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HYPOSENSE: AN INTEGRATED SENSOR DEVICE FOR HYDROPONICS FARM MONITORING

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ABSTRACT

In recent years, the monitoring of hydroponics farms has undergone a significant transformation due to the integration of sensors. However, the conventional method of manually observing measurements from multiple sensors has proven to be excessively time-consuming and costly. Additionally, the lack of automatic data recording options in most sensors has been a limiting factor. To address these challenges, we conducted an experimental study to introduce a novel integrated sensor device named "HypoSense", designed to monitor essential parameters such as temperature, humidity, pH, light intensity, Total Dissolved Solids (TDS), and Electrical Conductivity (EC) in hydroponic systems. HypoSense consists of three microcontroller units (MCUs) incorporated with two controlling circuits based on the Arduino platform: the Arduino UNO, ESP32, and the ESP8266 (NodeMCU) microcontrollers. The device is designed using high-precision sensors, including the DHT11 for temperature and humidity monitoring, an Analog pH sensor kit for pH measurement, BH1750 for light intensity, and an Analog TDS sensor kit for TDS and electrical conductivity measurements. These sensors were chosen for their reliability, accuracy, and compatibility with the Arduino platform, ensuring that HypoSense delivers precise and consistent readings. HypoSense is a cost-effective, portable sensor device specially designed for monitoring growth parameters simultaneously in hydroponic farming, saving growers time and effort. The evaluation was carried out in two phases. Firstly, field sensors were employed to calibrate HypoSense device sensors. Next, a secondary evaluation was conducted to confirm the practicality and user-friendliness of the HypoSense device. To facilitate the evaluation of HypoSense, we set up an indoor hydroponic system for growing tomatoes and lettuce. The results of these evaluations, focusing on the performance and applicability of the HypoSense device, will provide valuable insights for hydroponic growers and future researchers in precision agriculture.

KEYWORDS: *Hydroponics Cultivation, Internet of Things, Sensors, Growth Parameter Monitoring*

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1. INTRODUCTION

Hydroponics is an advanced technique for cultivating plants using water-based solutions instead of soil. It has gained popularity as an efficient and ecological method of agriculture because it enables sustainable and efficient crop production (Khan, 2018). Plants in hydroponic systems get all of their nutrients and water from a specific nutrient solution, and their roots are supported by inert materials like perlite, rock wool, or coconut fiber (Sardare, 2013). Hydroponics offers advantages over soil-based agriculture, such as lower water usage, greater control over plant growth conditions, and higher crop yields (Resh, 2022). Furthermore, hydroponic systems can be used in a variety of settings, including urban areas where traditional agriculture may be limited (RufíSalís et al., 2020). Several environmental factors such as pH, Electrical Conductivity (EC), Total Dissolved Solid (TDS), Temperature, Humidity, and Light Intensity must be monitored and controlled to maintain optimal plant growth and healthy plant conditions in hydroponic systems (Tagle et al., 2018). Failure to maintain optimal conditions can harm plant growth, cause nutrient deficiencies, and lead to plant death (Jones Jr, 2004).

Monitoring and maintaining optimal conditions in a hydroponic system can be challenging for small-scale individual growers. This is because they need to constantly check various parameters using separate, expensive devices regularly. Additionally, these devices do not have a built-in feature to store data after measurements are taken, so growers have to manually observe and record all the measurement data daily, which is a highly time-consuming process.

To address these limitations, we have designed and developed an innovative solution: HypoSense, an affordable, sensor-integrated, portable, and IoT-enabled device. This operates as an IoT-based multisensory system that is specifically designed for collecting data from hydroponic farming. The sensors used in this device allow simultaneous monitoring of all relevant parameters, and the collected data, along with the date and time, can be transmitted wirelessly and stored in a cloud.

Hence in this paper, we present HypoSense as a practical remedy to overcome the above challenges in hydroponic farming. HypoSense is a portable sensor device specially designed for monitoring growth parameters simultaneously in hydroponics farming. It is a cost-effective device that saves growers time and effort when compared to state-of-the-art devices available in the existing research.

The paper is structured as follows: In Section 2, we provide an overview of the current state-of-the-art IoT sensor-based research on hydroponics farming. Section 3 focuses on the development and design of the HypoSense device. We then discuss the evaluations we conducted on the HypoSense device in Section 4. Finally, in Section 5, we summarize our research findings, highlight the limitations of our study, and suggest directions for future research.

