2024 IEEE Flagship International BIT Conference (BITCON-24)

Farming 4.0: Integrating Technology for Smart Agriculture

Ch. Varaha Narasimha Raja
Department of Electrical & Electronics Engineering
Anil Neerukonda Institute of Technology & Sciences
Visakhapatnam, India
chvnraja.eee@anits.edu.in

J.Ankamma Rao, Member, IEEE
Electrical and Computer Engineering
Assosa University
Assosa, Ethiopia
jaraoeee04@asu.edu.et

Botta Naidu
Department of Electrical & Electronics Engineering
Vignan's Institute of Engineering for Women
Visakhapatnam, India
naidu.gostani@gmail.com

Batta Madhusudhana Rao
Department of Electrical and Electronics
Avanthi Institute of Engineering
Cherukupally, Vizianagaram, India
venkatbatta49@gmail.com

Thamatapu Eswara Rao
Department of Electrical Engineering
Vignan's Institute of Information Technology
Visakhapatnam, India
eswareee@vignaniit.edu.in

Vikash Gurugubelli, *Student Member, IEEE*
Department of Electrical & Electronics Engineering
Anil Neerukonda Institute of Technology & Sciences
Visakhapatnam, India
vikas0225@gmail.com

Abstract*—The Hydro Growth system presents an innovative approach to hydroponic farming, integrating Arduino microcontroller technology, mobile application, and solar panel power sources. In regions facing water scarcity, such as arid areas, this system offers a sustainable solution by utilizing dehumidifiers as a fresh water source for hydroponics, powered by solar panels. This study aims to design and develop a hydroponics application that monitors water quality parameters, including pH, TDS, and temperature, providing accurate management of hydroponic environments. Employing a qualitative and experimental research design, an Iterative Waterfall model is utilized for system development, ensuring alignment with user and business requirements. Arduino microcontroller capabilities facilitate hardware and software integration, while sensors such as pH, TDS, and temperature sensors, along with GSM and temperature sensors, enhance system functionality. Development of the mobile application is achieved through Android Studio, JAVA, Node.js, and other relevant technologies, ensuring a robust and secure platform for user interaction. Evaluation of the Hydro Growth system demonstrates its scalability and intelligence in providing effective hydroponic farming management. Regional agricultural experts consistently rate the system as effective, reinforcing its potential as an innovative tool for sustainable agriculture. Additionally, hydroponically grown food is recognized for its nutritional benefits over soil-based farming methods. The system continuously monitors water quality and sends SMS notifications to users, not only alerting them to abnormalities but also providing guidance on corrective actions, such as adding organic chemicals, to maintain optimal growing conditions.

Keywords*—*Sustainable agriculture, Hydroponics, Arduino-based monitoring system, Solar-powered dehumidifiers

I. Introduction

Hydroponic cultivation has emerged as a promising solution to address the challenges of traditional soil-based agriculture, offering increased efficiency, reduced resource consumption, and greater control over crop growth conditions. In recent years, there has been a surge in research and development efforts aimed at enhancing the performance, sustainability, and automation of hydroponic systems. This introduction provides an overview of the evolving landscape of smart hydroponics systems, drawing insights from recent literature and research endeavors. Recent studies have demonstrated the potential of integrating advanced technologies such as Internet of Things (IoT), wireless sensor networks, and machine learning algorithms to create smart hydroponic systems capable of real-time monitoring, precise control, and automated management. For instance, [1] proposed a wireless sensor network-based smart hydroponics system for precision agriculture, enabling remote monitoring and control of key parameters. Similarly, Patel et al.

In [2], the researchers developed a solar-powered IoT hydroponic system with remote monitoring and control capabilities, leveraging renewable energy sources for sustainable operation. Furthermore, advancements in sensor technology and data analytics have played a pivotal role in enhancing the intelligence and efficiency of hydroponic systems. The paper [3] demonstrated real-time monitoring and control of hydroponic systems using IoT and machine learning techniques, enabling adaptive management strategies for optimal crop growth. Additionally, the paper [4] presented a smart hydroponics system with automated nutrient management using machine learning algorithms, facilitating precise nutrient delivery based on plant requirements.

