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HydroNutriGuard: A Mobile-Based Hydroponics Nutrient Tracker with Recommender System for Lettuce

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RESEARCH ARTICLE INFORMATION	ABSTRACT
Received: May 26, 2023 **Reviewed:** November 08, 2024 **Accepted:** December 29, 2024 **Published:** December 31, 2024	This project focuses on developing and evaluating a mobile-based application to have an efficient and timely way of tracking remotely the nutritional content of the hydroponics solution for lettuce. The researchers designed an IoT-based sensor to detect the values of nitrogen (N), phosphorus (P), potassium(K), and water solution levels, which are among the hydroponic nutrients that are very vital to monitor to properly manage the hydroponic nutrient system. The NPK values acquired by the sensor were transmitted to the cloud server, which then displayed in the mobile application in a graphical format with color coding for the growers to easily interpret the result and recommend a solution if it detected a nutrient deficiency. Moreover, when the ultrasonic sensor detects that the hydroponics have reached the critical level of water for the plants to grow, it will automatically pump water solution from the reservoir. The mobile application was initially evaluated by 17 horticulture students and 2 agriculture faculty members who studied hydroponics with field exposure and manually checked the nutrients in the greenhouse through readily available devices in the market. It was also tested and evaluated using the mobile application acceptance model and obtained a grand mean of 3.93. This implies that the mobile application met the needs and expectations of the evaluators, hence, it is believed that using the mobile app ensures that the nutrient levels are well-guarded and maintained at optimal levels.

Keywords: *Hydroponics, IoT-based sensors, mobile application acceptance model, nutrient analysis, recommender system*

Introduction

Due to a rise in industrialization, agricultural farmland has decreased significantly. In daily existence, the human population is growing, which increases the demand for food. Food is the primary fundamental necessity for human survival on earth. Hydroponics represents a significant technological advancement in the agriculture industry today (Vidhya & Valarmathi, 2018). Vegetables and flowers have been grown effectively using hydroponics farming. It is more energy-intensive than conventional agriculture but more productive because it uses a nutrient solution and largely regulated ambient conditions (Torres et al., 2021). The benefits of hydroponic growing systems include minimizing water waste (recirculation), producing crops in controlled environments (control of pests, nutrients, and attributes required for optimal plant growth), and enabling the control of conditions to maximize output in limited space (vertical gardens) (Treftz & Omaye, 2016).

In the Philippines, hydroponic farming is becoming more and more well-liked as an innovative and environmentally friendly substitute for conventional soil-based farming. Given the country's small amount of arable land, propensity for natural disasters, and rising food demand, hydroponics is especially well-adapted to the Philippine context (Esguerra, 2016). According to a report by the Philippine News Agency, hydroponics farming offers a more efficient use of resources and can produce higher yields than traditional farming methods. The report also highlights the potential of hydroponics farming to address food security challenges in the country. The Philippines has also seen the potential of hydroponic farming and has started several measures to encourage local farmers to use it. In fact, the Department of Agriculture has put into place the High-Value Crops Development Program (Department of Agriculture, n.d.), which offers financial and technical support, and the Hydroponics and Aquaponics Program was established by the Department of Science and Technology to train and assist farmers interested in these technologies (Department of Science and Technology, n.d.).

Hydroponics farming was then massively grown as hydroponics farmers increasingly grow a variety of vegetables using a vertical farming system (Agustin, 2019). In 2022, the provincial government, under the leadership of Cagayan Governor Manuel Mamba, launched a training program for about 50 provincial government employees to learn the new hydroponic food production technique. Dr. Chito Sace of Hydroponics Technology at the Central Luzon State University (CLSU) in Munoz, Nueva Ecija, suggested that learning science and new technology is both beneficial and engaging, especially if it is done as a form of recreation – a hassle-free gardening experience using hydroponics. Concerns with hydroponics include nutritional inadequacies, infestation (algae, pests), system clogging, and seedlings (wilting, dead roots) (Nigussie et al., 2020). Inadequate watering or excessive heat are two of the many causes of wilting (Sharma et al., 2022). Although this approach is not always accurate and can often result in incorrect conclusions, a grower can typically determine a specific nutrient deficit by evaluating the symptoms. Check the water's temperature, the nutrient solution's pH, and the solution's electrical conductivity before deciding whether a problem exists (Karar et al., 2022).

