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ORIGINAL

IoT Agri-Care Advisor Mobile Application for Monitoring Paddy Plant Health and Delivering Smart Farmer Advisory Toward Sustainable Agriculture

Aplicación Móvil IoT Agri-Care para el monitoreo de la salud del cultivo de arroz y la entrega de asesoramiento inteligente al agricultor hacia una agricultura sostenible

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ABSTRACT

The agriculture sector significantly supplies rice, which is a staple food in Malaysia. Thus, there is a considerable demand for an increase in paddy production. However, the quality of soil is crucial to the health of paddy. This is because poor soil quality leads to unhealthy paddy, which results in the degradation of crop yields. In addition, traditional methods and hardware-based monitoring systems are often inaccessible to farmers with limited technical knowledge. Thus, this research aims to develop and evaluate an innovative mobile application named IoT Agri-Care Advisor to assist farmers with real-time soil analysis and nutrient advisory on the paddy health. This is done by measuring and collecting levels of nitrogen, phosphorus, potassium, electrical conductivity, and potential Hydrogen of the soil nutrients through embedded sensors. Then, the collected data are transmitted to the cloud, which will be analyzed and used to generate advice for the farmers. Firebase is used to ensure secure data storage and real-time synchronization. In addition, this developed mobile application has several easy-to-use features such as interactive maps, historical data visualization, and customized advice to the farmers. The application was tested on two types of paddy fields—general and plowed—in Perlis, Malaysia. Results showed variations in soil nutrient levels in the general and plowed paddy fields, which guided specific fertilizer recommendations. Hence, this IoT Agri-Care Advisor mobile application offers a promising solution for enhancing agricultural practices, supporting food security, and sustainable farming in Malaysia.

Keywords: IoT Agri-Care Advisor; Sustainable Agriculture; Mobile Application; Smart Agriculture; Soil Nutrient Management.

RESUMEN

El sector agrícola contribuye significativamente al suministro de arroz, alimento básico en Malasia. Por ello, existe una considerable demanda para aumentar la producción de arroz. Sin embargo, la calidad del suelo es crucial para la salud del cultivo, ya que un suelo deficiente conduce a un arroz poco saludable, lo que resulta en la degradación del rendimiento de los cultivos. Además, los métodos tradicionales y los sistemas de monitoreo basados en hardware suelen ser inaccesibles para los agricultores con conocimientos técnicos limitados. Por lo tanto, esta investigación tiene como objetivo desarrollar y evaluar una aplicación móvil innovadora llamada IoT

Agri-Care Advisor, para ayudar a los agricultores con un análisis en tiempo real del suelo y con recomendaciones nutricionales para mejorar la salud del cultivo. Esto se logra mediante la medición y recolección de niveles de nitrógeno, fósforo, potasio, conductividad eléctrica y potencial de hidrógeno del suelo a través de sensores integrados. Luego, los datos recopilados se transmiten a la nube, donde se analizan y se utilizan para generar recomendaciones a los agricultores. Firebase se utiliza para garantizar un almacenamiento seguro de datos y una sincronización en tiempo real. Además, la aplicación móvil desarrollada incluye varias funciones fáciles de usar, como mapas interactivos, visualización de datos históricos y asesoramiento personalizado. La aplicación fue probada en dos tipos de campos de arroz —general y arado— en Perlis, Malasia. Los resultados mostraron variaciones en los niveles de nutrientes del suelo, lo cual permitió recomendaciones específicas de fertilización. Así, esta aplicación móvil IoT Agri-Care Advisor representa una solución prometedora para mejorar las prácticas agrícolas, apoyar la seguridad alimentaria y fomentar la agricultura sostenible en Malasia.

Palabras clave: IoT Agri-Care Advisor; Agricultura Sostenible; Aplicación Móvil; Agricultura Inteligente; Gestión de Nutrientes del Suelo.

