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VOICE-ACCESSIBLE IOT HYDROPONIC MONITORING FOR THE VISUALLY IMPAIRED INDIVIDUAL

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Abstract:

This paper presents the development of a voice-accessible IoT hydroponic monitoring system, specifically designed for individuals with visual impairments. Visually impaired individuals often face challenges in managing hydroponic systems due to the reliance on visual indicators for monitoring parameters such as water levels, nutrient concentrations, and plant health. The lack of accessible tools to interpret these parameters hinders their active participation in modern agriculture. To address these limitations, the integration of sustainable hydroponics with IoT technologies in this project offers an inclusive and empowering experience. The system's hardware comprises ESP32 microcontrollers that collect data and manage devices, alongside water level and TDS sensors to assess critical parameters such as water availability and nutrient concentration. Environmental sensors monitor temperature and humidity to support precise climate regulation, while automatic water pumps manage irrigation, promoting optimal plant growth with minimal operator intervention. A key component of the system is a website designed for real-time data reporting that is accessible to blind individuals. This allows users to remotely access vital agricultural data and understand their system's performance. To further enhance accessibility, the web interface integrates voice-assistive technology, delivering audio feedback

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on essential parameters such as water levels, fertilizer concentration, temperature, humidity, and plant development stages. The voice-activated interface empowers blind users to manage their hydroponic systems independently through intuitive audio commands. This initiative, funded by the Sarawak Branch of the Society of the Blind, Malaysia, in collaboration with Politeknik Kuching and supported by Sarawak's Information Technology and Communication Department, highlights the potential of IoT to bridge accessibility gaps. Beyond technological innovation, the project equips visually impaired individuals with practical skills, promotes autonomy, and creates sustainable income opportunities. It emphasizes the importance of collaborative efforts in developing inclusive, community-centered solutions. By leveraging IoT and voice-accessible technologies, the initiative not only removes barriers but also fosters social inclusion and demonstrates the transformative power of technology in agriculture and beyond.

Keywords:

ESP32, Hydroponic, IoT, Visually Impaired, Voice Assistive

Introduction

Creating opportunities for individuals with disabilities through innovative and inclusive technology is a significant step toward building a more equitable society. Recognizing this, the Sarawak Branch of the Society of the Blind, Malaysia, in collaboration with Politeknik Kuching Sarawak's Information Technology and Communication Department, has launched a hydroponic farming project powered by the Internet of Things (IoT). This initiative aims to empower visually impaired individuals by equipping them with practical agricultural skills and fostering greater independence in managing hydroponic systems. Despite the benefits of hydroponics—such as efficient water use, faster crop cycles, and suitability for small or urban spaces—visually impaired individuals often face several challenges when engaging with this form of agriculture. Traditional hydroponic systems rely heavily on visual indicators such as water level gauges, nutrient concentration meters, and digital displays, which are inaccessible without assistive tools. Monitoring and responding to critical environmental changes, such as temperature fluctuations or nutrient imbalances, becomes difficult, reducing the ability of blind individuals to independently manage the system. To address these challenges, this project proposes the development of a voice-accessible IoT-based hydroponic monitoring system that allows real-time tracking and management of key farming parameters through audio interfaces. With RM10,000 in funding, the project is designed to create a fully functional, low-cost prototype that integrates ESP32 microcontrollers, various environmental and nutrient sensors, and an accessible web-based platform enhanced with voice-assistive technology.
The objectives of the research are as follows:

- To identify the key barriers faced by visually impaired individuals in managing hydroponic systems.
- To design and develop an IoT-based hydroponic monitoring system that provides audio feedback for real-time decision-making.
- To evaluate the system's usability, accessibility, and effectiveness in supporting independent farming activities among blind users.

The scope of this study includes the development of a prototype hydroponic monitoring system with at least three sensor types such as water level, TDS, temperature and humidity, integration of a voice-assisted interface for system feedback, and usability testing with selected

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participants from the Society of the Blind Malaysia (Sarawak Branch). This collaboration highlights the power of interdisciplinary teamwork in driving meaningful change. Beyond just providing technological solutions, the project aims to build confidence, promote autonomy, and generate sustainable income opportunities for visually impaired individuals. By leveraging IoT and inclusive design, the initiative demonstrates how innovation can remove barriers, promote social participation, and enable underprivileged communities to thrive through accessible agriculture.