Due to the simultaneous monitoring of several factors, dietary recommendations, and a plant diagnosis system, hydroponics farming monitoring is a difficult undertaking. Hydroponics for plant minoring has recently benefited greatly from the use of AI-based autonomous robots with a range of hardware controllers and industrial robots. However, in order to address the aforementioned challenges, they have been unable to simultaneously monitor numerous sensors (Pang et al., 2021). With the rapid advancement of technology and IoT applications for smart farming (Qazi et al., 2022), there is still hope for the agricultural sector to adopt controlling algorithms based on artificial intelligence (Raju et al., 2022). Thus, these issues urged the researchers to conduct a study on the development and evaluation of a mobile-based application that provides efficient and timely tracking of the nutritional content of the hydroponics solution for lettuce remotely, namely, HydroNutriGuard: A Smart Hydroponics Nutrient Tracker with Recommender System for Lettuce. Specifically, this study aimed to: a) develop an Arduino-based nutrient analysis and deficiency tracker; b) design a mobile-based application that provides growers with user-friendly, easy-to-interpret data using graphical representations, enables real-time monitoring and management of their hydroponic nutrient system, and suggests solutions whenever it detects nutrient deficiencies; and c) evaluate the user's acceptance of the mobile application based on completeness of the system, basic needs, performance expectancy, perceived usefulness, subjective norms, attitude towards using mobile app, and behavioral intention.

Methods

Research Design

This study involved a product-development process that entails analysis, description, and evaluation of the final output. It is also geared towards the impact of the application to the selected end-users. In this study, the researchers chose Rapid Application Development (RAD) in the design and development of the system because of its ability to reduce development time, improve the reusability of each part resulting in accuracy, and promote the incorporation of phases that will solve the slower conventional method (Martin, 1991). The diagram shows the different stages of the Rapid Application Development model as the basis of the researchers in the design and development.

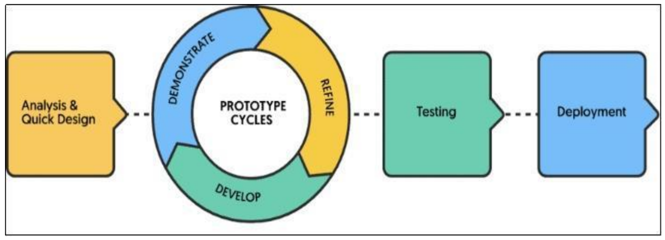

Figure 1. *The Rapid Application Development (RAD) Diagram.*

Figure 1 displays the several phases of the Rapid Application Development (RAD) software development approach. As indicated in the figure, four phases were followed by the researchers in order to come up with a high-quality output of the system.

The following are the activities undertaken by the researchers per phase after gathering pertinent information, gaps, and requirements through literature reviews and observations on the current tourism industry situation.

Analysis and Design

In this phase, the researchers analyzed all the gathered information, gaps, and problems related to hydroponics farming and management. Based on these, the researchers came up with a proposed alternative solution to solve problems encountered. In this phase, initial prototyping (wireframes) and database modeling were also done. It is in this phase that the researchers came up with a concrete plan on how the project would be developed, what software development tools would be used, data analysis strategy, and deployment/implementation activities.

Prototype Development

The researchers incorporated all the planned development and system testing procedures into the identified alternative solution. The system was designed and developed based on the identified functional requirements. Every developed module or functionality of the system was demonstrated to hydroponics growers and experts, and they evaluated the content and process. The coding, module, and integration testing of all the functionalities of the system were also performed in this phase. Figure 2 shows the project framework of the study.

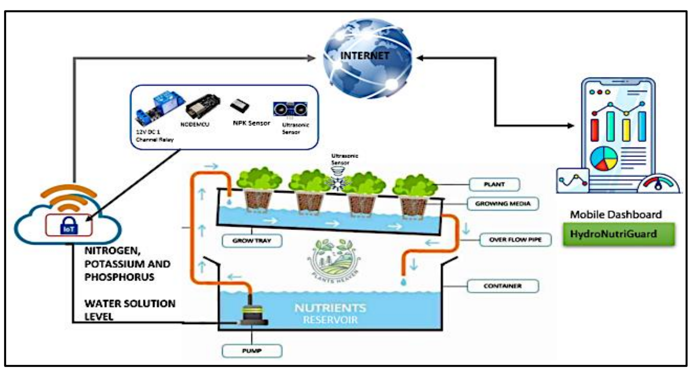

Figure 2. *HydroNutriGuard Technical Framework*

The HydroNutriGuard: A Smart Hydroponics Nutrient Tracker with Recommender System for Lettuce was developed as a mobile-based application using Arduino IDE, Android Studio, and Visual Studio Code, uploaded to a server to be monitored real-time. The nutrient tracker was developed with Arduino-based technology such as a micro-controller, NPK sensor, 12V DC channel relay, and ultrasonic sensor.