INTRODUCTION

Agriculture is a crucial sector that significantly contributes to the global economy by supplying various crops and foods to people worldwide. Rice which is produced from paddy, serves as a fundamental food source for countless individuals around the world.[1,2] In Malaysia, continuous efforts have been made to increase paddy production and improve paddy farming efficiency, leveraging the use of modern technologies such as precision farming and the adoption of sustainable farming practices.[3,4,5] For example, several researchers utilize all-terrain vehicles (ATVs) and drones for precision farming as in.[6,7] These efforts are intended to ensure that paddy remains an important contributor to Malaysia in ensuring food security.[8,9,10] However, these advanced technologies might be costly for farmers especially those who live in rural areas. On top of that, the success of agriculture depends on various factors. Specifically, the quality of soil brings a vital significance to the health of the crops.[11,12,13,14,15,16] Poor soil quality significantly leads to unhealthy crops which results in degradation or reduction of crop yields. Several critical parameters of key soil such as levels of nitrogen (N), phosphorus (P), potassium (K), electrical conductivity (EC), and potential Hydrogen (pH) should be balanced to ensure a healthy paddy.[14,15,16,17,18] Thus, the application of these key soils is crucial in addressing nutrient deficiencies, yet incorrect or excessive use can lead to environmental harm, increased costs, and reduced crop profitability.[19]

Several previous types of research have extensively focused on real-time monitoring systems, especially in developing hardware in various types of agriculture which offer numerous benefits, including enhanced decision-making, increased efficiency, and reduced environmental impact. These systems enable farmers to monitor crop conditions continuously and receive immediate feedback on any changes. This leads to more precise applications of inputs and early detection of issues such as pest infestations or nutrient deficiencies.[20] In addition, real-time monitoring can help in optimizing irrigation schedules and reducing water usage, which is critical in regions facing water scarcity. With the current advancement in technology nowadays, mobile applications have become an important tool for farmers in providing them with easy access to valuable information and data. According to,[21] mobile applications can deliver real-time weather updates, market prices, and expert advice, helping farmers make informed decisions. In the context of Internet of Things (IoT) based monitoring systems, the mobile application serves as an interface that allows farmers to interact with the system, view data, and receive recommendations to improve crop health and yield. The ease of use and accessibility of mobile applications make them an effective tool for disseminating information and enhancing the adoption of modern farming practices.[22,23]

However, these existing researches are mostly focused on monitoring systems through hardware rather than developing mobile applications which are more convenient for the farmers as in.[24] This is especially true for the farmers who have limited skills and knowledge in hardware. In addition, the existing monitoring systems have been focusing on various types of crops which might face different requirements compared to paddy crops. Thus, to improve the aforementioned previous works, the novelty of this research emphasizes a conceptual framework to provide an efficient mechanism based on the limitations of the previous works. Specifically, this research focuses on the mobile strategy through integrating real-time IoT-based soil monitoring for paddy with a mobile application that provides suitable feedback and recommendations for farmers. As compared to previous works that are only focused on delivering general raw data or alerts through the existing systems, this research proposed a real-time system by analyzing several critical key soil parameters such as N, P, K, EC, and pH through integrating the use of mobile applications. Precisely, the developed mobile application namely IoT Agri-Care Advisor provides precision-focused advice on fertilization practices and soil management. This is done by analyzing and interpreting the condition of the soil from the paddy field. To sum up, this IoT Agri-Care Advisor mobile application delivers a significant solution that optimizes paddy productivity which directly contributes to the Sustainable Development Goals (SDG) Goal 2 which is Zero Hunger[25] through ending hunger, achieving food security, improving nutrition, and promoting sustainable agriculture.

METHOD

This section emphasizes the mobile application development of the IoT Agri-Care Advisor, with a particular focus on the user interface (UI) design, usability features, and integration of core functionalities tailored for real-time agricultural monitoring. Specifically, this mobile application features a clean, intuitive interface that allows farmers to visualize soil nutrient levels, receive system-generated alerts, and access GPS-based location tracking for field-specific data. Key components include the Firebase real-time database for cloud data storage, the Global System for Mobile Communication (GSM) module for remote communication, and Global Positioning System (GPS) integration for geotagging sensor data. The application also includes a dashboard view summarizing key environmental parameters, and a notification system for critical soil conditions. This mobile application was tested on two types of paddy fields—general and plowed—in Perlis, Malaysia. The application assumes that sensor data acquisition and transmission from the field are stable and reliable to ensure the effectiveness of the advisory functions delivered through the mobile interface.

