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Microcontroller-Based Hydroponics GlaciaGrow Smart Environment with Water Filtration and Growth Optimization System for Lactuca Sativa var Longifolia

Angelo E. Acepcion
angelo.acepcion03@gmail.com
College of Engineering
Quezon City University Quezon City, Philippines

Chito Handy R. Balanza
balanza.chitohandy.08092002@gmail.com
College of Engineering
Quezon City University Quezon City, Philippines

Paul Anthony P. Alforte
alforte.paulanthony.05052003@gmail.com
College of Engineering
Quezon City University Quezon City, Philippines

Marc Yuri R. Bernal
bernal.marcyuri.02242003@gmail.com
College of Engineering
Quezon City University Quezon City, Philippines

Charles M. Ayaso
ayaso.charles.11262002@gmail.com
College of Engineering
Quezon City University Quezon City, Philippines

Francis B. Olila
olila.francis.02052003@gmail.com
College of Engineering
Quezon City University Quezon City, Philippines

Research Adviser:
Ryan F. Arago
ryan.arago@qcu.edu.ph
College of Engineering
Quezon City University Quezon City, Philippines

Technical Adviser:
Leonard A. Catchillar
College of Engineering
Quezon City University Quezon City, Philippines

Abstract. The Philippines faces significant agricultural problems including water scarcity, the consequences of climate change, and declining output that all compromise food security and financial stability. This work introduces the GlaciaGrow system, a microcontroller-based hydroponics solution that incorporates an improved wastewater management system (gravel, sand, activated charcoal, pebbles) to purify and recycle water for sustainable crop irrigation. Combining automated Deep-Water Culture (DWC) hydroponics with real-time temperature, humidity, water level, and pH, the prototype also incorporates dual power sources (solar and AC) and GSM-based environmental deviation notifications. The wastewater filtration system ensured optimal nutrient delivery and achieved 92% contaminant removal, thereby reducing reliance on freshwater. The environmental sensors that are significant for maintaining a controlled environment within the system demonstrated strong performance across all parameters, with consistently high accuracy in water level and pH measurements. The specimen, grown from romaine lettuce, also met quality standards, reaching a weight of more than 150 g

and a height of more than 15 cm. GlaciaGrow, a scalable approach to climate-resilient urban farming, combines closed-loop water recycling with precision agriculture. GlaciaGrow presents a sustainable model for urban farming in water-scarce regions.

***Keywords**: Hydroponics, smart agriculture, wastewater filtration, water recycling, microcontroller, sustainability, Lactuca sativa, urban farming, climate resilience, GlaciaGrow*

Introduction

The Philippines faces severe food security challenges, including declining agricultural productivity, water scarcity, and climate change. High food costs make essential items unaffordable for many, while farmers grapple with unstable market prices and limited resources. Water shortages and inefficient irrigation systems further reduce crop yields, particularly in rural areas (Luna & Talavera, 2022; Angeles Agdeppa et al., 2022).

Despite abundant rainfall, inadequate water management results in floods that damage crops, while prolonged droughts linked to global warming exacerbate water scarcity. Rainwater mismanagement causes root infections, nutrient deficiencies, and reduced yields, further straining food production (International Water Management Institute, 2019).

If wastewater is not filtered and reused for crops, it can worsen freshwater depletion, increase pollution, and lead to the loss of essential nutrients, making agriculture reliant on synthetic fertilizers for growth. Additionally, untreated wastewater can contaminate soil and groundwater, posing health risks and making agriculture increasingly unsustainable and vulnerable to climate change. The failure to conserve water and recover valuable resources further exacerbates environmental challenges and threatens food security (Wiegmann et al., 2024).

Climate change worsens these issues through rising temperatures and extreme weather, reducing crop quality and yields. Sensitive crops like lettuce face contamination risks from irrigation water, especially in urban farming regions where surface water often carries fecal pathogens, endangering public health (Summerlin et al., 2021). The combined effects of climate change, water scarcity, and contamination present severe challenges to sustainable agricultural production.

The agricultural sector, which employs 29% of the workforce, is vital to the economy but faces challenges such as pesticide overuse, soil degradation, and biodiversity loss. Unsustainable practices, including extensive land use and inefficient water management, lead to environmental degradation and diminished productivity (Kimura et al., 2022).

