Development of A Smart Tower Hydroponics System

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***Abstract*— Smart farming is thought to be the way of the future for agriculture since it improves crop quality by giving farms greater intelligence in terms of tracking and controlling key parameters. When multiple devices are integrated and connected, large amounts of data can be examined. This research paper presents an automated smart hydroponics system that integrates technologies to achieve faster and larger harvests while providing user updates. The system features drip irrigation, a sensor and actuator network for monitoring and controlling pH level, total dissolved solids, light intensity, temperature, humidity, and water level, as well as a web camera. This research employs the Raspberry Pi 4 B to power plant type identification using the YOLOv5 architecture. This study uses the YOLOv5 architecture on a Raspberry Pi 4 B to identify the type of power plant. This hardware acceleration enables the detection of lettuce, mustard greens, and spinach in a modular, scalable tower arrangement through the effective, real-time implementation of deep learning algorithms. The system's capacity to identify plant maturity stages and assess harvest readiness is further improved by YOLOv5. The user interface, which displays sensor data and allows for real-time monitoring, is a mobile application. With the goal of improving hydroponic farming methods in the Philippines with more sustainability and precision, this study emphasizes the integration of innovative technology and agriculture.**

Keywords—Raspberry Pi 4 B, YOLOv5, Hydroponics, Sensors

I. INTRODUCTION

The evolution of Smart tower hydroponics systems has transformed the landscape of modern agriculture by bringing a highly efficient and sustainable food production method. Unlike traditional farming methods, which rely primarily on agricultural land and face issues such as soil depletion and climate fluctuation, Smart tower hydroponics systems utilize vertical space and controlled settings to grow crops all year. By eliminating the need for soil and improving nutrient delivery through water-based solutions, these systems not only preserve resources but also reduce pest and disease risks, leading to higher yields and consistent crop quality.

Furthermore, employing smart technologies in hydroponic farming has increased its efficiency and precision. Sensors, actuators, and Internet of Things (IoT) connectivity enable these systems to monitor and alter environmental parameters, such as temperature, humidity, pH levels, and nutrient concentrations in real time. This level of automation enables exact control of growing conditions, resulting in optimal plant development and less resource waste. Furthermore, the data generated by these systems can be utilized to continuously enhance agricultural practices, resulting in more sustainable and resilient food production systems for future generations.

II. BACKGROUND OF THE PROBLEM

Traditional agriculture faces numerous challenges in meeting the demands of a growing population, including limited space, resource inefficiency, and environmental concerns. The emergence of hydroponics as a soil-less cultivation method offers a solution, but conventional systems often lack the precision necessary for optimal plant growth. The need for smart hydroponic systems is evident, and the integration of sensors becomes imperative to monitor key variables such as temperature, humidity, pH levels, water levels, and nutrient concentration. This background underscores the necessity for a Smart Tower Hydroponics System that not only maximizes space but also optimizes resource utilization for sustainable and high-yield crop production.

In light of these challenges, the backdrop of the problem accentuates the urgent need for the Development of A Smart Tower Hydroponics System. The integration of advanced sensor technologies into this system becomes imperative as it seeks to bridge the existing gap between technology and agriculture. This transformative initiative aims to optimize conditions for enhanced crop productivity, offering a solution that propels hydroponics into a realm of efficiency and sustainability previously unattainable with traditional methods. The envisioned Smart Tower Hydroponics System emerges as a beacon of innovation, poised to revolutionize crop cultivation and pave the way for a more sustainable future in agriculture.

III. OBJECTIVES

The study aims to design and fabricate a smart vertical tower-type hydroponics system

1. To integrate sensors to the hydroponics system to monitor the temperature and humidity within the system and pH level, water level, and total dissolved solids (ppm) of the nutrient solution.

2. To automatically set the condition of the system according to the optimum growth parameters of the plants to be tested; lettuce, spinach, and mustard green.

3. To test the effectiveness and reliability of the system and the maturation period of the plants compared to a conventional hydroponics set up.

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IV. REVIEW OF RELATED LITERATURE

According to Gashgari, R. et al. (2018), hydroponic planting systems allow plants to reach their full height faster than traditional soil-based systems. However, the planting system does not affect the length of the leaves. Additionally, the type of seed or the interaction between the seed type and the planting system does not affect plant growth. Likewise, this study is able to establish that hydroponic planting has an advantage over soil-based planting and is suitable for urban farmers today.