Moreover, research efforts have focused on addressing the practical challenges associated with deploying and operating hydroponic systems, such as cost-effectiveness, energy efficiency, and scalability. The paper [5] designed and implemented a low-cost hydroponic monitoring system using wireless sensor networks, providing an affordable solution for small- scale growers. The paper [6] explored the real-time monitoring and control of hydroponic systems using IoT and cloud computing, demonstrating the potential of these technologies to streamline operations and improve crop management practices. In parallel, the design and implementation of wireless sensor networks have revolutionized hydroponic crop monitoring, enabling growers to collect real-time data on environmental conditions and crop health. The paper [7] developed a wireless sensor network for hydroponic crop monitoring, facilitating precise data collection and analysis to inform decision-making processes.

Furthermore, researchers have emphasized the sustainable aspects of hydroponic cultivation, highlighting its potential to address environmental challenges and

979-8-3315-1839-4/24/$31.00 ©2024 IEEE

promote future agricultural practices. The work in [8] discussed the sustainable approach of hydroponic cultivation, underscoring its significance in achieving long-term food security and environmental sustainability goals. Moreover, the application of machine learning algorithms has shown promise in optimizing hydroponic systems' performance through predictive control and adaptive management strategies. The paper [9] investigated the application of machine learning algorithms for predictive control of hydroponic systems, demonstrating their effectiveness in optimizing nutrient delivery and maximizing yields. The design and optimization of nutrient delivery systems play a crucial role in ensuring optimal nutrient uptake by plants and maximizing crop productivity. The work in [10] focused on the design and optimization of nutrient delivery systems for hydroponic agriculture, contributing to improved nutrient efficiency and crop performance. Hydroponic systems represent a cutting-edge approach to agricultural cultivation, offering numerous advantages in terms of resource efficiency, crop yield, and environmental sustainability. Our hydroponics project is informed by a rich body of literature that showcases the diverse array of technologies and methodologies driving innovation in this field.

The work in [11] underscores the importance of affordability and accessibility in hydroponic systems, particularly for small-scale and resource-limited growers. The work in [12] highlights the transformative potential of IoT and Arduino-based solutions in revolutionizing hydroponic agriculture. These smart monitoring and control systems leverage the power of connectivity and data analytics to optimize growing conditions, minimize resource wastage, and maximize crop yield. Similarly, the work in [13] demonstrates the versatility and adaptability of Arduino-based IoT monitoring systems in precision agriculture applications, further expanding the scope of hydroponic cultivation technologies. The work in [14] explores the integration of IoT technology in indoor hydroponic systems, advancing the field of precision agriculture. By enabling real-time monitoring of environmental parameters and nutrient levels, these systems empower growers to make data-driven decisions to ensure optimal plant growth and health. Furthermore, the use of renewable energy sources, as demonstrated by [15] holds promise for enhancing the sustainability of hydroponic farming practices, reducing reliance on fossil fuels, and mitigating environmental impact.

Incorporating machine learning techniques into hydroponic systems, as investigated by [16] opens new avenues for automation and predictive control. By leveraging historical data and advanced analytics, these systems can anticipate plant needs, optimize resource allocation, and proactively mitigate potential risks, ultimately enhancing overall system efficiency and productivity. Moreover, research focusing on low-cost monitoring systems and wireless sensor networks addresses the need for scalable and adaptable solutions in hydroponic agriculture. These technologies facilitate real-time data collection, analysis, and decision-making, empowering growers to optimize growing conditions and maximize yield while minimizing operational costs and environmental impact. In parallel, studies on nutrient delivery system optimization and the application of machine learning algorithms for predictive control [17] provide valuable insights into improving nutrient management and system automation. By fine-tuning nutrient delivery protocols and leveraging predictive analytics, growers can optimize plant nutrition, minimize waste, and achieve consistent and high-quality crop production [18, 19]. From the above kinds of literature, the dynamic and interdisciplinary nature of hydroponic agriculture. By integrating insights from diverse research domains, our hydroponics project aims to contribute to the ongoing dialogue and innovation in this field, ultimately driving toward more sustainable, efficient, and resilient agricultural systems for the future.

Considering these developments, this thesis aims to contribute to the evolving field of smart hydroponics systems by designing, developing, and implementing a solar-powered hydroponic system equipped with remote monitoring and control capabilities. Drawing inspiration from the aforementioned research endeavors, our system seeks to integrate renewable energy sources, advanced sensor technology, and IoT connectivity to create an efficient, sustainable, and user-friendly solution for hydroponic cultivation. Through the exploration of emerging technologies and innovative approaches, this thesis endeavors to advance the state-of-the-art in hydroponic agriculture, paving the way for more efficient, resource-conscious, and resilient food production systems.