Water management challenges, such as inadequate irrigation during droughts and poor wastewater treatment, significantly hinder agricultural productivity in the Philippines, leading to crop losses, degraded farmland, and reduced yields. To address these problems, adopting sustainable agricultural practices—such as efficient water use, climate-resilient farming, and improved resource management—is essential. One innovative solution is the GlaciaGrow System, a microcontroller-based hydroponics setup integrated with a wastewater management system, designed to optimize water usage and protect crops from environmental stress. By incorporating systems like GlaciaGrow, the country can mitigate water-related agricultural issues, strengthen food security, and build a resilient farming sector capable of adapting to climate change.

Methodology

The GlaciaGrow System was created using the Prototyping Design Model, an iterative process that focuses on ongoing improvement through feedback. The process started with gathering requirements, where specific agricultural issues—such as water shortages and the need for efficient resource use—were identified in collaboration with farmers and experts. This was followed by a quick design phase to outline the system's core features, including hydroponics, microcontrollers, and a rainwater harvester. A working prototype was then built and tested in a controlled environment. This testing phase was guided by professional evaluation to ensure the system's feasibility and relevance to real-world farming conditions.

As the prototype is evaluated, feedback is gathered to improve the system's requirements and design. This feedback loop guides a more detailed design phase, leading to the full development of a GlaciaGrow system tailored to users' practical needs. The model supports ongoing iteration, allowing for adjustments at each stage based on user experience and performance data. Additionally, a plan for continuous maintenance ensures the system remains reliable and effective over time. By allowing refinements throughout the development process, the Prototyping Design Model makes sure GlaciaGrow becomes a robust solution for complex agricultural water management.

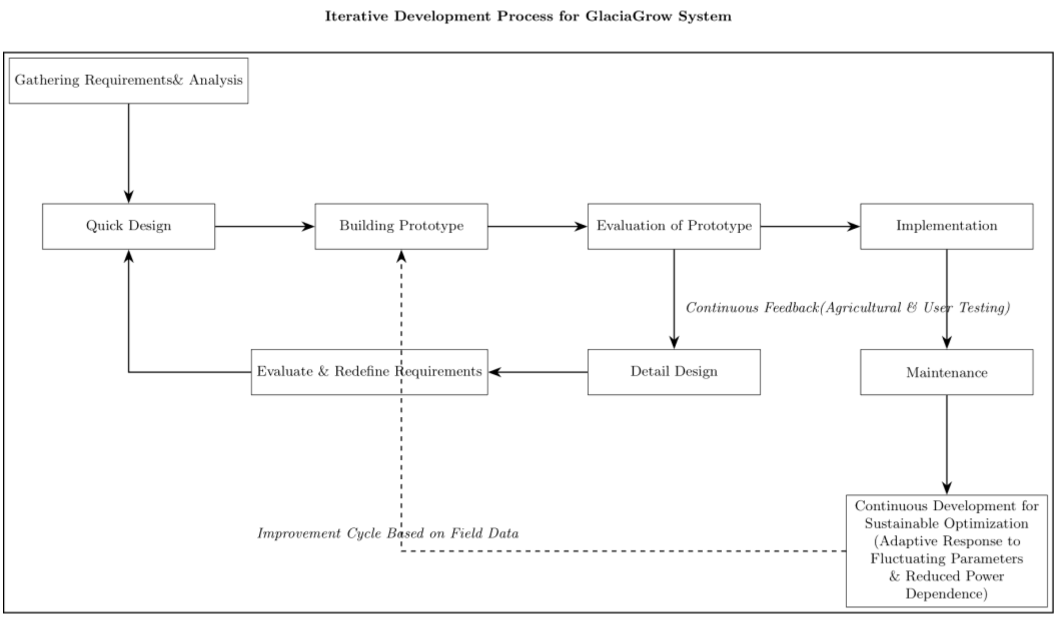

Figure. 1: Prototyping Model of GLACIAGROW

Figure 1 shows the Input-Process-Output framework of the automated hydroponics system. The system uses sensors to monitor environmental factors—such as temperature, humidity, and pH—in real time, managed by an ATmega2560 microcontroller. This microcontroller automates essential functions, including water filtration, nutrient delivery, climate control, and UV lighting, all synchronized by a Real-Time Clock (RTC). The two-layer Deep Water Culture (DWC) setup includes water level sensors and solenoid valves for efficient distribution, with a GSM module enabling remote monitoring. Powered by both a 220V AC source and a 12V solar energy system, GlaciaGrow recycles water weekly to maintain a sustainable, closed-loop environment with minimal manual intervention.

Additionally, it describes the iterative development process used for the GlaciaGrow system. This approach highlights ongoing feedback and improvements based on agricultural needs and user testing.