Testing and Deployment

The researchers conducted system demonstrations and user simulations of the mobile application. In a controlled environment hydroponics garden, the IoT sensors were deployed, and the growers installed the mobile application on their mobile phones to simulate real-time monitoring.

System Evaluation

The researchers used a questionnaire method to gather feedback, receive comments and suggestions, and validate the content provided and displayed by the application. They also adopted and utilized an evaluation questionnaire to assess the end-users' acceptance of Mobile Applications Acceptance Theory in terms of completeness of the system, basic needs, performance expectancy, perceived usefulness, subjective norms, attitude towards using mobile apps, and behavioral intention. The questionnaire captured positive perceptions developed among users regarding the effectiveness of the software in meeting their expectations. The acceptance rate was measured based on the feedback provided by the users and the frequency of use when purchasing products and services.

Data Analysis

A purposive sampling technique was utilized to identify the evaluators of the mobile application, and a five-point Likert scale was used to measure the level of agreement of the evaluators with the criteria. To achieve the study's objectives, a self-administered questionnaire was adopted, and the evaluators' ratings were calculated using descriptive statistics.

Ethical Considerations

Given that this research involves technology, user data, and agricultural practices, the researchers observed a non-disclosure agreement of gathered demographic profile of the system evaluators, and a data privacy notice agreed upon was conducted before the evaluation process.

Results and Discussion

Figure 3 shows the developed Arduino-based nutrient analysis and deficiency tracker, which serves as a data-gathering tool for HydroNutriGuard, to be displayed in the mobile application for monitoring. This consists of components such as the NPK sensor, ultrasonic sensor, Esp32, water pump, and microcontroller. The NPK sensor determines the fertility of the soil, the ultrasonic sensor measures the distance to the target by measuring the time between the emission and reception. The microcontroller automates the integration of prototypes and code. Because of the Wi-Fi module, a connection to the mobile-based was made possible by the sensors' collection of real-time data. The water pump controller has the threshold value that receives a signal when to turn on/off.

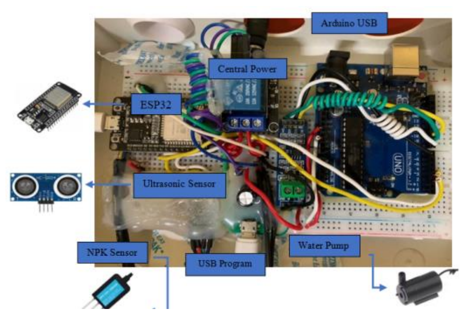

Figure 3. Arduino-Based Nutrient Analysis and Deficiency Tracker

The circuit diagram shows the different modules and results of the prototype: the NPK module is positionally designated in hydroponics lettuce and the ultrasonic sensor measures the nutrient solution resulting in the water pump triggering when it detects the high/low level. The researchers had the configuration that uses program codes, the NPK sensor, ultrasonic sensor, water pump, and Wi-Fi module libraries in the Arduino IDE to provide an exact functionality to be used in sketches. The program codes for the application were uploaded to the Wi-Fi module, when the Esp32 was chosen as the board to use as well as the serial ports to which the Esp32 was connected. When the Esp32 was connected to the internet, the data gathered from the different sensors was sent to the server of mobile-based application.

