Team 2 – Autonomous Greenhouse

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***Abstract*—This report introduces Team 2's idea for the 2023-2024 Capstone Design Project. The following report introduces the introduction to the problem followed by the objective and scope of the project. System description using block diagrams and further details, background information, constraints, and standards will also be established and discussed. The report will include professional considerations, possible solutions, obstacles, available solutions, implications, ethics, and responsibilities related to the solutions. Finally, the resources used for completing the project will be described including the components, funding, personnel, and timeline.**

Keywords — Greenhouse, measurements, sensors, zones, temperature, humidity, PLC

I. Introduction

A. Formulated Problem

Team 2 plans on addressing the issue of automation within greenhouse environments utilizing a PLC system. The design that Team 2 will implement shall install two separate zones for the cultivation of different types of plant life. The design shall also include several sensors and exterior controls, such as fan controls and humidity sensors. This design shall activate fans within the greenhouse when an internal temperature of 85ºF is reached. It shall also send an automated alert if carbon dioxide levels within the greenhouse reach either below 800ppm or below 1200ppm. The humidity sensors shall send an alert if the humidity level is outside of a manually set range, which will typically be 50-80% humidity. The design shall also contain an interface which will offer a customizable schedule for daily waterings as well as providing for a manual override in cases where excess watering is needed. Finally, the design shall offer soil nutrient and moisture sensors that will send alerts if the nutrient and moisture levels of the soil are not within a set ideal range provided by the customer.

B. Ethical Concerns

There are several ethical and professional concerns that are going to affect the design, implementation, and outcome of this project. Some examples of the ethical concerns are water usage efficiency, energy consumption, cybersecurity, and data asset protection. There are also several professional considerations that must be observed over the course of this project. One example would be preventative maintenance which is required when working with PLC systems. For more information about the professional considerations Team 2 is planning on observing, see the professional considerations section below. Team 2 also has several standards to consider in the design and implementation of the greenhouse project. Some examples of these standards are the NFPA 70 and the IEEE 160. For more information about the ethical and professional concerns as well as the standards Team 2 plans to address in this project please see the ethical, professional, and standards considerations section below.

C. Broader Impacts

There are multiple outcomes that can come from team 2's automated greenhouse. Team 2's greenhouse shall help to provide an easier workload for gardeners/farmers who have a lot to do already. This can help reduce human exhaustion and allow for more work to be done in a day, which in turn helps to provide more of a living to those selling plants being grown. Team 2 shall also provide a greenhouse with the means to grow non-native plants so that farmers/gardeners can have a variety of products or so that said plants do not invade and endanger the surrounding ecosystem.