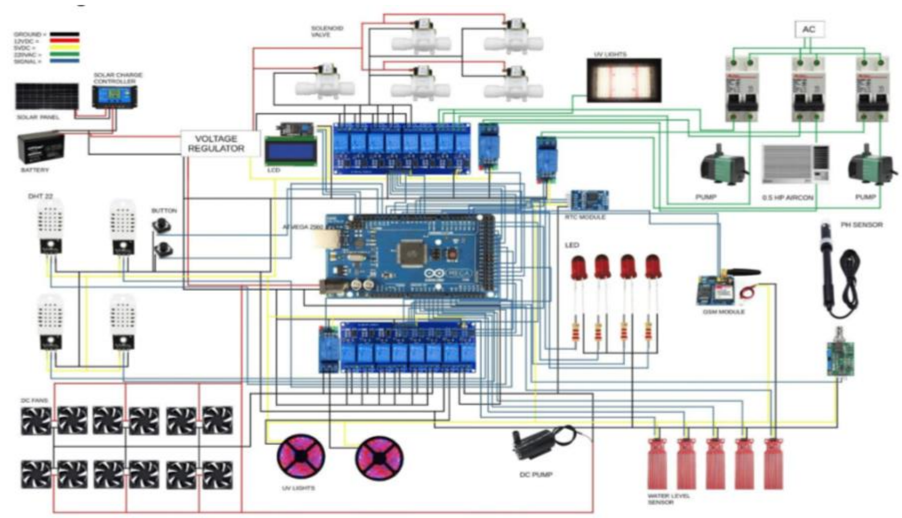

Figure. 2: System Pictorial Diagram of GLACIAGROW

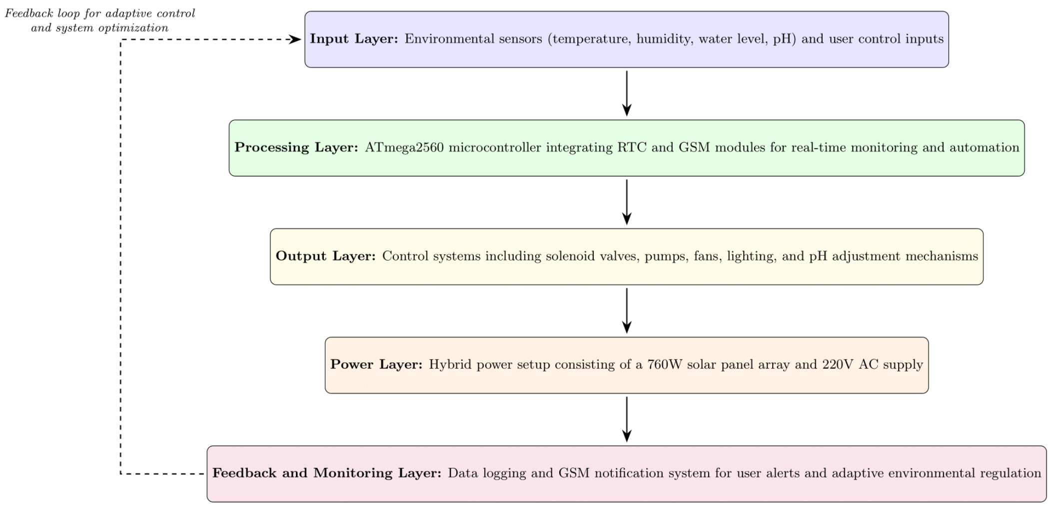

Figure. 3: Summary System Architecture of GLACIAGROW

Results

A. Design of the system

The proponents analyzed the key requirements for designing GlaciaGrow, a hydroponic system for Lactuca sativa (lettuce) based on an ATmega2560 microcontroller. The analysis included the lettuce's specific climatic requirements, system dimensions, and mass-production optimization, prioritizing cost-effectiveness, energy efficiency, durability, and reliability. Through careful component selection, the system ensures automated, sustainable cultivation with minimal maintenance.