2. RELATED WORK

Over the last decade, hydroponic farming has greatly benefited from Internet of Things (IoT) technology. This technology has been utilized in large-scale hydroponics farms to monitor parameters such as pH, EC, light intensity, temperature, and humidity (Mehra et al., 2018), (Saha, 2021). IoT-driven hydroponics enables the remote surveillance and control of real-time system parameters, thereby facilitating decision-making capabilities through user-friendly interfaces (Lakshmanan et al., 2020).

Domingues et al. (2012), introduced an automated system for controlling pH and nutrient solution concentration, which was assessed in hydroponic lettuce production. This system enables continuous monitoring of pH and nutrient solution concentration 24 hours a day throughout the entire production cycle. Any variations can be automatically and instantly adjusted, resulting in increased productivity and the preservation of the nutritional quality of the product. The authors described the system as a fixed automated solution; however, they did not disclose pertinent details such as the financial investment and the electricity consumption required for continuous 24-hour operation within a greenhouse.

M. Fuangthong and P. Pramokchon, (2018) explored the use of fuzzy logic for the automatic control of electrical conductivity and pH in hydroponic systems to reduce resource waste. While their research demonstrated the potential for improved control and precision, it faced several limitations. The study was constrained by the specific parameters and conditions under which it was conducted, potentially limiting the generalizability of the results to different hydroponic setups or crop types. Additionally, the implementation complexity and the need for specialized knowledge to fine-tune the fuzzy logic system are challenging for growers with varying levels of technical expertise. Moreover, the study did not extensively address the long-term reliability and maintenance requirements of the control system, which are critical factors for practical deployment in real-world farming scenarios. Recently, Chowdhury, et al. (2020) introduced an IoT-based automated vertical hydroponics indoor farming system in Qatar, highlighting advancements in automated agriculture. Notably, their system is independent of outside climate variations, and as a result of IoT, they can automate labor-intensive hydroponics farm maintenance tasks. However, the system scalability was not extensively tested, potentially limiting its application to large-scale operations. The setup lacks portability and requires substantially fixed and extra additional space. Additionally, the study did not deeply explore the long-term economic viability or the environmental impact of the system. The specific environmental conditions of Qatar may also limit the generalizability of the findings to other regions with different climates.

Additionally, the study conducted by Patil et al. (2020) proposed and designed an automated system that monitors various parameters of hydroponic systems. This system uses sensor-derived data to provide real-time access to the hydroponic system via a mobile application in order to monitor and enhance crop yield. The solution, however, lacks portability and requires a substantial amount of space for the setup.

H. Andrianto, Suhardi and A. Faizal, (2020) introduced a smart greenhouse system for hydroponics agriculture to measure temperature, humidity, TDS, pH, and light conditions. Moreover, they develop a mobile application that controls the IoT modules, to regulate the aforementioned measurement factors and facilitate optimal growth conditions for the plants. Further, Tatas et al. (2022) proposed a low-cost and low-power IoT-based system to control and monitor water quality, greenhouse temperature, and humidity in hydroponics farms. In addition to that they have used an inference engine to investigate the behavior of the plant irrigation. The authors have introduced both of these systems as low-cost IoT-based control and monitoring solutions for greenhouse hydroponics systems. However, the study lacks information regarding the incurred costs associated with the development, making it difficult to understand the total financial investment required. Moreover, the long-term feasibility, sustainability, and practicality of the solution in real-world applications are not clear.

The existing studies have explored the application of IoT in monitoring and controlling hydroponics systems' growth parameters, such as temperature, humidity, pH, TDS, and EC levels. However, there is a visible gap in the current state-of-the-art solutions. Many studies have not highlighted the cost incurred for setting up the IoT System. Hence it is required to emphasize cost-effective hardware development for creating a comprehensive solution capable of efficiently managing multiple parameters to drive actionable decisions in hydroponics farming. These solutions are fixed, lacking portability and handheld functionality, which restricts their flexibility and adaptability.

Small-scale hydroponic growers are less interested in investing a high cost in infrastructure. On the other hand, indoor growers do not prefer rigid setups because of space constraints. These setups cannot be easily moved or reconfigured, making it difficult to adapt to different growing conditions or experiment with new setups. Moreover, setting up a fixed IoT system for monitoring parameters can be complex and time-consuming, requiring specialized skills and knowledge that small-scale growers might lack. Therefore, small-scale hydroponic growers require cost-effective, portable, and handheld solutions to collect, store, and process multiple parameters simultaneously.

