TCN 4940 – Senior Project
Fall 2025

Automated Hydroponic System

Final Report

Team 1
William K. Coleman (6404570)
Boris Navaro (6334916)

GitHub

December 14, 2025
Florida International University
Department of Electrical and Computer Engineering
Instructor: Dr. Gustavo Chaparro-Baquero
Mentor: Dr. Alexander Perez-Pons

Commented [BN1]: Please add your Panther ID

Table of Contents

4

Acknowledgements

Abstract

For centuries, we have observed and seized the usefulness of planting, growing, and harvesting crops. Compared to solely hunting and gathering, it is a much more sustainable approach to survival. Today, we gain our food by traveling to stores and purchasing either ready-made food or their ingredients to cook later. These purchase prices have been on the rise, and our automotive field has been moving towards more sustainable forms of transportation. Gardening at home tackles both concerns, reducing food expenses and potential automobile pollutants. Albeit, gardening can be considered an arduous task, so we are focusing on a specific kind of gardening: hydroponics. Hydroponic gardening includes suspending plant's roots in nutrient rich water, rather than being buried and watered in soil. Proposed and implemented is an automated version of hydroponic gardening, aiming for our users to set up once, monitor health/progress, receive alerts remotely, act accordingly, then harvest when their fruit or vegetables have fully grown. To determine objectives and specifics, we surveyed our client and potential users and conducted our own brainstorming session. After some more analysis on needs, feasibility, risks, and the current market, we came up with our automated hydroponic system. Compared to other systems, we have included monitoring and the remote adjustment of PH and nutrient levels to our user's fingertips. With our product, users will be able to grow their food effortlessly, from the comfort of anywhere they choose. Addressed as well are ethical concerns, health and safety, intellectual property claims, and standards to reassure the user of a properly thought-out product. To also help the user understand their impact they are causing by gardening at home, we have explained the sustainable aspect of our system, including water conservation, energy usage, material lifecycle/recycling, and carbon footprint reductions. Some parts could not be implemented, such as a solar powered version, custom-designed enclosure, and artificial intelligent camera to monitor plant health. This solution does not violate any intellectual property rights. The product prototype was expanded on and realized within one semester, from September 2025 to November 2025.

I. Problem Statement

With food prices rising and quality often compromised, many people are seeking healthier, more affordable alternatives. Studies suggest that home/community gardening results in "greater fruit and vegetable consumption, better access to healthy foods, greater valuing of cooking, harvest sharing with family and friends, enhancing importance of organic production, and valuing of adequate and healthy food [1]." However, many do not even attempt to start growing their own vegetables and fruits because of factors such as time, filthiness, space, etc.

Our project proposes a clean space-efficient hydroponic automation system that enables users to grow fresh leafy vegetables at home with reduced human intervention. The system uses 2″ PVC pipes that hold net cups and circulates water filled with nutrients, using a ½″ PVC for the return line to a central reservoir. A water pump drives recirculation on a timer, while a nutrient feeder pumps plant food solution to the water reservoir when a total dissolved solids (TDS) sensor detects low level of nutrients, and a pH sensor module activates pH-UP or pH-DOWN solutions when it detects high basic or high acidic levels in the nutrient solution accordingly. An ultrasonic level sensor placed on the plant food's container continuously measures feed level.

A microcontroller-based control unit houses the electronics with batteries and a power outlet, and runs closed-loop logic for timing, dosing, and safety interlocks. A lightweight server records water and nutrient levels, displays a simple dashboard for readings and pump activation, and notifies users (In-app notifications) when thresholds are reached. The design is modular and scalable—from countertop units to multi-channel systems.

II. Assumptions and Limitations

A. Assumptions

The following assumptions were made during the design and implementation of the automated hydroponic system. These assumptions represent design decisions that directly influence system architecture, component selection, and control logic.

Single-Reservoir Operation
The system assumes a single main water reservoir supplying all plants with nutrient-rich water. All sensor measurements and dosing decisions are based on the conditions of this shared reservoir.

Fixed Target Ranges
The system assumes predefined acceptable ranges for pH and TDS based on a general plant growth profile. Dynamic adjustment based on crop type or growth stage is not implemented.

Uniform Nutrient Mixing

It is assumed that the circulation pump provides sufficient mixing such that sensor readings accurately represent the overall reservoir conditions after dosing events.

Sensor Calibration Validity

The control logic assumes that pH and EC/TDS sensors are properly calibrated prior to operation and that calibration remains valid during normal use.

Stable Power Supply

The system assumes a stable and continuous power source. Sudden power loss during dosing or measurement cycles is not actively mitigated.

Single Control Unit

The design assumes one microcontroller is sufficient to handle sensor acquisition, control logic, and cloud communication without timing conflicts.

B. Limitations

The following limitations arise from factors outside the team's direct control or from practical constraints of the prototype implementation.

Sensor Degradation Over Time

pH and EC probes are subject to wear, fouling, and drift due to prolonged exposure to nutrient solutions, which can reduce measurement accuracy over time.

Scalability Constraints

The current system implementation is limited in scalability. Expanding to multiple reservoirs or larger grow areas would require additional sensors, actuators, and modified control logic.

Network Dependency

Cloud-based monitoring depends on Wi-Fi availability. Loss of network connectivity prevents remote monitoring but does not stop local automation.

Limited Visual Feedback

The current implementation does not include visual plant health monitoring, limiting system awareness to water chemistry parameters only.

Mechanical Layout Constraints

The cylindrical reservoir and PVC pipe diameter impose physical limitations on sensor placement, water flow capacity, and overflow prevention.

Fixed Dosing Resolution

Dosing is performed in discrete time-based intervals rather than precise volumetric control, which limits fine-grain nutrient and pH adjustment accuracy.

III. Needs & Feasibility Analysis

A. Needs Analysis

From our client's interview and users' survey responses (see Appendix A) to our brainstorming, we gather that many believe growing plants requires intensive human labor measuring the different parameters that will allow plants to grow and thrive, a large space where to grow them, and a costly infrastructure. The project aims at reducing that, adding pH, TDS, and nutrient level reading capabilities and automating dosing/feeding, and regulating pH and TDS levels in addition to adding a visualization dashboard that would allow users to act if needed.

Below is a closer look at our refinement process via user input, our client's suggestions, and a separate brainstorming session:

Client (mentor) Interview

TABLE I. CLIENT ATTRIBUTES

Source	Attribute
Client	The project should be easy to build
Client	The project is developed quickly
Client	The project includes use of Artificial Intelligence (Optional)
Client	The system should look nice.
Client	The product should reduce human labor.
Client	The product should send data to a server.
Client	The product is intended for leafy vegetables.

User Survey

TABLE II. USER SURVEY ATTRIBUTES

Source	Attribute
Survey	The product should have an interactive interface.
Survey	The product should have a mobile interface.
Survey	The product should have a pump powerful enough to bring water up to at least 6 feet.
Survey	The product should not cost over $300.
Survey	The water in the reservoir should not go dry.
Survey	The product should have some sort of barrier to minimize the threat of pests.
Survey	The product should add solar power to allow for powering
Survey	The product should allow the growth of herbs, houseplants, and fruiting plants
Survey	The setup instructions should be around six or seven steps max.
Survey	This product should be applicable to indoors and outdoors applications

Brainstorming

TABLE III. DESIGNER ATTRIBUTES

Source	Attribute
Team	The ESP32 board should be powered with a 5V battery.
Team	The microcontroller unit casing should be waterproof.
Team	The dosing and pH pumps should be powered with a 12V battery.
Team	The pH range should be between 5.5 - 6.2
Team	The EC should be measured 2-3 times a week.
Team	The water should circulate 1.5 to 2 L/min
Team	The product should be placed close to a water source.
Team	The product should have a long battery life.
Team	The plants should have a certain amount of direct sunlight every day.
Team	The water in the plants bed should be constantly running
Team	The plants' food should make up for the ingredients they typically obtain from the soil.