Flowchart of IoT Agri-Care Advisor mobile application

This IoT Agri-Care Advisor mobile application utilized the Agile software development process.[26] It is significant in the process of continuous integration, iterative testing, and rapid development cycles, which are essential for the mobile approach throughout this research. Each development sprint in Agile process focused on implementing key functionalities such as soil data visualization, location-based tracking, and real-time alert notifications. This mobile application enables farmers to have real-time access, receive personalized suggestions, advice, or recommendations, and effectively manage their agricultural practices. The flowchart of the IoT Agri-Care Advisor mobile application which consists of several significant features is illustrated in figure 1 as follows.

Figure 1. Flowchart of IoT Agri-Care Advisor mobile application

The flow chart includes the following features such as Login which requires the user to enter a username and password to access the dashboard. The user inputs for the username and password are verified and authenticated with the Firebase. If the username and password match, the user is redirected to the dashboard page. On the Dashboard page, the menu for the application will be displayed. Then, if users select Soil Nutrient Check, they will be redirected to a page containing instructions on how to use the application. The user must select the plant type before proceeding. The next feature is Instructions which requires the user to read and follow the instructions. Once completed, the user clicks the next button, sending the instructions to the Raspberry Pi through the Firebase to read the sensor. On the part of sensor data, the Raspberry Pi will respond to the sensor data, which will be sent to the Firebase. The user clicks the retrieve button for the current coordinates in the application and requests the coordinates from the GPS module attached to the Raspberry Pi.

Meanwhile, in data processing, all collected data from the Raspberry Pi is sent to the Firebase, where the Android application processes the data and gives recommendations about soil fertilizer to the user. In addition, with the developed feature of Map, it will show the location pinpoint with N, P, K, EC, pH, and soil moisture on the map. Each pinpoint on the map shows the data, and if selected, it shows the details for each location. For the Plant Advisor feature, if the user selects the Plant Advisor option, it will retrieve and show all data collected. Last but not least, the History feature in this application allows users to access and view all the data retrieved from Firebase. Once a specific historical record is selected, the application displays the relevant information related to the location associated with that record. Additionally, users can click on the advisor button to retrieve and display information about the advisor connected to that location. Moreover, the application provides a navigation button that, upon clicking, enables users to navigate to the selected location. With these features, users can seamlessly explore historical data, access location-specific details, retrieve advisor information, and easily navigate to desired locations.

To simplify, several features contribute to the realization of this IoT Agri-Care Advisor mobile application. The first feature is User Interface and Navigation which enables the application to start with a login page where users enter their credentials to access the dashboard. The dashboard displays several menu or icon options such as Check Soil, Train Data, Contact Us, Map, History, and Logout. Another feature is Soil Nutrient Check which allows users to select the plant type and the users need to follow the instructions to connect with the sensors. The application communicates with the hardware setup, allowing users to retrieve real-time data from the sensors. Then, the collected data will be processed in the cloud and suggestions or recommendations are generated for the user. Apart from that, the map's feature visualizes all collected data with pinpoint markers on an interactive map. Meanwhile, the history feature allows users to access and view all retrieved data, including comprehensive details for each location and advisor recommendations. Last but not least, the feature of Database Implementation utilizes Firebase software for data storage and real-time synchronization. Also, the design of this database ensures efficient data storage and retrieval, with user information securely stored using Firebase authentication.