Literature Review

Urban agriculture (UA) is increasingly recognized as a key solution to sustainability challenges in urban environments. According to Yuan et al. (2022), UA offers significant socio-environmental benefits, including enhanced food security, improved public health, disaster risk mitigation, and strengthened urban resilience. However, economic barriers limit its widespread adoption. To address these challenges, advanced technologies such as vertical farming and plant biotechnology can enhance UA's feasibility and efficiency. The authors highlight the importance of adaptive policies that integrate UA into urban planning and align with sustainable development goals (SDGs). By merging technology with agriculture, UA has the potential to create inclusive food systems that serve diverse urban populations. Building on this integration of technology in agriculture, aquaponics presents an innovative approach that combines aquaculture and hydroponics. Goddek et al. (2019) examine the environmental, economic, and technical advancements that make aquaponics a viable solution for global food security challenges. Innovations such as decoupled systems, advanced nutrient cycling, and energy-efficient designs have improved its efficiency and scalability. The study emphasizes the need for interdisciplinary strategies to address high startup costs and regulatory hurdles, reinforcing the role of technology in enhancing resource efficiency and reducing environmental impact. While aquaponics has primarily been explored for sustainable food production, similar technological advancements can be applied to hydroponics to improve accessibility for individuals with disabilities. Hydroponics, a controlled-environment agricultural method, has been investigated as an accessible and automated solution for individuals with impairments. Juneja et al. (2023) developed an automated hydroponic system using Arduino microcontrollers and Tinkercad software, enabling automated temperature regulation and fertilizer delivery. This system enhances accessibility for visually impaired individuals by reducing the need for manual labor and thereby promoting sustainability and inclusivity. The integration of hydroponics with the Internet of Things (IoT) demonstrates its potential to empower marginalized communities while addressing urban resilience and food security concerns. Further emphasizing the role of inclusive agricultural systems, Akter (2022) examines how accessible gardens impact the well-being and social integration of individuals with spinal cord injuries. The study highlights the significance of inclusive designs—such as elevated beds and wheelchair-accessible pathways—in fostering psychological and physical well-being. These findings align with the broader goal of creating tailored agricultural solutions to meet the needs of people with disabilities, providing valuable insights into designing accessible hydroponic farming systems. Similarly, Saarani et al. (2024) explore hydroponics as a low-effort agricultural method that accommodates individuals with disabilities. Their research underscores the therapeutic, educational, and economic benefits of hydroponic farming, demonstrating how automated equipment and practical training can enhance food security, independence, and meaningful participation for individuals with disabilities. The study further supports the integration of IoT with hydroponics to overcome physical barriers, particularly for visually impaired individuals, thereby making agriculture more inclusive and

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accessible. Expanding on this theme of inclusion, Billah et al. (2022) introduce the concept of "Inclusive Villages" in Indonesia, where communities empower persons with disabilities through skills training and inclusive employment opportunities. The study highlights the role of community-driven initiatives and legislative support in fostering independence and economic self-sufficiency through agricultural activities. These results support the idea that hydroponic and IoT-based solutions can be scaled up at the community level. They are in line with larger efforts to include inclusive practices in farming systems. At a policy level, Fundación ONCE and the ILO (2023) explore the intersection of disability and sustainable development, advocating for inclusive employment within the green economy. Their research identifies agriculture as a key sector for creating green jobs for individuals with disabilities, aligning with the SDGs. Using the Internet of Things (IoT) and hydroponics as tools to help people who are blind or have low vision is similar to ideas that have already been put forward for incorporating technology and inclusive design into farming. This makes the case for sustainable and accessible food production systems even stronger. The impact of community-based agricultural initiatives is further illustrated by the Perlis Special Teens Centre (PeSTeC) in Malaysia. Abdullah et al. (2023) evaluate how PeSTeC empowers individuals with learning impairments through organized training programs that involve families, communities, and stakeholders. By integrating agriculture, food production, and craft-making, PeSTeC promotes social and economic independence. A thematic analysis of qualitative case studies and in-depth interviews shows that these kinds of programs are critical for removing social and cultural barriers that keep disabled people from participating. These findings reinforce the importance of community-led approaches in fostering inclusion and independence through agriculture. From a global perspective, Oba (2023) compares Japan's Noufuku Renkei project with similar social agricultural programs in the U.S., the Netherlands, and Italy. While social farming has proven to be an effective means of addressing labor shortages and promoting inclusivity, implementation challenges persist due to financial constraints, limited government support, and a shortage of experienced specialists. The study calls for stronger legislation, specialized training, and increased collaboration to enhance the effectiveness and scalability of inclusive agricultural programs. Collectively, these studies underscore the transformative potential of integrating hydroponic gardening with IoT to empower visually impaired individuals and other marginalized groups. Inclusive design principles in gardening provide a foundation for adapting hydroponic systems to offer accessible, autonomous agricultural solutions. The research demonstrates that hydroponics, as a low-effort farming method, can meet the needs of individuals with disabilities while benefiting from IoT-driven automation to optimize environmental conditions and improve efficiency. Furthermore, community engagement and sustainable practices support the idea that combining IoT with hydroponics can facilitate community-based, scalable farming solutions. This approach enhances agricultural accessibility and promotes long-term sustainability and social inclusion. This research framework uses technology to connect agriculture, disability inclusion, and sustainability. It provides a useful example for giving visually impaired people more power in the agricultural sector. Incorporating IoT ensures accessibility and operational efficiency, reducing both physical and sensory barriers while fostering social and economic empowerment. The summary of key findings from previous studies, as presented in Table 1, highlights the growing integration of technology in agriculture—particularly hydroponics and IoT—as a means to enhance accessibility, sustainability, and social inclusion for individuals with disabilities.