II. SYSTEM DESCRIPTION

A. Block Diagram and Detail: Overhead

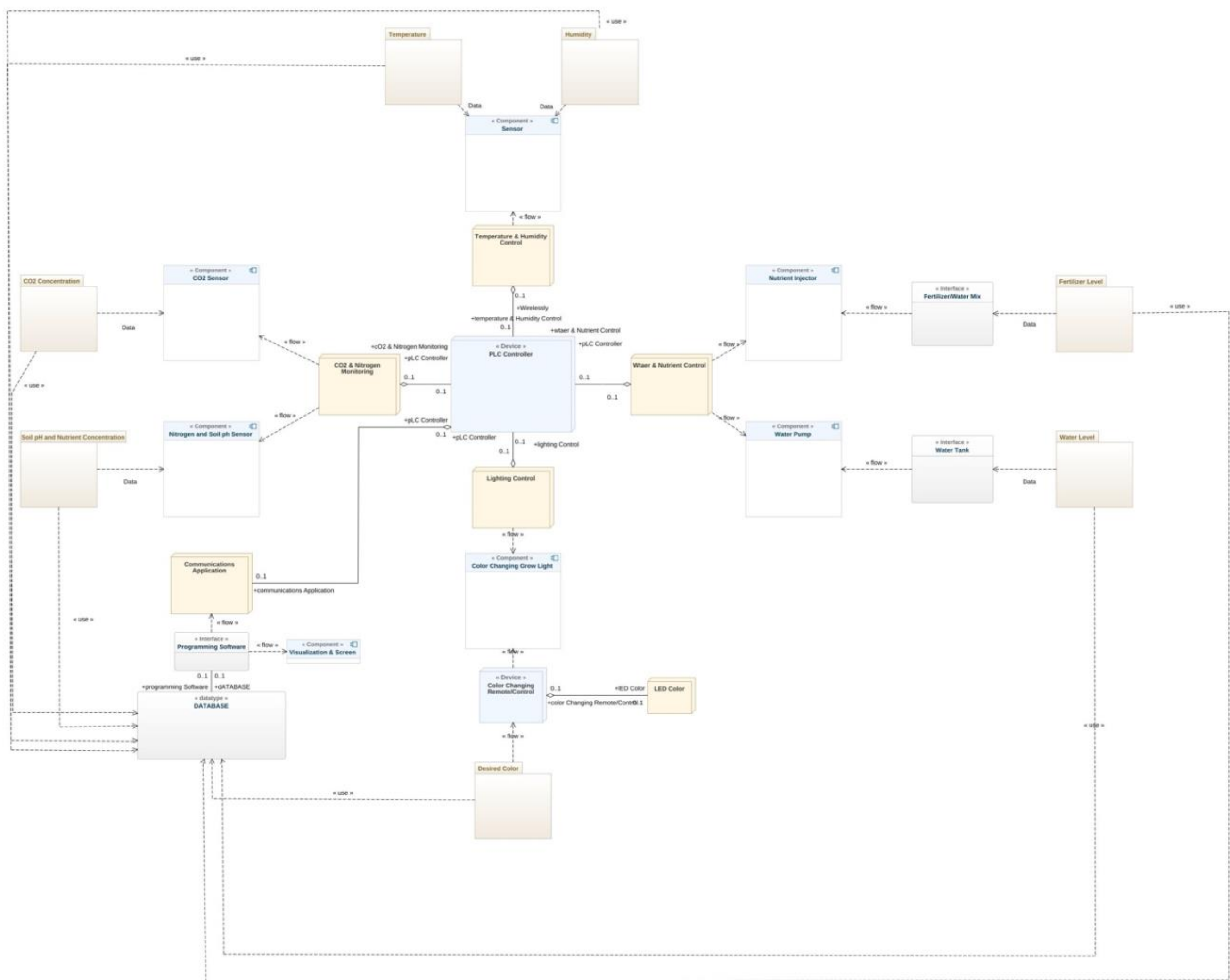

Figure 1. Block Diagram and Detail: Overhead

1. PLC Controller

This is the main control center for the entire system. It controls the five sub-systems by taking in data from the communications application, processing it, and sending back the desired response to the systems.

2. Water and Nutrient Control

The water and nutrient control subsystem shall consist of tanks of water with water level sensors that will relay the amount of water back to the communications application as well as a water pump to carry water to the different plants being grown. This subsystem will also include a manually mixed solution of fertilizer and nutrient injectors to deliver nutrients into planting soil. Inputted to the system will be the data from the PLC telling if the plants need water, nutrients, or fertilizer. It will output feedback to the database to be processed again.

3. Lighting

The lighting subsystem shall consist of several color changing LEDs controlled by a color changing remote that allows the user to input the desired color for the LEDs. The color of these lights will then be sent to the communications application to be reported to the user.

4. CO2 and Nitrogen Monitoring

This subsystem shall consist of a series of sensors that will continually monitor the level of carbon dioxide in the air as well as the percentage of nitrogen within the soil. If said level stray from a predetermined range, then the sensors will send an alert to the communications application to inform users of the deviation.

5. Communications Application

The communication application shall consist of a screen that displays the different levels and percentages we plan to monitor and will relay that information to the user. Each individual subsystem will send their different data to the applications database to be presented to the user.

6. Temperature and Humidity Control

This subsystem shall consist of a temperature and humidity sensor that will monitor both parameters and will turn on the fans once the temperature reaches 85ºF and both parameters shall be reported to the communications application.

