AUTONOMOUS HYDROPONIC FARMING SYSTEM AND LETTUCE GROWING

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ABSTRACT

This initiative aims to automate hydroponic lettuce cultivation through an electronic circuit board. Sensors collect data to optimize plant growth and monitoring. The board manages parameters like irrigation and nutrient supply, providing ideal conditions. Collected data is stored via a dedicated Discord bot, allowing real-time tracking. Remote control via Discord empowers users to adjust parameters, ensuring efficient cultivation. In summary, this project enhances hydroponic lettuce growth by automating processes and enabling remote monitoring and control.

Keywords: Hydroponic lettuce cultivation, Automation, Electronic circuit board, Discord bot, Remote control, Agricultural technology

1. Introduction

1.1 What is the Hydroponic System?

Hydroponic systems, also known as soilless cultivation[1], have gained significant attention in modern agriculture due to their efficient use of resources and ability to overcome limitations posed by traditional soil-based methods. This innovative approach to farming involves growing plants in nutrient-rich water solutions[2], without the need for traditional soil. The primary advantage of hydroponic systems lies in their water-saving potential, as they can use up to 90% less water compared to conventional soil-based farming[3]. Furthermore, the precise control over nutrient delivery in hydroponics leads to faster and healthier plant growth, resulting in higher yields and better quality produce.

1.2 Electronic Part

In this system, we needed an electronic circuit for motor control and reading sensor values. We designed the schematic and PCB layout of this circuit using the EasyEda program, thanks to its user-friendly interface[4] and functionality, we chose EasyEda for this purpose.

The circuit design mainly consists of the following components: power supply, sensor connections, LCD screen connection, buttons, motor connections, and the MCU (Microcontroller Unit). Initially, we converted the 12-volt power source to 5 volts using the LM7805[5]regulator. This 5-volt output was used to power the sensors, LCD screen, button LEDs, and the 5V used for the pumps of nutrient and medication supplementation.

The buttons in the circuit are used to control the three motors installed in the system. the LCD screen[6] provides real-time status updates, allowing users to monitor the system's performance visually. The MCU (Microcontroller Unit) communicates with the main computer via UART[7] to send sensor data. This enables effective monitoring and analysis of the system's operating data.

Thanks to the EasyEda program, we efficiently designed this electronic circuit, ensuring all components of the system work seamlessly together. As a result, the automation system successfully accomplishes motor control and real-time monitoring of sensor data, functioning as a reliable and effective setup.

1.3 Data Storage

The data sent by the microcontroller to the main computer via UART communication is forwarded to the Discord bot[8], which stores the data simultaneously on Discord servers and in Google Sheets using the Google Sheets API[9]. This ensures that the collected data is securely stored and easily accessible for analysis and monitoring.

To provide redundancy and prevent data loss in the event of a possible internet connection issue, a fail-safe mechanism is implemented. If the communication between the main computer or the Discord bot is disrupted due to an internet connectivity problem, the data will be stored locally on the main computer in an Excel spreadsheet. This local data collection ensures that critical information is preserved even during temporary network outages.

Once the internet connection is restored, the stored data in the Excel spreadsheet is automatically synchronized with the Discord bot and sent to the designated channels on Discord and Google Sheets. This seamless data transfer process allows for uninterrupted monitoring and analysis, guaranteeing data integrity and reliability.

By combining the Discord bot and Google Sheets API, this system ensures efficient data management and provides real-time access to critical information for the hydroponic farming process. Additionally, the fail-safe mechanism safeguards against potential internet disruptions, offering a robust and reliable solution for data collection and storage in the automated hydroponic farming system.

2. Materials and Methods

2.1 Electronic Circuit Board Design

A specialized electronic circuit board is meticulously designed to address the intricate requirements of the hydroponic system. This board encompasses microcontrollers, sensor interfaces, power management components, and auxiliary peripherals. The microcontrollers function as the central hub, acquiring raw data from sensors, implementing processing algorithms, and ultimately making data-driven decisions to finely regulate the system's parameters.

During the design of the circuit board, various factors have been carefully considered. The arrangement of components on the board, signal pathways, power management, and thermal design are among the technical details that have been meticulously addressed. During the design process, possible electromagnetic interactions between different components were carefully examined. As a result, the layout of the circuit board and the arrangement of components were meticulously crafted. Additionally, special coatings and insulation methods were employed to prevent electromagnetic waves from propagating to other components. This ensured the stable and seamless operation of the system and minimized the adverse effects of external influences. This meticulous design approach has been adopted to ensure the stable and reliable operation of the hydroponic system.