Overview interfaces of features in the IoT Agri-Care Advisor mobile application

The overview of the interfaces for several aforementioned features of the developed mobile application and functionality for each interface are explained from figure 2 to figure 5. Specifically, figure 2 presents the login, register, and forgot password pages of the IoT Agri-Care Advisor mobile application. The login page serves as the entry point for users, requiring them to input their credentials to access the application. The register page allows new users to create an account by providing the necessary information, while the forgot password page facilitates password retrieval in case users forget their login credentials. Once successfully logged in, users are directed to the dashboard page, which provides a menu that includes options such as "Check Soil," "Train Data," "Contact Us," "Map," "History," and "Logout.".

Meanwhile, figure 3 showcases the dashboard menu of the IoT Agri-Care Advisor mobile application, providing users with various options to navigate and interact with the application. The menu includes options such as "Check Soil," "Train Data," "Contact Us," "Map," "History," and "Logout." When the user clicks on the "Check Soil" option, they are directed to the instruction page, where they are required to read the instructions carefully before proceeding. After reading the instructions, users can select the plant type and proceed to the "Read Sensor" page. On this page, the application communicates with the hardware setup, allowing users to retrieve real-time data from the sensors. Users can then wait for the data to update and view the latest information.

Another feature that illustrates the result and advisor section of the IoT Agri-Care Advisor mobile application is shown in figure 4. This feature provides insights and recommendations or suggestions in terms of identifying potential causes for each soil parameter, including nitrogen (N), phosphorus (P), potassium (K), electrical conductivity (EC), and potential Hydrogen (pH). Users can access this information to have a better understanding of the current quality of the soil and make informed decisions regarding the quantity of fertilizer to be applied to the paddy.