3. METHODOLOGY

In this research, we employed an ethnographic research methodology to understand the needs of hydroponic growers. We continuously observed daily operations, interactions, and challenges within hydroponics farming. The holistic understanding of the issues related to hydroponic farm monitoring was done through participant observation and in-depth interviews with domain experts. After analyzing expert knowledge and existing research, we developed a prototype to simplify hydroponic farm monitoring and reduce daily data collection issues.

In hydroponic farming, numerous growth parameters are required to ensure optimal nutrition levels and environmental conditions. The pH, TDS, EC of the nutrient solution, the lighting condition for photosynthesis, temperature, and humidity of the environment are to name a few essential parameters in Hydroponic cultivation. Hence, in designing HypoSense, we considered the aforementioned parameters and further explored the best sensor modules for accurate measurement of the parameters. Individual sensor modules were selected with the consultation of the field experts analyzing the cost to cater towards the cost-effectiveness of the designed solution. Iterative design strategies were employed throughout the design and development of the HypoSense device. The design was refined throughout the iterations to ensure the device's compactness and portability. We conducted frequent field trials and the feedback received through such trials was incorporated to enhance the user-friendliness of the device.

Software and Hardware Infrastructure

The device's control circuit was designed, incorporating advanced microcontrollers such as ESP8266 (NodeMCU), ESP32, and Arduino (UNO) to fulfill the needs of the hydroponic growers. To ensure compatibility with the main circuit, only Arduino-based sensors were utilized for collecting growth parameter data. Specifically, a BH1750 (GY-30) digital light intensity sensor and a DHT11 sensor were used for measuring environmental temperature, and humidity. Additionally, an Arduino-compatible Gravity Analog pH sensor and the Gravity Analog TDS sensor were utilized to measure the pH level, TDS, and EC values of the nutrition solution. Table 1 provides a summary and cost overview of the aforementioned hardware equipment. All prices are quoted for the year 2022/2023.

Table 1: Hardware Equipment used in HypoSense

Hardware equipment	Purpose	Price (USD)
Arduino (UNO)	Data collection and processing	8.52
ESP8266 (NodeMCU) and ESP32	Wireless communication to transfer data to the cloud	10.04
BH1750 (GY-30)	Measure light intensity	1.51
DHT11	Measure Temperature and Humidity	1.00
Gravity Analog pH sensor	Measure pH level	12.71
Gravity Analog TDS sensor	Measure TDS and EC values	10.70