Moreover, Touliatos, et al. (2018) stated that the vertical farming method demonstrated that it is a viable alternative to conventional horizontal growth systems by maximizing growing space utilization efficiency and so generating more crops per unit area. Similarly, this study showed that vertical farming is more efficient than horizontal farming. This will implement the vertical farming method.

Furthermore, based on Mir, M. et al (2022), vertical farming offers numerous advantages in terms of environmental, social, and economic sustainability compared to traditional rural farming. The utilization of advanced cultivation methods such as hydroponics, aeroponics, and aquaponics is challenging the necessity for soil-based farming. Vertical farming is gaining popularity as an effective approach for enhancing crop production. In the same way, this study helped in further understanding of vertical farming.

Also, according to Jan, S. et al. (2020), the hydroponic system including the main types which are the wick, ebb and flow, drip, deep water culture (DWC), and Nutrient Film Technique (NFT) systems, as well as the advantages of hydroponics over the traditional farming. Correspondingly, it helped in further understanding the various hydroponics techniques and establish the type of hydroponics system to be used.

Additionally, Jagdish (2022) stated that the hydroponics drip system technique, types and advantages. Alike, this study will use the Drip System method for the hydroponics system. It also helped in conceptualizing the design of the system and proper positioning of important materials and equipment.

Further, based on the literature discussed by Meselmani M. (2022), the optimum ranges of pH level, EC value, and temperature of a nutrient solution for specific plants and hydroponics plants in general. Similarly, this study lists down the optimum range of pH level, EC value, and temperature of the nutrient solutions for the plants the study will test.

Besides, according to Tondo, Martin (2021), Coir, the fibers derived from coconut husks, possess versatility and can be used in a diverse range of products. For instance, coconut husk chips are utilized as a planting medium that aids in moisture retention and fungal resistance for plants. Likewise, the utilization of coconut coir as a medium for hydroponic system planting holds great potential in promoting lignin growth. This is particularly beneficial for urban residents seeking to enhance their plant growth in urban environments.

V. METHODOLOGY

A. System Architecture

This project is focused on designing and fabricating a hydroponics system which automatically maintains an optimal growing environment in a greenhouse and nutrient solution for plants particularly lettuce, spinach, and mustard green. This project runs in a negative feedback loop for parameter correction and optimization. The parameters included in the project are the ambient temperature, humidity, and light intensity inside the greenhouse and total dissolved solids (tds), pH level, and water level of the nutrient solution in the reservoir.

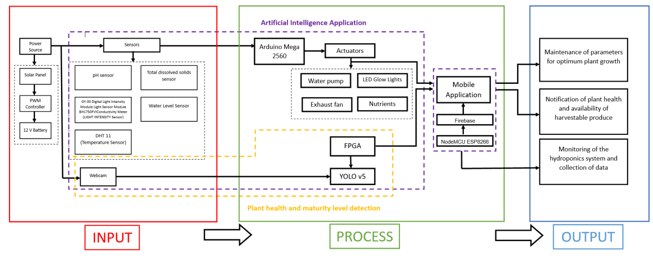


Figure 1: Block Diagram

Figure 1 shows the block diagram of the project. It utilized a microcontroller. Sensors are used to monitor the parameters of the project. The data gathered from the sensors are then processed by the microcontroller and actions are taken by the actuators such as fans, pump, solution and water distributor, and grow lights to maintain or revert back the parameters to the optimum level needed by the plants. Those parameters are pre-programmed and are set in the microcontroller. If the sensors detected data out of the set parameter, the microcontroller will send a signal to the actuators to activate and correct the parameters that are out of range.

B. Testing of the System

Figure 2 shows the overall setup of the study and figure 3 shows the comparative setup without automation. To test the validity of the study, two setups are created and comparison of data are done. The length of the leaves, width of the plants from end-to-end and their heights are measured every 5 days for the span of 30 days. The reliability of the system automation will be tested by comparing the accuracy of the sensors with calibrated measuring tools in different sets of time and the responsiveness of the actuators to different set of parameters.

Figure 2: Automated Hydroponics System

Figure 3: Manual Hydroponics System

C. Circuit Diagram of Sensors

Figure 4 shows the circuit diagram of the sensors connected to the Arduino Mega 2560, which reads the data from the sensors simultaneously. The NodeMCU ESP 8266 is also connected to the Arduino Mega to send the sensor data to the firebase database and display it in the Mobile Application.

