advised that the system be trained on datasets specific to African climates, soil types, and crop varieties. This would make the predictions more accurate and relatable for local farmers, thus increasing the credibility and effectiveness of the insights.

- **Comprehensive Project Documentation:**
  Proper documentation of the project—from architecture to implementation—was seen as crucial. This will allow others (including future

collaborators or developers) to understand, replicate, and enhance the system for broader use.

- **Explore Patent and Intellectual Property Options:**
  Since the system design, hardware integration, and logic were all developed from scratch, stakeholders recommended looking into intellectual property protection, such as filing for a patent, to safeguard the innovation and potentially open avenues for commercialization or funding.

Evaluation of SMS Communication Approach

The SMART-AG program was also praised for its great use of SMS as a vehicle of communication, particularly in rural areas. This method avoided the necessity of having sophisticated mobile apps and made accessibility feasible even in areas that lack good internet coverage or have poor smartphone penetration. The messages were crafted with simplicity and readability in mind, incorporating Human-Computer Interaction (HCI) principles to improve readability and comprehension by farmers of varying degrees of digital literacy. The interaction based on SMS significantly improved the system's usability and overall performance under real farming conditions.

Accessibility of the SMART-AG system:

The SMART-AG method emphasizes accessibility because it can be used to farms of all sizes, from large farms to modest home gardens. Farmers of various skill levels can benefit from the system's insights and recommendations due to its versatility. By using low-tech, affordable components and SMS for communication, the project promotes inclusive and responsible agricultural innovation. It advances the goal of guaranteeing that everyone has access to modern farming methods, irrespective of size or technical proficiency.

In conclusion, a review of the findings in the context of the SMART-AG system's goals reveals notable progress and strict adherence to the project's declared objectives. The project's findings, which were shared at the presentation, demonstrate a methodical and successful approach to promoting moral behavior. Farmers of various skill levels can benefit from the system's insights and recommendations due to its versatility. By using low-tech, affordable components and SMS for communication, the project promotes inclusive and responsible agricultural innovation.

2. Discussion

Upon detailed review of the project outcome, I conducted research on the implications of the results and its possible areas for future research. While presenting the project, I carefully paid attention to the comments and observations made by the stakeholders and, through this, gained a better idea of their requirements and tastes. I was able to develop an exhaustive plan for the future projects that will ensure even more success in the future by taking into account all of these factors.

Discussion of Implications and Potential Future Work:

Implications of Project Outcomes:

The positive feedback of the project's SMS notification strategy points out how critical it is to position accessibility and simplicity at the heart in rural locations. The approach appropriately assists farmers by prioritizing concise, easily readable language and brief, actionable guidance in the SMS, especially in areas with slow internet access or sophisticated technology. This strategy is focused on continuing to develop the SMS format more specifically to the farmer's stage and gaining more popularity based on various regional requirements and needs.

Future Work: Moving forward, several areas for improvement and expansion can be explored to enhance the effectiveness and scalability of the system:

1. **Tailored Messaging:** Developing an algorithm that personalizes SMS messages based on the farmer's progress and current needs, ensuring that repeated or irrelevant crop suggestions are avoided.

2. **Simplifying Information:** Focusing on the readability of the SMS content to ensure that the farmer receives only the most essential, actionable advice and recommendations, avoiding overwhelming them with too much technical information.

3. **Localization:** Incorporating locally relevant agricultural data to make the system more relatable and effective for farmers in specific regions, using datasets that represent African crop varieties and environmental factors.

4. **Affordability and Accessibility:** Exploring ways to make the system more accessible to a broader range of farmers, especially those with small-scale or household farms, ensuring that it is cost-effective and easy to implement in diverse farming environments.

Future Development: Personalization, African Crop Recommendations, and System Scalability

To further improve the overall performance and scalability of the SMART-AG system, some key areas will be the focus of future research. Firstly, the recommendation engine will be fine-tuned to give more personalized suggestions considering the individual farmer's needs, farm condition, and past records. This will render the system more pertinent and useful by making it provide personalized crop recommendations, actionable information, and step-by-step solutions for fixing soil deficits or anything else.

African farming information will also be incorporated into the recommendation system so that farmers in different regions are given recommendations that are based on crops that are locally produced and culturally sensitive. In order to give farmers more precise and useful information, this will entail consolidating regional databases with respect to local farming practices, soil, and climate.

