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IMPLEMENTING A COST-EFFECTIVE SOIL MONITORING SYSTEM USING WIRELESS SENSOR NETWORKS TO ENHANCE FARMING PRACTICES FOR SMALL-SCALE FARMERS IN DEVELOPING ECONOMY COUNTRIES

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Abstract: Small-scale farmers in Africa often face challenges in monitoring soil and environmental parameters essential for informed agricultural decision-making. This study addresses this issue by developing a cost-effective soil monitoring system utilizing Wireless Sensor Networks (WSN). Our approach integrates real-time data analysis and visualization components to offer timely insights into soil conditions, weather patterns, and crop development, thereby enhancing agricultural decision-making processes. While commercial soil monitoring systems exist, their high cost presents a barrier to widespread adoption, particularly in African contexts. To address this issue, our proposed system utilizes WSN sensor nodes transmitting data to a central database via Arduinos functioning as web servers. This innovative approach extends monitoring capabilities to remote areas beyond the reach of individual nodes, thus promoting accessibility and affordability through the utilization of open-source software. In conclusion, our study aims to revolutionize farming practices in Africa by providing an affordable solution that empowers farmers with actionable insights for optimized agricultural outcomes, thereby aligning with the distinctive African perspective on the theory and practice of information systems.
Keywords: Small-scale farmers; Wireless sensing networks; Soil monitoring systems; Affordable technology; Wireless Sensor Networks (WSN); Agricultural data; Open-source software.

1 INTRODUCTION

The integration of wireless sensing network technology into soil monitoring systems marks a significant evolution from traditional methods, providing automation to reduce human labor and enable data collection from distant locations. Soil monitoring systems, equipped with distributed sensors within wireless sensor networks (WSNs), are capable of collecting and broadcasting weather data automatically, even in remote locations [1]. Typically housed in mast-mounted, weatherproof enclosures, a soil monitoring system comprises essential components such as a data recorder, rechargeable battery, telemetry (if desired), and meteorological sensors [2]. The system's configuration may include solar panels or wind turbines, allowing for flexibility in data storage or almost real-time reporting over a web server [3]. Historically, automatic soil monitoring systems were constrained to locations near electrical and communication infrastructure. However, advancements in solar panels, wind turbines, and mobile phone technology have liberated these systems from reliance on the electrical grid or landline telecommunications network [1].
Despite these advancements, several challenges persist, including energy depletion, packet loss, gateway failure, and sensor node failure [1]. To address these issues, we propose a novel system, Implementing Soil Monitoring System with Wireless Network, designed to electronically and continually communicate meteorological and climate parameters across diverse geographic areas [4]. This innovative technology allows meteorology agency controllers to remotely access weather climate nodes, enhancing efficiency and conserving time and energy [4]. The implementation of data analytics is essential for deriving insights into the soil monitoring system's health, especially given challenges such as increased data volume, transmission, or arrival rates, and potential data loss due to packet dropping [5].
Our proposed system also capitalizes on the widespread accessibility of news media outlets and the prevalence of communication devices in households. By strategically employing sensor nodes in fields, the system facilitates real-time communication of soil condition updates to individuals in affected areas via Short Message Service (SMS) [6]. In potential emergencies, sensor nodes relay critical data to a central station for processing, alerting locals about potential threats [6]. Leveraging WSN technology, this online monitoring framework overcomes challenges associated with wired systems [3]. For instance, in agriculture, applications such as tea plantation monitoring demonstrate the potential of WSNs. Image processing techniques applied to tea leaves tracked by sensors, with wireless communication to the central station, determine ripe areas for harvesting [7]. This paper highlights the pivotal role of WSNs in creating integrated information and production-based agricultural systems, contributing to increased farm productivity and efficiency.

Given the distinctive African perspective on the theory and practice of information systems, our work emphasizes its relevance to the African context. Africa, with its unique agricultural challenges and technological landscape, stands to benefit significantly from adopting innovative soil monitoring solutions using WSN technology. By addressing the specific needs and constraints faced by African farmers, our proposed system aims to advance agricultural practices and enhance food security across the continent.