II. Overview Of Integrating Technology For Smart Agriculture

In hydroponics, a system is established where an ESP32 module serves as the central component for data acquisition and control. This module is connected to various sensors on one side and to a relay module and buzzer on the other side. The prototype system is designed for hydroponic cultivation and operates primarily on the ESP32 module. It is integrated with an LCD display to visualize the process, a 5V buzzer, and multiple sensors including a flame sensor, temperature sensor, and gas sensor. Additionally, a 2-channel relay module is incorporated, which is connected to water and CO_2 pumps. The functionality of this hydroponic system can be monitored remotely from any location using Blynk software. Through the software, users can access real-time data and monitor the surroundings, enabling efficient management of the hydroponic environment.

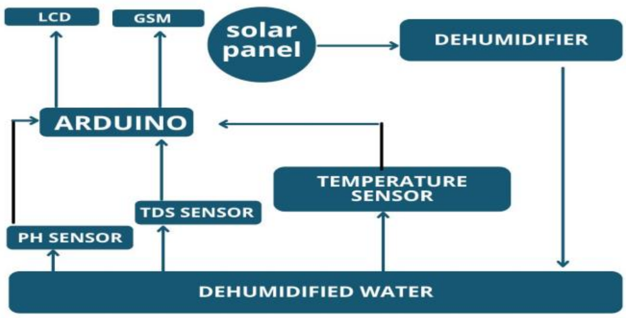
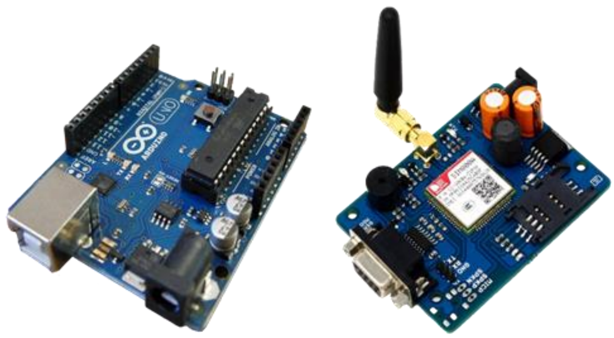


Fig. 1. Block Diagram of Solar Powered Dehumidifier Smart Hydroponics system

The block diagram of the solar powered de-humidifier smart hydroponics system is shown in Fig. 1. The basic components of the hydroponic system can be explained below:

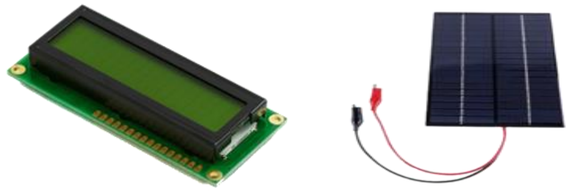
A. Arduino: A microcontroller platform used for building digital devices and interactive objects. It serves as the brain of electronic projects, controlling inputs and outputs.