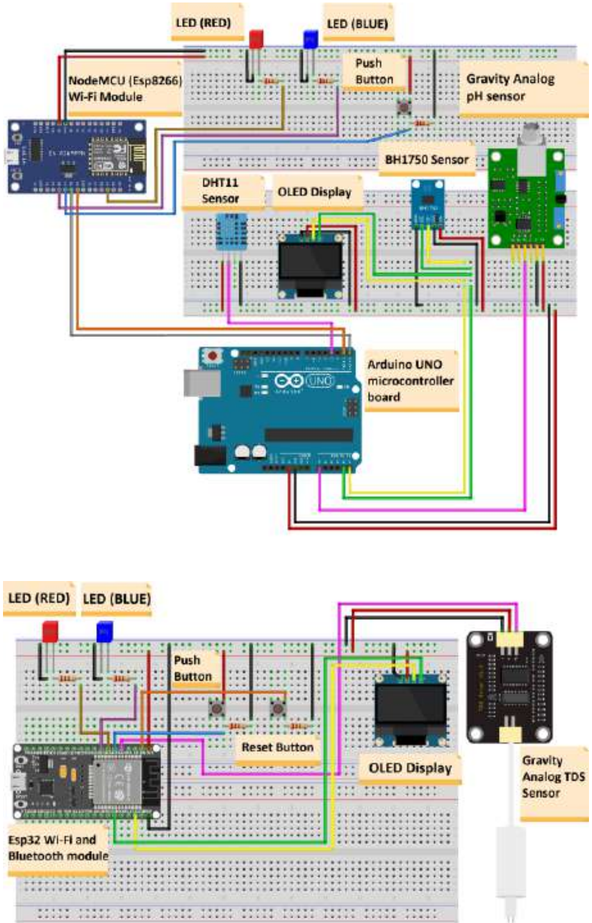

Figure 1: Circuit Diagram of HypoSense

Figure 1, provides a comprehensive visualization of the circuit diagrams employed in the development of the HypoSense device. It depicts the interconnection between the components in the structural design. We have conducted several field trials while designing the model. Measurements were obtained from the sensors to ensure the operational feasibility. Subsequent trials revealed an operational conflict between the pH and TDS sensors when measured simultaneously. In instances where the TDS probe and the pH sensor were immersed in the same nutrient solution, the pH sensor readings were observed to be unusually high. This phenomenon was attributed to the electronic pulses delivered to the nutrient solution by the TDS sensor during its operation.

The integrity of the system structure was improved to address the issues encountered. We have reassessed the sensor integration by conducting different operational protocols. We have come up with multiple designs, and the optimal one, prioritizing compactness and incorporating all refinements to ensure portability, was selected for the implementation of the device.

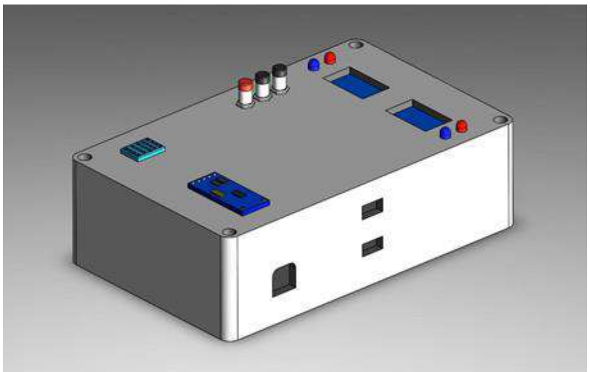

Figure 2: Three-Dimensional Visualization Model: Detailed Representation

Figure 2 shows the user visual representation of the detailed Three-Dimensional (3D) model designed to compact the circuit above. The 3D model visualizes the design elements, dimensions, and spatial relationships of the individual components, providing a comprehensive virtual rendering of the device's physical structure. We have designed several ports to facilitate the plug-and-play functionality of the sensors. Three control buttons were placed to control the data handling and data transfer. During the design phase, several research students were given a working model to measure parameters and transfer data. We observed their operation procedures to enhance the design. An OLED Display was used to display the multiple sensory values measured through sensors. The final alignment of elements was determined based on the practical working model of the solution and the ease of use of the device.

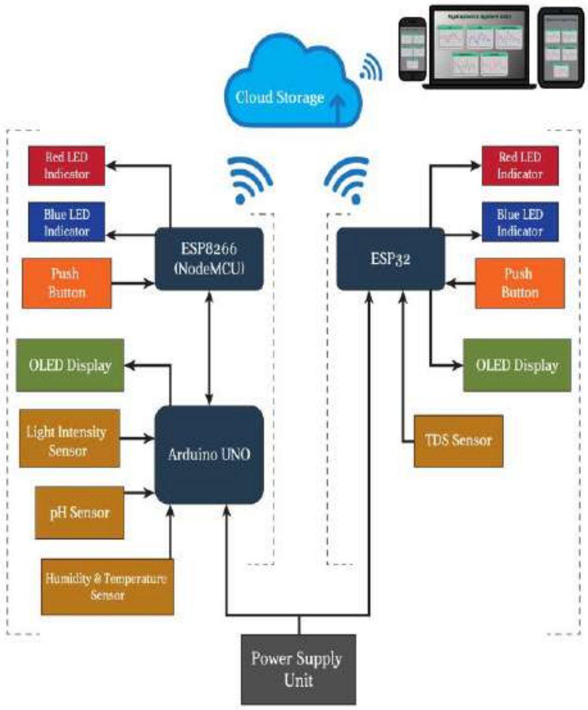

Figure 3: System Architectural Flow Model

The enhanced system architectural flow model of the HypoSense device is depicted in Figure 3. It visualizes the different components and their interaction. The collected data will be transferred to the cloud for further processing. The data stored in the cloud will be displayed to the user via a mobile application.

The final functional prototype of the HypoSense device implemented integrating the sensors is illustrated in Figure 4.The device was also designed with a portable battery to facilitate efficient data gathering over extended periods. Hence, the device is self-sufficient, making it highly portable as it doesn't rely on external power sources.