To accommodate a wider range of users and farm types—everything from small home farms to large-scale agricultural operations—the scalability of the system will also be critical. To reach more users, especially those in rural and underserved communities with limited access to advanced technology, future efforts will include scaling the SMS platform and increasing the system's capacity to accommodate a wider range of farming conditions.

In order to promote more lucrative and sustainable farming practices, upcoming releases will primarily address enhancing crop suggestion accuracy, making the system more personalized, and making it scalable and accessible to a larger set of people.

Potential Future Work:

Moving forward, potential future work for the SMART-AG system could involve

- **Enhancing Recommendation Accuracy:** Continuously improving the crop recommendation engine by integrating new machine learning models, enabling more precise, context-aware suggestions based on diverse farm conditions, climate variations, and soil health.

- **Incorporating Additional Sensors:** Expanding the range of sensors used to capture more environmental and soil parameters, allowing the system to provide deeper insights into farm conditions, such as pest activity, water levels, or crop growth stages.

- **Personalized Feedback Mechanisms:** Developing a more personalized feedback system tailored to each farmer's unique situation, ensuring that advice, insights, and recommendations are based on the individual's specific soil health, crop history, and local farming practices.

- **Integrating Localized Data Sources:** Incorporating more localized datasets, including climate data, regional crop performance, and agricultural best practices specific to different African regions, improving the system's relevance and practicality for farmers across the continent.

- **Expanding Scalability:** Ensuring that the system can handle larger-scale deployments by enhancing its scalability to cater to a wider range of users, from small household farms to large-scale commercial farms.

- **Improving SMS and Communication:** Optimizing the SMS-based communication system to make messages even more accessible, ensuring that the information delivered is clear, concise, and actionable for farmers, regardless of their technological expertise.

- **Collaborating with Agricultural Experts:** Engaging with agricultural scientists and local experts to continuously refine the system's advice and ensure that the information provided remains up-to-date, scientifically sound, and effective in improving farming outcomes.

- **Exploring Mobile Integration:** Investigating the potential to integrate the system with mobile platforms or apps, providing farmers with even more flexibility and real-time access to recommendations, notifications, and insights.

CHAPTER FIVE: LIMITATION OF THE TECHNOLOGY AND CHALLENGES

1. General Limitations:

1. **Hardware Compatibility Issues:** One of the major limitations of the SMART-AG system was hardware incompatibility. As I built the connections from scratch, there were several challenges in ensuring that all components worked seamlessly together. This was especially evident when trying to use a smaller version of the RS485 to TTL converter, which proved incompatible with the Raspberry Pi. As a result, I had to revert to an older USB version of the RS485 to TTL converter. This limitation delayed the process and required adapting existing components to fit the system's needs.

2. **Limited Data Availability:** A significant limitation faced during the development of the system was the lack of accurate and up-to-date datasets for African crops and soil conditions. This gap forced me to rely on foreign datasets and attempt to adapt them to the African context. However, this resulted in the system recommending crops that were not commonly found in many parts of Africa, reducing the relevance and practicality of the suggestions for local farmers.

3. **System Automation Challenges:** Automation of the entire system posed several challenges, particularly when trying to ensure real-time processing of data from the NPK sensor and the delivery of actionable SMS messages. There were delays in processing and occasional errors due to the integration of various software and hardware components, making full automation harder to achieve in the initial prototype.

4. **System Accessibility:** Another limitation was ensuring accessibility for all farmers. While the system was designed to send SMS notifications, some farmers, especially in remote areas, faced difficulties with network coverage and SMS delivery. This lack of consistent access to communication channels hindered the effectiveness of the system for certain groups of users.

2. General Problems:

1. **Hardware and Software Integration:** Integrating various hardware components, especially the sensor data collection system and the Raspberry Pi, posed several technical challenges. The process of ensuring compatibility between these components, some of which were older versions or had limited support, led to delays in development and required troubleshooting and constant adjustments.

2. **Data Collection and Adaptation:** The process of collecting and adapting data was another challenge. I faced difficulties obtaining relevant datasets specific to African agricultural conditions. The datasets I had to rely on were often incomplete or did not reflect local farming practices, necessitating extensive adaptation. This issue contributed to the challenge of providing crop recommendations that were truly tailored to the African farmers' context.