Attributes

From here the collected attributes are combined and our solution's objectives are isolated by removing duplicates and pruning attributes that do not describe a possible objective of our proposed solution (tables IV-VI). The objectives are then grouped (table VII):

TABLE IV. COMBINED ATTRIBUTES

Item No.	Source	Attribute	Duplicate
1	Client	The project should be easy to build	X
2	Client	The project is developed quickly	
3	Client	The project includes use of Artificial Intelligence (Optional)	
4	Client	The system should look nice.	
5	Client	The product should reduce human labor.	
6	Client	The product should send data to a server.	
7	Client	The product is intended for leafy vegetables.	
8	Survey	The product should have an interactive interface.	X
9	Survey	The product should have a mobile interface.	X
10	Survey	The product should have a pump powerful enough to bring water up to at least 6 feet.	
11	Survey	The product should not cost over $300.	
12	Survey	The water in the reservoir should not go dry.	X
13	Survey	The product should have some sort of barrier to minimize the threat of pests.	
14	Survey	The product should add solar power to allow for powering	

15	Survey	The product should allow the growth of herbs, houseplants, and fruiting plants	
16	Survey	The setup instructions should be around six or seven steps max.	X
17	Survey	This product should be applicable to indoors and outdoors applications	
18	Team	The ESP32 board should be powered with a 5V battery.	
19	Team	The microcontroller unit casing should be waterproof.	
20	Team	The dosing and pH pumps should be powered with a 12V battery.	
21	Team	The pH range should be between 5.5 - 6.2	
22	Team	The EC should be measured 2-3 times a week.	
23	Team	The water should circulate 1.5 to 2 L/min	X
24	Team	The product should be placed close to a water source.	
25	Team	The product should have a long battery life.	
26	Team	The plants should have a certain amount of direct sunlight every day.	
27	Team	Water in the plants bed should be constantly running	X
28	Team	Plants' food should make up for the ingredients they typically obtain from the soil.	

TABLE V. CATEGORIZED COMBINED ATTRIBUTES

Source	Attribute	Type
Client	The product should be easy to build	
Client	The product is developed quickly	Constraint
Client	The product includes use of Artificial Intelligence (Optional)	Constraint
Client	The system should look nice.	
Client	The product should reduce human labor.	
Client	The product should send data to a server.	Constraint
Client	The product is intended for leafy vegetables.	Constraint
Survey	The product should have an interactive interface.	
Survey	The product should have a pump powerful enough to bring water up to at least 6 feet.	Constraint
Survey	The product should not cost over $300.	Constraint
Survey	The product should have some sort of barrier to minimize the threat of pests.	Implementation
Survey	The product should add solar power to allow for powering	Implementation
Survey	The product should allow the growth of herbs, houseplants, and fruiting plants	
Survey	This product should be applicable to indoors and outdoors applications	
Team	The ESP32 board should be powered with a 5V battery.	Constraint

Team	The microcontroller unit casing should be waterproof.	Constraint
Team	The Dosing and pH pumps should be powered with a 12V battery.	Constraint
Team	The pH range should be between 5.5 - 6.2	Constraint
Team	The EC should be measured 2-3 times a week.	Constraint
Team	The water should circulate 1.5 to 2 L/min	Constraint
Team	The product should be placed close to a water source.	
Team	The product should have a long battery life.	
Team	The plants should have a certain amount of direct sunlight every day.	
Team	The plants' food should make up for the ingredients they typically obtain from the soil.	Constraint

TABLE VI. PRUNED LIST OF OBJECTIVES

Source	Attribute
Client	The product should be easy to build
Client	The system should look nice.
Client	The product should reduce human labor.
Survey	The product should have an interactive interface.
Survey	The product should allow the growth of herbs, houseplants, and fruiting plants
Survey	This product should be applicable to indoors and outdoors applications
Team	The product should be placed close to a water source.
Team	The product should have a long battery life.
Team	The product's plants should have a certain amount of direct sunlight every day.
Team	The plants' food should make up for the ingredients they typically obtain from the soil.

TABLE VII. ATTRIBUTES GROUPED AS OBJECTIVES

Source	Attribute	Objective Group
Client	The product should be easy to build	Marketable
Client	The system should look nice.	Marketable
Client	The product should reduce human labor.	Marketable
Survey	The product should have an interactive interface.	Marketable
Survey	The product should allow the growth of herbs, houseplants, and fruiting plants	
Survey	This product should be applicable to indoors and outdoors applications	
Team	The product should be placed close to a water source.	Longevity
Team	The product should have a long battery life.	Longevity
Team	The product's plants should have a certain amount of direct sunlight every day.	Longevity

Team	The plants' food should make up for the ingredients they typically obtain from the soil.	Longevity

Now, below are the solution's finalized objectives and constraints, followed by a refined problem statement that reflects the needs of our client, users, and selves.

Objectives:

1. Marketability
   1.1. The product should be easy to build
   1.2. The product should look nice
   1.3. The product should reduce human labor
   1.4. The product should have an interactive interface
2. Longevity
   2.1. The product should be placed close to a water source
   2.2. The product should have a long battery life
   2.3. The product's plants should have a certain amount of direct sunlight every day
   2.4. The plants' food should make up for the ingredients they typically obtain from the soil
3. The product should allow the growth of herbs, vegetables, houseplants, and fruiting plants
4. The product should be applicable to indoors and outdoors applications

Constraints

1. The product is developed quickly
2. The product includes use of Artificial Intelligence (Optional)
3. The product should send data to a server
4. The product is intended for leafy vegetables
5. The product should have a pump powerful enough to bring water up to at least 6 feet
6. The product should not cost over $300
7. The ESP32 board should be powered with a 5V battery
8. The microcontroller unit casing should be waterproof
9. The Dosing and pH pumps should be powered with a 12V battery
10. The pH range should be between 5.5 - 6.2
11. The EC should be measured 2-3 times a week
12. The water should circulate 1.5 to 2 L/min

Refined Problem Statement

With the rising cost of food and the demand for healthier, chemical-free produce, individuals are increasingly turning to home and community gardening to ensure access to fresh vegetables and herbs. However, many people are discouraged from growing their own plants due to the

perceived challenges of limited time, lack of space, maintenance effort, and the mess associated with traditional soil-based gardening [1].

To address these challenges, this project proposes the development of an **automated hydroponic system** that is affordable, marketable, and user-friendly. The system will reduce human labor by automating essential tasks such as nutrient dosing, pH balancing, and water circulation, while also providing an interactive interface for users to monitor plant health. Designed for both indoor and outdoor use, the product will support the growth of herbs, leafy vegetables, houseplants, and select fruit plants.

The system will be compact, aesthetically appealing, and easy to build. It will utilize a water pump capable of circulating 1.5–2 L/min and lifting water up to six feet, while dosing and pH regulation pumps ensure that plants receive the nutrients typically provided by soil. Sensors will track environmental parameters such as pH (maintained between 5.5–6.2), nutrient concentration (TDS, measured 2–3 times weekly), and plant food levels, with data transmitted to an online dashboard for user analysis and alerts.

Powered by an ESP32 microcontroller running on 5V and 12V support for dosing/pH pumps, the control unit will be waterproof, durable, and capable of long-term operation near a water source. The design emphasizes cost efficiency, with a target production cost of under $300. While artificial intelligence integration is optional, the system will ensure longevity and adaptability by supporting modular scaling and maintaining optimal conditions for plant growth with minimal user intervention.

This solution aims to make hydroponics accessible, efficient, and sustainable, empowering individuals to grow fresh produce at home or in community spaces without the traditional barriers of time, space, and manual labor.

B. Needs Specification

The refined problem statement and objectives are excellent starting points to narrow down the specifications of our proposed solution. Below is our understanding of what is necessary for our implementation to be a successful iteration of our proposed automated hydroponics system. Specifications are derived from the objectives determined our needs analysis. These specifications are the detailed parameters that will be included in our implementation.