Block Diagram and Detail: Water and Nutrient Control

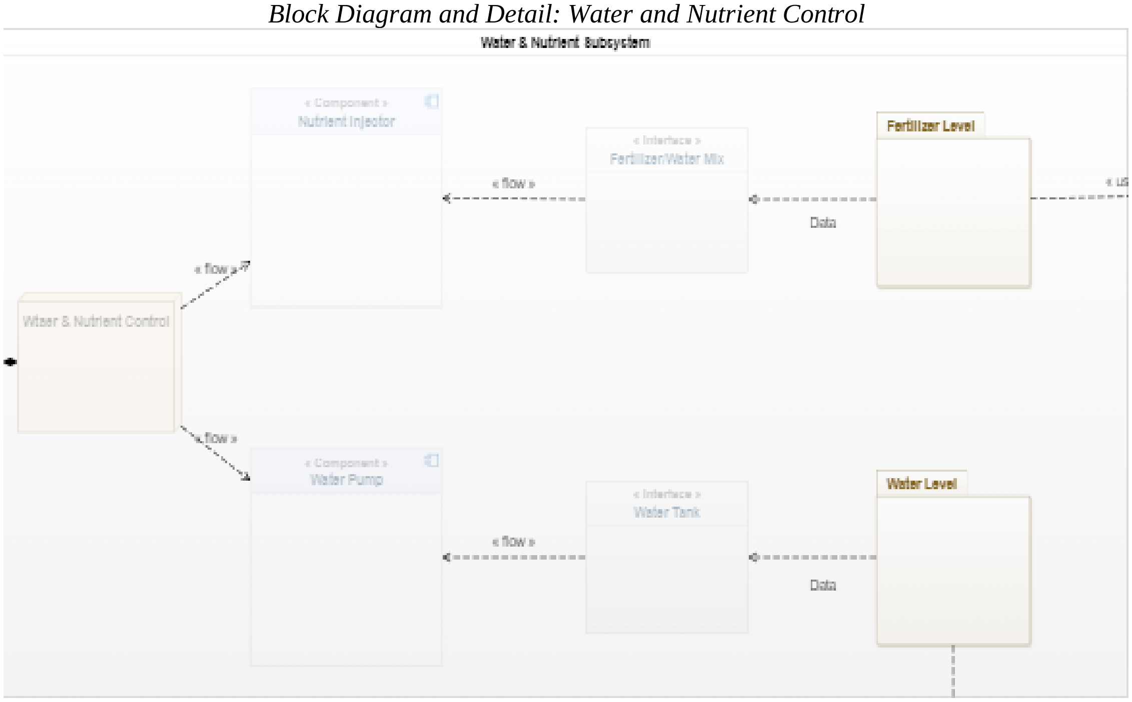

Figure 2. Block Diagram and Detail: Water and Nutrient Control

1. *Water & Nutrient Controller*

This controller is what sends water and nutrients to the plants. From the PLC, data is sent telling the controller to turn on the water pump and/or nutrient injector and for how long.

2. *Nutrient Injector*

The nutrient injector gives liquid nutrients to plants by releasing it into the soil near their roots. The injector will be turned on by the water & nutrient controller for the programmed time, or until it is manually overridden.

3. *Fertilizer/Water Mix*

This is what will be sent through the nutrient injector. The solution will have to be mixed outside of the automation system. However, the amount of the solution given to the plants is determined by the controller or by manual override.

4. *Water Pump*

The water pump is what will pull the water and fertilizer mixture from the water tank for automated irrigation.

5. *Water Tank*

The water tank holds the water that will be manually mixed with the fertilizer to be delivered to the plants via the water pump.

Inputs:

1. *Water*
2. *Optimal Fertilizer Mix*

Outputs:

1. *Water Level Percentage*
2. *Fertilizer Mix Percentage*

Block Diagram and Detail: Lighting

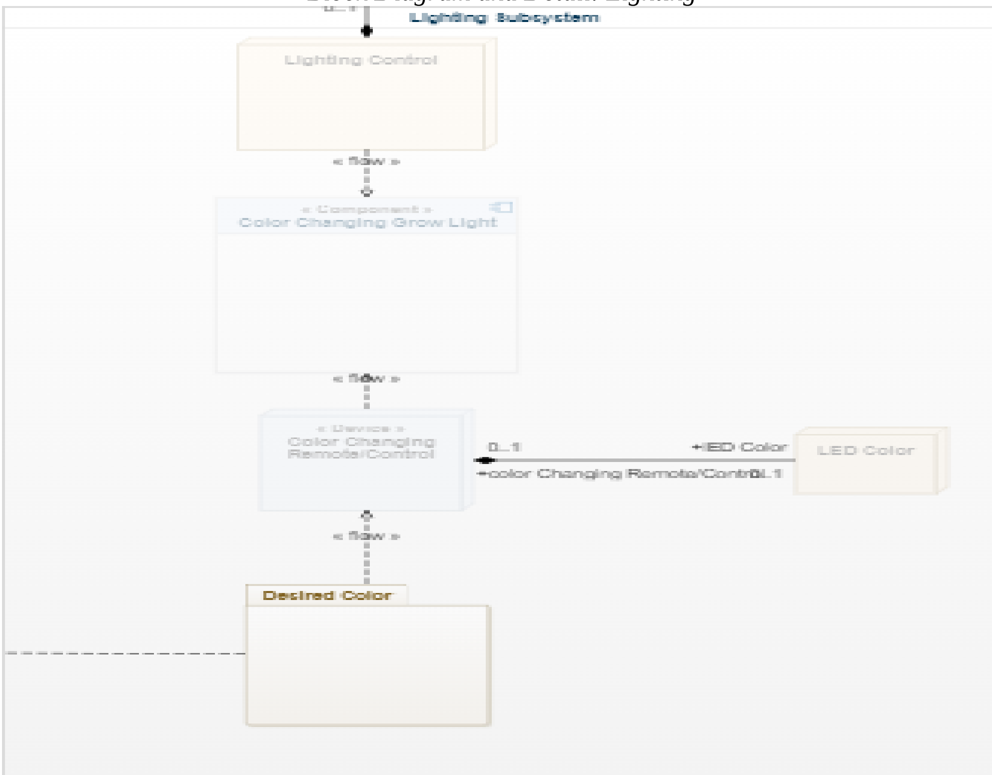

Figure 3. Block Diagram and Detail: Lighting

1. *Lighting Controller*

This controller is what controls the different colored lights to the plants. From the PLC, data is sent telling the controller to turn on the light, what color the light with be, and for how long the light will be on.

2. *Color Changing Grow Light*

The grow light will turn on via the controller which will determine its color and for how long.

3. *Color Changing Remote Control*

This remote will manually change the color of the light turned on by the controller.