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Table 1: Summary of Key Findings

Author(s)	Focus Area	Key Findings
Yuan et al. (2022)	Urban Agriculture (UA) and Sustainability	UA enhances food security and urban resilience, but economic barriers limit adoption. Advocates tech integration and adaptive policy.
Goddek et al. (2019)	Aquaponics Innovation	Decoupled systems and efficient nutrient cycling improve scalability. High startup cost and regulations remain challenges.
Juneja et al. (2023)	Automated Hydroponics for the Visually Impaired	Arduino-based system automates key processes, increasing accessibility and reducing manual labor.
Akter (2022)	Accessible Gardens for People with Spinal Cord Injuries	Designs like elevated beds improve well-being and integration, showing value of inclusive agriculture.
Saarani et al. (2024)	Hydroponics and Disability Inclusion	Automated hydroponics offers therapeutic and economic benefits, promoting IoT integration for accessibility.
Billah et al. (2022)	Inclusive Villages Initiative (Indonesia)	Community-led hydroponic training empowers persons with disabilities, aligns with inclusive employment.
FundaciÃ³n ONCE & ILO (2023)	Disability and Green Jobs in Agriculture	Advocates for inclusive employment in sustainable agriculture, emphasizing IoT and hydroponics.
Abdullah et al. (2023)	PeSTeC (Malaysia) Empowerment Model	Training programs combine agriculture and crafts to foster inclusion and family-community engagement.
Oba (2023)	International Social Farming Programs	Compares Japan, US, EU. Highlights labor solutions and inclusive models but notes financial and legislative gaps.

Material and Methodology

Hydroponic System

Silva et al. (2021) look at the Nutrient Film Technique (NFT) hydroponic system as a long-term solution for urban farming. They highlight how research interest in this system grew from 2016 to 2019 because it is effective and beneficial for the environment. Their findings highlight NFTs' ability to enhance productivity, conserve resources, and support future agricultural development. The system's compact design makes it an effective solution for small-scale agricultural initiatives, particularly in urban settings where space optimization is crucial. The NFT hydroponic system consists of 40 planting pots and is structured with dimensions of 34 inches in height, 25 inches in width, and 69 inches in length, making it suitable for limited spaces. This complete system has everything you need for hydroponic farming, like an NFT setup, a long-lasting water reservoir, and a reliable water pump that makes sure there is a steady supply of nutrients. The inclusion of 40 white net pots facilitates easy plant installation, while growth media like rockwool provide superior water retention and aeration, promoting strong root development. To optimize plant growth, the system integrates a pipe mechanism for efficient water circulation and utilizes Micronutrient Hydro AB fertilizer to meet the nutritional needs of the plants. Gillani et al. (2023) looked at the energy-use efficiency (EUE) of NFT and

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deep-water culture (DWC) systems for growing lettuce hydroponically. They found that NFT is a better way to grow plants. Their research indicated that both systems produced about the same number of leaves and plant heights, but NFT did better in terms of shoot fresh weight, leaf area, and root length, resulting in a higher EUE (31.3 g kWh^{-3} vs. 24.53 g kWh^{-3}). These findings suggest that NFT is a more energy-efficient option for controlled environment agriculture, particularly in plant factories and aquaponic systems. The NFT system's simplicity, compact structure, and comprehensive setup ensure a user-friendly and sustainable solution for optimizing crop production. Its ability to enhance productivity while minimizing resource consumption makes it a promising technology for modern agriculture, aligning with efforts to develop efficient and scalable hydroponic solutions. The Nutrient Film Technique (NFT) system, as illustrated in Figure 1, is designed to support 40 planting pots at our location, reinforcing its practicality for urban and controlled-environment farming.