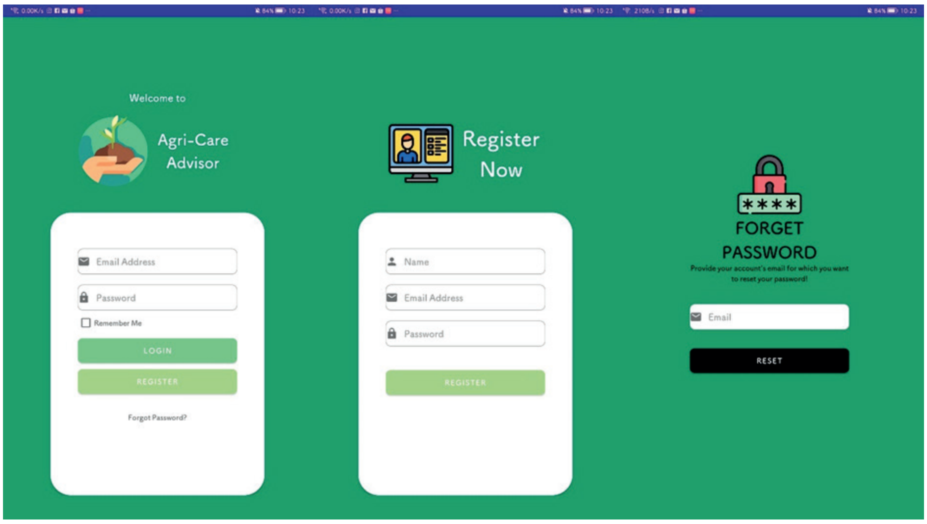

Figure 2. Interface, Register, and Forgot Password interfaces

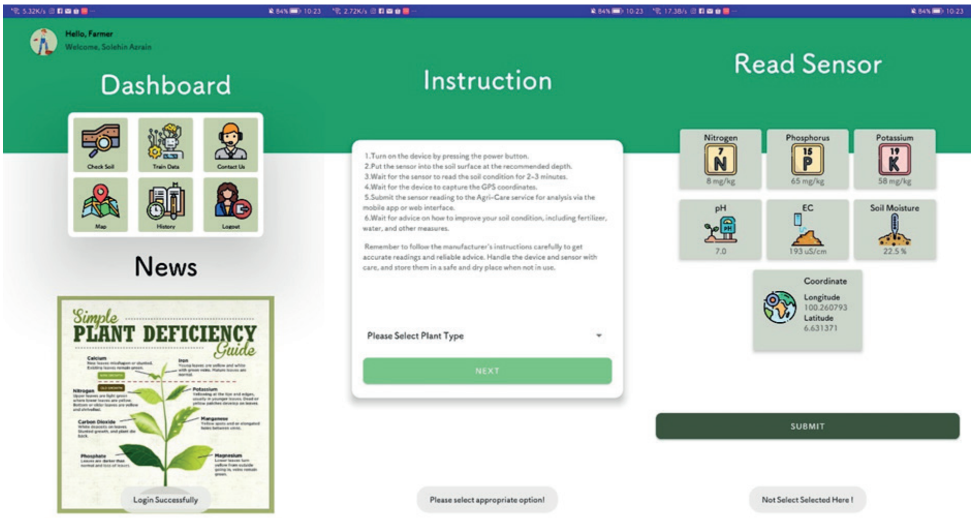

Figure 3. Dashboard, Instruction, and Read Sensor Interfaces

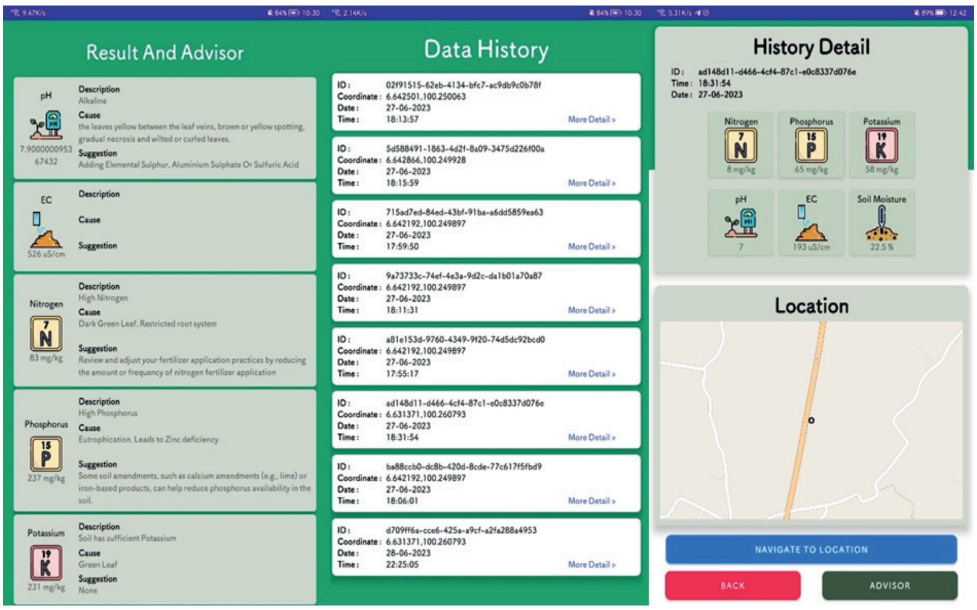

Figure 4. Advisor, History, and History Detail Interfaces

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Additionally, this mobile application features a history page that displays all the collected data from the field. Each entry includes a Universally Unique IDentifier (UUID), coordinates, date, and time of the data collection. By clicking on the "More Detail" option, users can access comprehensive information about each parameter and view the location on the map. This page also includes buttons for navigating to the specific location on the map and accessing the advisor for each dataset. The history page offers a comprehensive overview of the collected data, empowering users to track the progress of their soil conditions over time and make data-driven decisions for optimal agricultural practices.

In addition, figure 5 displays the maps page of the IoT Agri-Care Advisor mobile application, where users can visualize all the collected data on an interactive map with pinpoint markers. By clicking the "Retrieve" button, users can retrieve all the data from the database and view it represented as pinpoint markers on the map. Clicking on a specific pinpoint marker provides users with detailed information and data associated with that location. Furthermore, this application includes an "Add Nutrient" page, which serves as a platform for training the application with data. Users can input and provide nutrient data through this page, which will be utilized by the application to generate recommendations and suggestions for farmers. The training data plays a vital role in enhancing the accuracy and effectiveness of the Agri-Care Advisor mobile application, ensuring that the recommendations provided are tailored to the specific needs of the farmers based on their collected data.