Inputs:

1. *Desired Lighting Color*

Outputs:

1. *Desired Lighting Color*

Block Diagram and Detail: CO2 and Nitrogen Monitoring

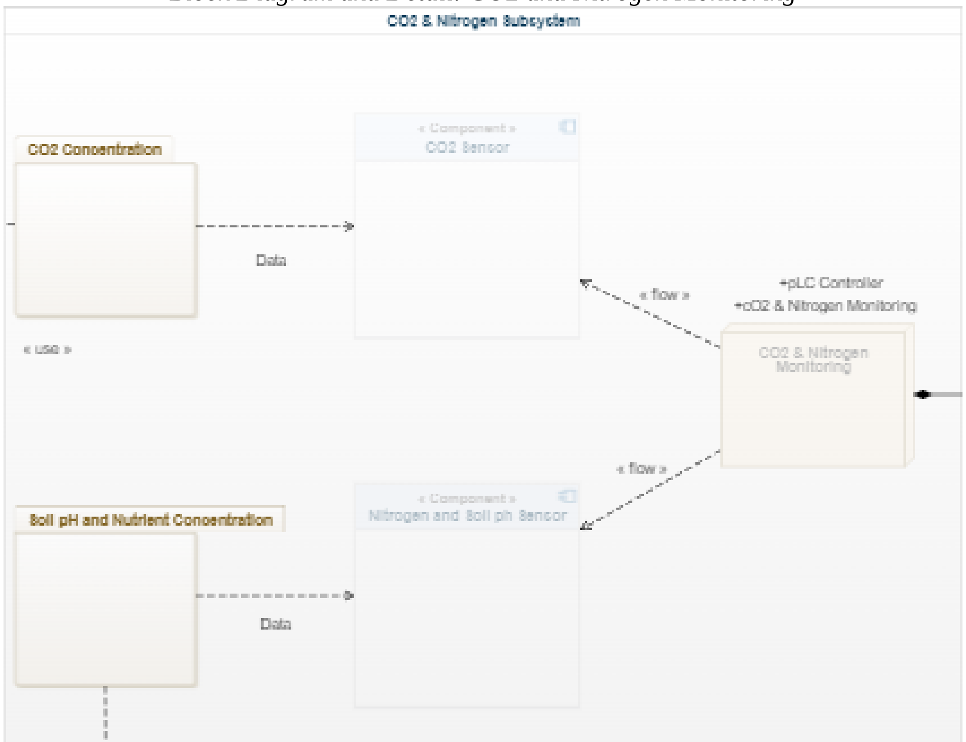

Figure 4. Block Diagram and Detail: CO2 and Nitrogen Monitoring

1. *Soil Nitrogen Sensor*

   This sensor will report the percentage of nitrogen that is found in the soil and relay that information back to the communications application.
2. *CO_2 Sensor*

   The carbon dioxide sensor will report the concentration of carbon dioxide in the greenhouse's atmosphere and will relay the information to the communications application.

Inputs:

1. *CO_2 Concentration*
2. *Soil Nitrogen Content*

Outputs:

1. *CO_2 Concentration*
2. *Soil Nitrogen Content*

Block Diagram and Detail: Communications Application

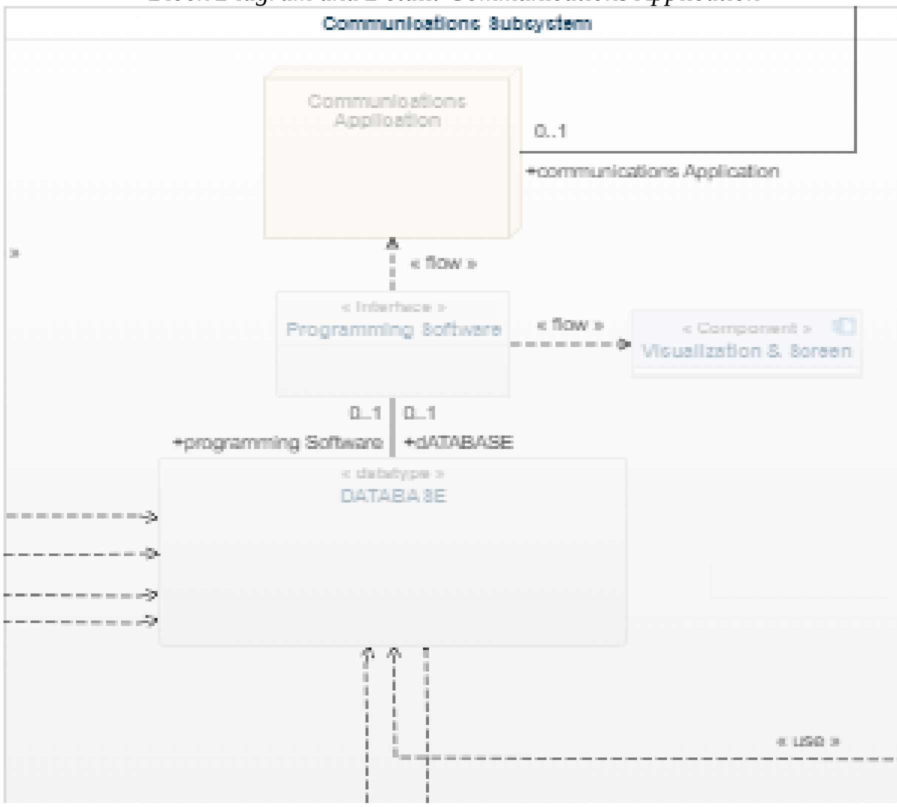

Figure 5. Block Diagram and Detail: Communications Application

1. *Communications Application*

   The communication application will be the primary source of information for the users of this system. It will report all the information provided including temperature, humidity, water level, fertilizer percentage, nitrogen concentration, and carbon dioxide level.