2.2 Installation of Sensors

A comprehensive monitoring system is established within the hydroponic environment through the strategic installation of a network of sensors. These sensors play a pivotal role in providing real-time data about the growth conditions and overall health of the plants[10]. The carefully chosen sensors encompass a diverse range, each selected for its specific capability to gather critical data about the growth medium and the surrounding environment.

- **EC (Electrical Conductivity) Sensors:** They measure the density of the nutrient solution to ensure that the necessary minerals are provided to the plants.
- **pH Sensors:** pH levels directly impact nutrient availability to plants. pH sensors continuously measure the acidity or alkalinity of the nutrient solution, allowing the system to adjust the pH to the ideal range for the specific plants being cultivated. Proper pH levels enhance nutrient absorption and overall plant health.
- **Temperature Gauges:** Temperature is a fundamental factor affecting plant growth. Sensors monitoring temperature fluctuations ensure that the hydroponic environment remains within the optimal temperature range. Maintaining consistent temperatures promotes optimal metabolic processes and prevents stress-induced growth issues.
- **Light Sensors:** These sensors monitor the correct amount of light required for photosynthesis, thus optimizing plant growth.
- **CO2 Sensors:** They monitor the carbon dioxide level necessary for photosynthesis in plants.
- **Oxygen Sensors:** Monitoring the oxygen intake of roots, these sensors maintain root health.
- **Air Humidity Sensors:** By tracking air humidity, these sensors facilitate comfortable plant growth.

Each of these sensors is carefully chosen for its specific role in creating an ideal growth environment. Their collective data contributes to a comprehensive understanding of the hydroponic system's performance. By continuously gathering and analyzing data from these sensors, the system can adapt and fine-tune its processes to provide optimal conditions for plant growth. The integration of these sensors underscores the commitment to precision, efficiency, and excellence in hydroponic farming practices.

2.4 Integration of Discord Bot and remote control

The central aspect of the data transmission process lies in the astute integration of a tailored Discord bot. This virtual entity takes on a significant role by facilitating the real-time transmission of processed data to specific Discord servers. Users gain direct access to this data through a user-friendly interface, thereby creating a symbiosis between technological advancement and user interaction.

Capabilities offered by the Discord bot:

- **Data Transmission:** Processed data is conveyed to specific Discord servers through a customized Discord bot. This enables users to acquire instant information about crucial parameters such as plant growth conditions, water levels, pH levels, temperature, and humidity.
- **Remote Manipulation:** Users exert authoritative control over plant growth dynamics through remote manipulation, achieved through command-based interactions. They can manage a range of

vital activities remotely, from adjusting irrigation schedules to fine-tuning nutrient injection rates and controlling the lighting environment.[11]

- **User Interaction:** The Discord interface provides a platform for users to interact with real-time feedback and requests. This empowers users to inquire about the current status of the system, make suggestions, and make adjustments as needed.

This integration of the Discord bot enhances users' ability to monitor, manage, and optimize hydroponic system performance. Through remote access and interaction, users can shape plant cultivation conditions effectively. By merging technological innovation and user participation, this integration revolutionizes plant cultivation processes in unprecedented ways.

3. Problem of the Study

Hydroponic farming, with its ability to cultivate plants without traditional soil-based methods[12], offers promising opportunities for countries with unsuitable soil conditions for agriculture. This project's focus on developing an Arduino-based AI-enhanced automated hydroponic farming system lays the foundation for overcoming the limitations imposed by inadequate soil quality. By utilizing water as the growth medium and providing essential nutrients through a controlled system, hydroponics allows for efficient plant growth in areas where conventional farming practices may not yield desirable results.

In regions with arid or infertile soils, hydroponics offers a viable solution for sustainable food production and increased agricultural resilience[13]. The automated control unit, powered by Arduino microcontrollers, plays a pivotal role in ensuring the precise delivery of nutrients, water, and environmental factors, thereby optimizing plant growth and health. AI algorithms and image processing techniques enhance the system's capabilities, enabling real-time monitoring of plant health and early detection of nutrient deficiencies or diseases.