Figure 4: Final Functional Prototype of the HypoSense

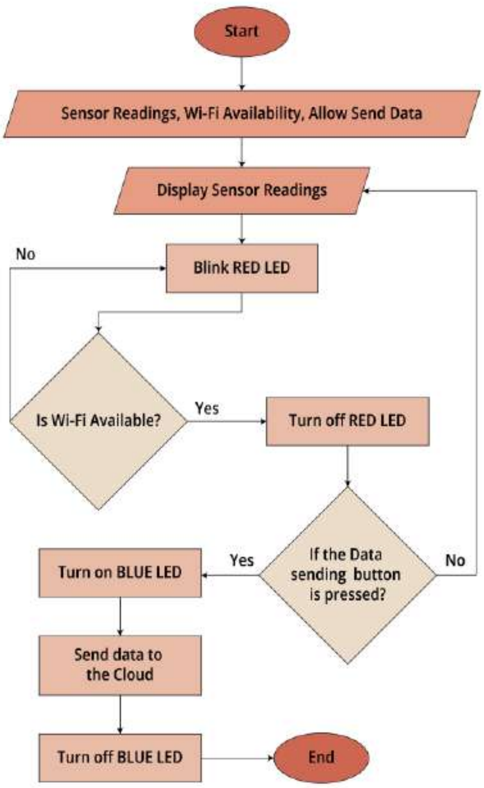

Figure 5: System Working Flow Chart

The system working flow chart of the HypoSense device is illustrated in Figure 5. The Arduino microcontroller acquires data from all the sensors and presents the readings on the OLED Display. We used several LED indicators to visualize the process to the end user. The end user will be notified of the status through the light and the blinking patterns. While the measurements are being recorded, the device's red LED indicator initiates a blinking pattern, serving as a visual cue for the ongoing process and indicating the sensor's Wi-Fi accessibility status. Once Wi-Fi connectivity is established, the red LED ceases to blink.

When measuring sensor readings, the user interacts with the device by pressing the dedicated send button to record the relevant data. The device's blue LED indicator lights up after the send button is pressed, indicating that the data has been stored.

4. RESULTS AND DISCUSSION

The evaluation of the "HypoSense" integrated sensor device was carried out to determine its effectiveness in measuring and recording the parameters in hydroponic farming. Our test was carried out using an indoor hydroponic system set up for growing tomatoes and lettuce (Figure 6).

Figure 6: Indoor Hydroponic System for Tomatoes

The evaluation was carried out in two phases. Initial evaluation was conducted using field sensors to calibrate the sensors of the HypoSense device. We assessed the accuracy of the HypoSense device by conducting a comparison with pH and EC measurements obtained using a device from the reputable brand "Extech." Renowned for its high accuracy in measuring environmental parameters, Extech devices are commonly utilized in industrial applications. Two Extech instruments were used for this comparison: the 'Extech PH100 ExStik' for measuring pH and the 'Extech EC400 ExStik' for measuring TDS and EC. The comparison involves assessing the performance of these instruments under controlled laboratory conditions and in real-world hydroponic settings. Two samples, mud water, and salt water, were utilized for this comparison. The measurements we received from both devices are illustrated in Figure 7 below.

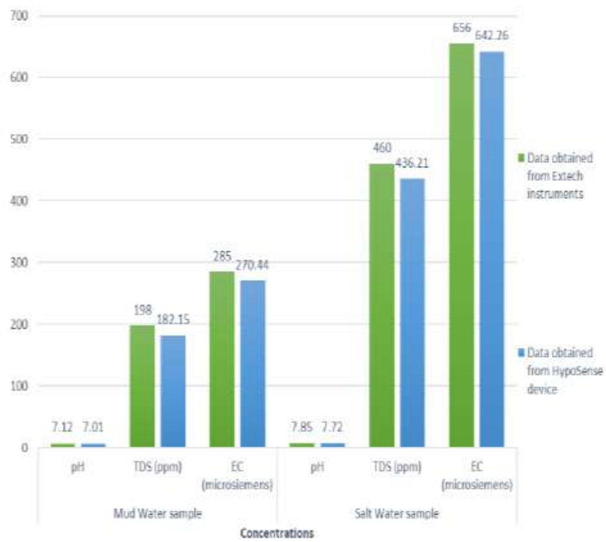

Figure 7: Value comparison with 'Extech' Industrial Instruments

The findings provide valuable insights into the accuracy of the HypoSense device for measuring nutritional parameters in hydroponic systems. In conclusion, the comparative analysis highlights the effectiveness of the HypoSense device in monitoring the parameters in a hydroponic system with high precision and accuracy.