- **B. GSM**: Global System for Mobile Communication. A communication module used to establish cellular connectivity, enabling devices to send and receive data via mobile networks. The Arduino board and GSM module are shown in Fig. 2(a) and 2(b), respectively.
- **C. LCD**: Liquid Crystal Display. A flat-panel display commonly used in electronic devices to present alphanumeric characters or graphical information in a visual format.
- **D. Solar Panel**: Provides electrical energy to operate electronic devices. It converts input solar radiation into required voltage and current levels for powering the components like Dehumidifier and other electronics mentioned. The LCD module and solar panel are shown in Fig. 3(a) and 3(b), respectively.
- **E. TDS Sensor**: Total Dissolved Solids Sensor. Measures the concentration of dissolved solids in water, indicating its purity or contamination level.
- **F. Temperature Sensor**: Detects and measures the temperature of its surroundings. Common types include thermistors, thermocouples, and digital temperature sensors like the DS18B20. The TDS sensor and temperature sensor are shown in Fig. 4(a) and 4(b), respectively.
- **G. pH Sensor**: Measures the acidity or alkalinity of a solution. pH sensors are crucial in hydroponic systems for monitoring and controlling the pH level of nutrient solutions to ensure optimal plant growth. Dehumidifier: Dehumidifier serves as a crucial water source by extracting moisture from the air and condensing it into liquid water. This water can then be utilized for various purposes, such as watering plants in hydroponics farming or supplying clean water for other applications. The dehumidifier's role is to efficiently remove excess moisture from the environment, providing a convenient and reliable source of water that can contribute to the project's success.
- **H. Dehumidifier**: The dehumidifier serves as a crucial component in moisture control systems, extracting excess moisture from the air and condensing it into liquid water for various applications. By reducing humidity levels in indoor environments, dehumidifiers prevent mold and mildew growth, improve air quality, and create a more comfortable living or working space. In hydroponic farming, dehumidifiers serve as a reliable source of clean water by extracting moisture from the air and converting it into usable liquid water for watering plants or supplying nutrient solutions. With their efficient moisture removal capabilities and user-friendly operation, dehumidifiers play a vital role in maintaining optimal growing conditions in hydroponic systems, contributing to higher yields, healthier plants, and overall project success. The pH sensor and De-humidifier are shown in Fig. 5(a) and 5(b), respectively.
- **I. Arduino IDE**: The Arduino IDE is a user-friendly software used to write, compile, and upload code to Arduino microcontroller boards. It provides a simple interface for programming projects, supports multiple programming languages, and offers a library of pre-written code examples. With its easy-to-use features, it's ideal for beginners and professionals alike in creating a variety of electronic projects.
- **J. Embedded C:** Embedded C is a specialized version of the C programming language designed for programming embedded systems. It prioritizes efficient resource usage and direct hardware control, making it ideal for developing firmware for microcontrollers and other embedded devices.



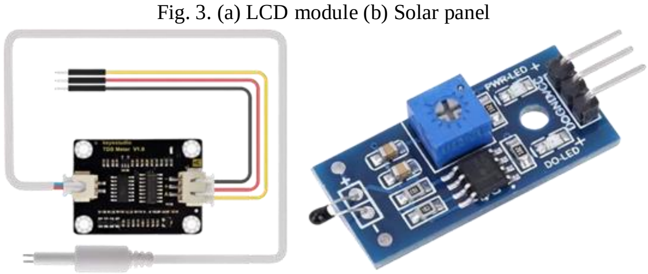
(a) (b)

Fig. 2. (a) Arduino board (b) GSM module



(a) (b)

Fig. 3. (a) LCD module (b) Solar panel



(a) (b)

Fig. 4. (a) TDS sensor (b) Temperature sensor

(a) (b)

Fig. 5. (a) pH sensor (b) De-humidifier

III. Methodology

Component Selection and Integration: Based on the identified requirements and insights from the literature review, select appropriate hardware components such as Arduino microcontrollers, sensors (pH, temperature, TDS), GSM modules, LCD displays, solar panels, and dehumidifiers. Ensure compatibility and integration of these components to achieve the desired functionalities.

In the process of component selection and integration for designing a solar-powered smart hydroponic system with remote monitoring and control capabilities, careful consideration of identified requirements and insights from the literature review is paramount. This involves selecting appropriate hardware components such as Arduino microcontrollers, sensors (pH, temperature, TDS), GSM modules, LCD displays, solar panels, and dehumidifiers, ensuring compatibility and seamless integration to achieve the desired functionalities.

The selection of Arduino microcontrollers involves choosing a model that offers sufficient processing power and input/output capabilities to interface with sensors and actuators effectively. Factors such as the number of digital and analog pins, communication interfaces (e.g., UART, SPI, I2C), and programming flexibility are considered to ensure compatibility with the chosen sensors and communication modules. For sensors, including pH, temperature, and TDS sensors, the focus is on selecting high-precision and reliable sensors that can accurately measure key parameters in the hydroponic environment. Compatibility with the Arduino microcontroller and availability of calibration options are essential factors to consider when choosing sensors to ensure accurate and consistent measurements.

GSM modules are selected based on factors such as network compatibility, data transmission rates, and power consumption. The chosen module should support the required communication protocols for sending and receiving data from remote locations, enabling real- time monitoring and control of the hydroponic system. LCD displays are chosen based on factors such as size, resolution, and interface compatibility with the Arduino microcontroller. The display should provide clear and legible information about system status, sensor readings, and user prompts, facilitating easy operation and troubleshooting for end-users.