The potential of this hydroponic system extends beyond its efficiency in resource utilization; it holds the promise of transforming regions with previously challenging agricultural landscapes into flourishing hubs of crop cultivation. By eliminating the dependency on traditional soil quality, this technology-driven approach opens new avenues for food security, economic growth, and sustainable development in otherwise marginalized areas.
Furthermore, the adaptability of this system to different plant species allows for diverse agricultural production, catering to local food preferences and nutritional requirements. By promoting water conservation and reducing the need for arable land, this innovative hydroponic approach aligns with global efforts to address climate change and resource scarcity.

In conclusion, the Arduino-based AI-enhanced automated hydroponic farming system offers a transformative solution for countries facing adverse soil conditions. Its ability to cultivate plants without relying on traditional soil-based agriculture makes it a promising option for sustainable and resilient food production in challenging environments. Through effective resource utilization, real-time monitoring, and adaptability to various crops, this technology-driven approach has the potential to contribute significantly to food security and agricultural development worldwide

4. Purpose of the Study

The main objective of this study is to develop an advanced control system to manage the hydroponic lettuce cultivation process in a more efficient and optimized manner. This system will continuously monitor and analyze the growth conditions of lettuce plants based on data obtained through various sensors. These sensors will encompass a wide range of components, including water mineral levels, pH values, temperature levels, and environmental humidity detections. Collecting this data aims to provide important insights into the intricacies of the growth environment, ultimately aiming to enhance the efficiency of hydroponic farming.

The system is designed to operate independently from human intervention, thereby reducing the need for human involvement and labor. Drawing upon data acquired from sensors, the system will automatically regulate and optimize critical processes such as irrigation, nutrient supply, and environmental factors. This approach is anticipated to boost efficiency and data accuracy in agricultural processes, leading to reduced operational costs and fostering a more sustainable approach to farming.

Furthermore, the system targets data storage and remote control through various commands. This will enable access to historical data for analysis and facilitate flexible and effective management of agricultural processes through remote access and intervention. For instance, users can remotely monitor the system, access data, and receive automated alerts for specific conditions via the Discord bot, enabling prompt intervention and early detection of potential issues.

In conclusion, the fundamental objective of this study is to optimize the hydroponic lettuce cultivation process through sensor-driven mechanisms, securely store collected data on Discord servers, and enable remote control via the Discord platform. This comprehensive approach not only aims to enhance the potential of hydroponic farming but also presents a novel paradigm for the future sustainability and efficiency of agriculture.

5. Data Storage and Remote Control System with Discord BOT

Discord bots are helpful software that can be created using Discord servers and the Discord developer interface. These bots can serve various purposes and are customizable to meet individual needs. In this project, we developed our bot using the Python language, focusing on creating a bot that detects specific commands, stores system data, and adds entries to Google Sheets.

The bot operates within a dedicated Discord server for the project. It efficiently stores environmental data received from the system by creating specialized channels based on the date of the data. Whenever the date changes, the bot automatically generates a new channel to continue storing the incoming data. Additionally, it utilizes the Google Sheets API to store the data in a project-specific Google Sheet. This ensures the security and persistence of the data, reducing the risk of data loss.

Furthermore, the bot's software includes various command functionalities, enabling users to control and monitor the system through Discord. Users can issue specific commands to activate water motors, vitamin motors, or even capture real-time photos from the system's cameras.

The development of this Discord bot significantly contributes to data management and system control, ensuring the smooth and effective functioning of the project. By efficiently handling data and providing remote control capabilities, the bot enhances the overall performance of the hydroponic system.

In this project, a Discord Bot has been developed for storing system data. This custom bot, written in Python, operates within a dedicated Discord server specifically created for the project. The bot stores environmental data received from the system in separate channels based on dates. When a new date is detected, a new channel is created, and data continues to be stored in this channel. Additionally, it utilizes the Google Spreadsheets API to store data in a spreadsheet specifically designed for the project.

In case of a potential internet connection loss in the system, data will be stored locally on the main computer in an Excel file, and once the internet connection is restored, the data from the Excel file will be transferred back to the Discord and Spreadsheets environments, ensuring uninterrupted system operation.

Apart from data storage, various commands have been implemented in the bot's software to enable system control and monitoring through the Discord Bot. For instance, the **!water [time]** command activates the water motors for the specified duration, ensuring irrigation of the plants. Similarly, the **!vitamins [time]** command activates the vitamin motors for the specified time, providing nutrient supplementation to the plants. Moreover, when the **!takephoto** command is used, real-time photos taken from the system's cameras are sent to the Discord server. These commands enable users to monitor the system's status in real-time and intervene when necessary.

