Team 2 – Autonomous Greenhouse

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***Abstract*—This proposal introduces Team 2's idea for the 2023-2024 Capstone Design Project. The following proposal introduces the project, formulates the problem, and surveys the solutions. The measures of constraints, specifications, potential obstacles, and resources are also included.**

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

I. Introduction

In a world where climate change poses an increasing threat to crop production, there is an innovative solution that is readily sustainable and efficient. Team 2 proposes to design and build an automated greenhouse system for the Agricultural Department at Tennessee Technological University.

There are many benefits of a greenhouse compared to outdoor farming. "The advantages of protected cultivation compared to outdoor production of vegetables have a mostly better product quality with higher input efficiencies of water, nutrients and crop protection agents" [1]. A greenhouse also allows for year-round crop growing, while outdoor farming has certain limitations depending on the weather season.

While there are many benefits of a greenhouse, there are also some concerns that can be raised. One main concern is that there needs to be someone present to tend to the different plants and ensure they are getting the proper care needed. A greenhouse cannot run efficiently without the assistance of human labor present. [2]

The objective of Team 2's project is to provide the necessary tools and equipment to allow the greenhouse at Hyder-Burks Agriculture Pavilion to monitor and control the different aspects of the building without a person present. By achieving this goal, the Agricultural faculty and students will be able to prioritize their labor to other greenhouses that require more attention. In the upcoming sections, the problem formulation will be described, which will include the following: background information, specifications for the project, constraints, and the standards that will need to be considered. Some formulated solutions and researched solutions will then be outlined. Finally, the team skills, budget, and timeline will be shown.

II. Formulating The Problem

A. Background

The term "greenhouse" has been around for centuries with records dating back as far as 14 CE in Rome; however, modern greenhouse concepts did not begin to appear until around the 20th century. There are also several different versions of the greenhouse including, but not limited to: the Venlo-style, the Westland-style of the Netherlands, and Parral-type. In the southern region of the United States, as well as other warm regions of our country, the arch-style greenhouse that are gutter-connected and have a plastic film covering the exterior have become the most popular [3].

The greenhouse that Team 2 proposes to automate is one of the arch-type greenhouses with plastic coverings around the edges of the house itself. The house is heated and cooled via a system of fans and heaters connected to a thermostat. The hydration and nutrient levels of each plant are required to be measured by hand. These current features of the greenhouse are time consuming and require the Agricultural faculty and students to monitor the temperature of the house as well as the pH, soil nutrient, and soil hydration levels manually.

The greenhouse that Team 2 proposes to automate is planned to be split into planting zones for the growth and development of different types of plant life. With the world population projected to reach 2050 by the Food and Agriculture Organization, automation of safe and sustainable agricultural practices is becoming more and more paramount [4].

B. *Specifications & Constraints*

This proposal includes specific requirements desired by TTU's Agricultural Department, which is the customer for the project.

There will be zones created in the greenhouse to control the nutrient levels and water levels for the shrubs and ferns. The nutrient levels will contain nitrogen and carbon dioxide measurements. A manual override for the water levels will be implemented in case there is a need for more watering of certain plants.

Sensors will be placed throughout the greenhouse to accurately measure temperature, humidity, and carbon dioxide (CO2) levels.

In each of the zones, there will be containers for the plants. Sensors will be placed into these containers to measure the nutrient levels and moisture levels. This will provide an accurate measurement to each plant to ensure they are receiving the correct amount of nutrients and water.

Table 1: Greenhouse Item Specifications

Item	Specifications
Zones	Greenhouse shall contain two separate zones.
Communication Application	User Interface shall correctly show current and past data.
CO_2 Level	Sensors shall alert if carbon dioxide levels reach below 800ppm or above 1200ppm.
Humidity Level	Sensors shall alert if humidity levels are not within set range, usually 50-80%.
Water Control	Interface shall be able to offer customizable amount of scheduled waterings per day as well as manual overrides for watering.
Nutrient & Moisture Levels	Sensors shall alert if nutrient and moisture levels are not in ideal range.

Many of the specifications above were based on the desired needs of the Agricultural Department. The department provided the detailed temperatures and numbers they thought would be sufficient.