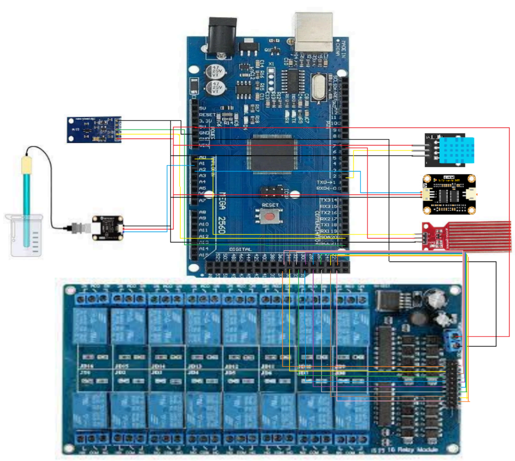


Figure 4: Circuit Diagram

VI. RESULT AND DISCUSSION

A. Project Technical Description

This research aimed to create an innovative smart hydroponics system that could monitor and notify plants about their health and maturity. The system, which takes advantage of recent breakthroughs in automation technology, sensor hardware, and machine learning, includes tower-style hydroponics suited for outdoor usage and a high level of autonomy. Multiple sensor modules monitor important growth factors such as pH, dissolved solids, water level, light, temperature, and humidity. An Arduino microcontroller captures sensor data and transfers it to cloud databases over WiFi, allowing continuous system monitoring. A machine vision component detects plant health concerns by training a YOLOv5 model on an image collection of leaf states.

B. Project Structural Organization

The Greenhouse and Hydroponics Set-up

The greenhouse dimensions are 2.2 m x 2.2 m x 1.2 m. It is made of UV plastic sheeting stretched over a frame of angle and flat bars. Three 12V DC fans are positioned on the bars to ventilate the enclosure by removing damp air and introducing fresh air. This airflow promotes quick and profuse plant development. An automated tower-style hydroponics system within the greenhouse uses drip irrigation to regularly feed nutrient-rich water, increasing plant health and reducing stress. The towers are made of PVC pipe and include holes through which plants can be hung above a recirculating water reservoir. The system consists of a single pump for continuous water circulation, a valve on the pipe to adjust the flow rate, and an automatic pH balancer. The holding tank has pH, water level, and temperature sensors.

Figure 5: The Greenhouse and Hydroponics Set-up Inside View

Figure 6: The Greenhouse and Hydroponics Set-up Outside View

Connections of Sensors, Actuators to Relay and Arduino Mega 2560

Figure 7 shows the sensor array, which includes pH, TDS, DHT22 temperature/humidity, GY-30 light intensity, and water level sensors, interfaced with an Arduino Mega 2560 R3 microprocessor. Serial communication methods permitted data flow from the sensors to the Arduino. Actuators such as the 12V DC fan, water pump, and grow lights were linked via relays and controlled by the Arduino.

The Arduino code included predefined thresholds for each sensor parameter. Sensor values were regularly checked against these thresholds. If any sensor value fell outside of the permitted range, the Arduino actuated the appropriate actuator after a predetermined wait time. This stopped the actuators from cycling at high rates. The actuators would then switch off after the sensor reading had returned to the target zone. This automated, responsive system guaranteed that the hydroponic plants grew under ideal circumstances. The Arduino functioned as the control hub, collecting real-time sensor data and intelligently controlling the outputs.

