Indoor Vertical Farming

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***Abstract*—For this Project, our proposal and area of concentration will focus on microgreen vertical farming and the effects of plant growth under different lighting conditions. Today's top industries are constantly seeking lighting conditions that will optimize plant growth in indoor environments to maximize profits and to control photosynthetic active radiation and intensity provided to plant organisms. Through our project, we will explore the benefits of growing microgreens under light emitting diodes (LED). This project will focus on the environment, lighting, and Irrigation systems. We are also capturing the Images of the plants to apply Leaf Instance Segmentation on it. Using AI and computer vision we can obtain quantitative information on plant phenotyping and plant growth development behavior. The indoor vertical farming system sought to reduce water consumption, increase growth output in a shorter range of time, and provide feedback-based automation, allowing the vertical farm to run with minimal user input. Within this project we aim to achieve multiple growth cycles with precise growing conditions via lighting watering and environmental conditions. The system is based around the Raspberry Pi microcomputer and open-source software and components.**

***Index Terms*—Vertical Farming, Computer Vision, Raspberry Pi**

I. Introduction

Indoor vertical farming encompasses a broad range of processes and procedures. It requires knowledge across many fields such as agriculture, plant biology, chemistry, and lighting technology. Based on research on hydroponic systems and environmental effects associated with plant growth, we are working to configure a system which satisfies lighting, watering, Image Capturing and environmental effects. This system will allow the user to control the Photosynthetic Active Radiation (PAR) spectrums and intensities, watering intervals and quality, and relative humidity as well as temperature for a variety of plant organisms. The indoor vertical farming system was selected due to its efficiency, relatively limitless growing capabilities, and large scalability, that can also be used by industries alike.

Current industry vertical farms grow traditional greens such as tomatoes, leafy greens, herbs, and a vast variety of other plants; however, our project is focused on herbs. Through our project predecessors, we learned that the six different types of herbs (cilantro, basil, marjoram, oregano, mint, thyme) are most grown in vertical farming industries today. Therefore, in our plant selection process we were able to determine that growing microgreen herbs was the overall better solution when compared to growing traditional herbs grown in vertical farming industries today.

II. Design Objectives

As the current industry of microgreen vertical farming stands, traditional systems include the use of HPS, and fluorescent bulbs which provide limited light intensity and spectral quality. However, by using LED lighting technology microgreen growers will have the ability to control light intensity as well as the photosynthetic active radiation spectrum (PAR). We plan to carry out an all-inclusive participatory investigation into plants currently used in vertical farming, hydroponic systems, air conditioning/humidity systems, and lighting systems. In response to this problem, our study proposes to investigate several options for developing solutions to the design objectives below:

• Design of a feedback-controlled lighting system that supports up to 8 different wavelengths with the ability to run 4 independent experiments at once.
• Development of an automated environmental control system for growing microgreens.
• Development of cameras setup for capturing the Images.
• Development of a feedback-controlled water quality and quality correction system.
• Development of a system for characterizing the light inputs to plant growth outputs to optimize plant yields.

III. Vertical Farm Overview

Fig. 1. Preview of the Farm

Figure 1 gives an overview of the farm tent from outside and inside.Four trays are stacked during the growth cycle.

IV. Irrigation System

When it comes to the irrigation system in a sense of indoor vertical farming, there is much more control over different

Fig. 2. Internal View of the Farm

properties that are needed to maximize the yield. As the entire scope of our project is focused heavily on the lighting system and emittance to maximize the yield of our growth cycles, we needed to maintain all other properties. For this system the purpose was to maintain various properties such as electrical conductivity, dissolved oxygen, pH levels. Measuring and stabilizing these properties are a critical part to accomplish the design of experiments with the lighting. Establishing a stable environment will start with the irrigation system and is a huge part to establishing a valuable plant yield.

The pH of water used to grow microgreens can drastically affect the overall yield and growth of the plants. To prevent the possibility of root rot (via water molds like phytophthora or parasites and fungi such as Fusarium and Pythium), and the growth of bacteria that may harm the plants root systems or the plants themselves, ultraviolet radiation was considered. The usage of UV (ultraviolet) radiation in all concentrations greatly reduced bacterial populations, specifically killing many of the bacteria responsible for root rot. It was found, however, that usage of UV radiation also killed non-targeted bacterial populations and did not eliminate the fungal populations responsible for root rot. Thus, UV radiation would be beneficial in eliminating some risk factors for plant growth, but not all. A risk factor of UV radiation treatments is the probable destruction of beneficial bacteria at the root system, which could prevent the root system from intaking valuable and necessary dissolved nutrients, for which the bacteria are responsible for breaking down for the root system to easily intake these nutrients.