Solar panels are selected based on factors such as wattage, efficiency, and physical dimensions. The chosen panels should generate sufficient power to meet the energy requirements of the hydroponic system, taking into account factors such as daily sunlight exposure and energy consumption of individual components. Dehumidifiers are selected based on factors such as capacity, energy efficiency, and compatibility with the hydroponic system. The chosen dehumidifier should effectively regulate humidity levels in the environment, ensuring optimal conditions for plant growth and preventing moisture-related issues such as mold and mildew.

Overall, the selection and integration of hardware components involve a meticulous assessment of compatibility, functionality, and performance to ensure the seamless operation of the solar-powered smart hydroponic system. By carefully evaluating each component based on identified requirements and insights from the literature review, researchers can design a robust and efficient system that meets the needs of growers while leveraging the latest advancements in technology.

System Architecture Design: Develop a high-level system architecture design that outlines the interactions between the hardware components, data flow, control mechanisms, and communication protocols. Define how sensor data will be collected, processed, and communicated for remote monitoring and control.

In the system architecture design phase of developing a solar-powered smart hydroponic system with remote monitoring and control capabilities, a high-level overview of the system's structure and functionality is essential. This design outlines the interactions between hardware components, data flow, control mechanisms, and communication protocols, defining how sensor data will be collected, processed, and communicated for remote monitoring and control.

At the core of the system architecture is the Arduino microcontroller, serving as the central processing unit responsible for interfacing with sensors, controlling actuators, and facilitating communication with external devices. The microcontroller interacts with a variety of sensors, including pH, temperature, and TDS sensors, to collect real-time data on key environmental parameters within the hydroponic environment. Sensor data is collected by the Arduino microcontroller through analog or digital interfaces, depending on the type of sensor used. The microcontroller processes the raw sensor data using programmed algorithms to perform tasks such as calibration, filtering, and normalization, ensuring accurate and reliable measurements of environmental variables.

In addition to data collection and display, the system architecture incorporates control mechanisms to adjust environmental variables based on predefined setpoints or user commands. This includes activating actuators such as water pumps, nutrient dosing systems, or ventilation fans to maintain optimal growing conditions within the hydroponic environment. Overall, the system architecture design outlines the flow of data and control within the solar-powered smart hydroponic system, ensuring seamless interaction between hardware components, efficient processing of sensor data, and reliable communication for remote monitoring and control. By defining clear interactions and protocols, the architecture design lays the foundation for the development and implementation of a robust and efficient hydroponic cultivation system.

Prototype Development: Build a prototype of the solar-powered smart hydroponic system based on the designed architecture. Assemble the selected hardware components, write necessary code for sensor data acquisition, processing, and control logic using Arduino IDE or similar platforms. In the prototype development phase of the solar-powered smart hydroponic system, the focus is on building a functional prototype based on the designed architecture. This involves assembling the selected hardware components and writing the necessary code for sensor data acquisition, processing, and control logic using Arduino IDE or similar platforms.

Sensor data acquisition is implemented using analog or digital input pins on the Arduino microcontroller, depending on the type of sensor used. Raw sensor data is read at regular intervals and processed using programmed algorithms to perform tasks such as calibration, filtering, and normalization. Processed sensor data is then transmitted to external devices or remote servers for monitoring and analysis via GSM modules or other communication interfaces. Control logic is implemented to adjust environmental variables within the hydroponic system based on predefined setpoints or user commands. This involves activating actuators such as water pumps, nutrient dosing systems, or ventilation fans to maintain optimal growing conditions. Control algorithms may incorporate feedback mechanisms to dynamically adjust system parameters in response to changing environmental conditions or user inputs.

Throughout the prototype development process, thorough testing and debugging are conducted to ensure the reliability, functionality, and performance of the solar-powered smart hydroponic system. This involves validating sensor readings, verifying control logic, and troubleshooting any issues or inconsistencies encountered during testing. By building a functional prototype based on the designed architecture and implementing the necessary hardware and software components, researchers can validate the feasibility and effectiveness of the proposed system design. The prototype serves as a proof-of-concept demonstration, showcasing the integration of renewable energy sources, advanced sensor technologies, and remote monitoring capabilities in a real-world hydroponic cultivation environment. Fig. 6 shows the architecture of the proposed system.