2. *Programming Software / Back-end*

   The back-end software will be the primary running source for the communications application. This software will allow the application to display the information it has been sent.

3. *Database*

   The database will contain all relevant information that has been passed from the subsystems to the communications application.

4. *Visualization & Screen*

   The screen will allow the information that is passed to the communications application to be displayed visually for the user of the system.

Inputs:

1. *CO_2 and Nitrogen Concentrations*
2. *Water and Fertilizer Mix Percentages*
3. *Lighting Color*
4. *Temperature and Humidity Percentages*

Outputs:

1. *All inputted information is relayed through the app*

Block Diagram and Detail: Temperature and Humidity Control

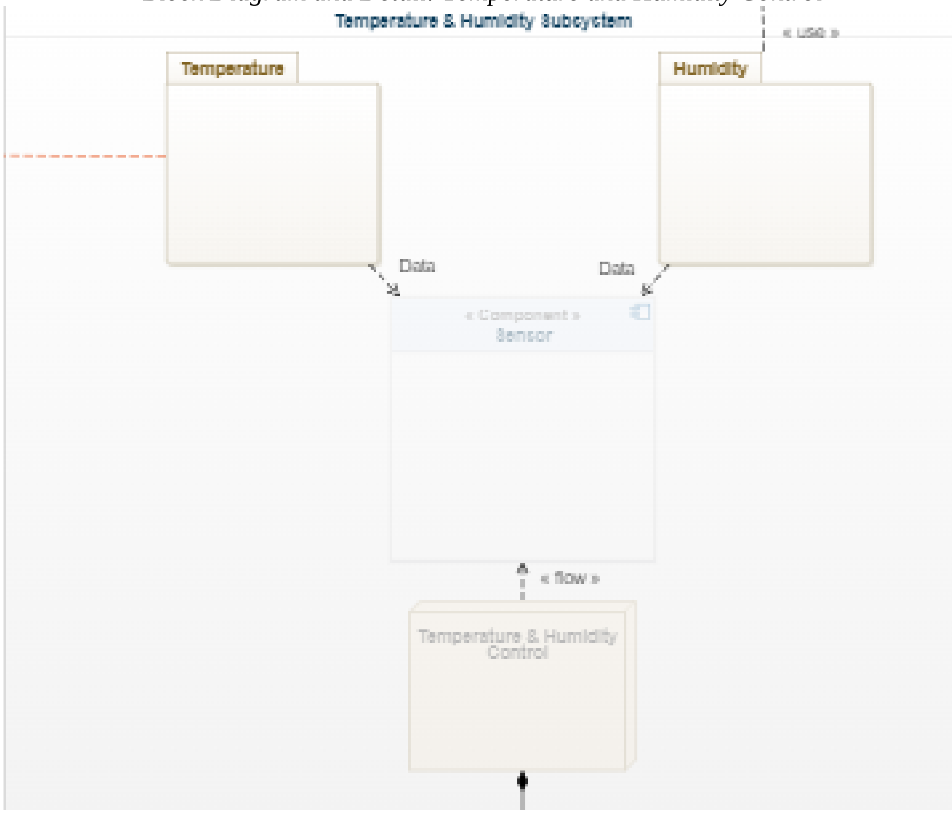

Figure 6. Block Diagram and Detail: Temperature and Humidity Control

1. *Temperature & Humidity Controller*

This controller is what changes the temperature and humidity around the plants. From the PLC, data is sent telling the controller to turn on and whether to make it humid and/or hotter or colder.

2. *Sensor*

The sensor will determine whether the humidity or temperature exceeds the desired measurements and tell the controller whether to turn on and make changes.

Inputs:

1. *Greenhouse Internal Temperature*
2. *Greenhouse Humidity*

Outputs:

1. *Greenhouse Temperature*
2. *Greenhouse Humidity*

B. Constraints

1. *PLC Controller*

The constraint for using this application is that it will have memory, input/output, communication, and power supply limitations. This is mostly due to budget constraints which limit how advanced the controller itself will be. It can be tested by ensuring that the data collected by the controller is being processed correctly in the code and being sent to the correct system. The PLC also contains a constraint based on the ISA-99/IEC 62443 standard. The PLC must be protected from any outside threat of hacking, and the data shall be restricted exclusively to the Agricultural Department.

2. *Water and Nutrient Control*

Constraining this system is sensor calibration, which is due to the different types of plants to be grown using the system. This can be tested by having set options for each type of plant and ensuring that each type stays healthy under these settings.

3. *Lighting*

The constraint on this system is ensuring that the lights are at the correct illuminance level. Based on what stage of life the plants are at, different levels are desired. To test this, a photometer will be used to measure the illuminance.

4. *CO_2 and Nitrogen Monitoring*

The difficulty of monitoring these levels inside of a greenhouse is the fact that there could be outside interference from different gases already inside. These could be caused from outputs of other plants or fertilizers used. To accurately examine this, the sensors would need to be placed in an area where no outside gases could easily reach them.