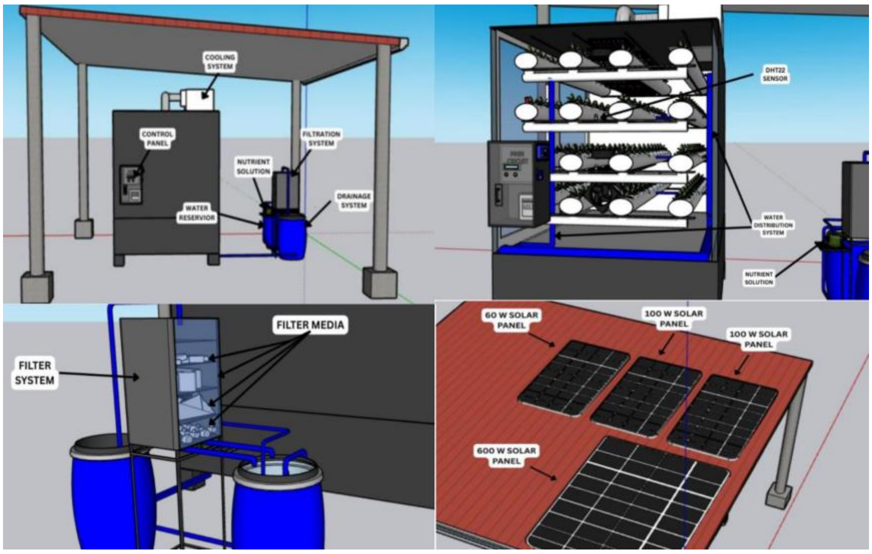

Figure. 4: Three-dimensional design of the GLACIAGROW

B. Prototype of the System

The prototype facilitates superior plant growth by establishing a controlled environment. Key functionalities include a seedbed system that supports seed germination, a nutrient delivery system that provides consistent nourishment, and a filtration system that ensures the purity of the water and growing medium.

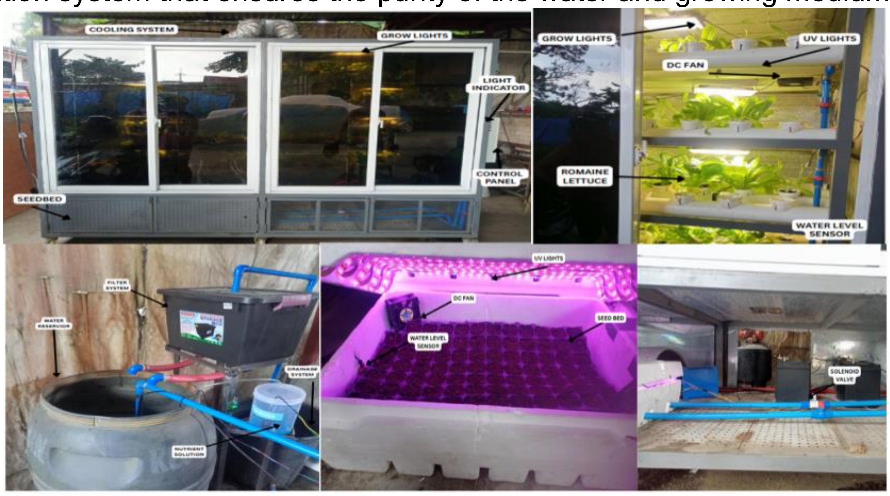

Figure. 5: Actual Prototype of the GLACIAGROW

C. Functionality Testing

Functionality testing confirmed that all major subsystems of the GlaciaGrow System operated reliably and met their specified requirements. The Power Management System—comprising a 760W solar panel, charge controller, batteries, and a circuit breaker—provided a stable power supply throughout the tests. The Cooling System, which includes a 12V DC fan and an AC unit, maintains the temperature within the optimal range for plant growth. The Control System, featuring an LCD, GSM module, RTC module, and relays, successfully enabled real-time monitoring and automation, with all components passing rigorous functionality checks.

Further validation was performed on the core operational systems. The Sensor System (DHT-22, water level, and pH sensors) accurately monitored environmental conditions and passed all 15 test cases. The Water Distribution System, using solenoid valves and a water pump, demonstrated precise, automated irrigation control. The Lighting System performed consistently; the 30W grow light was fully validated, while the 5V UV light provided partial but sufficient functionality. Finally, the Water Recycling System, driven by a 220V pump, confirmed efficient water circulation. Collectively, these results affirm that the GlaciaGrow System is functionally sound and ready for sustainable, automated hydroponic farming.

D. Accuracy Testing

I. Overall Accuracy Percentage Test Rating for Temperature from 4 DHT-22 Sensors

The DHT-22 sensors reliably monitored the environmental conditions for romaine lettuce cultivation. Humidity measurements were consistently more accurate than temperature readings. Across three daily test periods (6:00 AM, 12:00 PM, and 6:00 PM), temperature accuracy averaged 90%-91.5%, peaking at 95.78% with Sensor 3 at dawn. In contrast, humidity accuracy ranged from 92% to 96%, peaking at 98.86% with Sensor 2 in the morning. All sensors operated within acceptable parameters, with Sensor 3 demonstrating the most stable temperature readings and Sensor 2 excelling in humidity detection.