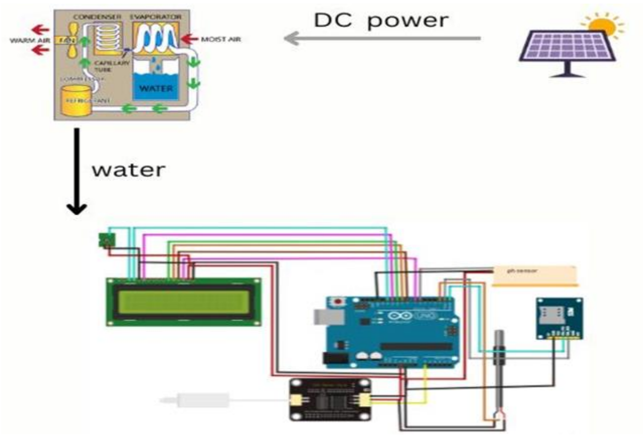


Fig. 6. Architecture of the Smart Hydroponics system

IV. ANALYSIS AND DISCUSSION

The primary goal of this research is to design, implement, and evaluate an Arduino-monitored hydroponics system integrated with a solar-powered dehumidifier. By combining advanced monitoring technology with renewable energy sources, the aim is to develop a sustainable and efficient solution for indoor agriculture that optimizes plant growth, conserves resources, and reduces environmental impact.

The system working flow can be briefed as follows. The model can be pictured as three different levels comprising the data acquisition level, control level and the output or display level. The data acquisition level consists of multiple sensors viz., pH sensor, temperature sensor, TDS sensor; the controlling level consists of Arduino board which will act as the heart of the project; and the display level consists of LCD screen to display the levels obtained from sensors like pH and temperature and GSM module which transmits the data to a selected mobile phone via SMS in case of abnormalities. The data fetched from the sensors are continuously monitored by Arduino and displayed on the LCD screen. When the readings of temperature or humidity or pH exceed or precede the normal levels a buzzer is set off and an alert is sent to the owner' phone as an SMS indicating the levels by the help of GSM module. This process is continuous and helps foster algorithms to automate framework activity in light of predefined setpoints and environmental circumstances. This idea also empowers remote monitoring and control capacities to work with the executives and change of framework boundaries. The experimental setup diagram is shown in Fig. 7.

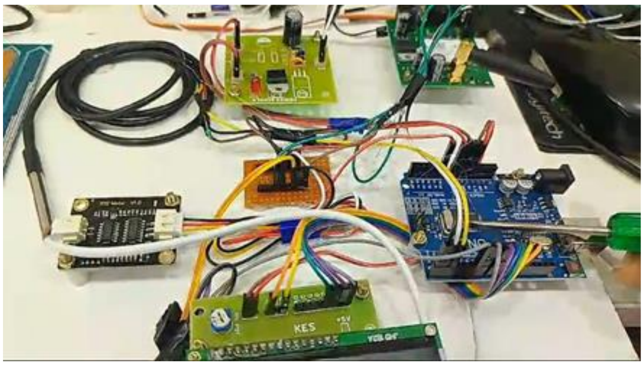
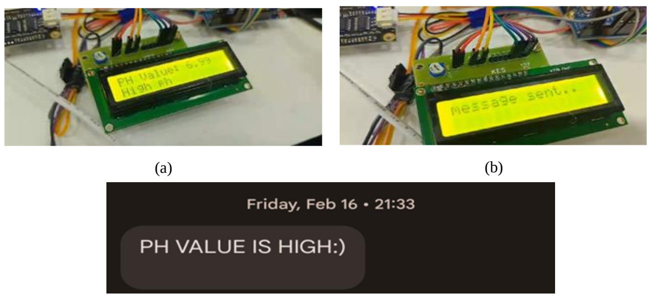


Fig. 7. Experimental setup

The model has been tested out on field under different conditions to obtain real time work results to determine its efficiency in the terms of remote sensing. In this work, authors considered three different case studies as explained below

Case-1 (High pH value): The first sample tested has a high pH level. The value is detected to be abnormal and displayed an alert on LCD screen. An SMS is sent to the owner mobile indicating the abnormality. When the pH reading of water exceeds or precedes its normal range it gains an acidic or basic nature for itself which we call hardwater. Hard water is not suitable for plant growth in return it suppresses the reproductive health of plant. The results of this case study as shown in Fig. 8.