The secondary evaluation was carried out to ensure the applicability and usability of the HypoSense device. A user questionnaire was used at that stage to gather feedback. A sample of 34 undergraduate students were selected for the evaluation out of which 76.5% were hydroponic growers and 23.5% were not. The user questionnaire covered aspects related to the sensor accuracy, ease of use, user-friendliness, power consumption, cost-effectiveness, ease of data acquisition, transmission, analysis, and user satisfaction.

First, we provided all the participants with a thorough understanding of how HypoSense works and how it is used. Then, the participants were given a 10-minute trial period to become familiar with the HypoSense device, as it was their first hands-on experience with using the device. All the selected participants used different, commercially available sensors to measure various parameters in the lab settings in their coursework. They were given specific instructions to follow a standardized protocol for collecting data in order to ensure accuracy and consistency. First, they used the standard lab sensors to measure the parameters. Then, they used the HypoSense device to take readings of the same parameters. Next, they were asked to compare the results with the readings from the HypoSense device. Finally, participants were given a questionnaire that comprised of Likert scale and open-ended questions. Users were asked to rate their level of satisfaction with the Likert Scale questions regarding the HypoSense device on a scale ranging from 1 (very unsatisfied) to 5 (very satisfied).

Accuracy and Precision

User satisfaction with respect to the device's sensor accuracy and precision was obtained to get an overall idea about the performance of the device. The results are summarized in Table 2, which shows an overall satisfaction rating of 4 out of 5, indicating good performance. The rating places the device at the median value in the overall assessment. However, improvement can be further done to increase the accuracy and the precision of the sensory equipment used in the device which we will address in commercializing the product.

Table 2: User Satisfaction w.r.t Sensor Accuracy and Precision

Name of the Parameter	Likert Scale Value				
	1	2	3	4	5
Temperature	0%	2.9%	5.9%	58.8%	32.4%
Humidity	0%	0%	23.5%	61.8%	14.7%
Light Intensity	0%	0%	3.2%	10.2%	86.6%
pH level	0%	3.9%	4.3%	37.7%	54.1%
TDS and EC level	2.9%	8.8%	29.4%	38.2%	20.6%

Usability

The HypoSense device was easy to use according to the majority of respondents. 32.4% were very satisfied and 64.7% were satisfied with the measuring process. Furthermore, we gathered user feedback on the ease of storing measured parameters with the HypoSense device for further analysis compared to other devices they currently use. As per the feedback, 79.5% of the users were very satisfied with the device's ability to store the measured parameters.

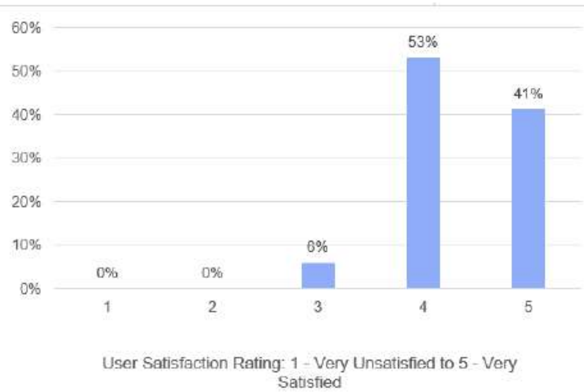

Figure 8: Overall User Satisfaction w.r.t Ease of Use.

The HypoSense device is used for measuring, collecting, and storing data related to hydroponics farming. As shown in Figure 8, the device is considered to be more user-friendly and easier to use than other alternatives available in the market. In a survey, approximately 41% of the respondents were highly satisfied with the device's ease of use, while the majority of users, accounting for 53%, found it satisfactory. A smaller group of users, comprising 6%, indicated that they found it to be average user-friendly. They mentioned that obtaining the measurements was difficult due to the external battery that had to be carried along with the device. As per the comments, we will look into the possibility of integrating the battery into the device to make it more portable in the future. Overall, the feedback suggests a high level of satisfaction with the device's usability and ease of use compared to the commercially available sensors that they are currently using in the lab settings.