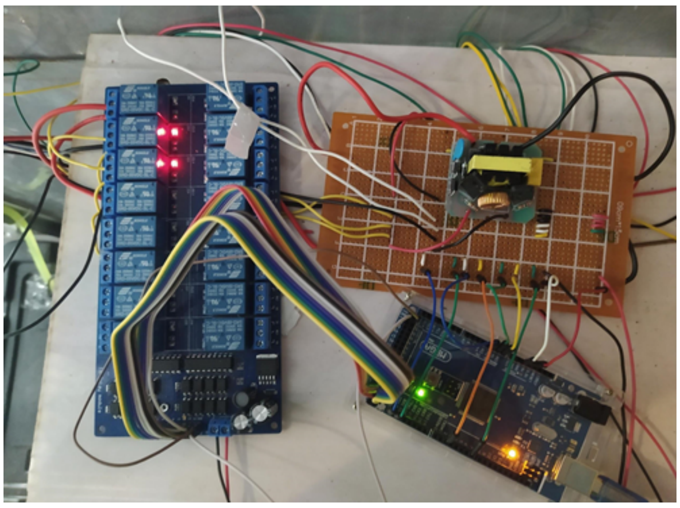


Figure 7: Connections of Sensors, Actuators to Relay and Arduino Mega 2560

C. Manual and Smart Set-up Comparison

Data comparison between the manual and smart settings from April 29 to May 17 is shown in line graphs in Figures 8 and 9. The development of lettuce in Towers 1 and 5 with each arrangement is specifically shown in Figures 8 and 9. Eventually, compared to the conventional setup, the lettuce plants in the smart system grew larger and taller. In the smart setup, Tower 1 also displayed higher end-to-end readings, but Tower 3's end-to-end measurements showed a different trend.