TABLE VIII. SPECIFICATIONS

Objectives	Specification	Justification
2, 4	Should have a sleek design without too many rough edges.	Users purchasing parts and following our lead want to be happy with their final product.
1, 3	Will have fewer than 30 steps to fully build and implement.	Users want to quickly start gardening with their hydroponics system. It is possible if enough is planned out and specific parts are chosen. Code deployment is simple.

2, 5, 7	Will be placed in an optimal spot for plants to thrive.	Whether indoors or outdoors, there is a proper place to put hydroponics. They will always need some sort of light since they are plants.
7, 10	Documentation will include optional placements for hydroponic plants.	Users have personal preferences, and some like having plants indoors. Possible with alternate setups.
8, 9, 3	Nutrients circulated will have at least 50% of the nutrients typically found in good soil.	Reassuring users of nutrition and ensuring hydroponic plants are thriving the best they can. Ideally, monitored and replenished when necessary.
3, 6	The system will have 12V and 5V power sources where necessary	The pumps and microcontrollers need a power source to operate unmanned.
3, 4	Digital displays will be available for viewing.	The appeal of an automated system is the ease of certain things, in this case access to information— particularly, plant health and water quality levels.

Objectives
1. The product should be easy to build
2. The product should look nice
3. The product should reduce human labor
4. The product should have an interactive interface
5. The product should be placed close to a water source
6. The product should have a long battery life
7. The product's plants should have a certain amount of direct sunlight every day
8. The plants' food should make up for the ingredients they typically obtain from the soil
9. The product should allow the growth of herbs, vegetables, houseplants, and fruiting plants
10. The product should be applicable to indoors and outdoors applications

C. Feasibility Analysis

With the specifications and objectives in mind, a well-defined problem statement, and a clear needs analysis, it is time to analyze whether our project is viable or not. We have considered seven types of feasibility: technical, resource, economic, schedule, cultural, legal, and marketing. Each type has considerations, scored from zero to five based on how feasible the product with the consideration in mind.

Technical Feasibility Analysis

TABLE IX. TECHNICAL FEASIBILITY ANALYSIS.

Consideration	Score	Reasoning	Solution
Does the necessary technology exist?	5	All components are available	N/A
Is it locally available?	5	All parts can be found locally	N/A
Can it be obtained?	5	Locally and online	N/A
Are new inventions required?	5	No new inventions required	N/A
Are there technical risks?	2	WiFi range, calibration accuracy	Add WiFi extenders, Testing and code optimization
Total	22		
Average	4.4		

Resources Feasibility Analysis

TABLE X. RESOURCES FEASIBILITY ANALYSIS

Consideration	Score	Reasoning	Solution
Do I have sufficient skills?	4	Calibrating pH, and EC sensors	Research on calibration of such sensors
Do I have sufficient equipment?	5	Yes	N/A
Is there a sufficient number of people?	4	A team of two may feel overwhelmed at times.	Clear task division and effective time management
Total	13		
Average	4.3		

Economic Feasibility Analysis

TABLE XI. ECONOMIC FEASIBILITY ANALYSIS

Consideration	Score	Reasoning	Solution
Is the project possible, given budget constraints?	5	Low-cost components	N/A
How much economic risk is there?	4	Cheap hardware is always a risk.	Buy extra parts in case
Total	9		
Average	4.5		

Schedule Feasibility Analysis

TABLE XII. SCHEDULE FEASIBILITY ANALYSIS

Consideration	Score	Reasoning	Solution
Can the intermediate mileposts be reached?	5	We have a schedule with clear due dates.	N/A
Can preliminary design review requirements be met in time?	5	As long as we stay on task	Staying on task
Can critical design review requirements be met on time?	5	As long as we stay on task	Staying on task
How much schedule risk is there?	4	Any unforeseeable event happening	Working ahead of schedule whenever possible.
Total	19		
Average	4.75		

Cultural Feasibility Analysis

TABLE XIII. CULTURAL FEASIBILITY ANALYSIS

Consideration	Score	Reasoning	Solution
Will there be a positive impact on the local culture?	5	Promotes sustainable food production and water conservation	Proper advertising
Will there be a positive impact on global culture?	4	In certain countries, nutrients are unavailable in the market or have prohibitive prices	Showcase how nutrients can be locally made.
How much cultural risk will there be?	5	No risks	NA
Total	14		
Average	4.7		

Legal Feasibility Analysis

TABLE XIV. LEGAL FEASIBILITY ANALYSIS

Consideration	Score	Reasoning	Solution
Are there any organizational conflicts or policies?	5	No conflicts	N/A
Are there any laws or regulations impeding the project?	5	No regulations or laws on the use of this product	Complies with general safety and electrical standards.
Are there any laws or regulations limiting the project?	5	Same as above	N/A

How much legal risk will there be?	5	Our system does not involve hazardous materials, high-voltage systems, or wireless communication protocols that require special licenses.	N/A
Total	20		
Average	5		

Marketing Feasibility Analysis

TABLE XV. MARKETING FEASIBILITY ANALYSIS

Consideration	Score	Reasoning	Solution
Will the general public accept the product?	5	It makes food production easier, more efficient, and environmentally friendly	Creating a sleek design that appeals to most.
Will the intended user accept the product?	5	Food production is low maintenance and provides fresh produce	
Will the product be on par with similar products?	3	There are similar established products in the market, which is a challenge	Integrating with mobile and cloud-based platforms to monitor the system.
How much marketing risk will there be?	4	That new similar systems emerge as we develop ours	Staying up to date with the new trends
Total	17		
Average	4.25		

IV. Risks Analysis

Now we are taking a last detour before development for a risk analysis. Here risks to the success of our product are listed, visualized on a graph, and later scored in a risk assessment. This explains the difficulties that we knew of before beginning to implement our solution.

1. Technical [T]

    T.1. Wi-Fi range & calibration accuracy

2. Resource [R]

    R.1. Team size
    R.2. Knowledge of calibrating pH and EC sensors

3. Economic [E]

    E.1 Low-cost parts may not last long.

4. Schedule [S]

    S.1. An unforeseeable event occurring

5. Legal [L]

    L.1. No legal risks identified

6. Marketing [M]

    M.1. Similar established products in the market

7. Fault Tree Analysis

GRAPH I: FAULT TREE ANALYSIS
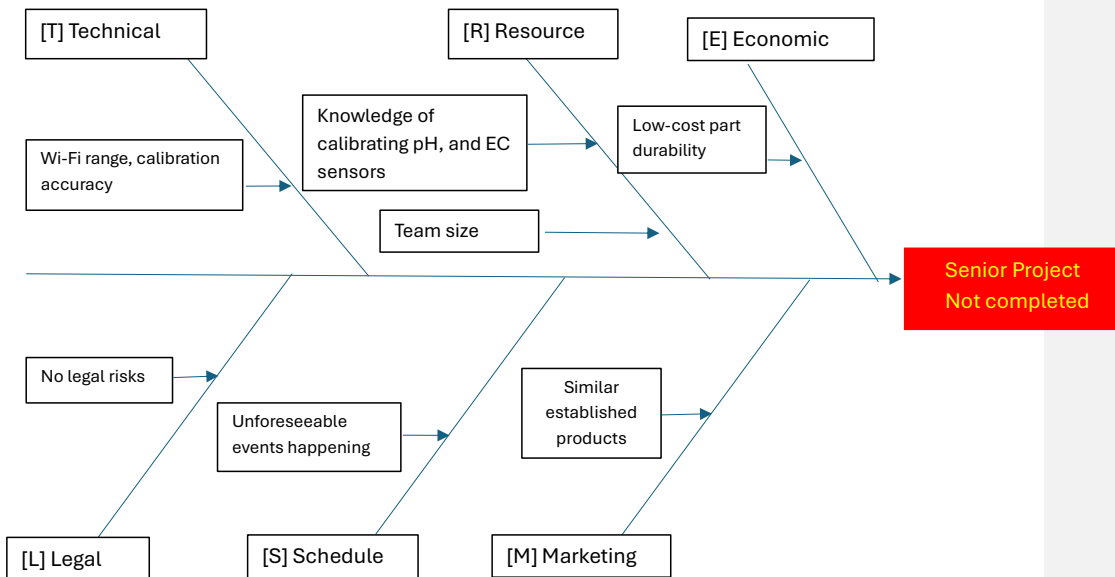
The Fault Tree Graph above shows a visual view of the risks we are facing during the preparation and implementation of our solution. In the technical area, we identified two areas of concern: Wi-Fi range and the distance of our system to the nearest hotspot. Regarding resources: this is a team of two which may become overwhelming overtime, and we identified that calibrating the pH and TDS sensors can be a challenge; not being able to calibrate TDS and pH sensors can put our implementation in jeopardy. In economics, the most challenging part is the durability of our TDS and pH sensors, which will be exposed to water for long periods of time. For scheduling, we identified that any unforeseeable event could hinder our progress. Our hydroponic system conforms to any regulatory use of electronic devices. Finally, Marketing is always something we will need to keep monitoring in case a similar products comes in the market.