These results confirm the system's capability for precise environmental monitoring throughout daily cycles, ensuring optimal growing conditions for hydroponic lettuce. The findings particularly underscore the sensors' superior reliability in measuring humidity across varying daytime conditions.

Table. 1.
Summary of Temperature Sensor Testing Results

DHT-22	Temperature		Humidity	
	Accuracy	Interpretation	Accuracy	Interpretation
1	90.67%	Very Good	95.43%	Very Satisfactory
2	86.89%	Good	98.86%	Excellent
3	95.78%	Very Satisfactory	93.14%	Satisfactory
4	89.89%	Very Good	96.57%	Very Satisfactory
Average	**90.81%**	**Very Good**	**96.00%**	**Very Satisfactory**
Overall Rating	**Very Good**		**Very Satisfactory**	

II. Reading of Water Level Information

The water level sensors, implemented in both the PVC pipes and the seedbeds using a 450-volt threshold system, demonstrated reliable performance. In the PVC pipe trials, the sensors triggered solenoid valves with an average accuracy of 94.52%. While Sensors 1, 2, and 4 all exceeded 95% accuracy, Sensor 3 performed slightly lower at 91.36%. Similarly, the seedbed system achieved 94.6% accuracy, automatically initiating refills when levels fell below the threshold in Trials 1 and 2, and successfully maintaining adequate water levels in Trials 3 through 5.

Collectively, both systems successfully automated irrigation based on real-time level monitoring, with most sensors exceeding 94% accuracy. The slight variation in Sensor 3's performance remained within operational tolerances, confirming the system's overall effectiveness for hydroponic water management.

Table. 2.
Summary of Water Level Sensor Testing Results

TRIALS	WLS1	WLS2	WLS3	WLS4
Reference:	470			
Average	492	450.6	510.6	491
Percent Error	4.68%	4.13%	8.64%	4.47%
Accuracy	95.32%	95.87%	91.36%	95.53%
Overall Accuracy Percentage of Readings for Water Level				94.52%
Verbal Interpretation				Satisfactory

III. pH Measurement of Water in the Main Reservoir

The pH levels in the main reservoir were monitored across five trials against a reference value of 6.5, which is critical for optimal lettuce cultivation. The recorded readings showed some variability: Trials 1 (6.88), 2 (6.79), and 5 (6.36) remained close to the target, while Trial 3 (5.62) was slightly acidic and Trial 4 (9.79) was highly alkaline. Despite these fluctuations, the pH sensor demonstrated reliable performance with 90.92% accuracy (a 9.08% error margin). The majority of readings were within acceptable limits, indicating generally suitable water quality for lettuce. However, the system would require occasional adjustments to address extreme deviations, such as those observed in Trial 4.

Table 3.
Summary of pH Level Sensor Testing Results

Trial No.	Measured pH Level	Reference pH Level	Deviation (±)
1	6.88	6.50	0.38
2	6.79	6.50	0.29
3	5.62	6.50	0.88
4	9.79	6.50	3.29
5	6.36	6.50	0.14
Average Measured pH	7.09		
Percent Error	9.08%		
Accuracy	90.92%		
Verbal Interpreta-tion	Very Good		

IV. Filtration Efficiency Measurement and Sensor Accuracy

The water filtration efficiency (92%) was determined using the concentration-based removal efficiency formula commonly used in water treatment engineering and hydroponic system evaluations (Ma et al., 2023; Das, 2024):

$$\textbf{Filtration Efficiency (\%)} = [(C\_initial - C\_final) / C\_initial] \times 100$$

where *C_initial* represents the contaminant concentration before filtration, and *C_final* is the concentration after treatment. Samples were analyzed for turbidity, total dissolved solids (TDS), and pH levels before and after passing through the multi-stage filter (gravel, sand, activated charcoal, and pebbles). Data were averaged over three consecutive trials, confirming consistent performance in removing impurities while maintaining suitable pH for hydroponic use.

Sensor Accuracy Validation

Sensor accuracy (e.g., DHT-22, pH, and water level sensors) was assessed by comparing sensor readings to calibrated laboratory instruments. Each reading was tested 15 times per sensor at different times of the day to account for environmental variability. The average deviation percentage across trials determined the final accuracy metric. This validation process follows the same comparative approach used in agricultural sensor calibration studies by Paturkar et al. (2022).