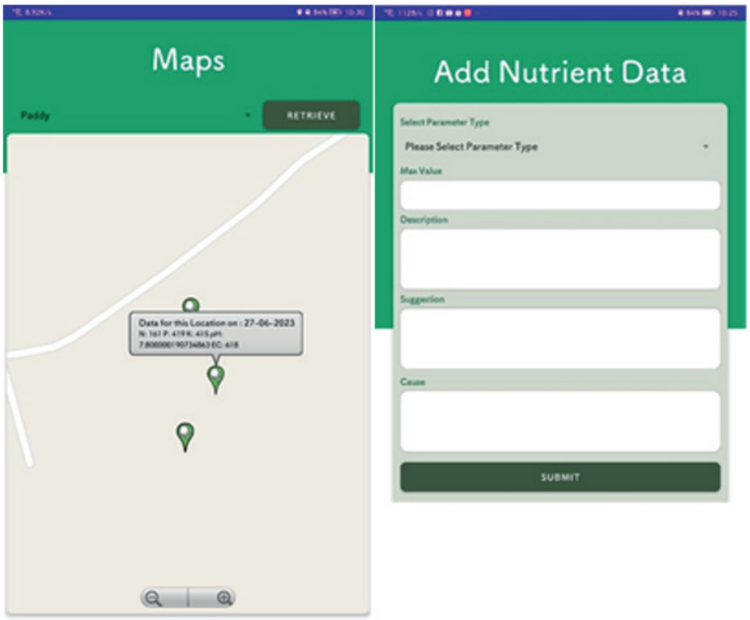

Figure 5. Map and Train Data interfaces

To sum up, there are some software and databases used to design and develop this IoT Agri-Care Advisor mobile application such as Android Studio IDE, and Raspbian OS in this research. The Android Studio is an Integrated Development Environment (IDE) developed by Google for building Android applications. It is built on top of the IntelliJ IDEA platform, which provides a powerful code editor and developer tools.[27] Meanwhile, Raspberry Pi OS, formerly known as Raspbian, is a free operating system based on the Debian Linux distribution, specifically optimized for the Raspberry Pi family of compact single-board computers.[28,29] Firebase is one of the products from Google that helps developers build, manage, and grow their applications easily. It is a serverless service and provides services such as authentication, storage, and real-time databases.[30]

RESULTS

The implementation of IoT Agri-Care Advisor mobile application has positively resulted in improvements of paddy soils and their effects on crop productivity. This mobile application offers data-driven recommendations to farmers based on observed nutrient imbalances and soil deficiencies. The mobile application was tested on two types of paddy fields: general and plowed. The overview of the general paddy field is illustrated in figure 6 as follows.

The quality of the measured soil for N, P, K, EC, and pH, and suggestions or recommendations for handling the quality of soil are shown in figure 7. From the sensing, monitoring, and collecting phases which were carried out from hardware, the pH level was measured at 7,9 indicating a slightly higher than desired value from a sample taken in the general paddy field. To rectify this, the developed IoT Agri-Care Advisor mobile application advised the farmers to utilize elemental sulfur as a means to lower the pH level. Meanwhile, the EC reading of 576 us/cm falls within the normal range, indicating no concerns regarding soil salinity. However, the N level detected at this location is higher than expected at 83mg/kg, which may lead to dark green leaves. Hence, this mobile application advised the farmers to adjust the fertilizer ratio for nitrogen to maintain a balanced nutrient uptake. Moreover, the analysis revealed elevated phosphorus levels at 237mg/kg, which contributed to a risk of eutrophication. To address this, the mobile application recommended the employment of calcium amendment to restore phosphorus balance in the soil. On a positive note, the potassium level in this area was determined to be sufficient at 231mg/kg, requiring no immediate action.