2 BACKGROUND

The agricultural landscape has transformed rapidly with the integration of Information and Communication Technology (ICT), facilitating the widespread dissemination of crucial information on agricultural products, market dynamics, and research findings [8],[5]. Precision agriculture, which merges horticulture, engineering, and agriculture, optimizes crop yield and efficiency by meticulously managing environmental variables such as illumination, nutrients, temperature, and humidity [6],[7]. Temperature and humidity significantly influence plant processes, affecting germination, photosynthesis, and nutrient absorption [6],[7]. For instance, temperature variations impact respiration rates and sugar content in plants, with higher temperatures increasing respiration and lower temperatures decreasing photosynthesis [6]. Humidity regulates temperature and moisture loss; high humidity reduces evapotranspiration (ET), leading to less water absorption by leaves, while optimal moisture levels enhance root development and plant growth [6],[7].

The Green Revolution of the 1960s met global food and fiber demands through high-yielding crop hybrids, increased farm inputs, and improved mechanization [8],[7]. However, the extensive use of agricultural inputs raised environmental concerns [9]. The Speaking Plant Approach (SPA), developed by Japanese scientists since the 1980s, uses sensor technology to observe plant responses to growth conditions [3]. This approach employs wireless sensors, including radiofrequency receivers, sensors, and microcontrollers, providing a cost-effective and user-friendly method for managing agricultural systems [3]. Environmental Sensor Networks (ESN), a subset of Wireless Sensor Networks (WSNs) in environmental monitoring, integrate autonomous sensors to detect critical environmental factors, with data exchanged via a Sensor Network Server (SNS) [2]. Research shows that distributed ground soil monitoring systems offer more accurate rainfall and soil condition data at various depths than satellite-based methods, providing valuable agricultural insights [3].

This background frames our exploration of wireless sensing technology in agriculture, highlighting its critical role in optimizing environmental conditions for better crop productivity. Africa, facing unique agricultural and environmental challenges, can significantly benefit from adopting wireless sensing technology. By addressing specific environmental factors and optimizing agricultural practices, our research aims to enhance sustainable agricultural development and food security across the continent. Utilizing wireless sensor networks and environmental sensor networks, our study seeks to provide innovative solutions tailored to African agricultural contexts, advancing the theory and practice of information systems in this region.

3 PROPOSED SOLUTION

Effective utilization of water resources and other agricultural inputs is crucial for developing sustainable agricultural systems, especially in African contexts where small-scale farmers predominate. Precision agriculture, which involves the precise application of water and inputs, is essential for enhancing profits and conserving the environment [2]. Soil moisture detection technologies have shown significant potential to increase profitability and protect the environment [1]. However, small-scale farmers, often working with limited land and traditional methods, face challenges in adopting precision farming due to the high costs of available soil monitoring systems [10],[11].

To address these challenges, this study proposes the development of a communication system for monitoring soil properties, specifically designed to empower smallholders [12]. The proposed platform facilitates data gathering, viewing, and sharing, using open-source hardware and software to ensure affordability and simplicity [13]. For remote agricultural lands, supervisory software programs employing multi-terminal control frameworks are recommended [4]. These programs allow soil conditions to be updated remotely, promoting flexibility and ease of monitoring through web accessibility. Open-source electronics, wireless data transfer, and Internet-of-Things technologies make soil moisture sensing devices more accessible and affordable for small-scale growers [1].

Deploying Wireless Sensor Networks (WSNs) across extensive monitoring regions is made efficient by linking dispersed WSN base stations to an internet cloud server [3]. This setup enables users to access meteorological data through an online web service. WSNs, known for their low-power, low-cost, multi-hopping capabilities, provide an extended network without line-of-sight coverage, self-healing data paths, and independence from external service providers [3],[2]. The integration of mobile access and cloud computing further enhances the reach and convenience of the proposed system [4]. A mobile application, developed using 'MIT App Inventor 2,' offers easy access to the system. This solution utilizes the Arduino UNO WiFi Rev2 board as a web server, providing an interactive webpage displaying sensor values. Users can remotely perform manual actions or automate soil condition adjustments based on sensor values, offering a reliable, low-cost technology tailored for small-scale farmers [1],[13].

By focusing on affordability, simplicity, and accessibility, this proposed solution aims to overcome the challenges small-scale farmers face in adopting precision agriculture. Our work seeks to empower African smallholders with the tools and technologies necessary to optimize soil conditions and enhance agricultural productivity in a contextually relevant manner.