5. *Communications Application*

The main difficulty in this is creating a system that not only allows the user to see the screen while at the greenhouse, but also conveying the necessary information to them while they are not physically present. This is an issue because the houses are not staffed 24/7 and still need attention when no one is around. To solve this, a system will need to be put into place to send the user an alert via message or e-mail to notify them if something has gone awry.

6. *Temperature and Humidity Control*

The constraint of this will be having multiple points of measurement which provide accurate levels to the application. This originates from the fact that the controller uses very specific values to engage the fans and humidifiers. To test the system, an outside thermometer and humidity sensor will be used to verify the results.

7. *Water and Nutrient Controller*

The difficulty in this is that the water and nutrients must be mixed by hand. Therefore, this system cannot be fully automated.

8. *Nutrient Injector*

This system is constrained by the fact that each plant type will need to be programmed specifically to their needs. The solution to this is getting feedback from the customer on specific measurements that will provide the best plant growth.

9. *Fertilizer/Water Mix*

Having to mix the solution manually is the biggest constraint on the system. To protect the pumps and injectors, a system will be put into place that will not allow the mixture to be pumped if it is below a set level.

10. *Water Pump*

One constraint on the water pump is that it must provide a variable amount of water pressure for optimum flow through the piping that team 2 plans to provide to each plant. Another constraint is that the pump must regulate its intake of water in order to not overload the system and cause a malfunction within itself.

12. *Color Changing Grow Light*

The lights will need to be able to change instantaneously when the desired color is selected. They will also need to be able to produce light within a given wavelength spectrum.

13. *Color Changing Remote Control*

The remote control for the lighting system will need to be able to relay the desired color to the light bulbs instantly and will have a limited range from which the remote will work. The remote will also need to be unobstructed by any solid surface for it to function properly.

14. *Soil Nitrogen Sensor*

The difficulty in this system is getting an accurate measurement due to the gases already present in the greenhouse. To ensure the accuracy of the sensors, each one can be tested by using a second measurement device and comparing the results.

15. *CO_2 Sensor*

Integrating a CO_2 sensor into an autonomous greenhouse will pose a few challenges and will have the following constraints. First, maintaining a precise and accurate system amidst a changing environment will prove challenging. So, the accuracy and the calibration will be vital to make sure the system is doing a proper job. CO_2 can fluctuate quickly in a greenhouse so response time and sampling rate will need to be appropriate for real-time decision making. Sensor lifespan and maintenance will also need to be considered. Lastly, integration with control and communications system is important because without that being done in the correct way, the system will be useless.

16. *Visualization and Screen*

This system will need to have a good balance of ease of use and comprehensive data representation. The system needs to present real-time sensor data, control options, and status. It will need to be simple, allowing for key metrics to be prioritized while continuing to be user-friendly. It will also need to be able to display current or past data.

III. Timeline and Conceptual Design Fit

A. *Timeline*

Team 2's conceptual design has been planned and organized, creating a structured timeline within the design report. Illustrated in Figure 7 below, the design process has been broken down into milestones, with each task assigned to a specific team member. This visual representation outlines the project's progress from its creation to the Final Conceptual Design Phase.

The next pivotal point in our timeline involves the completion of the presentation and design review, which will then be submitted for approval. Following this, Team 2 will carefully incorporate feedback received, refining, and finalizing the design. Then, the focus will shift towards completing detailed designs for all project subsystems.

For a comprehensive view of the entire project timeline, please refer to the complete Gantt chart provided in the Appendix of this report.

Name	Begin date	End date	Team Members
Team Contract:	8/23/23	8/30/23	
Team Contract Submission	8/23/23	8/30/23	
Project Proposal	8/28/23	10/23/23	
Proposal Submittal Due	8/28/23	9/15/23	
Proposal Presentations	9/25/23	10/23/23	
Proposal Revisions Due	9/18/23	9/22/23	
Conceptual Design & Planning	9/18/23	10/13/23	
Conceptual Design & Planning Tasks	9/18/23	10/4/23	
Introduction	9/18/23	10/4/23	Bryan Rhoton
System Description	9/18/23	10/4/23	Grant Hooper & Noah Jones
Timeline & Conceptual Design Fit	9/18/23	10/4/23	Jaxson Billings
Ethical, Professional, & Standard Considerations	9/18/23	10/4/23	Jared Hooker

Figure 7. Gantt Chart Task List from Project Start to Conceptual Design

B. *Conceptual Design Fit*

The conceptual design report serves as an essential analytical document crafted to identify and dissect critical design tools and aspects within the project. A key objective of this report is to pinpoint the components and elements essential to the project's scope. Table 1 outlines these components, indicating the specific subsystems to which they are to be implemented or associated. The arrangement is structured from top priority to lowest, based on criteria such as complexity, impact, availability, and cost. Each of the criteria was given a rating on if it was low, medium, or high priority which affects the scores and ranking of each individual component. Project Impact was of the highest priority and was given a three on the scale from one to three. This is because all parts of this project need to work together for the outcome to be successful. Second, cost was given a two on the scale because Team 2 has a moderately high, but not too high, budget that should allow for the project to be achieved. Next, complexity was given a two on the scale. This project has an achievable time frame in which the project is to be completed which allows for complexity to be worked through. Lastly, availability is given a one on the scale because all components should be readily accessible. The greenhouse material and programmable logic being used is a common market, so products have been deemed moderately available.