Figure 6. General paddy field

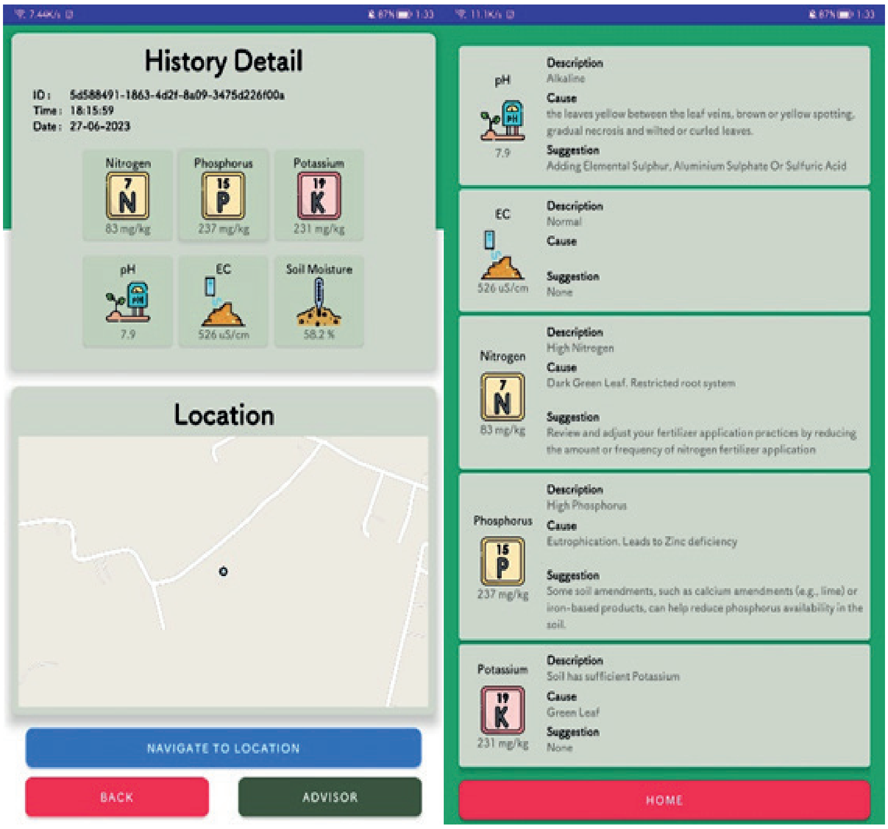

Figure 7. Result and Recommendation from IoT Agri-Care Advisor mobile application from a sample of general paddy field

Another sample taken which was from the plowed paddy field is illustrated in figure 8 used as part of testing and analyzing for this developed mobile application. Thus, the results for the quality of soil from samples taken in plowed paddy fields and suggestions or recommendations for handling the quality of soil are shown in figure 9. The finding signifies that the pH level of 7,1 in this sample was within the normal range for paddy cultivation. The EC measurement indicated that the soil salinity is also within acceptable limits. However, there is a detection excess of phosphorus at 140mg/kg, which can contribute to eutrophication. To address this issue, the IoT-Agri Care Advisor mobile application suggested using a calcium amendment to restore the balance of this element. On a positive note, the potassium level in this area was sufficient at 133mg/kg.