4 WEB-BASED SOIL MANAGEMENT SYSTEM

The integration of Information and Communication Technology (ICT) into small-scale farming practices holds immense potential for revolutionizing crop and soil management, particularly in regions like Africa where smallholder farmers predominate. Acknowledging the limited tech-savviness of many farmers, our proposed solution—a portable sensing box—aims to offer practical, seamless, and user-friendly ICT solutions tailored for digital farming in rural areas. Aligned with the second Sustainable Development Goal (SDG2) of the United Nations, which focuses on ending hunger, achieving food security, improving nutrition, and promoting sustainable agriculture, our project specifically targets marginalized areas, particularly in South Africa.

At the heart of our solution lies the development of a mobile soil management system, leveraging the Internet of Things (IoT). This system is designed to support humanitarian technology by meeting the specific needs of smallholder farmers. Comprising three main components—the Sensor application, the Farmer application, and the selected crops—the soil monitoring system utilizes various sensors to track crucial soil conditions and offer insights for optimized crop growth. Leveraging a web browser, the system accesses data from the IoT sensing platform, enabling the collection of parameters for all sensors within the sensing box.

The IoT sensing platform, combined with computer vision technology, provides comprehensive data on pH levels, soil moisture, humidity, pressure, air temperature, and light conditions, offering farmers a detailed understanding of soil characteristics. Built to withstand deployment environments, the hardware is designed for durability, ease of assembly, and transportation within a protective shell. Operationally, sensors collect data, transmit it to an Arduino, which then uploads the data over Wi-Fi to a web server. An Android app retrieves this data from the web server and presents it using the MIT App Inventor—an intuitive tool for creating Android apps. Through a graphical user interface, even non-programmers can develop mobile apps for Android smartphones, enabling users to visualize readings and take actions based on the collected data.

Our proposed web-based soil management system presents an innovative and user-friendly solution tailored to empower smallholder farmers. By facilitating sustainable agriculture and addressing the challenges of rural digitalization in Africa, our project aims to make a meaningful contribution to agricultural development and livelihood improvement in rural communities. Through accessible and practical ICT solutions customized for African farmers, we aspire to foster agricultural growth and enhance food security across the continent.

5 METHODOLOGY

This study employs a Design Science Research (DSR) methodology to develop and assess a mobile sensing device and accompanying mobile application with the goal of enhancing soil management practices for small-scale farmers, particularly within the African context. Following established principles within the DSR paradigm, the methodology focuses on designing innovative artifacts that address real-world agricultural challenges, specifically tailored to the needs and contexts of African small-scale farmers. The research initiates by identifying challenges encountered by small-scale farmers in Africa, particularly in soil management and agricultural productivity. Through a comprehensive literature review and stakeholder consultation, key issues are identified, highlighting the necessity for real-time soil monitoring solutions customized to the unique conditions and constraints faced by farmers in African regions.

Clear research objectives are defined to guide the development process, emphasizing the specific needs of African small-scale farmers. The primary objective is to design and assess a mobile sensing device and mobile application to deliver real-time soil condition information for small-scale farmers in Africa, aiding informed decision-making in agricultural practices. The Centre for Community Technologies (CCT) at Nelson Mandela University (NMU) has pioneered a state-of-the-art mobile sensing device capable of real-time measurement of soil moisture, light, humidity, and pH levels. Housed in a portable sensing box, this device is designed to furnish small-scale farmers in Africa with immediate and accurate information about their soil conditions. The data collected by the sensors is seamlessly integrated into a mobile farming application, purposefully crafted to meet the needs and preferences of African farmers. The design and development process adhere to a systematic approach within the DSR framework, comprising iterative stages of conceptualization, design, implementation, and evaluation, with a focus on cultural sensitivity and relevance to the African context.

Ideation and brainstorming sessions generate potential solutions to identified problems, concentrating on addressing the unique challenges faced by African farmers. Concepts are refined through extensive stakeholder engagement to ensure alignment with user needs and cultural preferences. Detailed design specifications are formulated, encompassing the selection of hardware components, sensor technologies, and software frameworks, while considering the availability and affordability of resources in African regions. Priority is given to usability, reliability, and scalability, taking into account the diverse socio-economic and infrastructural conditions prevalent in African agricultural settings.