The greenhouse system specifications cover a wide array of features that aim to create the perfect conditions for plant growth and care. It all starts with temperature control: fans start up when the temperature exceeds 85°F, ensuring good ventilation. The greenhouse is divided into zones, and each one can be tailored to suit different types of plants. Air quality is a priority too, thanks to CO2 sensors that keep an eye on carbon dioxide levels. They'll send out alerts if CO2 drops below 800ppm or rises above 1200ppm.

Maintaining the right moisture and humidity levels is critical, and humidity sensors will alert if the readings stray from the 50-70% range. This will also allow greenhouse laborers to have their say with water control interfaces, and will allow them to set up scheduled waterings and make manual adjustments. Finally, nutrient and moisture sensors keep plants thriving by issuing alerts if levels aren't where they should be. Together, these specifications make sure the greenhouse provides the best possible environment for the plants.

User Interface must be understandable and have ease of use for this project to truly be complete. Many hands and users will be involved with using the interface and they may or may not know what has and has not been done within the greenhouse within a recent period. They will also need to understand clearly what each option means so they do not click something that shouldn't be used on the plants at a certain time or for a total amount of times. A test can be conducted by surveying the people who will be hands on with the devices once installed.

Designing a communications application for an autonomous greenhouse will require facing a few challenges and finding a way through the following constraints. The system will need to operate in an environment where low bandwidth and unreliable connectivity will play a major role. It will be necessary to optimize data usage and appropriately handling network disruptions. The application will also need to be able to hold on to past data for this will be a main feature wanted and needed in a greenhouse environment. Data processing needs to be able to be done in a small amount of time to allow for quick decision making to allow all other subsystems to work correctly. It will need to be optimized for low power because the devices that it will be implemented on will require this. Lastly, the interface should be easy to use and not require any expertise. Addressing these factors should ensure effective function of the communications system within the autonomous greenhouse.

The TTU Agricultural Department has requested two zones in the greenhouse. Each zone will consist of their own sensors, water distribution, and nutrient distribution. This includes a total structure of the greenhouse being split into at least half, where each part can be monitored and controlled based on which sector it is in. The zones should all be separate and not have leaks of information from other sectors influencing the data.

Team 2 also will have a project budget that will be a constraint that includes approximately $1,300 in materials and work to conclude the project.

C. Standards

Electronics

- IEEE 1547 – Standard for Interconnecting Distributed Resources with Electric Power Systems
- IEEE 1451.4 – Standard for Smart Transducer Interface for Sensors and Actuators
- 1926.404b OSHA – Standard for Wiring Design and Protection
- 1910.133a OSHA – Standard for Electrical Protective Equipment
- NFPA 70 – National Electric Code: Guidelines for Safe Electrical Installations
- IEEE 1680 – IEEE Standard for Environmental Assessment of Electronic Products
- ISA-99/IEC 62443: Standard for Securing Control Systems

General

- 29 CFR 1910 Subpart S – Standard for Electrical Safety

Environmental

- ASABE S520 – Standard for Controlled Environment Agriculture Facilities

III. Survey of Solutions

A. Measures of Success

- *Manual Water Override:* Based on certain conditions inside the house, the customer has requested that the watering schedule have the option to be manually operated. This is for two main reasons, the first being that sometimes the plants need to be watered extra due to certain outside factors. The other being that if there were to be an issue with the components, the plants would obviously still need to be watered. The measure of success is for the water to be controlled manually or by the PLC.
- *Ease of Use:* It is imperative that the system is concise in the functions it can provide. A working and easy to follow control system for the automation is needed for evading mishaps towards the sheltered plants. The measure of success is for anyone working in the greenhouse to be able to easily operate it.
- *Individual Zones:* Variety in the amount of water and nutrients for plants in the green house is expected by the customer. Two zones in the greenhouse around 5-8 feet each is the ultimate objective for Team 2. The measure of success is for each zone to be able to independently provide needs for all subsystems including water, nutrient control, and precise measurement.