Figure 8. Plowed paddy field

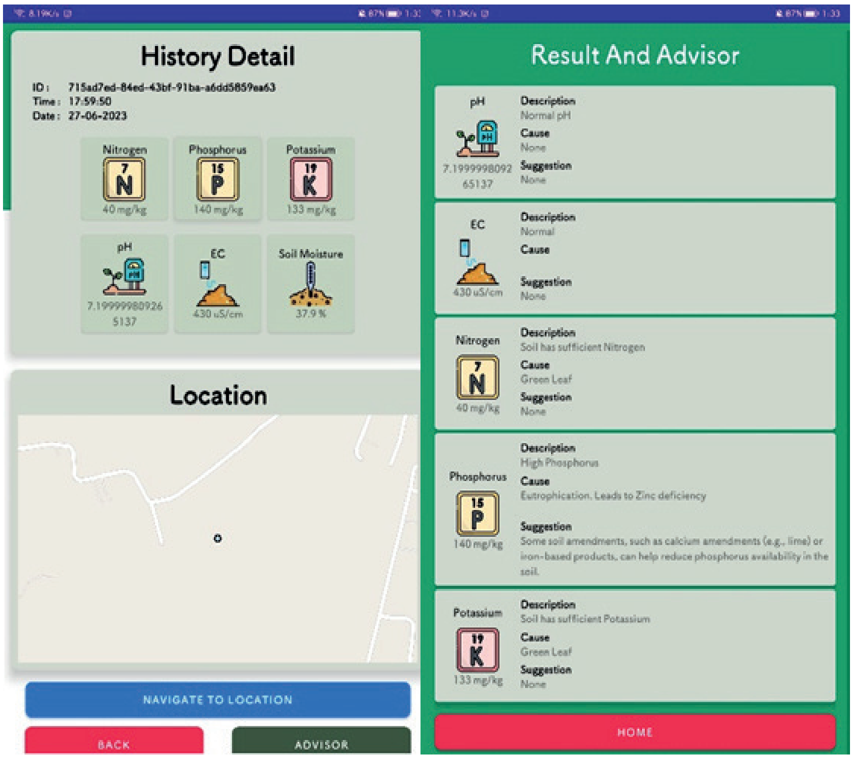

Figure 9. Result and Recommendation from IoT Agri-Care Advisor mobile application from a sample of plowed paddy field

DISCUSSION

Based on the results from two different samples of paddy fields which are general and plowed in figure 6 and figure 8 respectively, this developed mobile application has shown a successful implementation to the readings of the quality of the soil in terms of nitrogen (N), phosphorus (P), potassium (K), electrical conductivity (EC) and potential Hydrogen (pH) and managed to provide suggestions of recommendation to the farmers. To highlight, this research is only focused on the paddy field with its significant reading of nutrients such as N, P, K, pH, EC, and soil moisture levels to ensure the quality of the soil. However, this research has some limitations that need to be considered which is not adaptable for other types of crops due to different level of soils requirements. Additionally, this research is only implemented in the region of Perlis, Malaysia, and may not be suitable for other regions or climates. Hence, future works can be made in order to handle the limitations in this research. Thus, the scalability and applicability can be broader in the agriculture sector.

CONCLUSION

The developed IoT Agri-Care Advisor mobile application in this research represents a significant advancement in the field of agriculture, particularly for paddy farming in Malaysia. This application leverages modern technologies, including precision farming and sustainable practices, to enhance paddy production and efficiency.

This is done by providing real-time data on soil nutrient levels such as nitrogen (N), phosphorus (P), potassium (K), electrical conductivity (EC), and potential Hydrogen (pH) which helps in identifying the current paddy conditions. Also, this application empowers farmers to make informed decisions regarding their fertilization practices.

Precisely, this user-friendly mobile application serves as the primary interface for farmers, offering features such as soil nutrient checks, historical data visualization, interactive maps, and personalized recommendations. The use of Firebase ensures secure data storage and real-time synchronization, while the Android Studio IDE and Raspbian OS provide robust development and operational platforms. By continuously tracking soil nutrient levels and providing actionable insights, this IoT Agri-Care Advisor mobile application helps farmers optimize their agricultural practices, maximize crop yields, and reduce environmental impacts.

In addition, several future works can be implemented to improve this research through Artificial Intelligence (AI) and Machine Learning (ML) approaches. For example, developing an image-based soil analysis that focuses on soil texture classification and nutrient assessment. Also, to optimize the fertilization technique, dynamic recommendations to the farmers can be made by studying and analyzing the historical patterns and trends, external weather conditions, and paddy crop growth cycles. Overall, the implementation of this mobile application can lead to improvement in food security, reduced costs, and more environmentally friendly farming practices.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORSHIP CONTRIBUTION

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