Power Consumption and Cost-Effectiveness

Many of the users agreed that by using a single device they can easily measure parameters within seconds compared to the conventional methods. They also mentioned that this is a time and cost-effective solution rather than using different sensors to measure the parameters separately. Further, many agreed that the device consumes less electricity and the power bank was sufficient for obtaining the readings for more than 8 Hrs. As per the user feedback, majority around 62% were satisfied with the power consumption of the HypoSense device.

In addition to that majority agreed that it is a cost-effective solution to obtain accurate parameter measurements within a short period of time. In addition to the user survey, we conducted a comparative analysis to compare the prices of industrial equipment with those of the HypoSense device, as shown in Table 3.

Table 3: Price Comparison: Industrial Equipment vs. HypoSense Device

Device	Measurable Parameters	Price (USD)
HypoSense	Temperature, Humidity, Light Intensity, pH level, TDS and EC levels	55.19
Extech PH100: ExStik® pH Meter	pH level	103.99
Extech EC500: Waterproof ExStik® II pH/ Conductivity Meter	Conductivity, TDS, Salinity, pH, and Temperature	181.99
Extech 401025: Foot Candle/Lux Light Meter	Light Intensity	159.99
Extech 445580: Humidity/Temperature Pen	Humidity, Temperature	74.99

Accordingly, HypoSense is capable of measuring a wide range of parameters compared to other devices. Specifically, only the Extech brand meter offers measurements for Conductivity, TDS, pH, Salinity, and Temperature. However, none of these industrial devices have built-in data storage or the ability to send data to a cloud server with timestamps. In comparison, the cost of the HypoSense device is much cheaper than other industrial devices as illustrated in Table 3. Hence we claim that the device is a cost-effective solution to measure the most required parameters for Hydroponic Growers.

Ease of Data Collection, Transmission, Analysis and Deriving Insights

The majority of users expressed satisfaction with the device's ability to collect real-time data. Specifically, 50% of the sample reported being highly satisfied, while approximately 47% reported being satisfied. Only a small minority, about 3%, reported being neutral. Moreover, approximately 94% of users were highly satisfied or satisfied with the data transfer process and reported no delays. Overall, users were satisfied with the device's decision-making capabilities, and the visualization of the users' perspective is illustrated in Figure 9.

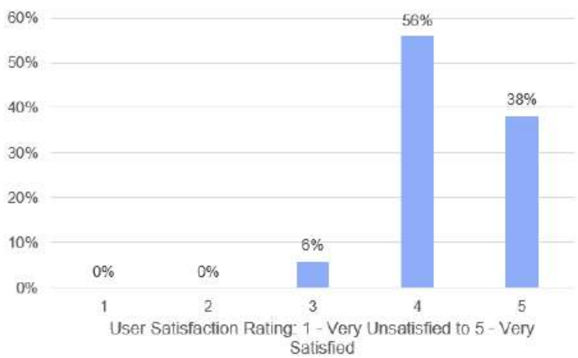

Figure 9: Overall User Satisfaction w.r.t Decision-Making Capabilities

In addition to that many highlighted the need to measure the nutrient concentrations in Hydroponics including Nitrogen(N), Phosphorus(P), and Potassium(P), which we will consider in the future enhancements of the device.

Overall Satisfaction and User Recommendations

Users have provided feedback on their overall satisfaction with the HypoSense device, which highlights its significance in hydroponics farming. They found the device to be extremely valuable, especially for its ability to measure various parameters and effectiveness. Its ease of use in the hydroponics field was also appreciated by over 90% of users. The device's effectiveness in achieving its intended purpose was acknowledged by the majority, as it performed efficiently in terms of collecting, transmitting, and analyzing data, empowering users to make informed decisions. Additionally, more than 90% appreciated the device's ability to consistently deliver accurate data that enables growers to make informed decisions and maintain optimal growth conditions for their plants.

Users have provided some recommendations for enhancing the device. The majority suggested including an internal power supply or a solar-powered solution, to make it more portable and cost-effective. Many have emphasized the importance of getting this to farmers, as it has the potential for wider adoption. Suggestions were given to improve user-friendliness by enhancing the interface and slightly increasing screen size. Additionally, users suggested broadening the device's measurement capabilities, minimizing its physical size for improved portability, and adapting it to measure new parameters in hydroponics systems. They also highlighted the importance of the inclusion of alert and notification features for real-time monitoring and automation. These insights offer a comprehensive view of user perspectives, highlighting the strengths and weaknesses and providing a clear path for future development and optimization of the HypoSense Device.