Figure 1: The Nutrient Film Technique

Planting Process for the Nutrient Film Technique (NFT) System
The planting process for the Nutrient Film Technique (NFT) system involves a series of steps designed to ensure optimal plant growth and efficient nutrient delivery. Here's a breakdown of the process:

Preparation Of Growing Medium
In our experiment, we use rock wool as the growing medium for our hydroponic system. Rockwool, a widely used medium in hydroponics, is manufactured by melting basalt rock and spinning it into fine fibers, resulting in a lightweight, porous structure as shown in Figure 2. This unique composition allows it to retain moisture efficiently while still providing ample oxygen to plant roots, creating an ideal environment for healthy growth. One of the key advantages of Rockwool is its ability to maintain an optimal balance between water and air, which is crucial for root development. Its high water retention minimizes the need for frequent irrigation, reducing water waste while ensuring consistent hydration for plants. Additionally, its excellent aeration properties help prevent root diseases caused by excessive moisture, making it particularly useful in controlled hydroponic environments. Rockwool comes in different sizes and shapes, like cubes, slabs, and loose granules. This versatility makes it useful for a range of hydroponic systems, such as drip irrigation, nutrient film technique (NFT), and deep-water culture (DWC). The cubes are particularly beneficial for seed germination and early-stage plant growth, while slabs are commonly used for larger plants requiring extended root space. Despite its benefits, Rockwool requires proper handling and preparation. Before use, it must be pre-soaked in a pH-adjusted solution to neutralize its naturally high pH, ensuring a suitable environment for plant roots. Additionally, protective gear such as gloves and masks should be worn when handling dry Rockwool, as its fine fibers can cause irritation to the skin and respiratory system.

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Figure 2: Rock Wool Medium

Seed Germination

Place 2–3 seeds in the center of each prepared net pot using a chopstick or tweezers to position them gently into the growing medium. Ensuring proper seed placement helps improve germination rates and prevents overcrowding as the seedlings develop. When using Rockwool, make a small indentation in the center of the cube to accommodate the seeds, ensuring they are not buried too deep, as this can affect sprouting. Lightly water the seeds to moisten the growing medium, ensuring even hydration without excessive soaking. Using a spray bottle or a gentle stream of water helps prevent the seeds from being displaced. Rockwool and other hydroponic media retain moisture effectively, so it is important to avoid overwatering, which can lead to fungal growth or seed rot. As shown in Figure 3, our team is actively engaged in preparing and seeding the hydroponic system.

Figure 3: Seedling Preparation

Allow the seeds to germinate in a shaded area or indoors for 3–5 days, ensuring they are kept moist but not waterlogged. Consistent temperature and humidity levels play a crucial role in successful germination. Budiman et al. (2022) used IoT monitoring to look at how physical factors affected bok choy (Brassica rapa) and water spinach (Ipomoea aquatica) in a hydroponic system. They found that TDS and light intensity significantly influenced growth, with optimal conditions at 25.4–31°C temperature and 70 g/m³ humidity. The study emphasizes the role of automated nutrient control in improving yield. The study by Chowdhury et al. (2021) revealed that in controlled plant factories, the ideal conditions for glucosinolate accumulation in kale are not the same as those for physical growth. The optimal conditions are 20-23°C, 85% RH, and 700-1000 ppm CO_2. The study also found that temperature and glucosinolate levels are inversely related, suggesting a trade-off between yield and bioactive compounds. The findings offer valuable insights for optimizing environmental settings in controlled agriculture, but their focus on a single plant species limits its scope. Covering the net pots with a humidity dome or placing them inside a propagator can help maintain adequate moisture and warmth. Check daily for signs of germination and ensure the medium remains damp. If using a hydroponic system, avoid placing the net pots directly under grow lights during the early stages, as excessive heat