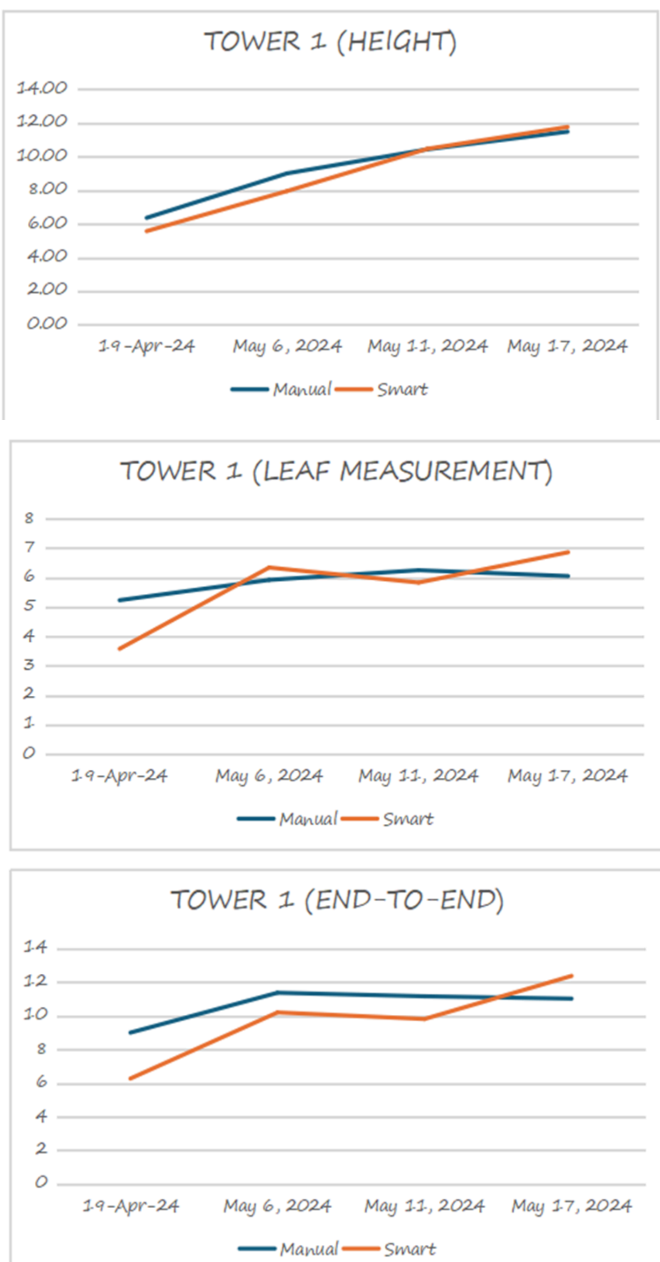


Figure 8: Line graph of data in Tower 1 from April 19 to May 17

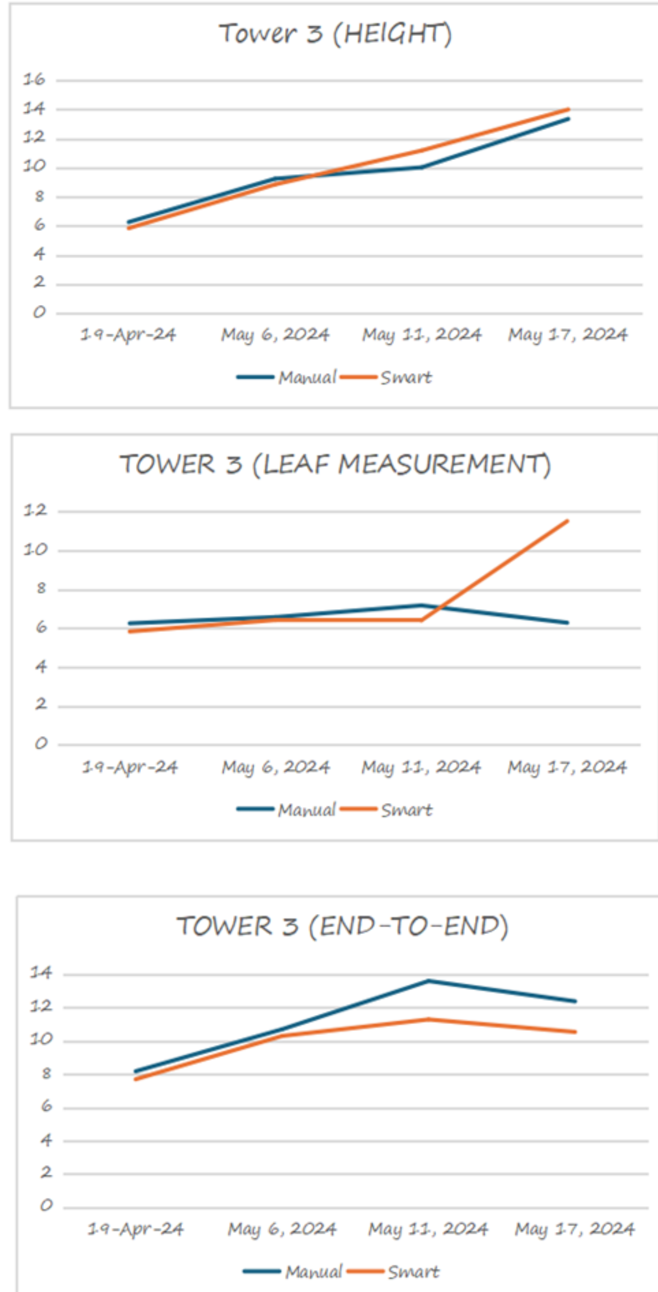
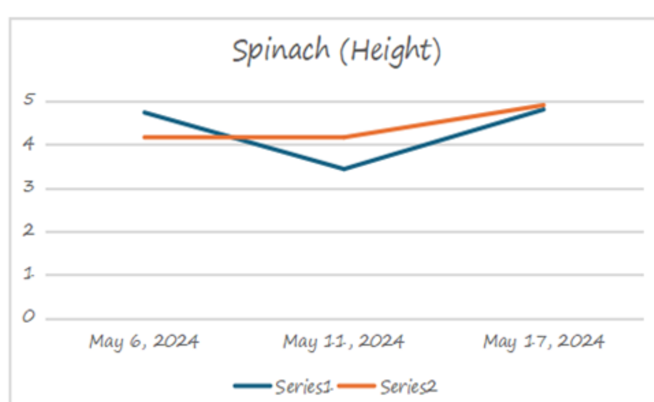


Figure 9: Line graph of data in Tower 3 from April 19 to May 17

Data from Tower 2, which grows mustard and spinach greens, are compared in Figures 10 and 11. During the duration of the observed period, both plant heights in the smart configuration grew consistently and surpassed those in the manual arrangement. Leaf and end-to-end measurements, nonetheless, indicated that the smart configuration grew slower than the manual setup. To help maintain the authenticity of the results, the graphs intentionally excluded data from deceased plants.