To offer a more detailed breakdown of these components, Table 2 is referred to in the appendix section. It provides a comprehensive analysis, enhancing our understanding of the project's details and ensuring a good foundation for our detail design.

Components	**Subsystem Used On**	**Rank**
Power Distribution	All	1
Wireless Communication	Communication	2
Database	Communication	3
CO2 Sensor	CO2 & Nitrogen Monitoring	4
Soil pH / Nitrogen Sensor	CO2 & Nitrogen Monitoring	5
Fertilizer Injector	Water & Nutrient Control	6
Water Pump	Water & Nutrient Control	7
Lighting Controller	Lighting	8
Temperature & Humidity Sensor	Temperature & Humidity Control	9
User Interface	All	10
Color Changing Remote	Lighting	11

Table 1. Critical Components Ranking

IV. Ethical, Professional, & Standards Considerations

A. *Ethical Considerations*

One ethical consideration is the efficient use of water irrigation and energy consumption. Using minimal, but efficient, amounts of water can reduce the waste in the greenhouse. A solution for this is to use drip irrigation in place of a sprinkler system, which will feed water directly to the roots of the plants. Using efficient lighting and renewable energy sources allows for less carbon emissions within the greenhouse.

Recycling materials and properly disposing of waste in the greenhouse will promote a healthier space for plants to grow. Reusing materials in the greenhouse will decrease the environmental impact and cost of disposal [1].

Maximizing the use of organic fertilizers will provide the greenhouse with healthier plants. Using synthetic fertilizers, pesticides, and herbicides can negatively affect the growth and quality of the plants if consumed at large levels due to the vast amount of nitrogen [2]. Keeping track of which fertilizers are used can reduce the chance of plants dying.

Cybersecurity and data protection is an ethical consideration when working with programmable logic controls (PLCs). Ensuring that data is stored securely and restricted to authorized personnel will prevent any hacking attempts and data breaches. Implementing security measures and routine system updates can allow for more data privacy for the customer.

B. *Professional Considerations*

Preventative maintenance is key when working with the sensors and PLCs. If any of the equipment becomes well-worn, it will be ideal to replace or fix it to provide the facility with sufficient materials. In turn, this will keep the data as accurate as possible for the greenhouse manager.

C. *Standards*

NFPA 70 – National Electric Code: this standard provides guidelines for safe electrical installations, including those in a greenhouse setting. Complying with the NEC will ensure safe practices are used when working with electrical components.

IEEE 1680 – IEEE Standard for Environmental Assessment of Electronic Products: This standard addresses the impact of the environment and society. It is meant to minimize energy consumption, waste, and other environmental impacts.

IEEE 802.11i – IEEE Draft Standard for Information Technology: This standard requires security for wi-fi networks. This keeps users' information safe and privacy intact.

ISA-99/IEC 62443: this standard provides guidelines for securing control systems, like PLCs, from cybersecurity threats. The Agricultural Department will need to have network security and control of their data, which will ensure it is accurate and that it has not been tampered with in any way.

References

[1] O. US EPA, “Recycling in the United States,” *www.epa.gov*, Apr. 16, 2013. https://www.epa.gov/recycle/recycling-united-states

[2] UNEP, “Fertilizers: challenges and solutions,” *UNEP*, Nov. 09, 2020. https://www.unep.org/news-and-stories/story/fertilizers-challenges-and-solutions