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or light intensity can dry out the seeds. Once the seedlings emerge and develop their first true leaves, gradually introduce them to light, preparing them for the next growth phase in the hydroponic system. The Hooks et al. (2022) study explores the impact of nutrient solutions on the growth of leafy baby vegetables like lettuce, pak choi, and spinach in deep-water hydroponic systems. They found that cooling solutions to 24°C during summer improve plant biomass, especially for heat-sensitive species like spinach, while heating solutions to 22°C in winter enhances the growth of lettuce. However, the study highlights the need for further research on optimal temperature ranges. Figure 4 shows the vegetables at the early seedling stage, after 3–5 days of germination. At this point, the seedlings have successfully sprouted and started developing their first true leaves, which are essential for photosynthesis and further growth. The true leaves, distinguishable from the initial cotyledons, indicate that the young plants are ready to transition from the germination phase to active growth. As part of this transition, the seedlings are gradually introduced to light. Initially, they are exposed to indirect light or placed under grow lights with low intensity to prevent shock or dehydration. Over the coming days, the light exposure is increased progressively to mimic natural growing conditions, allowing the plants to adjust and strengthen. During this period, the seedlings are carefully monitored for signs of healthy growth, such as vibrant green leaves and strong stems. Any weak or underdeveloped seedlings are removed to ensure only the healthiest plants are transplanted into the main hydroponic system. Once the seedlings have adapted to the light conditions and their root structures have developed sufficiently, they are prepared for transplanting. The net pots containing the seedlings are transferred into the hydroponic setup, where they will receive a continuous supply of water and nutrients. The nutrient solution is adjusted based on the plant's growth stage to ensure optimal absorption and development. This stage marks the beginning of the vegetative growth phase, where the plants will rapidly increase in size, developing a more robust root system and expanding their leaf structures. Regular monitoring of pH levels, nutrient concentration, and light exposure is crucial during this period to support strong, healthy plant development in the hydroponic system.

Figure 4: 3–5 Days of Germination

Transplanting the Seedlings

Once seedlings develop their first set of true leaves (approximately 7–10 days after germination), they are ready for transplanting. At this stage, their root systems are strong enough to absorb nutrients efficiently, ensuring a smooth transition into the hydroponic setup. True leaves indicate that seedlings can sustain growth in a nutrient-rich environment, making this stage critical for their development. Before transplanting, seedlings in net pots are inspected, and only healthy plants are selected as illustrated in Figure 5. We remove weak or underdeveloped seedlings to prevent nutrient competition. The NFT channels are then cleaned to remove any debris and ensure a steady water flow.

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To transplant, seedlings in net pots are carefully placed into designated slots in the NFT channels, ensuring that their roots extend slightly beyond the pot to make direct contact with the nutrient solution. This setup allows roots to absorb water, oxygen, and nutrients efficiently, supporting rapid plant growth. Once we place the net pots, we check the water flow to ensure an even distribution across all of them. Proper circulation prevents nutrient imbalances and ensures optimal oxygen supply. If needed, adjustments are made to the water pump and flow rate to maintain a thin film of nutrient solution running along the base of the channels. We perform regular monitoring during the initial days after transplanting to observe root adaptation and seedling response. Signs of stress, such as wilting or yellowing leaves, are addressed promptly by adjusting the nutrient concentration. This transition phase is crucial for establishing strong root systems, promoting healthy vegetative growth, and ensuring successful crop development under hydroponic conditions.

Figure 5: Healthy Seedlings

Monitoring And Harvesting

Visually impaired individuals can effectively monitor and harvest spinach and pak choi using assistive technologies, sensory-based techniques, and structured workflows. Covarrubias et al. (2024) introduce an innovative AR-based learning platform designed to enhance hydroponic agriculture and vertical farming training for young students with disabilities. Developed in collaboration with the Association for Cognitive Enhancement, the platform increases engagement, interactivity, and real-time feedback, creating a more inclusive learning environment. This research advances assistive technology in education and highlights AR's potential in sustainable agriculture. By integrating smart monitoring systems and tactile feedback, blind individuals can efficiently manage hydroponic crops with minimal assistance. Figure 6 illustrates one of our visually impaired participants inspecting the spinach.