Prototypes of the mobile sensing device and mobile application are developed and rigorously tested to validate functionality and performance in real-world African environments, with particular attention to usability and effectiveness in addressing identified challenges. Feedback from end-users and experts, especially those from African farming communities, guides iterative refinement to ensure that the artifacts meet the unique needs and expectations of African small-scale farmers. Continuous reflection and iteration refine the artifacts and address emerging challenges, with a commitment to ensuring cultural sensitivity and relevance to the African context. The research contributes to DSR and agricultural technology by presenting a novel solution for real-time soil monitoring tailored to the specific needs of African small-scale farmers.

Implications of the research findings are discussed in terms of their potential impact on agricultural practices in Africa and future research directions, focusing on promoting sustainable development and food security in African regions. The methodology outlined in this study adheres to established standards within the DSR paradigm, offering a rigorous framework for designing and evaluating innovative artifacts to address agricultural challenges in the African context. By prioritizing DSR principles and cultural sensitivity, this research aims to generate valuable insights and innovations to empower African small-scale farmers with actionable information for improved soil management practices.

5.1 Sensor Probe Collection:

The mobile sensing box incorporates a variety of sensor probes, each tailored to measure specific soil parameters. To ensure connectivity, the breadboard is utilized to extend power ports, providing essential 3.3 V, Ground, SDA, and SCL lines from the microcontroller board. The central component of the system, the Arduino board, operates with a single I2C bus consisting of two critical signals: SDA (Serial Data) for data transmission and SCL (Serial Clock) for clock synchronization. This configuration is crucial for the proper functioning of three of the probes within the system. The proposed IoT Sensing Platform represents a comprehensive integration of sensor arrays, corresponding software, and host hardware, all compactly housed within the portable sensing box. This platform aims to empower small-scale farmers by offering detailed insights into soil conditions, enabling informed decision-making for optimized agricultural practices.

The IoT Monitoring System encompasses a detailed set of processes and diagrams, providing a comprehensive view of system assembly, design, Arduino handling, IP addresses, and MIT App Inventor integration. This system is meticulously designed to ensure the seamless functioning of the sensors, efficient data transmission, and user-friendly interaction through the mobile application. The combination of advanced sensor technologies, IoT integration, and user-centric mobile applications positions this technology as a transformative tool for small-scale farmers, bridging the gap between traditional farming practices and modern, data-driven agriculture.

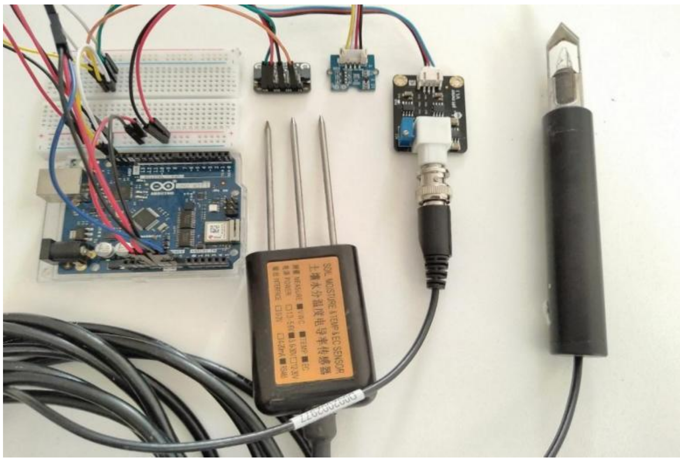

Figure 1: soil monitoring system Combined sensors

5.2 Hardware Integration and Remote Connectivity

To enhance durability and streamline integration, a 3D-printed protective shell (refer to Figure 2) is recommended to house all hardware components, including the single board computer (SBC), microcontroller, sensors, illumination, and mounting components constituting the IoT sensing platform. This protective shell ensures physical security while maintaining a compact and efficient design. Facilitating remote control and communication, the proposed sensor box leverages the Arduino UNO WiFi Rev2 board. This specific Arduino Uno variant integrates a WiFi module, allowing seamless wireless connectivity. With this configuration, the sensor box becomes remotely accessible, enabling real-time monitoring and control. To ensure autonomy and flexibility, the sensor box incorporates a battery to power the probes. This design choice allows the system to operate independently of external power sources, contributing to its versatility and suitability for deployment in various agricultural settings. By combining 3D printing technology for protective housing, Arduino Uno WiFi Rev2 for wireless communication, and a battery-powered setup for autonomy, the proposed sensor box stands as a robust and efficient solution for small-scale farmers. This integrated approach ensures not only the security and durability of the hardware but also the practicality of remote monitoring and control.