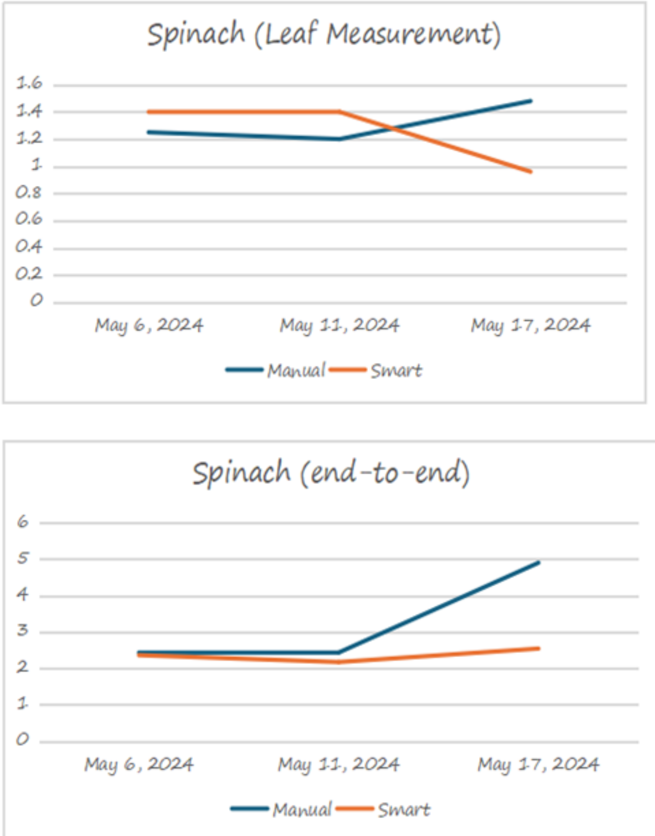


Figure 10: Line graph of data of Spinach from May 6 to May 17

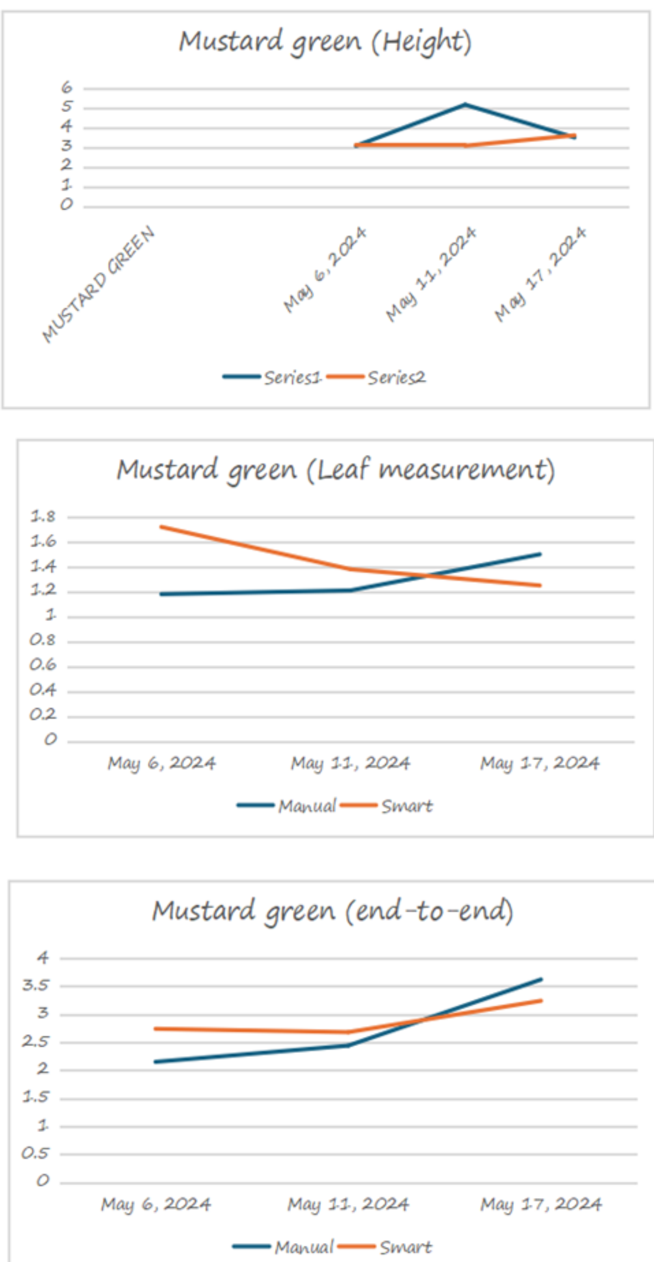


Figure 11: Line graph of data of Mustard Green from May 6 to May 17

D. Yielded Crops

Table 1 presents data collected on May 17, 2024, from the three towers of the smart setup. Tower 1 initially had twenty-one samples, but two deceased plants were excluded from averaging. Tower 3 had eighteen samples. Tower 2, which contains spinach and mustard greens, had seven and ten samples, respectively. The average heights of plants in Towers 1 and 3 were 11.76 and 14.00 centimeters, respectively. The average lengths of the largest leaves measured at the time were 6.86 and 11.52 centimeters for Towers 1 and 3, respectively. The end-to-end measurements for these towers were 12.37 and 10.53 centimeters, respectively. In Tower 2, spinach averaged 4.90 centimeters in height, with the largest leaf measuring 0.96 centimeters, and an end-to-end span of 2.54 centimeters. For mustard greens in Tower 2, the averages were 3.61 centimeters in height, 1.25 centimeters for the largest leaf, and 3.24 centimeters end-to-end.