A. Risk Assessment

A risk assessment can now be conducted. A risk exposure matrix has been developed to categorize each risk based on its severity and the likelihood of its occurrence. Class I risks fall below the acceptable threshold and need no active management. Class II risks are at the threshold and should be closely monitored. Class III risks go beyond the threshold and require proactive measures, while Class IV risks greatly exceed the threshold and demand immediate intervention. The likelihood of risk events is grouped into three levels: very unlikely, unlikely, and possible.

The table below shows how likely the risks, identified earlier, are to occur and the severity of their impact on our implementation.

TABLE XVI. LIKELIHOOD OF OCCURRENCE

Likelihood of Occurrence				
	Very Unlikely	Unlikely	Possible	Legend
Class IV			[M.1]	Catastrophic
Class III		[T.1]		Severe
Class II		[R.2]	[S.1] [E.1]	Moderate
Class I	[L.1] [R.1]			Low

To mitigate the impact of the risks outlined above, we have come up with a set of actions (see below) that will increase the chances of our implementation to succeed.

TABLE XVII. ACTIONS

Actions	
[L.1] [R.1]	None
[T.1]	Add Wi-Fi extenders for range, and code compensation functions to calibrate
[R.2]	Delegate responsibility and work ahead of schedule.
[S.1]	Work ahead of schedule to avoid unforeseeable events impact.

|	
[E.1]	Schedule sensors to work at specific intervals to extend their lives.
[M.1]	Research about similar products in the market
	Continue monitoring

V. Block Diagrams

Now we began our planning process, listing all the components we would need and how they might interact. Version one of our drawn designs focused on our system's components and their connection to the ESP-32 microcontroller. This worked for a while, until we looked at our electrical section and brought in relays. Version two of our drawn designs focuses on the flow of data and signals to and from the ESP-32 microcontroller.

A. Version 1 (components-based)

Though it might be difficult to read, (see below) this diagram showcases the ESP-32 collecting data from the TDS, liquid pH, and ultrasonic sensor, sending data to a cloud platform and displaying it on a user dashboard, and doing some sort of control, via pumps, to adjust and add nutrient and pH solutions. This was our first drawn-out design, but it was a bit clunky. So, we moved on to our second diagram.

IMAGE I: VERSION ONE OF SYSTEM DIAGRAM
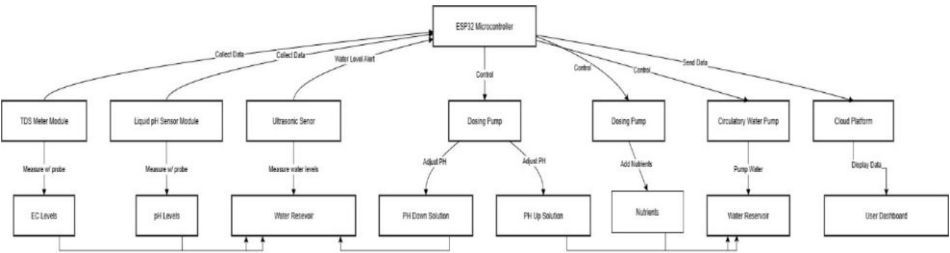
B. Version 2 (Signal-flow-based)

Version two of our system diagram (see below) kept much from the last but added our essential relays and showcases the activation of each relay, pumping the designated solution into the circulating waterway, which depends on the readings from the designated probe and sensor. An ultrasonic sensor watches the level of the nutrient container, so that the user knows when to refill it, and data is displayed directly to a Blynk dashboard (mobile user dashboard). Pipes are not included in this diagram.

IMAGE II: VERSION TWO OF SYSTEM DIAGRAM
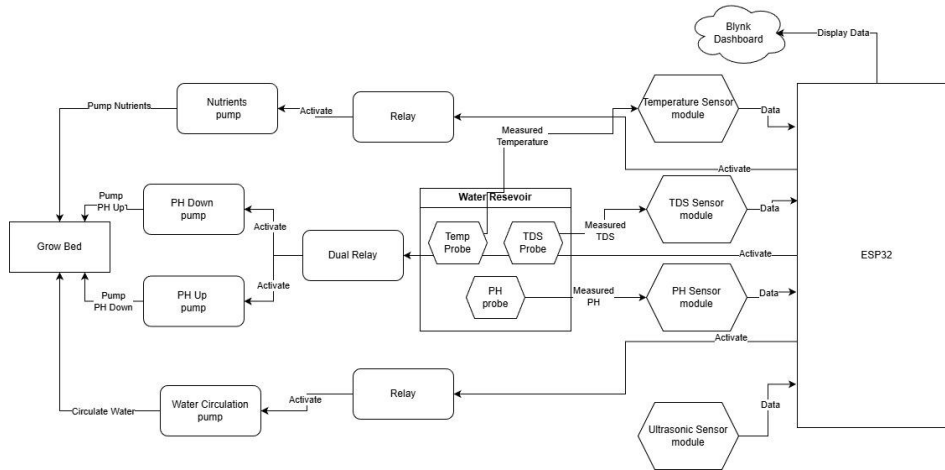
VI. Schematic

IMAGE III: SYSTEM SCHEMATIC
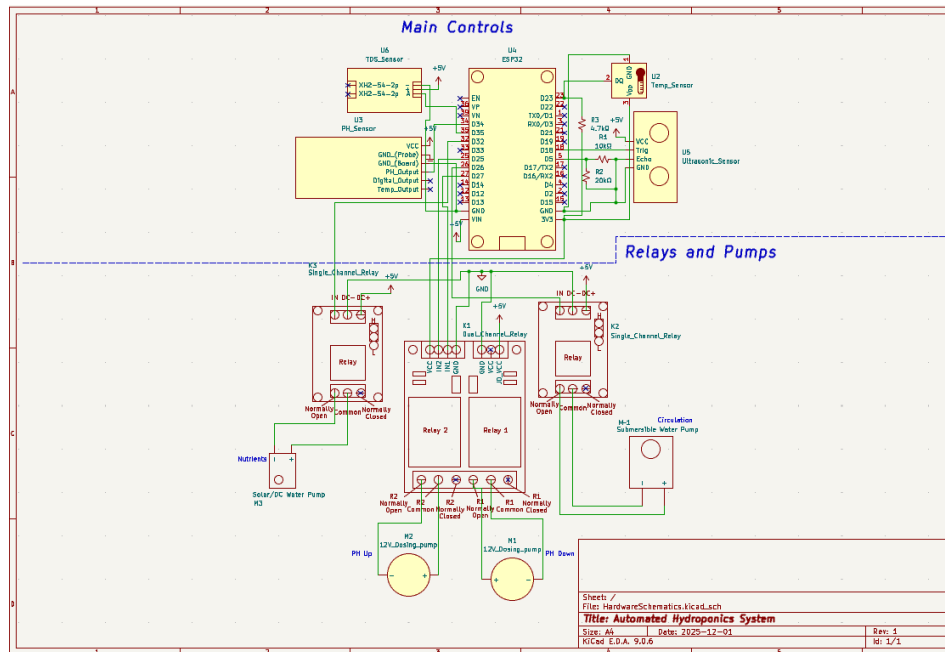
Besides block diagrams, we were also able to put together an electrical schematic (see above) to showcase all the necessary connections for our system's implementation. Compared to the block diagram, this schematic only includes the components of our system that need electrical power or need to collect and send data to our microcontroller. Pipe connections to the water reservoir or the fact of data transmission to a web platform are not included. Improvements could be made to ensure electrical perfection, such as resistors and dedicated ground modules. Next, we dive into our actual implementation, then we describe what our plan of action was, and finally some extra information is added for evaluators and users to know.