This Discord Bot serves as an essential tool for collecting, storing, and controlling system data. By automating all processes in the system, it enhances efficiency and productivity, contributing to more successful hydroponic lettuce cultivation

6. Electronic Schematic

The Electronic Schematic section generally includes the electronic block diagram, electronic circuit schematic, and PCB layout sections of the system, along with their descriptions. The block diagram part (Fig. 2) explains the purposes of the electronic components in the system. It provides an overview of the system's electronic modules and their functions, depicting the relationships and interactions between different components, helping us understand the operating principles of the system.

On the other hand, the circuit schematic (Fig. 2) illustrates in detail the units formed by electronic

components on the circuit board. This schematic clearly shows how the components are connected and interact with each other. The placement and connections of electronic components are visually depicted on the schematic, aiding in comprehending the functioning and interaction of the circuit components. Moreover, the circuit schematic plays a crucial role in identifying the components to be used in electronic circuit design and enhances the understanding of any modifications made during the implementation. A detailed and accurate circuit schematic increases the reliability of analyses and simulations during the system's design phase, resulting in improved electronic design outcomes.

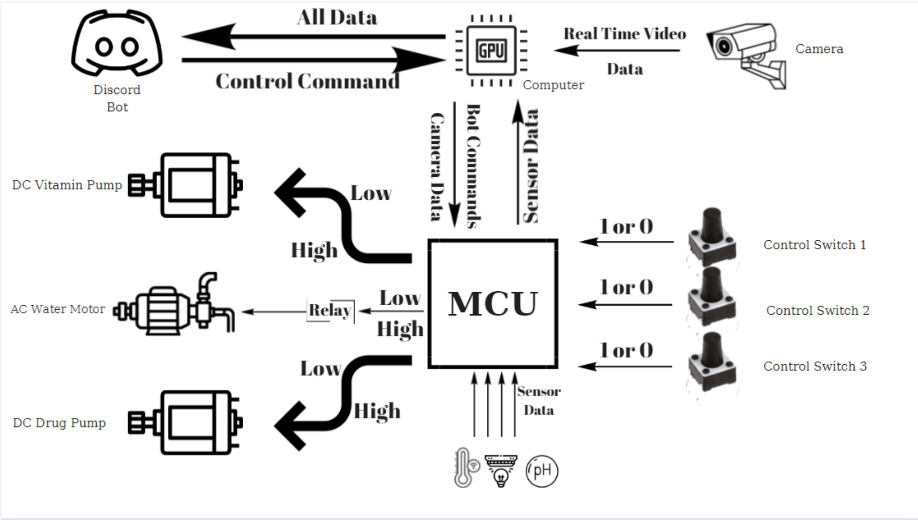

Fig. 1 - Block Diagram for autonomous lettuce growing system

The main elements of the automation system include Arduino boards, motors, and sensors. The Arduino boards serve as the microcontroller units that process incoming sensor data and generate output signals for motor control. Motors are responsible for actions such as adjusting the positioning of grow lights, controlling the flow of nutrient solutions, or regulating environmental parameters. Sensors, such as temperature and humidity sensors, light sensors, and pH sensors, provide real-time data on the growing conditions, allowing Arduino to make informed decisions and adjustments.

Through the programming and configuration of Arduino, the automation system enables precise control over critical parameters in lettuce cultivation. It can regulate factors like light intensity, temperature, humidity, and nutrient supply based on sensor readings. This ensures optimal growing conditions for lettuce plants, promoting healthy growth and maximizing yield.

In this project, due to the absence of an existing technology to directly measure the vitamin content in water, an average vitamin supplementation plan has been devised for the lettuce crop based on the available data from online sources[14] This supplementation is calculated considering the essential nutritional requirements of lettuce to support its growth and health. Information gathered from relevant literature and similar agricultural projects has provided valuable insights into the general vitamin needs of lettuce plants. Drawing upon this knowledge, an appropriate average vitamin supplementation has been computed and will be implemented for the specific lettuce variety chosen in the project.

This approach offers a practical solution in the absence of a direct measurement method for water-based vitamin content. By addressing the nutritional needs of lettuce plants, it ensures their well-being and proper development. Though direct measurement of water's vitamin content might be unattainable at present, this calculated average vitamin supplementation represents a viable approach to support the growth of lettuce crops and maintain their health throughout the hydroponic farming process.