B. Past Solutions

- One example of a past solution to the automated greenhouse problem is the Bluelab icons series of plant growth solutions. This collection of plant growth items includes pH and nutrient level sensors as well as a "scalable" kit that can measure pH and nutrient levels as well as set remote alarms and deliver set dosages of nutrients to desired plants. The kit itself is called the Bluelab "Autogrow Intellidose Kit." Bluelab is a company out of New Zealand who provide "flexible and scalable solutions" for commercial growers [5].
- Another past idea for the automated greenhouse is the Prospiant greenhouse automation system. Prospiant states that they provide an automated greenhouse system that provides a range of climate control systems that oversee temperature, humidity, carbon dioxide and light. The company also claims that these systems are used to create the ideal environment for crop growth and aim to reduce consumption of water, fertilizers, pesticides, and chemicals while also optimizing the use of manpower and crop growth and production. Prospiant also states that the upfront costs of such a system is a challenge to some growers, but the company claims that the long-run benefits far outreach the initial costs and worries [6].
- The company Priva has provided yet another solution to the automated greenhouse issue. Priva aims to provide a fully automated crop growth system that is completely remote and can be operated from the palm of one's hand with any cellular device. The company wishes to provide its customers with a solution that integrates and links all processes and systems in user greenhouses including, but not limited to irrigation, lighting, carbon dioxide levels, and plant nutrients. Priva states that its systems contribute to achieving desired climate conditions for greenhouses, help users to optimize their energy and water usage, providing fully remote capabilities and "futureproofing" its customers businesses [7].
- One final solution to the issue is the MVTEC software-based agriculture solution. The company aims to provide cost-effective resources, high quality and quantity of crop yields, and reduction of the environmental impact of greenhouses through its plant protection software and machinery. They are also looking to provide precise harvest times, availability, and reduction of harmful substances and plant diseases with their automated monitoring and harvesting processes [8].

C. Potential Obstacles and Implications

- A power outage can cause the automation system to shutoff and no longer control required variables for plant growth. A backup power supply, via battery or generator, could help keep the greenhouse in check for as long as the power is out. This could cause problems with the communication systems, which would need internet/power to operate.
- With many sensors being used, a vast amount of data will be accounted for. Ensuring that the data is

organized and maintained will be key in providing a suitable product to the Agricultural Department.

- Proper airflow inside the greenhouse is essential in keeping the plants healthy. A potential hazard arises since the house only has two fans which could fail before the completion of the design. This risk can be eliminated by having backup fans.
- The shipping and delivery of supplies could potentially slow down Team 2. Electrical components and supplies can sometimes be hard to come by within a reasonable amount of time. If the needed material is not available, they will have to use another item or potentially change the system entirely.

IV. Resources

A. Team Members

The following list is meant to reflect the key proficiencies of each team member.

Jaxson Billings

- C/C#/C++
- Java
- Python
- Assembly
- Digital/Embedded Systems
- Debugging
- Welding

Jared Hooker

- Power Generation
- Power Distribution
- Soldering
- LTSPICE Simulations
- Electronics
- MATLAB
- Wiring

Grant Hooper

- Electronics
- MATLAB
- LTSPICE Simulations
- Soldering
- Wiring
- 3D Modeling (and 3D printing if necessary)
- EM Fields

Noah Jones

- Project Management
- Wiring
- Electronics
- Soldering
- MATLAB

Bryan Rhoton

- Digital/Embedded Systems
- C/C#/C++
- Python
- MATLAB
- LTSPICE Simulations
- Circuit Analysis
- Assembly
- Circuit Design

B. Components and Project Budget

- Items Needed (Tentative)
  - Temperature Sensors (DHT11 or DHT22)
  - Humidity Sensors (DHT11 or DHT22)
  - CO2 Sensor
  - Soil Moisture Sensors
  - pH and Nutrient Sensors
  - Arduino/Raspberry Pi
  - Linear Actuator or Servo Motor
  - Relay Modules
  - Software Development Tools (Possibly)
  - Wiring
  - Connectors
  - Tubing
  - Arduino Water Kit
  - Contingency Plan
- Current Inventory
  - Greenhouse Structure
  - Power Supply
  - Breadboard

Team 2 can expect to see a budget of approximately $1,418.15 to be able to complete the autonomous greenhouse with a contingency plan of twenty-five percent included in the budget. The table below shows the projected cost of the Bill of Materials. These costs are not final and are only an expected amount per item. The item list is not final, and one can expect to see unpredicted materials not foreseen. Prices do not include shipping as the total number of orders and total number of suppliers are not yet known. Items could also be provided by the customer or sponsor if applicable and available. [9]

Table. Tentative Summary of Expected Project Costs

Item	Cost (USD)	Link to Example
Temperature And Humidity Sensors	$9.95 x 4	https://www.adafruit.com/product/385
Capacitance Soil Moisture Sensors	$250-350	https://extension.umn.edu/irrigation/soil-moisture-sensors-irrigation-scheduling#pros%2C-cons-and-costs-of-volumetric-water-content-sensors-1751860
		https://extension.umn.edu/irrigation/soil-moisture-