VII. Implementation

Our automated hydroponic system (see Appendix C) was implemented using a closed-loop control approach to continuously monitor and regulate the nutrient solution parameters required for optimal plant growth. The system integrates multiple sensors, a microcontroller-based control unit, and electrically actuated dosing mechanisms to maintain stable environmental conditions without constant human intervention.

A. System Initialization

Upon power-up, the microcontroller (ESP32 Dev Board) initializes all connected peripherals, including the pH module sensor, electrical conductivity (EC/TDS) module, water temperature (DS18B20), and the HC-SR04 ultrasonic sensor that measures nutrient solution level. Communication with the cloud monitoring platform, Blynk, is also established to allow real-time data visualization and system status reporting. Initial calibration values for pH and EC sensors are loaded from memory to ensure accurate measurements before entering normal operation.

B. Sensor Data Acquisition

The system operates in a continuous monitoring cycle at user-specified time intervals such as 7:00 am and 7:00 pm or manually activated via Blynk UI button. During each cycle, sensor data is collected in a structured sequence to ensure measurement stability:

- **Water temperature** is measured every two hours to modify the time at which pH and EC samples are taken.
- **EC/TDS** values are sampled multiple times and averaged to reduce electrical noise and transient fluctuations.
- **pH** measurements are taken using multiple analog samples and averaged to improve accuracy.
- **Nutrient water level** is monitored to detect low reservoir conditions and prevent pump operation when insufficient nutrient water is present.

All sensor readings are processed and converted into engineering units (°C, ppm, and pH) before being evaluated by the control logic.

C. Nutrient Concentration Control Logic

Nutrient concentration is regulated using the TDS (Total Dissolved Solids) value derived from EC measurements. A target TDS range is predefined based on the plant growth stage. The control logic compares the measured TDS value against this target range:

- If the TDS value falls **below** the minimum threshold, the system activates the nutrient dosing pump for a fixed duration to add concentrated nutrient solution to the main reservoir.
- If the TDS value is **within range**, no action is taken.
- If the TDS value exceeds the maximum threshold, dosing is inhibited to prevent nutrient overconcentration.

After each dosing event, the system enforces a delay period to allow thorough mixing before taking new measurements.

D. pH Regulation Logic

The pH control logic operates independently from nutrient dosing to prevent conflicting adjustments. A desired pH range is defined within the system code. Based on sensor feedback:

- If the measured pH is **below** the acceptable range, the pH Up pump is activated for a controlled time interval.
- If the measured pH is **above** the acceptable range, the pH Down pump is activated.
- If the pH is **within range**, no corrective action is performed.

Safety interlocks are implemented to ensure that only one pH correction pump can operate at a time. Similar to our nutrient dosing, a stabilization delay is applied after each pH adjustment before new measurements are taken.

E. Water Circulation and Mixing

A circulation pump is periodically activated (2 seconds ON / 5 minutes OFF) to ensure uniform distribution of nutrients and pH throughout the system and avoid overflowing. This prevents localized concentration gradients and improves sensor measurement accuracy. Circulation timing is coordinated with dosing operations to minimize unnecessary pump operation.

F. Fault Detection and Safety Handling

The system includes multiple safeguards to ensure reliable operation:

- Invalid sensor readings (e.g., out-of-range or disconnected sensors) are detected and ignored.
- Dosing operations are suspended if the nutrient solution level is below a safe minimum (25%).
- Maximum dosing limits are enforced within each control cycle to prevent runaway correction.

These safety mechanisms reduce the risk of plant damage and protect system hardware from operating under unsafe conditions.

G. Cloud Monitoring and User Interaction

All validated sensor data is periodically uploaded to a cloud platform (Blynk), where users can monitor system conditions in real time. Manual override options are available through the dashboard to allow user-initiated dosing or system adjustments when necessary. When nutrient water level reaches the threshold set (25%), an app notification is sent alerting the user that container needs refilling (see Appendix D) This hybrid control strategy combines automation with user supervision for improved reliability.

H. Control Cycle Summary

The overall system operation follows a deterministic control loop:

1. Acquire and process sensor data
2. Evaluate TDS and pH conditions
3. Perform controlled dosing if required
4. Allow solution stabilization and mixing
5. Upload data and system status
6. Repeat the cycle at fixed time intervals

This structured logic ensures consistent nutrient delivery, stable pH levels, and efficient resource usage while minimizing manual maintenance.

VIII. Plan of Action

One of the most critical aspects of effective project management is the development of a clear plan of action. This plan defines the tasks necessary to bring the project from concept to completion and outlines how those tasks will be organized, scheduled, and carried out. In a team-

based environment, a well-defined plan ensures that roles and responsibilities are clearly understood by all members. However, even in a solo project, establishing a plan of action is essential for maintaining structure, tracking progress, and managing time effectively. Without a defined plan, meeting deadlines and managing expectations would be significantly more challenging.

A. Statement of Work (SoW)

1. Scope

Our project consists of creating an automated hydroponics system that requires minimal manual intervention, but constant system values monitoring. The system will use a pump to keep the nutrients circulating through the system, dosing pumps for pH UP and pH DOWN solutions to stabilize the nutrient solutions based on the pH reading values, and an additional container with plant food to be pumped into the system depending on TDS sensor readings. The readings from all sensors will be sent to a platform to be displayed on the dashboard. This dashboard will also have buttons to manually activate reading and dosing.

2. Location

The Hydroponic System was set up at the house of one of the members.

3. Period

All work will be completed during the Fall 2025 semester, with a final delivery date of 12/14/25.

4. Responsibilities

 All the work was evenly distributed between the two of us. Distribution was based on location and individual strengths. These responsibilities were assigned by stages as we went.

B. Work Breakdown

For organizational purposes, the assignments were grouped into 5 major stages. The tasks for the project were divided into four main phases: research & writing, hardware, software, testing, and presentation. The following are detailed descriptions of these phases.

1. Stage 1: Research and Writing

Objective: Learn about how hydroponics work and successful practices; perform research regarding existing products, potential components, feasibility study and risk analysis.
Approach: Create a survey to get user / client data.
Expected Results: We should have an overall understanding of what the product should do.

2. Stage 2: Hardware

Objective: Select and acquire components, build prototype

Approach: Order components, start developing circuits to test each component individually to make sure they are functional, and calibrate some sensors before moving to the permanent stage. Putting all the components together and debugging any errors.

Expected Results: A working prototype.

3. Stage 3: Software

Objective: Sketching the code for the ESP32 Dev board; Setting up the controls and visualizations on Blynk app.

Approach: Creating portions of the code pertaining to specific sensors and actuators and build up from the previous one. Initially use the Serial monitor to debug any errors and then move to the Blynk app.

Expected Results: A responsive system that monitors sensors' values and activates actuators based on data thresholds or manually by the user.

4. Stage 4: Testing

Objective: Verify the proper operation of the hydroponic system prototype and identify and correct any hardware or software issues.

Approach: Testing will be conducted early and continuously throughout the development process, with validation integrated into both the hardware assembly and software implementation. Sensor readings such as pH, EC/TDS, temperature, and water level will be evaluated for accuracy by comparing them against calibrated reference instruments or known standard solutions. Actuators, including dosing pumps and circulation components, will also be tested to ensure correct response to sensor feedback. System stability and power consumption will be monitored over extended operation periods.