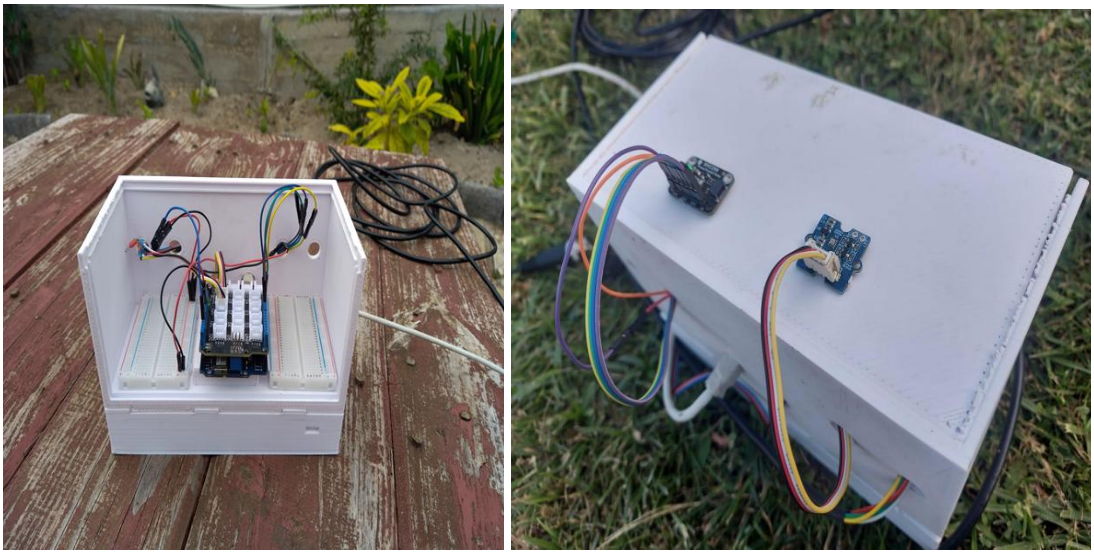

Figure 2: Showing the 3-D Casing design

5.3 Arduino Integration and Web Server Establishment

The proposed system utilizes the Arduino UNO WiFi Rev2 board in conjunction with the WiFiNINA library to effectively manage connected sensors and gather readings from diverse sensor components. This combination empowers the Arduino to compile these readings into a user-friendly web server interface, facilitating interaction with the sensor board. Upon successfully uploading the code to the Arduino UNO WiFi Rev2 board, users can initiate the Serial Monitor, which provides a visual representation of the system's functioning and status. While specific details of Figure 3 are not provided, it is expected to present relevant information and feedback regarding the sensor board's operation. The primary interface for interacting with the sensor board is the established web server. Users can access this interface to monitor sensor readings, control functionalities, and obtain real-time information about soil conditions. Facilitated by the Arduino UNO WiFi Rev2, the web server ensures a straightforward and accessible means of interaction. The Serial Monitor serves as a valuable tool for debugging, system analysis, and real-time observation of the Arduino's activities. Through seamless integration of the Arduino UNO WiFi Rev2 and WiFiNINA library, the system achieves a cohesive and efficient approach to sensor management, data collection, and web server establishment. This integration lays the foundation for a user-friendly and accessible interface for monitoring and controlling soil conditions in agricultural settings.