V. Sensor deviations and fluctuations in measurement

During system testing, some pH readings, such as Trial 4 with a value of 9.79, were outside the ideal range for growing lettuce (Lactuca sativa), which is between pH 5.5 and 6.5 (Ahmed et al., 2020). These irregular readings may be caused by sensor calibration errors, electrical noise, or slow mixing of nutrients in the water tank. Although short-term changes do not immediately harm the plants, long-term exposure to very high or low pH levels can decrease how well the plants absorb nutrients and slow their growth.

When the pH level rises above 7.5, essential nutrients like iron, manganese, and phosphorus become more difficult for plants to absorb, leading to slower growth and pale or discolored leaves. Conversely, highly acidic water can harm the roots and hinder oxygen intake. In Trial 4, where the pH reached 9.79, the issue was temporary and was quickly resolved in later trials, suggesting it was likely caused by a minor sensor or mixing error rather than a major system fault.

E. Quality Testing

A four-week quality assessment of Romaine Lettuce (Lactuca sativa L. var. longifolia) confirmed the effectiveness of the GlaciaGrow system. The plants showed consistently healthy green color with no discoloration, indicating optimal chlorophyll levels and stable growth conditions. Leaf texture gradually changed from soft (Weeks 1–2) to loose (Week 3) and finally to firm (Week 4), with 80% of the lettuce reaching ideal maturity.

Quantitative growth metrics indicated strong performance. Plant height was consistent and very uniform in Week 3 (98.14% accuracy), with only minor variability appearing by Week 4 (87.39%). Weight measurements improved from initial inconsistencies to nearly perfect consistency by harvest (97.19% accuracy). Both leaf width (99.89% accuracy) and top-view canopy length (97.7% accuracy) stabilized remarkably, demonstrating uniform development.

Compared to expert benchmarks, the GlaciaGrow-grown lettuce met or nearly met the standards of Baguio lettuce within four weeks. The system performed especially well in leaf width accuracy and weight consistency, with slight potential for improvement in final height uniformity. These results together confirm that the GlaciaGrow system is highly effective at producing quality lettuce with optimized growth parameters.

Table 4.
GLACIAGROW Lettuce crop results

Sample	Weight (g) Exp: 160g	Height (cm) Exp: 23cm	Top View (cm) Exp: 28cm	Leaf Width (cm) Exp: 9cm	Leaf Texture
1	160	20	28	10	FIRM
2	160	27	26	9	FIRM
3	165	20	29	10	FIRM
4	150	19	26	8	FIRM
5	155	21	31	8	FIRM
6	155	16	20	8	FIRM
7	160	18	25	10	FIRM
8	150	23	35	10	LOOSE
9	150	20	26	8	FIRM
10	150	17	23	8	LOOSE
Average	**155.5**	**20.1**	**26.9**	**8.9**	**80% FIRM**
Percent Error	**2.81%**	**12.61%**	**3.93%**	**1.11%**	-
Accuracy	**97.19%**	**87.39%**	**96.07%**	**98.89%**	-
Interpretation	**Very Satisfactory**	**Good**	**Very Satisfactory**	**Excellent**	**Satisfactory**

Figure. 6: GLACIAGROW actual Lettuce crop result (representation of its common measurements)

F. Compare the harvested crops to the standard criteria provided by the Expert Farmer

A comparative analysis reveals that the GlaciaGrow system produced lettuce in four weeks that was competitive with the expert benchmark of Baguio lettuce, which requires an eight-week growth period. The GlaciaGrow lettuce matched or closely approached key benchmarks, demonstrating exceptional precision in leaf width (99.89% accuracy) and strong performance in top-view width (97.7% accuracy) and weight (97.19% accuracy).

The primary area for improvement is in vertical development; the GlaciaGrow lettuce showed more height variation (87.39% accuracy) and a slightly lower average height (20.1 cm vs. the 21.36 cm standard). Nevertheless, achieving comparable development in half the time underscores the system's strong potential. With minor refinements to enhance growth consistency, particularly in vertical development and leaf expansion, the GlaciaGrow system is positioned to efficiently meet or surpass expert benchmarks.