Moisture Data Logger	$500-2500	sensors-irrigation-scheduling#pros%2C-cons-and-costs-of-volumetric-water-content-sensors-1751860
NPK Sensor	$47.53	https://www.amazon.com/Xinwoer-Precision-Nutrient-Intelligent-Fertilizer/dp/B07ZKTK8QR?crid=1U2ANHIIYBK9O&keywords=NPK+Sensor&qid=1671652004&sprefix=npk+sensor,aps,114&sr=8-1-spons&psc=1&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEzM0s1WDZKNTc0RjNJJmVuY3J5cHRlZElkPUEwMzM3MzQ2VkZXVzhESTFXQzVNJmVuY3J5cHRlZEFkSWQ9QTA5MjA1OTM5MjVTVVlUSFUxUDUmd2lkZ2V0TmFtZT1zcF9hdGYmYWN0aW9uPWNsaWNrUmVkaXJlY3QmZG9Ob3RMb2dDbGljaz10cnVl&linkCode=sl1&tag=howtoelect0e4-20&linkId=93f8528d4d6406797702aac10c3e8ccb&language=en_US&ref_=as_li_ss_tl
Arduino Nano Board	$16.49 x 4	https://www.amazon.com/HiLetgo-ATmega328P-Controller-Compatible-ATmega328/dp/B09KGVDXZY?crid=DQDQ282P2EMA&keywords=arduino+nano&qid=1670424115&sprefix=arduino+nano,aps,93&sr=8-1-spons&psc=1&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEzMU5EQ1NHUU1MWUVFJmVuY3J5cHRlZElkPUEwMDIxNzYwM0dKMkJST0FLMUZUJmVuY3J5cHRlZEFkSWQ9QTAwMzUwMDYzSzY4RzBMQ1NISjdNJndpZGdldE5hbWU9c3BfYXRmJmFjdGlvbj1jbGlja1JlZGlyZWN0JmRvTm90TG9nQ2xpY2s9dHJ1ZQ%3D%3D&linkCode=sl1&tag=howtoelect0e4-

		20&linkId=c2738d6089735de26f7e540e675af678&language=en_US&ref_=as_li_ss_tl
LCD Display	$8.49	https://www.amazon.com/HiLetgo-Serial-SSH1106-Display-Arduino/dp/B01MRR4LVE?crid=2AV7A4DBT94GK&keywords=0.96%2Binch%2Boled%2Bdisplay&qid=1671652070&sprefix=0.96%2Caps%2C133&sr=8-1-spons&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEyOTNZOVVXWENGOTgmZW5jcnlwdGVkSWQ9QTAxMDMxNzYyT0s0VDhLQjJYYlZFJmVuY3J5cHRlZEFkSWQ9QTA4ODg0NDQzTEFRQVdWMEhIVDRUJndpZGdldE5hbWU9c3BfYXRmJmFjdGlvbj1jbGlja1JlZGlyZWN0JmRvTm90TG9nQ2xpY2s9dHJ1ZQ&th=1&linkCode=sl1&tag=howtoelect0e4-20&linkId=4112e5002517c2bba3b24f2e60d3e783&language=en_US&ref_=as_li_ss_tl
MAX485 Modbus Module	$10.99	https://www.amazon.com/Transceiver-Instrument-Communication-Development-Accessories/dp/B094MKRTRC?keywords=max485+module&qid=1670426525&sprefix=max485,aps,95&sr=8-3&linkCode=sl1&tag=howtoelect0e4-20&linkId=6876a0862eaedae079ff26f5de62dcf3&language=en_US&ref_=as_li_ss_tl
		https://www.amazon.com/EDGELEC-Breadboard-Optional-Assorted-Multicolored/dp/B07GD2BWPY?crid=H7TZFJO1QGTK&keywords=jumper%2Bwires&qid=1670423829&sprefix=jumper%2Bwires%2Caps%2C96&s