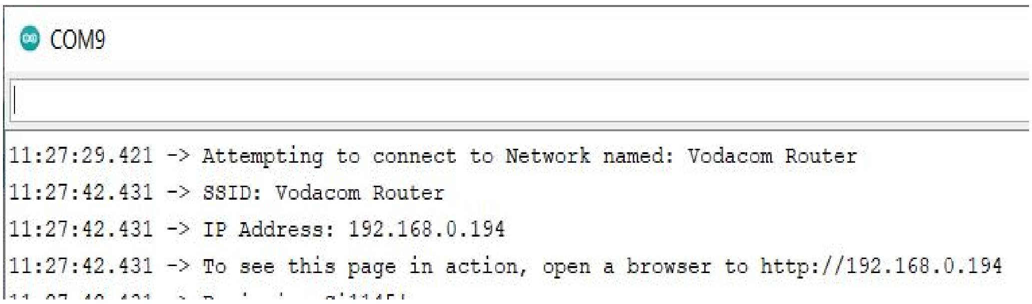

Figure 3: illustrating the serial monitor screen

5.4 Accessing Sensor Data via Web Browser

Upon successfully establishing the web server, users can access sensor values through a web browser. The process involves copying the IP address provided by the system, which is crucial for connecting to the web server hosted by the Arduino UNO WiFi Rev2 board. Users then open a web browser (e.g., Google Chrome, Mozilla Firefox) and paste the copied IP address into the browser's address bar. After entering the IP address, the web browser loads a page displaying all the sensor values. Figure 4 illustrates the expected layout of this web page, presenting a clear and organized presentation of information related to soil conditions, including moisture, light, humidity, and pH levels. By following these steps, users can effortlessly access real-time sensor data through a web browser, providing a convenient and user-friendly means of monitoring and analyzing soil conditions. The web page serves as a comprehensive dashboard, presenting essential information for informed decision-making in agricultural settings.

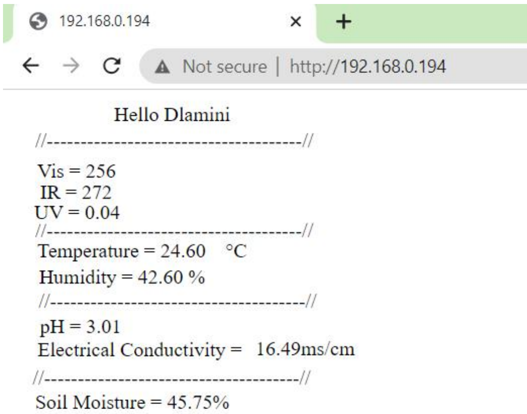

Figure 4: Web Browser Display of Sensor Values

5.5 Enhanced User Interaction with MIT App Inventor

Utilizing the MIT App Inventor, a sensor application has been successfully developed to improve user interaction with the IoT sensing platform. The Web component within the MIT App Inventor plays a crucial role in enabling users to access web-based features. The MIT App Inventor offers a user-friendly environment for creating Android applications, allowing users to design and implement app functionalities through a visual interface. The Web component, a key element of the MIT App Inventor, facilitates web-based interactions by empowering users to perform actions such as accessing URLs and posting text or files to web servers. This functionality enhances the interaction between the sensor application and the IoT sensing platform, providing users with the fundamental features of a web browser. Users can seamlessly navigate to specific pages on the Internet and post text or files to a web server through the Web component. Figure 5 depicts the MIT App Inventor interface, showcasing the integration of the Web component into the sensor application. This component enables users to access web-based functionalities seamlessly, thereby enhancing the overall user experience. The successful creation of the sensor application using MIT App Inventor provides a platform for convenient interaction with the IoT sensing platform. Through the Web component, users can harness the capabilities of a web browser, fostering a more intuitive and accessible application.