Based on Figure 10, the overall performance satisfaction of the device ranged from 6 to 10, with no responses falling below 5. The majority, 79% of users, rated the device's overall performance as satisfactory, providing scores between 8 and 10 indicating a very satisfactory level.

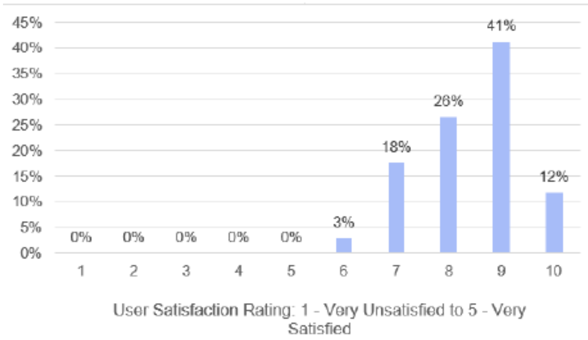

Figure 10: Overall User Satisfaction w.r.t Performance.

On the other end, Figure 11 illustrates the high willingness of users to recommend this device to hydroponic growers, with ratings ranging from 7 to 10 on a 10-point scale. This indicates that users found the device not only effective and reliable but also beneficial for improving hydroponic farming practices. The high scores suggest that users believe the device significantly enhances the monitoring and management of essential growth parameters such as temperature, humidity, pH, light intensity, Total Dissolved Solids (TDS), and Electrical Conductivity (EC).

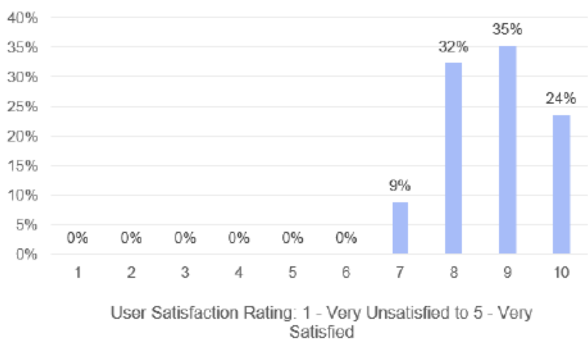

Figure 11: User Willingness in Recommending the Device to Those Who Grow Hydroponics.

This positive feedback reflects the device's overall usability, user-friendliness, and value in providing accurate and actionable data, thereby making it a valuable tool for both novice and experienced hydroponic growers.

5. CONCLUSION

Hydroponics is one of the most widely used cultivation methods that help increase crop production to satisfy urban food needs. Recent trends also show that people are increasingly interested in growing hydroponics to produce their daily healthy food needs. Mostly, hydroponics are carried out indoors to reduce the difficulties associated with outdoor hydroponics. However, due to natural light's limitations, and the need for measuring the parameters regularly, indoor hydroponics can present certain difficulties.

To address these challenges, we introduced a novel integrated sensor device for hydroponic farm growth parameter monitoring. The conventional method of manually observing measurements from multiple sensors has proven to be excessively time-consuming and costly. Additionally, the lack of automatic data recording options in most sensors has been a limiting factor. When compared to commercially available devices HypoSense is a cost-effective device that saves growers time and effort to measure essential parameters in Hydroponics farming. Compared to state-of-the-art solutions available in the existing research, HypoSense is a portable device tailored for the simultaneous monitoring of growth parameters in hydroponics farming. In particular, HypoSense can monitor temperature, humidity, pH, Light intensity, total dissolved solids, and electrical conductivity.

We evaluated the overall performance of the HypoSense device using a sample of 34 users. The overall results highlighted overall user satisfaction. They found the device to be extremely valuable, especially for its ability to measure various parameters and effectiveness. Its ease of use in the hydroponics field was also appreciated by many users. The ability of the device to continuously obtain data within a short time period will enable growers to make optimal decisions at the right time.

The feedback provided by users is highly valuable for the future development and improvement of the HypoSense device. It sheds light on practical considerations and features that users believe can further optimize the HypoSense device for the benefit of hydroponic farming and its users.

6. ACKNOWLEDGEMENT

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