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Figure 6: Tactile Plant Inspection

Internet of Things for Monitoring NFT System

Role of ESP32 in the Hydroponic System

The ESP32 microcontroller was used to collect, process, and transmit data from various sensors and actuators in the hydroponic system. It served as the central controller, ensuring real-time monitoring and automated adjustments. Multiple sensors and actuators interfaced with the ESP32 to monitor critical hydroponic parameters, as listed in Table 2 and Table 3, respectively:

Table 2: Sensors

Sensor	Parameter Measured	Function
TDS Sensor	Nutrient concentration (ppm)	Ensures optimal nutrient strength in the mixing tank
Water Level Sensor	Tank water levels (ON/OFF)	Prevents pump dry running and nutrient depletion
DHT11 Sensor	Temperature & Humidity	Monitors environmental conditions
Flow Sensor	Water flow rate	Ensures smooth nutrient circulation in NFT channels

Table 3: Actuators

Actuator	Function	Purpose in NFT Hydroponics
Peristaltic Doser Pumps	Adds Fertilizer A & B based on TDS readings	Ensures precise and automated nutrient dosing
Solenoid Valves	Regulates water flow for nutrient dilution	Prevents over-fertilization by controlling dilution levels

Dual-Tank Fertilizer Dosing System for NFT Hydroponics

In this experiment, a dual-tank system was implemented to store and dispense Fertilizer A and Fertilizer B, ensuring precise nutrient delivery to plants in the NFT hydroponic system. Each fertilizer solution was moved from one of the two separate tanks to a mixing tank by doser pumps. There, it was mixed in the right amounts before being sent to the hydroponic channels shown in Figure 7. The primary reason for keeping Fertilizer A and Fertilizer B in separate tanks is to prevent chemical reactions that might lead to precipitation, rendering the nutrients

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unavailable for plant uptake. Many hydroponic fertilizers contain calcium-based and phosphate-based nutrients, which, if mixed directly in concentrated form, form insoluble precipitates that can clog the system and reduce nutrient efficiency. By keeping them separate and only mixing them in diluted form, the system ensures maximum nutrient availability and absorption by plant roots.

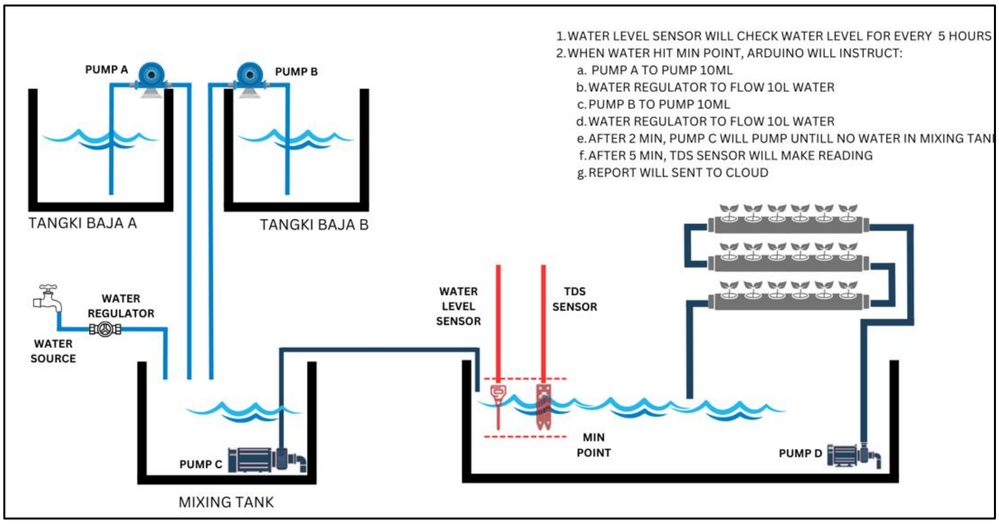

Figure 7: Dual-Tank Fertilizer Dosing System

Components of the Fertilizer Dosing System

A structured fertilizer dosing system with fertilizer storage tanks, peristaltic doser pumps, and a mixing tank was put in place to make sure that the NFT hydroponic system delivered nutrients accurately and efficiently. Fertilizer A and B were stored in separate tanks to prevent chemical precipitation, with each tank labeled and calibrated for accurate volume monitoring and timely refilling. Peristaltic doser pumps were added to measure out the right amount of fertilizers and move them to the mixing tank. This made sure that there was no contamination and that the dosing could be set so that the balance of nutrients was always the same. In the mixing tank, fertilizers were blended in the correct ratio, with a stirring mechanism ensuring even distribution before delivery to the plants. To make nutrient management even better, a TDS sensor was put in place to measure the amount of dissolved ions. This data was then turned into electrical conductivity (EC) levels, which were then turned into ppm values to show how strong the nutrients were. The sensor continuously transmitted data to the ESP32 microcontroller for real-time monitoring via a cloud-based dashboard. If TDS levels deviated from the optimal range, an alert system notified the grower to adjust the nutrient concentration, ensuring an automated and precise hydroponic nutrient management system. The Hydroponic Vegetable Chart outlines optimal pH, EC, CF, and PPM values to ensure proper nutrient balance for vegetable growth. It helps hydroponic growers adjust nutrient solutions for healthy plant development and maximum yield, as shown in Table 4.