3. **Limited Technical Support and Documentation:** Since I worked on the project alone, the absence of a larger team or external technical support slowed down troubleshooting and problem-solving. The lack of detailed documentation for some of the hardware components and frameworks also made the process more complex and time-consuming, limiting the system's development speed.

4. **Budget Constraints:** The budget limitations significantly impacted the scope of the project. With a limited budget, certain desired features, such as advanced automation, better sensors, or more comprehensive data integration, were not feasible. The need for more accurate data and sophisticated hardware was constrained by the budget, ultimately limiting the system’s potential for larger-scale implementation and more advanced functionalities.

3. Recommendations and Future Work

1. **Enhanced Crop Recommendations:** Future improvements can focus on refining the crop recommendation system by incorporating more locally relevant datasets specific to different regions in Africa. This could involve collaborating with agricultural experts and local farmers to create datasets that better reflect local soil conditions, crop varieties, and climate factors, ensuring more accurate and region-specific recommendations.

2. **Sensor Integration and Upgrades:** The system can benefit from incorporating additional sensors to collect more diverse and comprehensive soil data. For instance, integrating sensors to measure soil moisture levels, organic content, and additional environmental factors can provide a more holistic view of soil health. Upgrading the sensors would also ensure more accurate data collection, improving the effectiveness of the system's predictions and recommendations.

3. **User Customization:** The system could be enhanced to allow farmers to customize their profiles, including the type of crops they are growing and the specific soil conditions on their farm. This would allow the system to deliver personalized, tailored recommendations based on their unique needs, ensuring more practical and actionable insights.

4. **Offline Functionality:** Given that internet connectivity can be unreliable in rural areas, it is recommended to explore offline functionality for key aspects of the system. This would involve designing the system to work without an internet connection, allowing farmers to receive critical notifications and access data even when they are not connected to the network.

5. **Automation and Real-Time Alerts:** The system could be further developed to send real-time alerts for specific soil conditions, such as low levels of essential nutrients or high humidity, that could affect crop health. Automated alerts could be tailored to each user's situation, allowing farmers to take immediate action to optimize crop growth.

6. **Long-Term Data Storage and Analysis:** The system should incorporate a long-term data storage solution, where farmers' soil health and crop data are collected over time. This would enable the system to provide trend analyses, giving farmers insights into the long-term health of their soil and allowing for data-driven decisions on crop rotation and soil management strategies.

7. **Scalability and Future Expansion:** In the future, the system could be expanded to support additional features, such as integrating local weather data or creating a community platform for farmers to share advice and experiences. This would foster a stronger community of users and provide a collaborative space for farmers to learn from one another.

CHAPTER SIX: CONCLUSION

The SMART-AG system presents a promising solution for enhancing agricultural practices in rural areas, especially in African countries. With its ability to provide personalized recommendations, soil health monitoring, and timely feedback via SMS, it has the potential to significantly improve farming productivity.

Principal Advantages:

- **Fulfills a crucial need:** SMART-AG addresses the critical problem of inefficient farming practices by offering timely, actionable advice based on real-time soil data and crop recommendations.

- **User-friendly interface:** The system's SMS-based approach makes it accessible to farmers with limited technological resources, especially those in remote or low-connectivity areas.

- **Comprehensive features:** Beyond crop recommendations, the system provides personalized feedback based on individual farm conditions, empowering farmers with the knowledge needed for better crop management.

- **Scalability:** As the system gathers more data, it can scale to support more farmers, ensuring continuous improvement in its recommendations and features.

Points of Improvement:

- **Hardware compatibility:** The system faced challenges due to hardware incompatibilities, such as issues with connecting newer hardware to the Raspberry Pi, which affected system efficiency and required fallback to older versions of components.

- **Data limitations:** The use of foreign datasets to adapt to local African agricultural conditions posed challenges in accuracy, leading to crop recommendations that may not always align with local practices.

- **Offline functionality:** While the system relies on SMS for communication, expanding offline capabilities could further enhance its usefulness in areas with poor network connectivity.
- **Personalization:** Future improvements could include more advanced machine learning models to provide even more tailored and context-aware recommendations for different types of crops, farms, and environmental conditions.

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