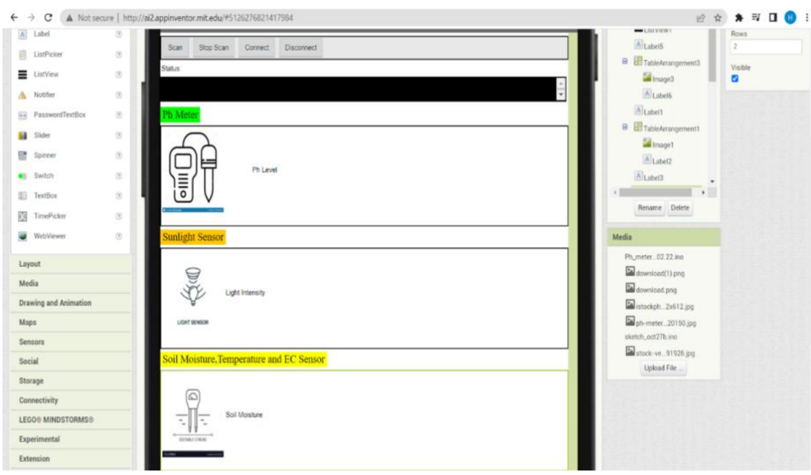

Figure 5: illustrating the MIT App Inventor

The development of the soil monitoring application was undertaken using the "MIT App Inventor 2," an open-source blocks platform-based environment endorsed by Google. This application, designed for Android devices such as tablets or smartphones, has been crafted by the Centre for Community Technologies (CCT) at Nelson Mandela University (NMU). MIT App Inventor 2 is a program that enables the creation of Android applications using a visual, blocks-based approach. It is an open-source platform supported by Google and is well-suited for developers aiming to build applications for Android devices. The smartphone application serves the purpose of providing valuable information to subsistence and small-scale farmers. Its primary focus is on educating farmers about practices that can enhance soil management, subsequently improving crop health and productivity. Recognizing that many farmers may lack literacy and e-literacy skills, special attention was given to ensuring the mobile application's user-friendliness. The design incorporates simplicity, making it easy for users to navigate and comprehend. Considering the potential literacy challenges, the application features text and images that are easy to read and view. This design choice enhances accessibility and ensures that information is effectively communicated to the target audience. The overarching goal of the mobile application is to empower farmers with actionable insights that contribute to the improvement of soil management. By providing relevant information in a user-friendly format, the application aims to positively impact crop health and productivity.

6 DISCUSSION

The findings of this study underscore the significance of leveraging cost-effective soil monitoring systems, particularly tailored for small-scale farmers in Africa. Our research addresses the existing gap in soil monitoring capabilities by developing a novel approach that integrates Wireless Sensor Networks (WSN) with real-time data analysis and visualization components. This innovative system offers timely insights into soil conditions, weather patterns, and crop development, thereby enhancing agricultural decision-making processes. Comparing our approach with existing commercial soil monitoring systems, we recognize the primary barrier to widespread adoption: high costs. By utilizing WSN sensor nodes transmitting data to a central database via Arduinos functioning as web servers, we have developed an affordable solution that extends monitoring capabilities to remote areas beyond the reach of individual nodes. This integration of open-source software ensures accessibility and affordability, aligning with the distinctive African perspective on the theory and practice of information systems.

Our study contributes to the existing body of literature by providing a critical synthesis and comparison of primary data with previous research findings. By addressing the limitations of commercial soil monitoring systems and proposing a cost-effective alternative, we bridge the gap between academic research and practical implementation, particularly in the African agricultural context.

The literature on smart home automation and intelligent interface systems provides valuable insights that can be applied to our study on developing a cost-effective soil monitoring system for small-scale farmers in Africa. [14] discuss the low-cost implementation of smart home automation, highlighting the importance of affordability and simplicity in technology solutions. Similarly, [15] present a GSM-based home automation, safety, and security system, emphasizing the integration of mobile phone technology for remote monitoring and control. These studies underscore the significance of leveraging accessible and user-friendly technologies to address real-world challenges, aligning with our approach to developing a cost-effective soil monitoring system for small-scale farmers.

Moreover, [16] introduce an Arduino family controller and its interactions via an intelligent interface, showcasing the potential of open-source hardware platforms like Arduino in designing innovative solutions. By integrating Arduino boards as web servers in our soil monitoring system, we adopt a similar approach to extend monitoring capabilities to remote areas beyond the reach of individual nodes. This integration of open-source hardware and software technologies ensures affordability and accessibility, which are critical factors in promoting the adoption of our proposed system among small-scale farmers in Africa. Overall, the literature on smart home automation and intelligent interface systems aligns with our research objectives and methodology, emphasizing the importance of affordability, simplicity, and user-centric design in developing technology solutions for real-world applications. By drawing insights from these studies, we strengthen the theoretical foundation of our research and provide practical implications for the design and implementation of cost-effective soil monitoring systems tailored to the needs of African small-scale farmers.

Furthermore, our findings highlight the importance of considering socio-economic and infrastructural conditions prevalent in African agricultural settings. The user-centric design of our soil monitoring system, emphasizing usability, reliability, and scalability, ensures its relevance and effectiveness in addressing the unique challenges faced by small-scale farmers in Africa. In conclusion, our study aims to revolutionize farming practices in Africa by empowering farmers with actionable insights for optimized agricultural outcomes. By developing a cost-effective soil monitoring system that aligns with the specific needs and contexts of African small-scale farmers, we contribute to the advancement of sustainable agricultural development and food security in African regions.