Case-2 (High Temperature): The second sample tested has a high temperature. The control flow is programmed to pass an alert for Temp. >32^0. An alert on LCD screen was displayed and SMS is sent to the owner mobile indicating the abnormality. The results of this case study as shown in Fig. 9.



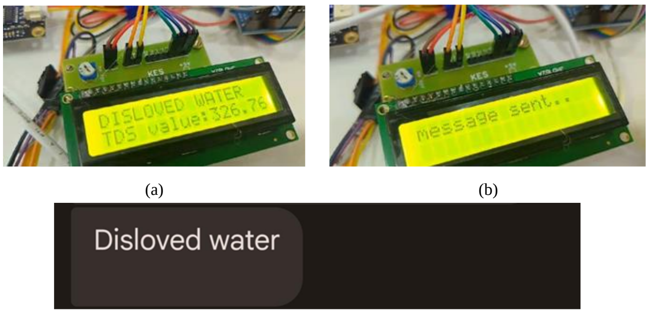
(a) (b) (c)

Fig. 8. (a) LCD output 1 (b) LCD output 2 (c) SMS output CASE 1

(a) (b) (c)

Fig. 9. (a) LCD output 1 (b) LCD output 2 (c) SMS output CASE 2

Case-3 (Dissolved Water): The sensor has detected dissolved impurities in the third sample shooting up the TDS value. An alert on LCD screen was displayed indicating dissolved water and the TDS value of the sample and SMS is sent to the owner mobile indicating the abnormality. The results of this case study as shown in Fig. 10.



(a) (b) (c)

Fig. 10. (a) LCD output 1 (b) LCD output 2 (c) SMS output CASE 3

V. Conclusion

In conclusion, the Hydro Growth system represents a significant advancement in hydroponic farming technology, offering a sustainable solution for addressing water scarcity in agriculture, especially in arid regions. By integrating Arduino microcontroller technology, mobile applications, and solar panel power sources, the system enables real-time monitoring and control of crucial environmental parameters essential for optimal plant growth. The implementation of solar-powered dehumidifiers as a fresh water source for hydroponics reduces reliance on conventional energy sources and minimizes environmental impact. This not only enhances the system's sustainability but also contributes to cost savings for growers.

Through rigorous experimentation and evaluation, the Hydro Growth system has demonstrated its effectiveness in improving crop yield, growth rate, water usage efficiency, and energy consumption. Additionally, the system's scalability and adaptability allow for customization to accommodate different plant species, cultivation environments, and operational requirements. Overall, the Hydro Growth system showcases the feasibility and effectiveness of integrating advanced technologies into hydroponic farming, paving the way for enhanced sustainability and efficiency in agriculture practices. It represents a significant contribution to the advancement of smart farming practices and environmental stewardship, with the potential to revolutionize indoor agriculture in water-scarce regions.

References

[1] S. J. Hong, H. Kim, and S. H. Han, “Development of a Low-Cost Monitoring System for Hydroponic Cultivation,” *IEEE Sensors Journal*, vol. 19, no. 14, pp. 5640-5647, Jul. 2019.

[2] M. A. M. Reda, M. M. Samy, and M. E. Hassanien, “Smart Monitoring and Control System for Hydroponic Greenhouses Using IoT and Arduino,” *IEEE Internet of Things Journal*, vol. 8, no. 7, pp. 5622-5631, Apr. 2021.

[3] N. R. Urena, C. A. Cuervo, and S. Garcia, “Development of an Arduino-Based IoT Monitoring System for Precision Agriculture Applications,” *IEEE Access*, vol. 8, pp. 150628-150637, Aug. 2020.

[4] G. Vikash, D. Funde, and A. Ghosh, “Implementation of the Virtual Synchronous Machine in Grid-Connected and Stand-alone Mode,” *DC—DC Converters for Future Renewable Energy Systems*, Springer, Singapore, pp. 335-353, Jan. 2022.

[5] G. Vikash, A. Anand, and A. Ghosh, “A New Hybrid Islanding Detection Technique for Microgrid Using Virtual Synchronous Machine,” *Advanced Power Electronics Converters for Future Renewable Energy Systems*, CRC Press, Taylor & Francis Group, Feb. 2023.

[6] J. K. Nayak, G. Vikash, and A. Ghosh, “Design and Control of Bidirectional SEPIC/Zeta Converter,” *Advanced Power Electronics Converters for Future Renewable Energy Systems*, CRC Press, Taylor & Francis Group, Feb. 2023.