Developed HydroNutriGuard Mobile Application

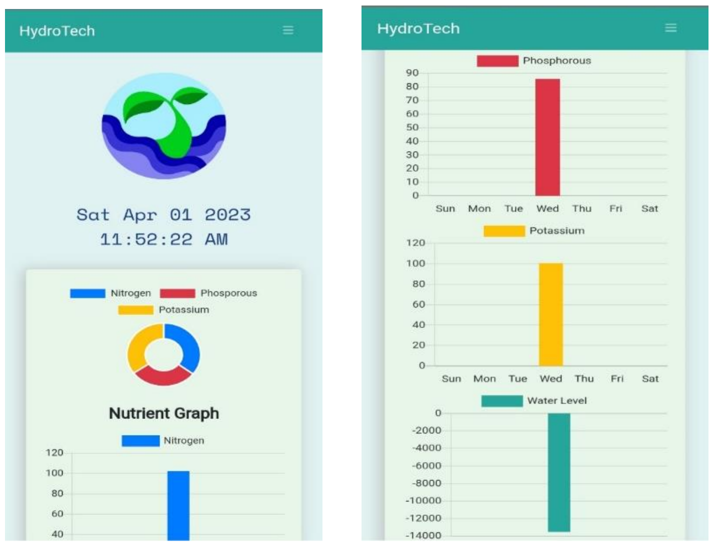

Figure 4. Daily Monitoring of Nutrients Level

The daily monitoring of nutrient levels was designed and developed in graphical representation for the growers to easily interpret the status of the hydroponics farm. This page displays the date and time to inform the grower of when the values presented on the screen were detected and gathered by the sensors.The figure above shows the pie graph analysis of nutrients of nitrogen, phosphorus, and potassium. The label of the nutrients was also added for the grower to be fully informed of the report and analysis the hydrotech mobile application is presenting. Nitrogen (N) is represented in blue, phosphorus (P) in red, potassium (K) in yellow, and the water level in green, as shown in the graph analysis. This feature facilitates the efficient way and timely monitoring of the hydroponics nutrients. Hence, this aided the burden of the growers on laborious and time-consuming monitoring and checking of the hydroponics solutions.

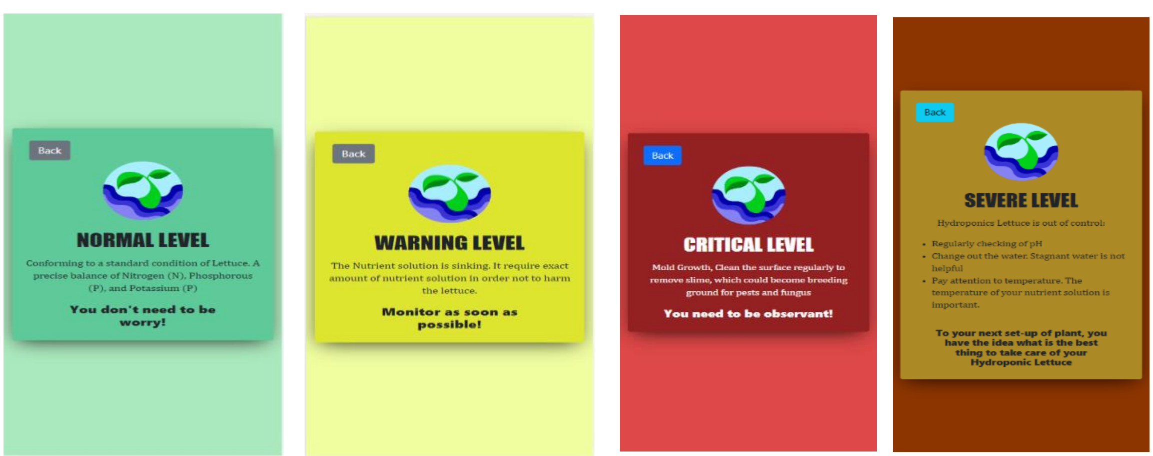

Figure 5. Recommender System

The researchers presented the different conditions of hydroponic lettuce, as shown above: the normal level (top left), represented in green, recommends "Conforming to the standard condition of lettuce. A precise balance of Nitrogen (N), Phosphorus (P), and Potassium (K) is required." The warning level (top right) recommends "The nutrient solution is sinking. It requires the exact amount of nutrient solution to avoid harming the lettuce." The critical level (bottom left) recommends "Mold growth. Clean the surface regularly to remove slime, which could become a breeding ground for pests and fungi." Lastly, the level on the bottom right recommends "Hydroponic lettuce is out of control. Regularly check the pH and change the water." Stagnant water is not helpful, pay attention to temperature. The temperature of your nutrient solution is important. Researchers designed this recommendation for the growers to easily find out what is next to do based on the nutrient level.