7 CONCLUSION

The integration of Information and Communication Technology (ICT) into small-scale farming holds significant promise for enhancing crop and soil management, thereby contributing to increased agricultural production, particularly within the African context. The adoption of precision agriculture, combining horticulture, engineering, and agriculture in a controlled environment, emerges as a vital strategy to maximize crop output and efficiency, aligning with the agricultural practices prevalent in many African regions.The Centre for Community Technologies (CCT) at Nelson Mandela University (NMU) has been at the forefront of developing practical and user-friendly ICT solutions tailored specifically for subsistence and small-scale farmers in Africa. One such solution is the soil monitoring application, crafted using the "MIT App Inventor 2" platform for Android devices. This application reflects our commitment to addressing the unique needs and challenges faced by African farmers, particularly those related to technological accessibility and usability.

The utilization of the Arduino UNO WiFi Rev2 board, in conjunction with the WiFiNINA library, forms the backbone of our soil monitoring system. This setup enables efficient sensor management, data collection, and the establishment of a user-friendly web server interface, catering to the technological capabilities of small-scale farmers in African rural areas. The soil monitoring application, designed specifically for Android devices, prioritizes ease of use and accessibility, ensuring that farmers with varying levels of technological proficiency can benefit from its functionalities. Our soil monitoring system integrates various sensors within an IoT sensing platform, facilitating the identification and addressing of soil requirements crucial for subsistence farming operations in Africa. Understanding the literacy and e-literacy constraints of small-scale farmers, our solutions emphasize simplicity, with text and images within the application designed for easy comprehension.

The overarching goal of our soil monitoring system is to contribute to humanitarian technology, particularly in marginalized areas of South Africa and other African regions. By empowering smallholder farmers with valuable insights for improved soil management, our system aims to enhance agricultural productivity and sustainability within the African context. In summary, the convergence of ICT solutions, precision agriculture, and practical design principles holds significant promise for transforming agriculture in rural Africa. The ongoing efforts by the CCT at NMU exemplify our commitment to leveraging technology for the betterment of subsistence and small-scale farming communities.

8 FUTURE WORK

The future development of the soil management system will focus on enhancing its functionality to better serve the needs of small-scale and subsistence farmers, particularly within the African context. This endeavor will involve the refinement and expansion of both the farmer and sensor applications, aiming to provide a comprehensive set of features tailored to the unique requirements of users engaged in agricultural practices in Africa.To ensure usability and effectiveness, two distinct Android mobile applications will be developed: one catering to farmers and the other to sensor applications. Detailed functional requirements will be defined for both applications, emphasizing a seamless and intuitive user experience. The sensor application will support the configuration of sensors, real-time observation of measurements (such as light, temperature, soil pH, and soil humidity), data logging, and data export functionalities. Additionally, a visualizer within the farmer application will assist users in capturing photos for soil type identification, leveraging the Zones of the Textural Soil Classification System.

Furthermore, the farmer application will incorporate user authentication features, enabling individuals to sign up, log in, and select between crops such as sweet potato and maize based on their cultivation site. Specific menus will be provided for each chosen crop, offering information on readings, pest and disease management, soil management practices, and fertilization techniques. Soil management menus will include submenus covering nutrient management, organic diversity, tillage methods, soil compaction mitigation, and strategies for adding organic matter to the soil. The system will also include a dedicated page focusing on soil nutrition, providing insights into various soil types and recommending actions to improve soil fertility. A weather page will be integrated, offering hourly, daily, and monthly weather readings to assist farmers in making informed decisions about agricultural activities. Leveraging the United States Department of Agriculture soil texture triangle acquisition system, the system will provide farmers with valuable insights into the type of soil present in their fields.

This future work aims to create a robust and feature-rich soil management system that empowers farmers with valuable information and tools for optimizing agricultural practices. By addressing the specific needs and challenges faced by small-scale and subsistence farmers in Africa, these envisioned developments underscore our commitment to technological advancements that contribute to the advancement of agriculture within the African context.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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