By utilizing Arduino's capabilities in motor control and sensor data processing, the automation system brings efficiency, accuracy, and consistency to the lettuce growing process. It reduces the manual effort required and allows for real-time monitoring and adjustment, leading to improved productivity and quality in lettuce cultivation.

In this system, 5V underwater submersible pump are used for providing vitamin and medication supplements to the plants. The motors of these pumps are directly connected to the MCU. The speed of the vitamin and medication supplements is not crucial for the system as they only need to be administered at low levels. However, the water circulation pumps that ensure the system's recirculation need to be powerful and have a high flow rate. For this reason, we utilized a 230V AC water pump motor triggered by a regulator. The water pump we used is the SYNCRA 1.0 Silent model [15], which consumes less energy compared to other models, approximately 16W. Additionally, with a flow rate of 950 liters per hour, this water pump effectively provides the desired circulation in our hydroponic system. This robust water pump ensures that the nutrient solution circulates evenly among the plants, promoting their healthy and balanced growth.

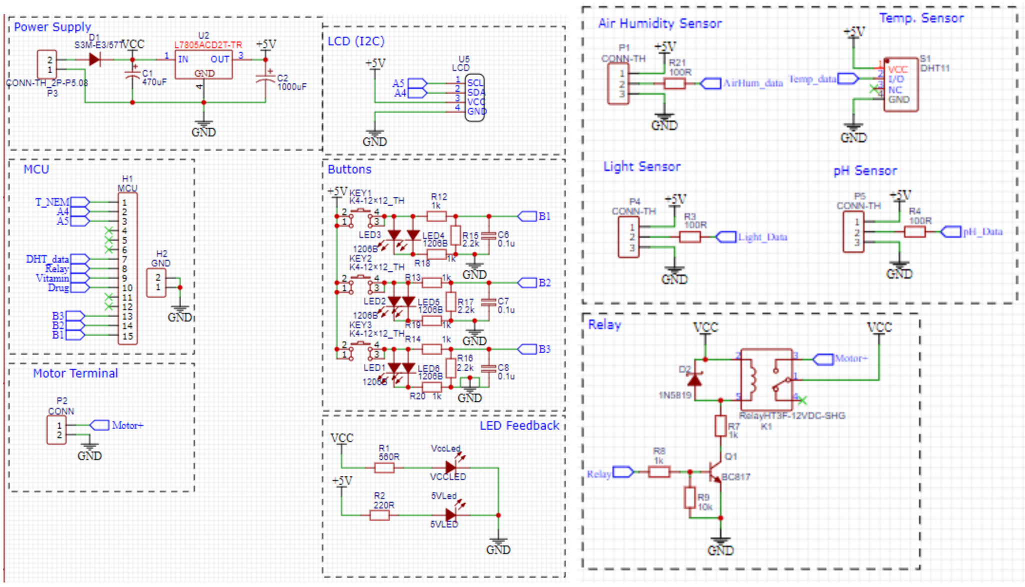

Fig. 2 - Circuit's electronic schematic; Power supply unit, sensor connections, terminal for motor connections, voltage feedback LED connections, I2C connected LCD screen connection, microcontroller unit, relay unit for controlling the AC water pump motor, button connections.

In this project, the electronic circuit schematic and PCB (Printed Circuit Board) layout were successfully developed using the EasyEDA software. The user-friendly interface and functionality of EasyEDA facilitated the design process and enhanced productivity. The electronic circuit schematic clearly depicted the fundamental components and connections of the project, effectively conveying the essential concepts of the design. The PCB layout transformed the electronic circuit schematic into a physically feasible printed circuit board, enabling the optimization of component placement and connections for a more organized and efficient production of the project. The convenience and flexibility offered by EasyEDA played a significant role in the successful completion of this project. facilitating the effective creation of the targeted electronic circuit. Electronic circuitry offers various advantages in this project[16]. In accordance with the project requirements, a custom circuit board has been designed. The power supply unit of this board (Fig. 2) utilizes the LM7805 Regulator to step down the 12V DC power from the source to 5V, meeting the general 5V power needs of the circuit. Capacitors C1 and C2 are employed to minimize power fluctuations and noise. To monitor the accuracy of the 12V and 5V sources without the need for measurements, two LEDs (Fig. 2) are used to provide feedback on these voltages.