Table 4: Hydroponic Vegetable Chart

Vegetable	pH	EC	PPM (500 Scale)
Pak-choi	7.0	1.5 – 2.0	750 – 1000
Spinach	5.5 – 6.6	1.8 – 2.3	900 – 1150

Source:(https://ponicslife.com/hydroponic-charts-for-fruits-and-vegetables-ph-tds-ec-cf-ppm/)

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Cloud-Based Monitoring for Visually Impaired Individuals

We transmitted the monitored parameters of the NFT system to the cloud in real time to enhance accessibility and inclusivity in hydroponic farming. This feature enabled visually impaired individuals to remotely monitor and manage their hydroponic setup via a smartphone. The cloud platform stored and processed data from the system's sensors, including nutrient concentration, temperature, and humidity, allowing users to receive real-time updates and alerts about the system's status. Figure 8 presents a screenshot of the website that illustrates the voice-assisted hydroponic monitoring system. The website is available at https://infotex.site/sbm/.

Figure 8:Voice-Assisted Hydroponic Monitoring

To facilitate accessibility, we integrated TalkBack, an app for screen reader accessibility that provides audio feedback for individuals with visual impairments. With this setup, users could receive verbal notifications about system parameters, enabling them to take necessary actions, such as adjusting nutrient levels, regulating water flow, or modifying environmental conditions. Furthermore, the cloud platform was designed to send automatic alerts through voice notifications feedback when critical thresholds were exceeded, such as a drastic nutrient level imbalance or a significant drop in water flow rate. This feature ensured that individuals could respond promptly to maintain optimal growing conditions without requiring visual inspection.Steps for blind individuals to use TalkBack for hydroponic monitoring are as follows:

Enabling TalkBack

- To activate TalkBack, users can:
- Navigate to Android Accessibility settings and enable the feature manually.
- Press both volume buttons for three seconds as a shortcut to activate TalkBack instantly.
- Upon activation, TalkBack provides spoken feedback, describing each element on the screen to assist navigation.

Navigating the Website

Once TalkBack is enabled, users can interact with the hydroponic IoT dashboard using intuitive gestures:

- Swipe left or right to navigate between different sensor readings, system parameters, and alerts.
- Single tap to select an element, allowing TalkBack to describe it.
- Double tap to activate a selected item, such as opening detailed sensor logs or triggering water pump controls.

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Accessing Real-Time Hydroponic Data

TalkBack enables users to access and interpret sensor readings through audio feedback, making real-time monitoring possible:

- TalkBack reads aloud numerical values for key hydroponic parameters, including:
- TDS reading – monitoring nutrient concentration.
- Temperature and humidity – optimizing plant growth conditions.
- If critical thresholds are exceeded, automated voice alerts notify users with messages such as:
    - Low water level detected, please refill the tank.
    - Nutrient concentration too high, adjust dilution.

While the hydroponic monitoring system provides real-time accessibility through TalkBack and voice alerts, it is not yet fully automated, requiring manual intervention for adjusting water levels. Blind individuals can monitor the system independently, but assistance from family members is needed when physical adjustments are required.

Result and Discussion

Over the 28-day monitoring period, temperature, humidity, water level, and nutrient PPM were tracked to ensure optimal conditions for hydroponic plant growth. The collected data helped identify necessary actions to maintain a stable growing environment. The temperature was monitored between 22°C and 30°C, with corrective actions such as activating cooling systems when exceeding 25°C or increasing temperature if dropping below 22°C as depicted in Figure 9.