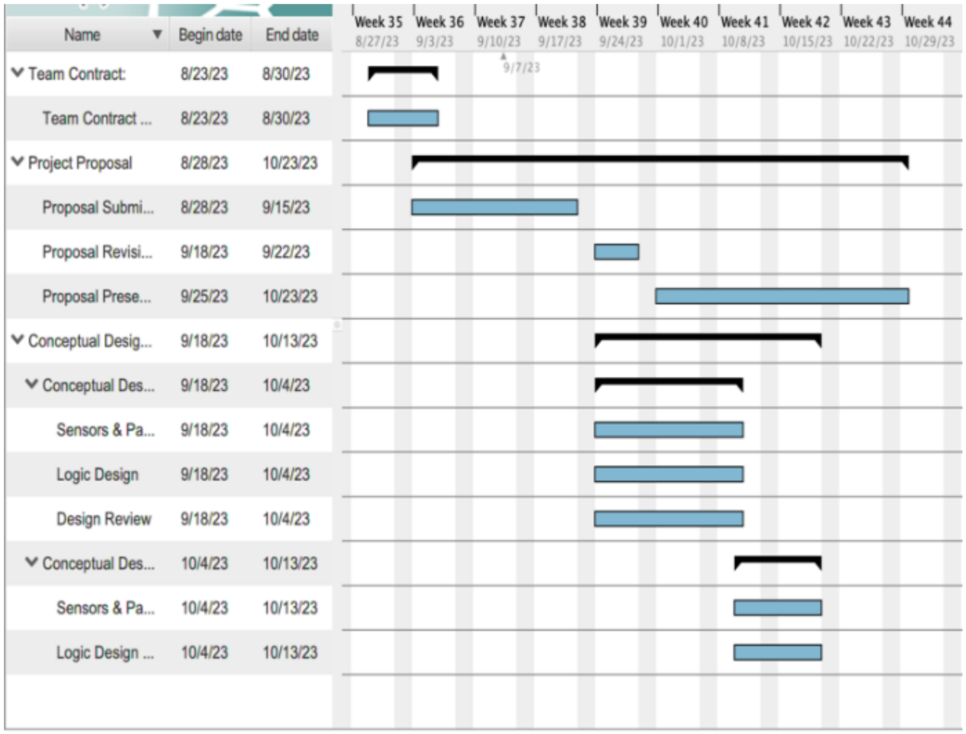

Figure 8. Gantt Chart Representing 1st Half Semester Dates

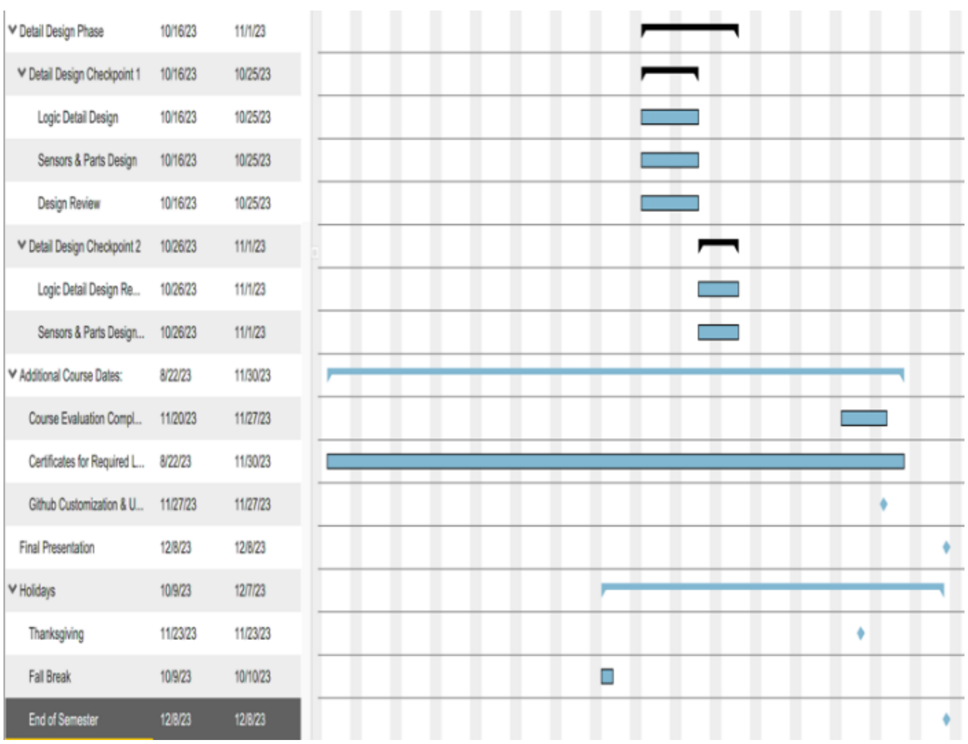

Figure 9. Gantt Chart Representing 2nd Half Semester Dates

Critical Component Decision Matrix

		Weight	2	Weight	3	Weight	2	Weight	1	
Components	**Subsystem Used On**	**Complexity**	**Score**	**Project Impact**	**Score**	**Cost**	**Score**	**Availability**	**Score**	**Total Score**
Power Distribution	All	3	6	3	9	1	2	1	1	18
Wireless Communication	Communication	3	6	3	9	1	2	1	1	18
Database	Communication	3	6	3	9	1	2	1	1	18
CO2 Sensor	CO2 & Nitrogen Monitoring	1	2	3	9	2	4	1	1	16
Soil pH / Nitrogen Sensor	CO2 & Nitrogen Monitoring	1	2	3	9	3	6	1	1	18
Fertilizer Injector	Water & Nutrient Control	1	2	3	9	2	4	1	1	16
Water Pump	Water & Nutrient Control	1	2	3	9	2	4	1	1	16
Lighting Controller	Lighting	1	2	3	9	1	2	1	1	14
Temperature & Humidity Sensor	Temperature & Humidity Control	1	2	3	9	1	2	1	1	14
User Interface	All	1	2	2	6	1	2	1	1	11
Color Changing Remote	Lighting	1	2	1	3	1	2	1	1	8

Priority	**Level**
Low	1
Medium	2
High	3

Criteria	**Weight**	**Weight Priority Justification**
Complexity	2	The project has a moderately sufficient amount of time for testing and research
Project Impact	3	All components are necessary for project completion
Cost	2	The project has a moderately high budget
Availability	1	All products should be avaliable for there is a wide market

Table 2. Critical Components Decision Matrix