Expected Results: The system should accurately monitor nutrient solution conditions and automatically respond to deviations by adjusting pH and nutrient concentration as required, maintaining an optimal environment for plant growth.

5. Stage: Presentation

Objective: Objective: Prepare and deliver the final project documentation and effectively present the hydroponic system prototype, demonstrating its functionality, design decisions, and overall performance.

Approach: Compile all project components into a comprehensive written report that documents the system architecture, hardware and software implementation, testing

procedures, results, and identified limitations. Develop a structured presentation that highlights the project motivation, system operation, and key technical features. During the presentation, the working prototype will be demonstrated to showcase real-time sensor monitoring and automated control actions. Clear explanations will be provided to communicate design choices, challenges encountered, and improvements for future work.

Expected Results: The final report and presentation should clearly communicate the project objectives, implementation, and outcomes. The prototype is expected to operate as intended during the demonstration, validating the system's ability to monitor and control hydroponic conditions while effectively conveying the project's technical depth and practical value to the audience.

C. Gantt Chart

GRAPH II: GANTT CHART
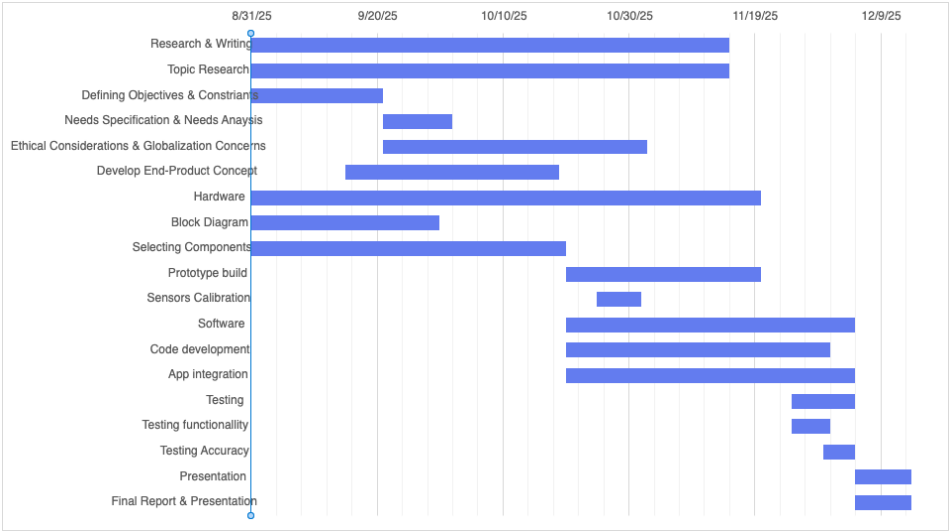
IX. Theory Model Analysis of Potential Ethical Dilemmas

In this section we explore a possible dilemma one of our users might run into and how we as engineers/developers should approach the situation from an ethical standpoint:

We follow the IEEE code of ethics in the design and production of our project. Specifically, we hold it dear that we work (1) "to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy

of others, and to disclose promptly factors that might endanger the public or the environment", (2) "to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, to be honest and realistic in stating claims or estimates based on available data, and to credit properly the contributions of others", and (3) "To treat all persons fairly and with respect, to not engage in harassment or discrimination, and to avoid injuring others."

We did some analysis of our product. The water system is close to the rest of a person's house, so there should not be any issue of disease transmission via our water pumping system. The nutrients used are not artificial, instead they are minerals and elements that are known to be desired by plants, like a highly fulfilling meal. However, in the instance that the nutrient-rich water is to be disposed of, there is a possibility that users do not already know how to do so. We will do a theory model analysis to decide how to handle such a dilemma:

We have devised three options to mitigate this dilemma: (1) Add warning labels about waste disposal and proper instructions, with acknowledgement of different product placements, (2) Trust that the user understands how to or can find out on their own how to dispose of their wastewater, or (3) Tell the user about the caution, but do not offer help.

We will score each option on Utilitarianism–the morally right action results the best for the most people, Ethical Egoism–the morally right action promotes your organization's best interest, and Rights Ethics—the morally right action is the one that respects society and the right of the individual. A 0 represents the option not satisfying the ethics theory, and a 1 is full satisfaction; acceptable satisfaction values: 0, 0.25, 0.5, 0.75, and 1. The resulting total will decide how far right the option is to being the most ethical (score of 3).

XVIII. ETHICS SCORING TABLE

Options	Utilitarianism	Ethical Egoism	Rights Ethics	Totals
1	1	0	1	2
2	0	0.75	0	0.75
3	0.25	0.25	0.75	1.25

After this analysis, we have determined it would be best for us to add warning labels about waste disposal and proper instruction on how to deal with the waste, acknowledging differing product placements. We will follow this same format for other dilemmas that our users find themselves in.

XI. Health and Safety

Here are some rules we have devised to ensure the safety and health of our users:

- NEVER consume the nutrient-rich water flowing through the system. Dangerous chemical compositions may have been added depending on your chosen solutions (i.e., pH, nutrient).

- DO NOT splash water on the electrical relay, converting 120V to 5V for the circulating pumps and ESP32 and 3.3V for the PH and EC sensors. Be careful with all connected power sources.
- Store pH adjustment solutions in clearly labeled, childproof containers away from food
- Ensure all electrical components meet IP65 or higher rating for moisture resistance
- Implement weekly water quality checks to prevent algae/bacterial growth
- Install overflow protection and water leak detection
- Keep first aid information and emergency contacts accessible
- Establish cleaning protocols using food-safe sanitizers

XII. Sustainability and Standards

In this section, we explored the sustainable aspect of our automated hydroponics system. You can find a description of its sustainability features and standards that our product will be following below.

A. Sustainability Analysis

Water Conservation:

Hydroponics uses approximately 90% less water than soil-based agriculture because the closed-loop system eliminates runoff and soil absorption losses. A traditional garden plot requires 50-100 gallons per week; our system maintains plant growth with 10-15 gallons in recirculation.

Energy Considerations:

- Estimated power consumption: 50W continuous (circulation pump) + 5W (ESP32) + intermittent dosing pumps (15W for ~5 min/day) = ~55-60W average
- Daily energy: ~1.3-1.4 kWh/day
- Optional solar integration can offset grid dependence (survey respondent request)

Material Lifecycle:

- PVC components (pipes, fittings): recyclable through specialized programs, 50+ year lifespan
- Sensors (pH, EC): 1-2 year replacement cycle, requires proper e-waste disposal
- Pumps: 3-5 year lifespan, metal components recyclable

Carbon Footprint Reduction:

Local food production eliminates transportation emissions (on average, produce travels 1,500 miles farm-to-table). A household producing 20% of leafy greens consumption reduces annual transportation carbon by ~50 lbs. CO_2 equivalent.

B. Standards

Below are the few standards that we believe pertinent to follow, to ensure that our users can set up, use, and eat their harvest safely and reassured.

UL 61010-1 or IEC 61010-1 (for electrical safety)

Specifies safety requirements for electrical equipment for measurement, control, and laboratory use. This standard is important since our product combines electrical components with water.

Possible Constraint targets:

- Use of Ground fault Circuit Interrupters (GFCIs) and GFCI integrated components
- Component Certification
- Enclosure and Isolation
- Proper Sizing and Surge Protection

ISO 22000 (for food safety)

According to iso.org [3], ISO 22000 maps out what an organization needs to do to demonstrate its ability to control food safety hazards to ensure that food is safe; it provides a layer of reassurance within the global food supply chain, helping products cross borders and bringing people food that they can trust. This standard is important since our product will be producing food for consumption by our users.

Possible Constraint targets:

- Water Source and Quality
- Material Selection
- Preventative Maintenance
- Monitoring and Alert Protocols

Our De Facto Standards:

These are standards we have personally developed on top of the other industry standards, in order to keep ourselves accountable for our user's understanding of how to safely utilize our product.