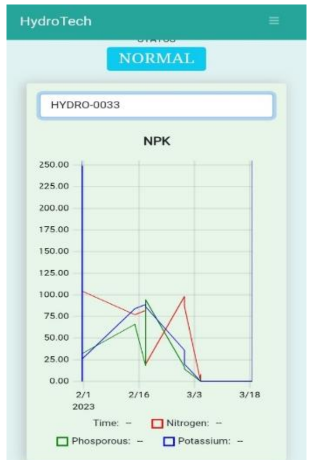

Figure 5. Graphical Representation of Nutrient Analysis

Figure 5 displays the screenshot of the HydroTech that can show the hydroponics grower the status and analysis of the nutrient level. The mobile application can provide analysis levels such as normal, warning, critical, and severe levels. As shown in the screenshot above, the application provides an analysis of the normal condition based on the given values. This feature of the system helps the grower to fully understand the values presented through the automatic analysis. Incorporating graphical representations of the nutrient analysis into a mobile application can significantly improve the user's experience by providing a clearer interpretation which results in better decision-making for the hydroponics growers in preparing the nutrient solution for the hydroponics.

Table 1. Performance Expectancy

Criteria	Quantitative Rating	Qualitative Rating
Completeness of the System	3.91	Agree
Basic Needs	4.00	Agree
Performance Expectancy	4.02	Agree
Perceived Usefulness	4.00	Agree
Subjective Norms	3.70	Agree
Attitude Towards Using	3.95	Agree
Behavioral Intention	3.93	Agree
Grand Mean	**3.93**	**Agree**

Table 1 presents the results of the end-user's level of agreement and acceptance towards the developed mobile application HydroNutriGuard in terms of Mobile Applications Acceptance Theory criteria: completeness of the system, basic needs, performance expectancy, perceived usefulness, subjective norms, attitude towards using mobile app, and behavioral intention. Based on the evaluation, the application HydroNutriGuard, a mobile-based nutrient tracker and recommender system designed for hydroponic lettuce growers, indicates a generally positive acceptance among users. The system's overall performance, as reflected by the computed grand mean of 3.93, suggests a high level of agreement regarding its effectiveness and utility in addressing the needs of hydroponics growers. Specifically, the system achieved high ratings in completeness with a mean of 3.91, indicating that it provides the necessary functionalities to support nutrient tracking comprehensively. The highest scores were observed in performance expectancy with a mean of 4.02 and basic needs with a mean of 4.00, signifying that users perceive the system as both reliable in meeting essential requirements and capable of enhancing productivity and efficiency in hydroponic farming practices. The system's perceived usefulness gained a mean of 4.00 highlighting its value in optimizing processes and improving decision-making. Subjective norms received the lowest rating of 3.70, despite the fact that the response was overwhelmingly positive. This suggests that external factors, like peer or expert endorsements, had a moderate impact on how users adopted the system. This suggests a chance to increase the system's social validity through focused advertising or support from well-known hydroponics personalities. The result also shows that the users trust the system's usability and long-term applicability by expressing a positive attitude toward using it with a mean of 3.95 and a high behavioral desire to keep using it with a mean of 3.93.

With this result, the HydroNutriGuard can help hydroponics farmers efficiently manage nutrients while encouraging environmentally friendly agricultural methods. It is not only a practical tool for individual growers but also a valuable innovation that can support the broader hydroponics industry. Addressing the identified gaps, particularly in social acceptance, the system could facilitate a more widespread shift towards technology-driven, sustainable farming practices, which will significantly contribute to increased productivity, profitability, and environmental sustainability in the hydroponics sector.

Conclusion and Future Works

With the results presented, it is therefore concluded that the study demonstrates that HydroNutriGuard is an effective and innovative solution for managing hydroponic nutrient systems, particularly for lettuce growers. With high user acceptance and positive feedback, the system addresses critical challenges in nutrient monitoring and management. The developed application's ability to track real-time data, provide actionable recommendations, and present information in a user-friendly graphical interface supports growers in improving efficiency, productivity, and decision-making. This reinforces its practical value not only for individual farmers but also for promoting sustainable agricultural practices on a broader scale. Despite the success of its development and implementation, this study acknowledges limitations, such as the evaluation sample size was relatively small, which might not fully represent the diverse experiences of hydroponics growers in different regions. Additionally, the system's reliance on IoT and cloud infrastructure might pose challenges in areas with limited internet connectivity. Future research should explore expanding the system's functionality, such as integrating machine learning for predictive nutrient analysis or adding features for pest and disease monitoring. Larger-scale field tests across various crops and geographic locations could provide a more comprehensive understanding of its adaptability and scalability. Furthermore, collaborative efforts with government agencies and agricultural organizations could enhance the system's adoption and address issues of social acceptance through targeted outreach and endorsements. These efforts can amplify the potential of HydroNutriGuard to transform modern hydroponic farming practices and contribute to global food security.

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Conflict of Interest

The researchers declare that there are no conflicts of interest regarding the publication of this paper.