Table 1: Measurements of plants in the Smart setup for Towers 1, 2, and 3 (May 17)

TOWER 1			
No. of Cups	Height (cm)	Middle (cm)	End to End (cm)
1	10.2	3.7	7.3
2	9.1	5.9	12.1
3	12	7.6	15
4	11.4	8.6	15.3
5	9	6.5	12.1
6	10.1	6.8	13.4
7	11.2	7.2	14.9
8	9.5	6.1	10.4
9	14.5	4.2	9.5
10	9.7	7.5	14.2
11	14.2	4.9	11
12	10.4	7.2	13.4
13	15	7.4	13.1
14	12.6	5.7	12.2
15	13.5	7.9	14.5
16	13.8	7.2	14.5
17	11.6	7.6	13.8
18	11.2	6.2	11.7
19	14.5	12.2	6.7
20	0	0	0
21	0	0	0
AVERAGE	11.76	6.86	12.37

SMART HYDROPONICS SYSTEM

TOWER 2			
Mustard			
No. of Cups	Height (cm)	Middle (cm)	End to End (cm)
1	6.8	2	5.8
2	2.7	1.3	3.4
3	2.9	1.1	2.4
4	2	0.9	2.3
5	2.5	0.9	2.5
6	3.7	0.9	2.6
7	4.5	1.4	4.2
8	3.3	1.2	3.1
9	4.1	1.9	3.5
10	3.6	0.9	2.6
Average	3.61	1.25	3.24

Spinach			
No. of Cups	Height (cm)	Middle (cm)	End to End (cm)
1	5.1	1	2.9
2	5	1	2.3
3	3.1	1	1.7
4	6.6	0.9	2.8
5	4.9	1.1	2.6
6	3.9	0.6	1.8
7	5.7	1.1	3.7
AVERAGE	4.90	0.96	2.54

Table 2 presents data collected on May 17, 2024, from the three towers of the manual setup. Tower 1 initially had fifteen samples, but five deceased plants were excluded from averaging. Tower 3 had fourteen samples. Tower 2, which contains spinach and mustard greens, had six samples each. The average heights of plants in Towers 1 and 3 were 11.48 and 13.35 centimeters, respectively. The average lengths of the largest leaves measured at the time were 6.05 and 6.29 centimeters for Towers 1 and 3, respectively. The end-to-end measurements for these towers were 11.02 and 12.37 centimeters, respectively. In Tower 2, spinach averaged 4.80 centimeters in height, with the largest leaf measuring 1.48 centimeters, and an end-to-end span of 2.67 centimeters. For mustard greens in Tower 2, the averages were 3.50 centimeters in height, 1.50 centimeters for the largest leaf, and 3.62 centimeters end-to-end.

Table 2: Measurements of plants in the Manual setup for Towers 1, 2, and 3 (May 17) (cont.)

TOWER 1			
No. of Cups	Height(cm)	Middle(cm)	End to End(cm)
1	12	7	13.5
2	10.1	5.8	9.1
3	11	5.6	10.1
4	13.2	3.9	10
5	10.9	6.2	11.1
6	9.2	6.2	11.5
7	12.4	6.4	10.5
8	13.2	5.6	11.1
9	11.5	6.9	12.9
10	11.3	6.9	10.4
11	0	0	0
12	0	0	0
13	0	0	0
14	0	0	0
15	0	0	0
AVERAGE	11.48	6.05	11.02

MANUAL SETUP

TOWER 2			
MUSTARD GREEN			
No. of Cups	Height (cm)	Middle (cm)	End to End (cm)
1	3.8	1.6	5
2	3	1.7	2.3
3	4.1	2	5
4	3.9	0.9	3
5	3	1.7	3.2
6	3.2	1.1	3.2
AVERAGE	3.50	1.50	3.62