The connections for the required sensors (Fig. 2) have been established, and their data pins are linked to the microcontroller unit (Fig. 2). The 5V submersible motors used for vitamin and medication supplementation are directly connected to the microcontroller unit (Fig. 2), while the AC water pump motor is controlled through a relay unit (Fig. 2). The LCD screen is integrated to display comprehensive system information. For direct system control, three buttons (Fig. 2) have been added to the circuit.

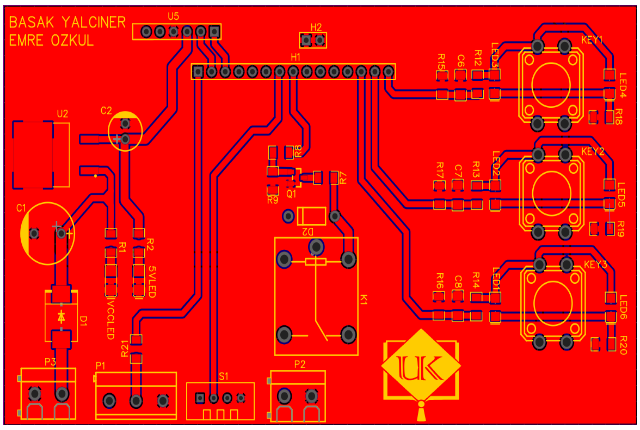

Fig. 3 - PCB Layout for autonomous lettuce growing system circuit schematic

Due to EasyEda's user-friendly interface, the electronic schematic of the circuit (Fig. 2) was designed using the EasyEda program for PCB layout. In the PCB design, all the connections specified in the electronic schematic were implemented accurately. One key aspect during component placement was to arrange them neatly to ensure clean and efficient connections. Considering all the requirements, the PCB layout was successfully completed. This step plays a crucial role in achieving the successful implementation of the project's electronic components and ensuring the circuit operates efficiently. The completion of the electronic schematic and PCB design facilitates the harmonious functioning of the hardware components, which is essential for the overall success of the project. The systematic and careful procedures carried out during this stage directly impact the project's overall performance and success

7. Conclusions

This study focuses on the significance of hydroponic systems in modern agriculture, which efficiently utilize resources and overcome limitations of traditional soil-based methods. This innovative approach involves growing plants in nutrient-rich water solutions, eliminating the need for conventional soil. The primary advantage of hydroponic systems lies in their potential for water conservation, using up to 90% less water compared to traditional farming. Additionally, precise nutrient control leads to healthier plant growth, resulting in higher yields and improved produce quality.

The design of the electronic circuit board, sensor selection, and their integration highlight the pivotal role in the future of hydroponic farming. This specialized circuit board comprises microcontrollers, sensor interfaces, power management components, and auxiliary peripherals. Microcontrollers gather raw data from sensors, implement processing algorithms, and make data-driven decisions to regulate system parameters effectively.

Sensor selection aims to establish a comprehensive monitoring system by strategically installing a network of sensors. These sensors provide real-time data about plant growth conditions and overall health. Soil moisture sensors regulate irrigation cycles, pH sensors adjust nutrient availability, temperature gauges maintain optimal conditions, and humidity detectors ensure proper water balance. The integration of these sensors contributes to a comprehensive understanding of system performance, enabling adaptation and fine-tuning of processes for optimal plant growth.

Integration of the Discord bot plays a central role in real-time data transmission. This virtual entity facilitates the transfer of processed data to specific Discord servers, granting users direct access through a user-friendly interface. This integration revolutionizes plant cultivation processes through remote manipulation, enabling users to adjust irrigation schedules, nutrient levels, and lighting conditions. The Discord bot enhances system monitoring, management, and optimization, merging technological innovation with user participation.

Moreover, this study emphasizes the meticulous design of the electronic circuit board, careful sensor selection, and component arrangement. These elements ensure stable and reliable operation. The article underscores the commitment to precision, efficiency, and excellence in hydroponic farming practices.

Furthermore, the article underscores the necessity of a backup mechanism to enhance data storage reliability during internet connection issues. This mechanism ensures seamless synchronization of data when the connection is restored.

In conclusion, this article highlights the creation of a system that optimizes hydroponic farming processes through electronic circuit board design, sensor integration, Discord bot utilization, and efficient data management methods. This innovative approach holds the potential to enhance the efficiency, resource utilization, and sustainability of plant cultivation

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