- Labeling for warnings must be adhered to by users

- System documentation must include Material Safety Data Sheets (MSDS) for all chemicals
- Installation guide must specify minimum clearances for ventilation and maintenance access
- User manual must include troubleshooting procedures and emergency shutdown protocols
- Component replacement schedule must be documented and communicated to users

XIII. Ethical Concerns

When designing, building and implementing any project, the impact on diverse areas of our lives must be considered, and depending on the magnitude, the type – either positive or negative – the project should move on, tweaked to meet the needs, or dropped if need be. Our hydroponic system design has kept those ethical values in mind and is complying.

Our project uses free open-source website/app such as Blynk to visualize data and display controls. This platform complies with online security norms by using an authentication token, a secret key, and a private key. That way, data can remain secure from public access.

Additionally, our system is intended to reduce manual labor, and lead to a more efficient method of growing leafy plants. It will not contribute to unemployment because it is meant to be used for home automation and small spaces.

Our hydroponic system will have a positive environmental impact and can be used in areas where water is depleted or scarce. Our system reuses water by recycling it and will only add more when and in the amount needed. Nutrients used are labeled organic and do not constitute a health concern.

XIV. Conclusions

This project successfully designed and implemented an automated hydroponic system capable of monitoring and regulating key water parameters essential for plant growth, including pH, nutrient concentration, temperature, and water level. By integrating sensors, microcontroller-based control logic, and automated dosing mechanisms, the system reduces the need for constant manual supervision while maintaining stable growing conditions.

The implemented control logic demonstrates the effectiveness of closed-loop automation in hydroponic applications, ensuring consistent nutrient delivery and pH balance through sensor-driven decision making. Cloud-based monitoring further enhances system usability by providing real-time visibility into system performance and enabling user interaction when needed.

Overall, this project demonstrates a practical and extensible approach to smart agriculture, highlighting the potential of embedded systems and IoT technologies in sustainable food production.

XV. Improvements

Although the proposed hydroponic system successfully automates nutrient and pH control, several enhancements can be implemented to improve reliability, scalability, and long-term durability. The following improvements are recommended for future iterations of the system.

A. Optimized Nutrient Reservoir Design

The current cylindrical nutrient reservoir limits the placement of sensors and actuators, increasing the risk of physical interference between components. A rectangular-based reservoir is recommended to provide greater internal organization and usable surface area. This design would allow pH probes, EC probes, water-level sensors, circulation pumps, and dosing tubes to be mounted in fixed, non-overlapping positions.

B. Automated Probe Lifting Mechanism

Continuous submersion of pH and EC probes can lead to premature sensor degradation, fouling, and calibration drift. A future improvement would incorporate a mechanical lifting mechanism that periodically raises and lowers the probes into the nutrient-rich water only during measurement intervals. The mechanism could be implemented using servo motors or similar components that would serve the same purpose controlled by the microcontroller.

C. Plant Health Monitoring Using ESP32-CAM

An additional improvement would be the integration of an ESP32-CAM development module to visually monitor plant growth and health. The camera module could capture periodic images of the plants and upload them to Blynk. Image data could be used to detect signs of stress, discoloration, or abnormal growth patterns. In future versions, automated comments or alerts could be generated based on visual analysis, providing users with early warnings of potential issues beyond water chemistry alone.

D. Increased PVC Pipe Diameter

The current PVC pipe grow bed diameter limits water flow capacity and increases the risk of overflow under high circulation or pump activity. Upgrading to a 3-inch or larger diameter PVC pipe would improve water throughput, reduce backpressure, and minimize overflow risks. A larger pipe also provides additional root space, improving oxygenation and overall plant health.

E. 3D-Printed Dosing Reservoirs and Control Unit Enclosure

To further improve system compactness, organization, and durability, future versions of the hydroponic system should incorporate custom 3D-printed components for the pH Up, pH Down, and nutrient solution reservoirs (see Appendix B), as well as a dedicated control unit enclosure. These reservoirs can be designed to match the exact volume requirements of the dosing pumps while minimizing unused space and reducing tubing length.

In addition to the dosing containers, a 3D-printed control unit housing would be used to securely mount the microcontroller, printed circuit board (PCB), power regulation components, and wiring interfaces. This enclosure would protect sensitive electronics from moisture, accidental contact, and environmental exposure while providing proper ventilation and cable management. Mounting points for relays, terminal blocks, and connectors can be integrated directly into the enclosure design to improve reliability and ease of maintenance.

F. Solar-Powered system

Lasty, one of our users gave the idea of using solar power to power our system and it is a great idea, especially since for those deploying the system outdoors. The Panel can be placed in any optimal location, however the panel would most likely need to be connected to a power storage (such as a 12V battery) then converted, or stepped down, to 5V for the ESP-32 development board, then maybe before the conversion split to the proper pumps. More electrical work will be necessary, unless modular components are found that happen to connect in a smooth way. We could not get to this improvement.
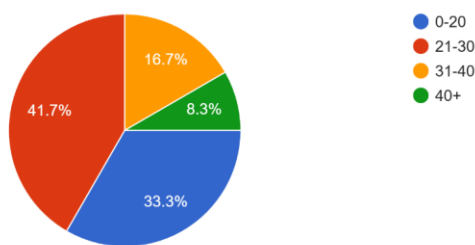
34

XVI. References

[1] G. M. S. A. CM;, "The impact of urban gardens on adequate and Healthy Food: A Systematic Review," Public health nutrition, https://pubmed.ncbi.nlm.nih.gov/29160186/ (accessed Sept. 1, 2025).

[2] "Global Home Gardening Market Size, trends, share 2025-2034," Custom Market Insights, https://www.custommarketinsights.com/report/home-gardening-market/ (accessed Nov. 4, 2025).

[3] "ISO 22000 - Food Safety Management," ISO, https://www.iso.org/iso-22000-food-safety-management.html#:~:text=ISO%2022000%20sets%20out%20the,ensure%20that%20food%20is%20safe. (accessed Nov. 9, 2025).

XVII. Appendix A: Raw Statistical Data

Gender:

12 responses

- Female
- Male
- Non-Binary
- Prefer not to say

75%

25%

Age:

12 responses

- 0-20
- 21-30
- 31-40
- 40+

16.7%

8.3%

41.7%

33.3%
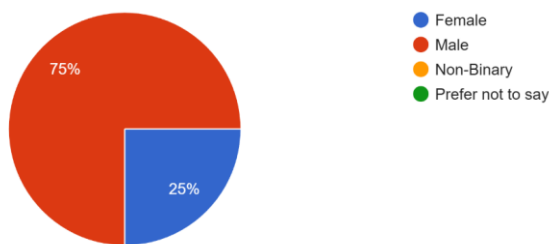
Marital Status
12 responses

- Single
- Married
- Divorced

16.7%
83.3%
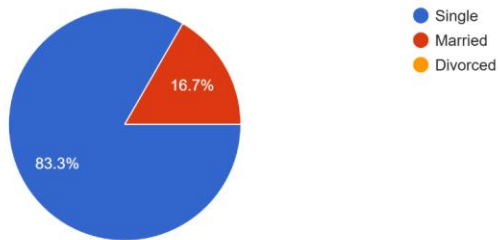
Have you ever done gardening?
12 responses

- yes
- no

41.7%
58.3%
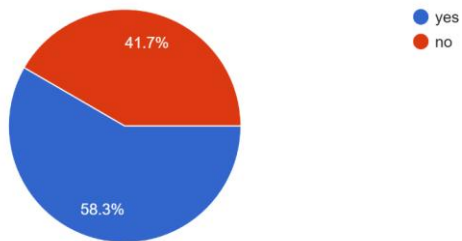
Have you ever heard of hydroponic gardening/planting prior to this survey?
12 responses

- yes
- no

33.3%
66.7%
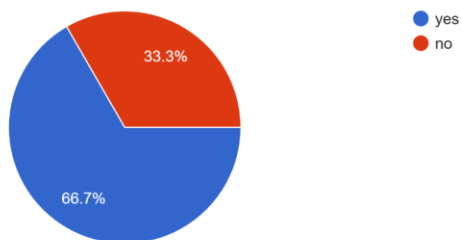
Do you currently have free time to tend to plants?