SPINACH			
No. of Cups	Height (cm)	Height (cm)	End to End (cm)
1	4.8	1	2.2
2	4.8	2.9	3
3	4.4	1.1	3.8
4	5.1	1.5	3
5	6.6	1.7	2.6
6	3.1	0.7	1.4
AVERAGE	4.80	1.48	2.67

TOWER 3			
No. of Cups	Height (cm)	Middle(cm)	End to End (cm)
1	11.9	7.2	15.7
2	12.6	1.7	3.7
3	12.5	1.7	3.7
4	12.4	1.9	3.4
5	11.3	7	13.7
6	11.8	6.7	11.3
7	15.9	66.3	14.1
8	23.3	6.7	12.2
9	17.8	3.3	5.4
10	16	7.4	14.8
11	12.7	4	7.4
12	8.2	6.5	13.5
13	13.4	7.3	15.6
14	10.1	55	9.8
15	16.2	7.4	12.7
16	14.5	4.9	9.2
17	19.4	6.8	13
18	12	5.6	10.3
AVERAGE	14.00	11.52	10.53

E. Statistical Analysis of Data

Table 3 summarizes the statistical analysis conducted to analyze the data. A paired samples t-test was employed to evaluate if the smart setup outperformed the manual configuration. The p-values for April 19 are 0.987, 0.973 for May 6, 0.414 for May 11, and 0.088 for May 17.

Table 3: Statistical Analysis of Data

Paired Samples T-Test ▼

Paired Samples T-Test ▼

Measure 1		Measure 2	t	df	p	Cohen's d	SE Cohen's d
April 19 (Manual)	-	April 19 (Smart)	2.276	56	0.987	0.301	0.199
May 6 (Manual)	-	May 6 (Automatic)	2.007	32	0.973	0.349	0.268
May 11 (Manual)	-	May 11 (Automatic)	−0.221	28	0.414	−0.041	0.249
May 17 (Manual)	-	May 17 (Automatic)	−1.393	27	0.088	−0.263	0.339
	-						
	-						
	-						

Note. For all tests, the alternative hypothesis specifies that Measure 1 is less than Measure 2. For example, April 19 (Manual) is less than April 19 (Smart).

Note. Student's t-test.

Descriptives ▼

Descriptives ▼

	N	Mean	SD	SE	Coefficient of variation
April 19 (Manual)	57	6.356	1.118	0.148	0.176
April 19 (Smart)	61	5.913	1.081	0.138	0.183
May 6 (Manual)	33	9.133	1.969	0.343	0.216
May 6 (Automatic)	39	8.364	1.326	0.212	0.158
May 11 (Manual)	29	10.231	1.645	0.306	0.161
May 11 (Automatic)	39	10.946	2.440	0.391	0.223
May 17 (Manual)	28	10.775	4.849	0.916	0.450
May 17 (Automatic)	39	12.192	4.142	0.663	0.340

VII. CONCLUSION

The research provides the ideal growth circumstances that result in increased yields and improved quality of lettuce, mustard greens, and spinach,by considering the various environmental parameters. The development of Smart Outdoor Hydroponics offers a productive and sustainable technique to grow plants. This innovative project aims to get rid of the requirement for soil by establishing a regulated environment that supports plant growth. Using advanced hydroponic approaches, it increases the yield and quality of crops including spinach, mustard greens, and lettuce. Advanced technologies such as YOLOv5, Raspberry Pi 4 B, and Arduino Mega 2560 can be integrated into a vertical hydroponics system to provide a complete automated and efficient plant growing system. With the Raspberry Pi 4 B speeding up machine learning operations for immediate plant recognition, the modular architecture increases adaptability. Computer vision analyzes harvest periods and helps with health monitoring. A user-friendly interface of the recently developed smartphone app allows for the real-time monitoring of important parameters like pH, TDS, temperature, humidity, light intensity, and water level.

VIII. RECOMMENDATIONS

To further improve and enhance upon this agricultural monitoring system the proponents recommend the advancing automation technologies might also improve functionality. The investigation and potential integration of automated harvesting technologies would move the system closer to total agricultural autonomy. This would allow for much easier deployment to new farm configurations, lastly to maintain measurement accuracy when device components degrade naturally, it is recommended that the different sensors and actuators be calibrated and upgraded on an ongoing basis. Regular sensor calibration and replacement guarantee the data feed's integrity and allow for suitable response changes.

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