Connecting Wires (120pcs)	6.99	r=8-1-spons&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUFKVFBCTEpDVEoxSEUmZW5jcnlwdGVkSWQ9QTA0NDg2ODAyN0RGWVlJU1VDREREJmVuY3J5cHRlZEFkSWQ9QTA5NDU0MzYxSkE3VExKQkZEQUxaJndpZGdldE5hbWU9c3BfYXRmJmFjdGlvbj1jbGlja1JlZGlyZWN0JmRvTm90TG9nQ2xpY2s9dHJ1ZQ%3D%3D&linkCode=sl1&tag=howtoelect0e4-20&linkId=fb9cb1bfdb1eac87858ef96885bb79f0&language=en_US&ref_=as_li_ss_tl&th=1
Arduino Relay Module	$5.00	https://usa.banggood.com/5V-8-Channel-Relay-Module-Board-PIC-AVR-DSP-ARM-p-74110.html?imageAb=2&p=MA240439985285201910&akmClientCountry=America&a=1694831231.834&akmClientCountry=America&cur_warehouse=CN
CO2 Sensor	$44.95	https://pmdway.com/products/mhz19-co2-carbon-dioxide-sensor
Plant Water Pump/Kit	$53.00 x 2	https://store-usa.arduino.cc/products/plant-watering-kit?selectedStore=us
Contingency Plan	$252.54	[25% of above items]
Total	**$1,418.15**	

C. Timeline

This time can be split into the following sections provided by the course syllabus:

- Team Contract
- Project Proposal
- Conceptual Plan
- Conceptual Design
- Detail Design Phase
- Additional Course Due Dates

All dates below have been established by Mr. Roberts. Each subsection in the Gantt chart below has assignees based on skill sets and will be documented below:

Logic Design – Jaxson Billings and Bryan Rhoton
Sensors & Parts Design – Jared Hooker, Grant Hooper, and Noah Jones

The Gantt chart is presented below. It is split into two figures. The first being the first half of the semester and the second figure representing the second half. All tasks have been spread out appropriately and should be adequate for completion as long as no unforeseen problems and conflicts occur. The final presentation is due on December 8th, 2023, and is the basis for all other deadlines.

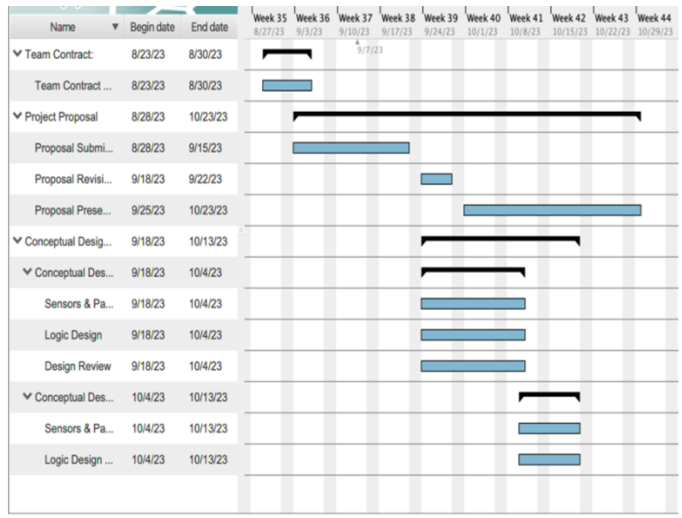

Figure 1. Gantt Chart Representing 1st Half Semester Dates

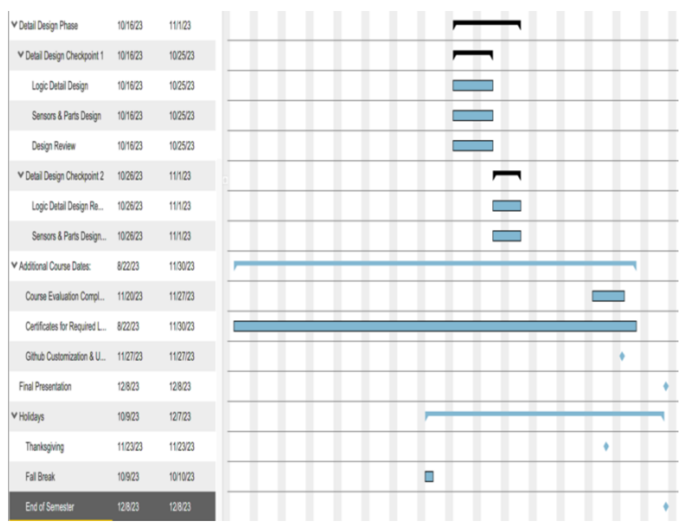

Figure 2. Gantt Chart Representing 2nd Half Semester Dates

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