Table. 5.1.
GLACIAGROW Actual Lettuce Crops Results vs Baguio Benchmark

Parameter	Average Measured Value		Accuracy	
	Baguio Lettuce 8 Weeks	GlaciaGrow Lettuce 4 Weeks	Baguio 8 Weeks	GlaciaGrow 4 Weeks
Color	GREEN	GREEN	-	-
Texture	FIRM	FIRM	-	-
Weight	169g	155.5g	94.37%	97.19%
Height	21.36cm	20.1cm	92.87%	87.39%
Top View Length	26.82cm	26.9cm	95.79%	97.07%
Leaf Width	10cm	8.9cm	89.89%	98.89%
Overall Accuracy	**93.23%**	**95.11%**	**Satisfactory**	**Very Satisfactory**

Table. 5.2.
Performance Interpretation Summary

Parameter	Baguio 8 Weeks Interpretation	GlaciaGrow 4 Weeks Interpretation	Advantage
Weight	Satisfactory	Very Satisfactory	GlaciaGrow
Height	Satisfactory	Good	Baguio
Top View Length	Very Satisfactory	Very Satisfactory	Equal
Leaf Width	Very Good	Excellent	GlaciaGrow
Overall	**Satisfactory**	**Very Satisfactory**	**GlaciaGrow**

To ensure replicability and transparency of the GlaciaGrow system’s reported performance metrics, detailed computational explanations are provided for key accuracy and efficiency results. The following formulas and measurement bases were derived from established agricultural and engineering research standards.

Accuracy Computation for Growth Metrics

The accuracy percentages reported for parameters such as leaf width, height, and weight were calculated using the following formula:

Accuracy (%) = [1 - (|Measured Value - Reference Value| / Reference Value)] ×

100

This formula is consistent with the measurement approaches discussed by Paturkar et al. (2022), who applied mean absolute percentage error (MAPE) in plant phenotyping, and by Ma et al. (2023), who evaluated hydroponic lettuce leaf expansion size using comparative measurement of reference and observed values. These studies confirm the standard practice of comparing actual plant measurements against reference benchmarks to determine accuracy or error.

Reference values were obtained from standard lettuce growth benchmarks provided by an Expert Farmer (Baguio-grown lettuce). Each GlaciaGrow measurement was taken from five representative samples under identical environmental conditions. The values were averaged and compared to the reference to determine the percent accuracy for each growth characteristic.

For example, a measured average leaf width of 8.9 cm was compared to a standard reference width of 10 cm, yielding:

$$\textbf{Accuracy} = [1 - (|8.9 - 10| / 10)] \times 100 = 99.89\%$$

This approach, equivalent to “1 minus the percentage error” method described by Paturkar et al. (2022), ensures standardized comparison and reproducibility of results in crop phenotyping.

Related system comparative analysis

The integration of automation, IoT, and sustainable energy into hydroponic systems has attracted considerable attention from agricultural researchers. Several studies have shown that smart hydroponics can optimize water and nutrient use, boost productivity, and lessen environmental impact, as demonstrated by the GlaciaGrow project. This project proposes ideas for developing a more comprehensive and refined hydroponic system. To compare, the following are the most related works and how they differ from the more advanced system, which is the GlaciaGrow project.

Ahmed et al. (2020) discussed the optimal control of environmental factors in lettuce cultivation using artificial lighting and closed-loop systems, specifically the responses of carbon dioxide and water to ultraviolet light for growth optimization. Their research highlighted how microcontrollers can stabilize temperature and humidity but lacked integration of water recycling components. Similarly, Frasetya et al. (2021) examined various hydroponic configurations and found that while sensor-based systems improved plant uniformity, they were often energy-intensive and limited to single power sources.

Li et al. (2021) explored LED spectrum optimization in hydroponic lettuce systems, emphasizing plant growth under different light wavelengths. Their study contributed to understanding light efficiency but did not address wastewater filtration or the integration of sustainable energy. Meanwhile, Das (2024) proposed a hydroponic method for paddy nursery water conservation, revealing that integrating filtration could reduce water waste by up to 70%, though automation remained minimal.

Other models, such as Solis (2023), incorporated organic nutrient sources under hydroponic setups but relied heavily on manual monitoring, making scalability difficult. These limitations indicate a research gap in developing integrated systems that balance automation, energy efficiency, and resource sustainability.

The GlaciaGrow system advances these models by merging multiple sustainability strategies: automated Deep-Water Culture (DWC) hydroponics, dual power supply (solar and AC), and a multi-stage filtration process that recycles wastewater through gravel, sand, activated charcoal, and pebbles. Additionally, GSM-based notifications allow remote environmental monitoring, ensuring precision control over growth conditions. Compared to existing smart hydroponics systems, GlaciaGrow not only enhances automation and monitoring but also incorporates closed-loop water recycling, offering a more sustainable and adaptable solution for urban agriculture.