[7] C. R. Ananthraj, G. Vikash, and A. Ghosh, “Modelling a Battery and SOC Calculation Using Coulomb Counting Technique and Simulation of Equalising Techniques Used in Battery Management Systems,” *Advanced Power Electronics Converters for Future Renewable Energy Systems*, CRC Press, Taylor & Francis Group, Feb. 2023.

[8] V. Gurugubelli, A. Ghosh, and A. K. Panda, “Droop controlled voltage source converter with different classical controllers in voltage control loop,” In 2022 IEEE International Conference on Power Electronics, Smart Grid, and Renewable Energy (PESGRE), pp. 1-6, Jan. 2022.

[9] V. Gurugubelli, A. Ghosh, and A. K. Panda, “Design of different classical controllers in the voltage control loop of a virtual synchronous machine in standalone mode,” In 2022 IEEE International Conference on Power Electronics, Smart Grid, and Renewable Energy (PESGRE), pp. 1-6, Jan. 2022.

[10] V. Gurugubelli, A. Ghosh, and A. K. Panda, “Different Oscillator Controlled Parallel Three-Phase Inverters in Standalone Microgrid,” In *Sustainable Energy and Technological Advancements: Proceedings of ISSETA 2021*, Springer Singapore, pp. 67-79, Mar. 2022.

[11] B. Sujith, A. Ghosh, and V. Gurugubelli, “Design of PFC Boost Converter with Stand-Alone Inverter for Microgrid Applications,” In 2022 IEEE Delhi Section Conference (DELCON), pp. 1-5, Feb. 2022.

[12] S. Dora, V. Gurugubelli, A. Ghosh, and A. K. Panda, “Parallel operation of inverters by using Model Predictive Control in Islanded Microgrid,” In 2022 IEEE 10th Power India International Conference (PIICON), pp. 1-6, Nov. 2022.

[13] P. K. Mahapatra, S. K. Gudla, V. Gurugubelli, A. Ghosh, and A. K. Panda, “Fuzzy Adaptive Droop Controlled Parallel Inverters for Microgrid Applications,” In *2022 IEEE 10th Power India International Conference (PIICON)*, pp. 1-6, Nov. 2022.

[14] V. Gurugubelli, A. Ghosh, A. K. Panda, P. K. Ray, and I. Sarkar, “Synchronization of Single-Phase Inverters using Deadzone and Hopf Oscillator based Controllers in Standalone Microgrid,” In 2023 IEEE IAS Global Conference on Renewable Energy and Hydrogen Technologies (GlobConHT), pp. 1-6, Mar. 2023.

[15] T. E. Rao, S. Elango and G. G. Swamy, “Power Management Strategy Between PV-Wind-fuel Hybrid System,” *2021 7th International Conference on Electrical Energy Systems (ICEES)*, Chennai, India, pp. 101-107, Feb 2021.

[16] T. E. Rao, E. Sundaram, S. Chenniappan, D. Almakhles, U. Subramaniam, and M. S. Bhaskar, “Performance Improvement of Grid Interfaced Hybrid System Using Distributed Power Flow Controller Optimization Techniques,” *IEEE Access*, vol. 10, pp. 12742-12752, Jan. 2022.

[17] T.Eswararao, S.Elango, U.Subramanian, K.Tatikonda, G. Gantaiahswamy, and S. Chenniappan, “Real-Time Implementation and Performance Analysis of Supercapacitor for Energy Storage,” Artificial Intelligence-based Smart Power Systems, pp. 115-127, Jan. 2023.

[18] T. E. Rao, B. Naidu, J. Ankamma Rao, G. T. Zelie, K. Avinash and M. Srisuresh, "Soft Computing Based Hybrid MPPT for Grid Connected Photovoltaic System," 2024 International Conference on Electronics, Computing, Communication and Control Technology (ICECCC), Bengaluru, India, pp. 1-6, 2024.

[19] T. E. Rao, P. Guruvulunaidu, S. R. Sura, V. N. Pudi, S. Karra and K. M. Tatikonda, "Implementation of MPPT Techniques to Improve the Reliability of PV-WIND Hybrid System," 2023 International Conference on Computational Intelligence, Networks and Security (ICCINS), Mylavaram, India, pp. 1-6, 2023.