11 responses

- 🔵 Yes
- 🔴 Maybe
- 🟠 not sure
- 🟢 No

36.4% / 27.3% / 36.4%
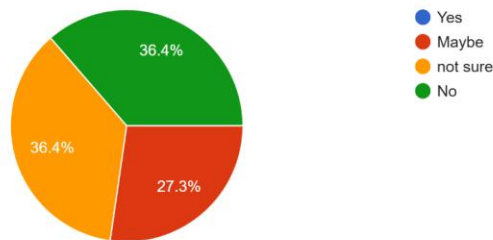
Do you think activities like gardening are a waste of time

12 responses

- No — 6 (50%)
- No they are a nice pass time — 1 (8.3%)
- No! — 1 (8.3%)
- No! I think it's a great hobby to have!… — 1 (8.3%)
- No, they are cool, js like any hobby — 1 (8.3%)
- Not at all — 2 (16.7%)
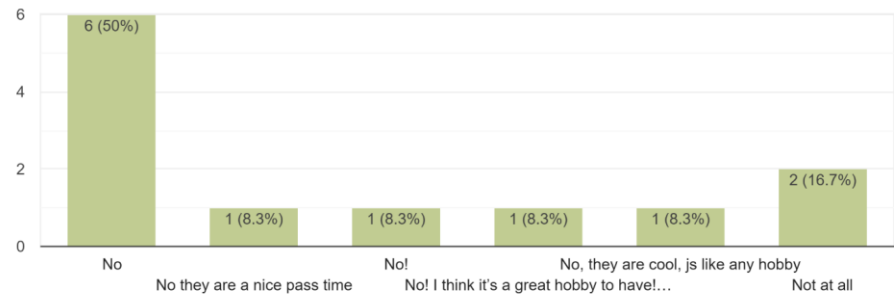
If you had the money, how likely would you be to start a hydroponics garden in your backyard or house?
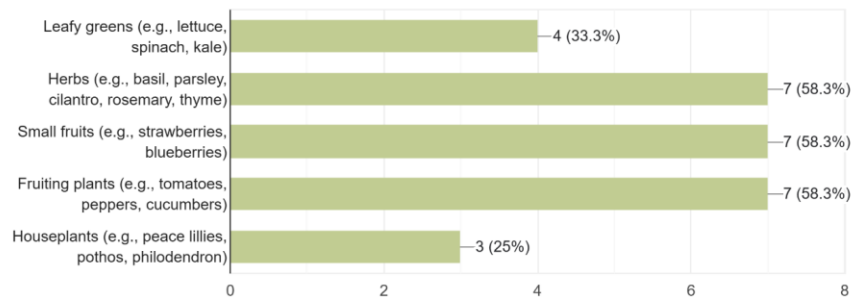
12 responses

- Very likely
- somewhat likely
- Neutral
- less likely
- Unlikely

16.7%
58.3%
16.7%
8.3%

=
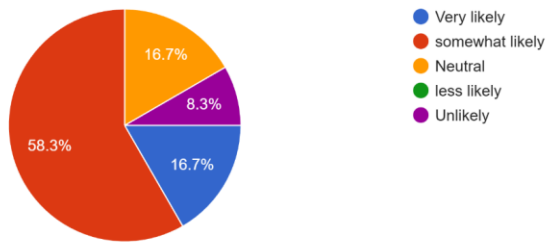
How much would you be willing to invest in hydroponics planting (no matter how small)?

12 responses

- $0-40
- $41-100
- $101-200
- $201-300

33.3%
8.3%
16.7%
41.7%
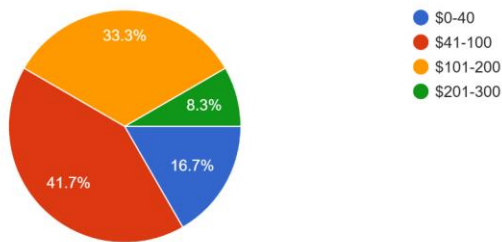
Only certain plants can be grown hydroponically due to space (e.g., trees, root vegetables). Which would you most likely grow?
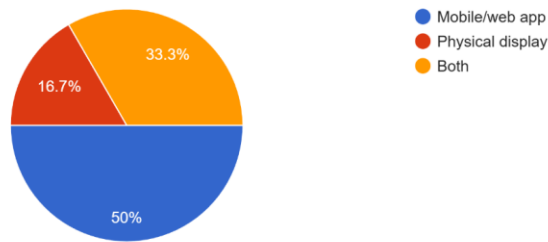
12 responses

If you were setting up a hydroponics system where would you look to do so?
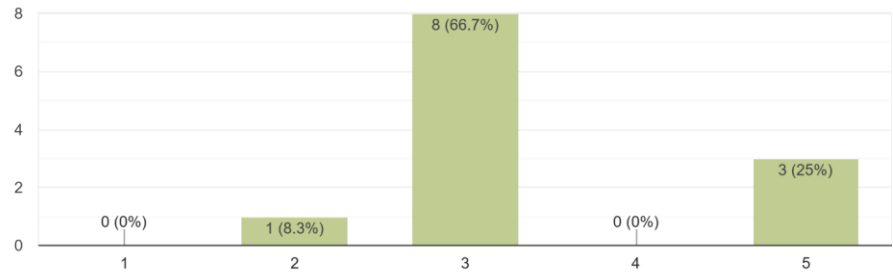
12 responses
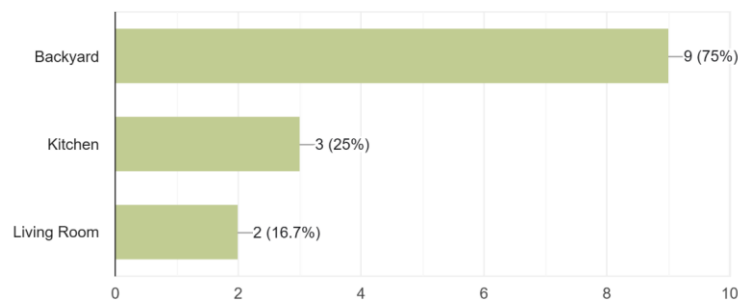
Would you rather download a mobile/web app to keep track of your water's nutrient levels and plant's health, or have a physical display to do so?
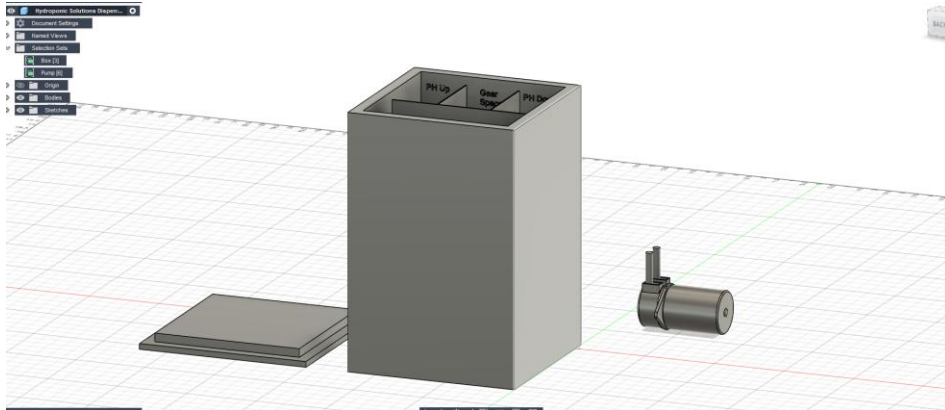
12 responses

- Mobile/web app
- Physical display
- Both

33.3%

16.7%

50%

How easy would you like the set up?

12 responses

0 (0%)   1 (8.3%)   8 (66.7%)   0 (0%)   3 (25%)

1   2   3   4   5

(1 = 0-3 steps | 5 = as many as needed)

XVIII. Appendix B: Drafted Solutions Enclosure

XIX. Appendix C: Our Hydroponic System

XX. Appendix D: Blynk Notification