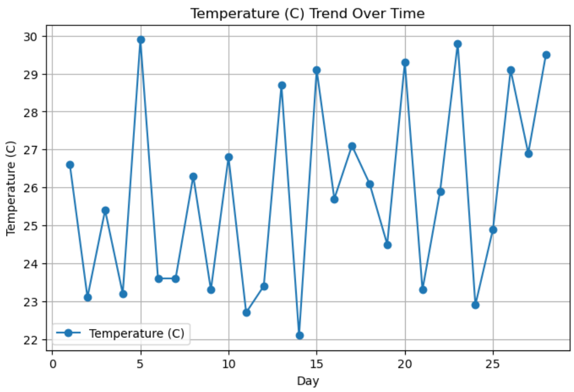

Figure 9: Temperature

Humidity levels fluctuated between 85% and 96%, necessitating adjustments such as ventilation or misting control when values surpassed 70% or fell below 50%. These readings were influenced by the rainy season and the sensor's placement in an open area with a roof overhead as shown in Figure 10.

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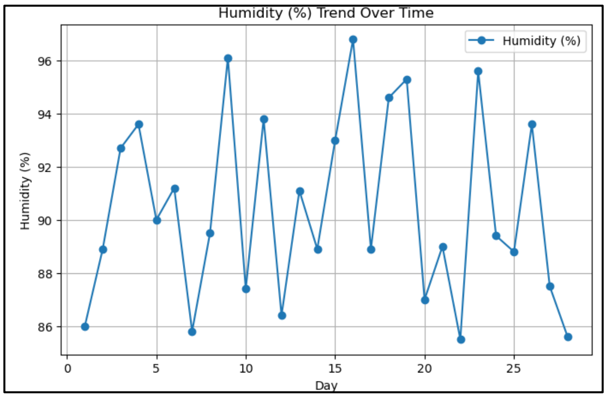

Figure 10: Humidity

Nutrient PPM readings ranged from 600 to 1200, requiring adjustments such as increasing nutrient supply when values fell below 700 or diluting solutions when exceeding 1100.

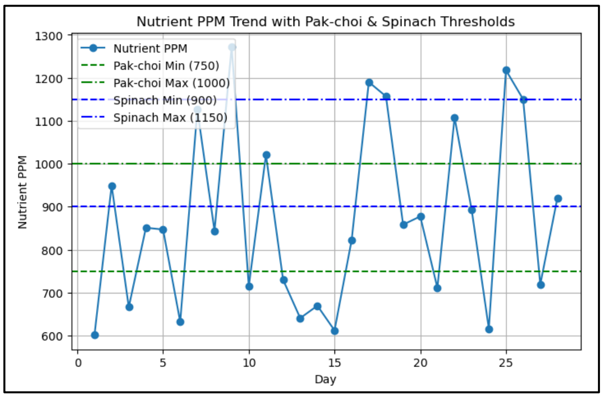

Figure 11: Nutrient Readings

The generated graphs illustrate trends in temperature, humidity and nutrient PPM over the 28-day period, providing insights into fluctuations and necessary interventions to maintain optimal hydroponic conditions.

Conclusion

The development of a voice-accessible IoT hydroponic monitoring system for visually impaired individuals demonstrates the transformative potential of assistive technology in modern agriculture. This study successfully achieved its objectives: (1) identifying the key barriers faced by visually impaired individuals in managing hydroponic systems, (2) designing and implementing an IoT-based solution with voice-assistive features, and (3) evaluating its accessibility, usability, and efficiency. The integration of ESP32 microcontrollers, environmental sensors, and automated water pumps enabled real-time monitoring and efficient control of hydroponic parameters. The incorporation of voice-assisted technology and cloud-based reporting allowed users to independently access and interpret critical agricultural data, significantly reducing their reliance on visual cues. Findings from the study highlight the effectiveness of IoT-based automation in enhancing accessibility and operational efficiency. Users reported greater confidence in managing nutrient levels, monitoring environmental conditions, and responding to system alerts. Additionally, environmental data analysis revealed seasonal fluctuations—particularly in humidity levels—that underscore the need for adaptive control strategies in hydroponic management. This research contributes meaningfully to the

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fields of sustainable agriculture, digital inclusion, and assistive technology by introducing a functional prototype that empowers visually impaired individuals. It demonstrates that with appropriate technological interventions, hydroponics can be made more accessible, thereby promoting autonomy, economic participation, and social inclusion. Supported by the Sarawak Branch of the Society of the Blind Malaysia and Politeknik Kuching Sarawak, the project serves as a model for community-driven, inclusive innovation. For future research, further improvements should focus on enhancing system intelligence through AI-driven decision-making, expanding voice-control functionality, and integrating mobile applications for broader device compatibility. Usability testing with a larger and more diverse user base is also recommended to refine the interface and support scalability. By advancing these areas, future iterations of the system can further bridge accessibility gaps and foster inclusive participation in agricultural innovation.

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