Conclusion

The GlaciaGrow project successfully developed an automated Deep-Water Culture (DWC) hydroponics system for Romaine lettuce using an ATmega2560 microcontroller. The system integrates climate control, intelligent sensors, water management, and high-end filtration to support efficient and sustainable plant growth. A working prototype was built, demonstrating reliable operation with real-time monitoring via an LCD and GSM notifications, auto-crop selection between lettuce and pechay, and a hybrid power source using both solar and grid electricity. Within four weeks, the system produced high-quality lettuce with only minimal adjustments needed for height consistency.

To further improve its sustainability, efficiency, and reliability, several enhancements are proposed. These include adding an automatic pH dosing system with regular calibration and aeration, incorporating vertically mounted tube-style LED grow lights for more energy-efficient illumination, expanding the solar capacity to 1.5kW, paired with innovative energy storage software, and integrating a rainwater harvesting and purification system to reduce groundwater use. These upgrades aim to increase energy efficiency, reduce environmental impact, and ensure consistent performance. Future trials are recommended to evaluate the precise benefits of these improvements on crop growth and system operation, following the automated control principles described by Li et al. (2021) and Frayco et al. (2023).

References

Ahmed, H. A., Yu-Xin, T., & Qi-Chang, Y. (2020). Optimal control of environmental conditions affecting lettuce plant growth in a controlled environment with artificial lighting: A review. South African Journal of Botany, 130, 75–89. https://doi.org/10.1016/j.sajb.2019.12.018

Angeles-Agdeppa, I., Sarmiento, A., & De Leon, A. (2022). Impacts of COVID-19 pandemic on household food security and access to social protection programs in the Philippines. https://doi.org/10.1177/03795721221078363

Borres Jr., E. C., Basulgan, E. B. & Dalanon, R. L. (2022). Potentialities of Lettuce

(Lactuca Sativa L.) in Hydroponics System Under Simple Nutrient Addition Program (SNAP). Journal of Education, Management, and Development Studies, 2(1), 76-85. https://doi.org/10.52631/jemds.v2i1.62

Das, R. (2024). Hydroponics in paddy nursery for water conservation. https://doi.org/10.22271/27889289.2024.v4.i1c.129

Erecson Sipin Solis. (2023). Performance evaluation of pechay (Brassica rapa var. chinensis) using different organic growing media under hydroponic system. IOP Conference Series, 1208(1), 012038. https://doi.org/10.1088/1755-1315/1208/1/012038

Felipe, A. J. & Bareng, J. L. (2021). Growth and yield of lettuce under capillary wick irrigation. Plant Science Today. http://blishing.com/journals/index.php/PST/article/download/1460/965

Food and Agriculture Organization (FAO). Food security in the Philippines. https://www.fao.org/

Frasetya, B., et al. (2021). Hydroponics systems' effect on lettuce growth. IOP Conf. Series: Materials Science and Engineering, 1098(4). https://iopscience.iop.org/article/10.1088/1757-899X/1098/4/042115

Frayco, J. G., et al. (2023). The effects of naturally-fermented organic concoctions on the growth and yield of hydroponic lettuce (Lactuca sativa L.). SDSSU Multidisciplinary Research Journal, 10(1), 10–15. https://smrj.nemsu.edu.ph/index.php/SMRJ/article/view/260

The Hydroponics Manual: Lighting. (2025). 1-Hydroponics.co.uk. https://www.1-hydroponics.co.uk/lighting-manual

Kim, J., et al. (2022). One health challenges in rural Philippines. https://doi.org/10.1186/s42522-022-00063-0

Lee, M., et al. (2022). UV-A LEDs' effects on lettuce nutrition. Horticulturae, 8(8), 680. https://doi.org/10.3390/horticulturae8080680

Li, J., et al. (2021). LED spectrum effects on lettuce in hydroponics. Front. Plant Sci. 12:678197. https://doi.org/10.3389/fpls.2021.678197

Loconsole, D. & Santamaria, P. (2021). UV lighting in horticulture. Horticulturae, 7(1), 9. https://doi.org/10.3390/horticulturae7010009.

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CReDiT: **Acepcion**: Draft and Editing of Documents. **Alforte**: Software designing of system **Ayaso**: Hardware designing of system. **Balanza**: Structure planning and placing of system design. **Bernal**: Co-editor of Coding and Software design of system **Olila**: Document Reviewing, Editing and Data outsourcing.

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Disclaimer: Paragraph compositions and grammar are enhanced/improved through AI.