Dissolved oxygen also known as molecular oxygen can be described as the amount of oxygen that is available to a living organism. This directly relates to water quality used for the plants. The optimal level of dissolved oxygen is needed to prevent the plants from suffocating. Plant roots contain microorganisms and bacteria which create a symbiotic relationship. The plant can only survive with the optimal amount of oxygen.

Oxygen in the water is controlled by temperature. The dissolved oxygen will decrease as the temperature increases, and as temperature decreases, the dissolved oxygen content increases, sharing an inverse relationship. Maintaining a constant temperature within the growing atmosphere is critical. To control the temperature of the water there is a direct correlation with the temperature of the growing atmosphere. The temperature affects plants capability to photosynthesize and seed germination. The ideal temperature for a growing atmosphere can range from 70 – 80 Fahrenheit (21.1 – 26.6 Celcius). This temperature is appropriate for the germination and growing stage of the plant's daylight (lights on) simulation from the lighting. The optimal temperature for the night (lights off) simulation can be from 55 – 70 Fahrenheit (12.8 – 21.1 Celcius). This allows the plants to exhibit similar conditions to outdoors. During the night simulation plants go through transpiration. Indoors, this can be achieved with an air conditioner and the lights. Physical factors to replace dissolved oxygen and aerate the water include an air pump connected to an air stone. Although they clarified an issue in this experiment that high readings suggested heavy aeration of the aerated beds, which also affects the control beds, a phenomenon owed to the small size of the system and closed water loop. This still shows that once the aerated system was introduced, the plants were reaching acceptable oxygen levels with the system.

Oxidation reduction potential (ORP) is a chemical reaction that is the waters' ability to accept and release electrons. To further explain, "Potential (voltage) at which oxidation occurs at the anode (positive) and reduction occurs at the cathode (negative) of an electrochemical cell". The reason electrons need to be added back into the water is the oxidizing elements pulls electrons from the cell membrane. This can influence the cell and cause it to become unstable destroying the integrity of the cell and causing a rapid death to the plants. ORP is an important property as it could allow plant growers to optimize the plant growth, by determining water quality and how to treat water.

Fig. 3. Water Quality Sensors

Measuring each of these properties will help to determine how stable our environment is. To measure each property, probes will be used. We have built a small water quality system using Ph, ORP, DO, RTD, EC sensors which captures the value of the water at regular intervals and stores it into a CSV file. A python script is written which captures the values say each hour for all the sensors and stores the readings with timestamp in a CSV file. This helps us to better understand the readings of the water so that we can know how fluctuating the values are and what insights we can get.

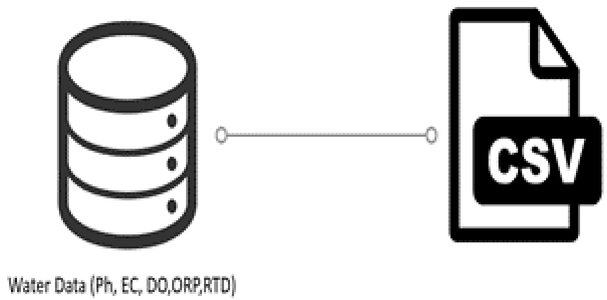

Fig. 4. Data Collection

V. Environmental Impact

Vertical farming has emerged to help the environmental impact of a growing population and demand for food sources. Vertical farming utilizes a controlled environment with the use of LED lighting and a hydroponic system to supply nutrients, therefore it is not affected by climate change. Advocates of vertical farming claim that it may increase productivity, reduce environmental footprints from production and transportation and offer many advantages to traditional greenhouses and agriculture by controlling the growing conditions in indoor climate-controlled spaces, typically in urban environments. While the energy consumption is a concern it is overlooked as vertical farming is a contender to replace traditional farming as population around the world increases. The overall environmental impact of our project is projected to be beneficial to the environment. The microgreens we are growing have no biomass and can be completely consumed or composted. The fibrous coconut fiber coir we are using can be compostable and any nutrients left in the coir mat will be distributed into the compost. Considering our project uses 90% less water than traditional farming methods we have a lower rate of water consumption. The overall system uses about 25-30 gallons of distilled and pH balanced water approximately every two weeks. Plants also absorb carbon dioxide emissions and essentially scrub the air of toxins. Helping reduce greenhouse gases affecting the current global warming changes we are facing.

VI. Control System Overview

Various components like Raspberry Pi which is a capable little device which has a system on a chip for computing, Camera used for capturing the plant images during the growth process so that we can do Image Analysis. A/C and Humidifier to maintain the optimum temperature inside the tent for the best growth conditions.

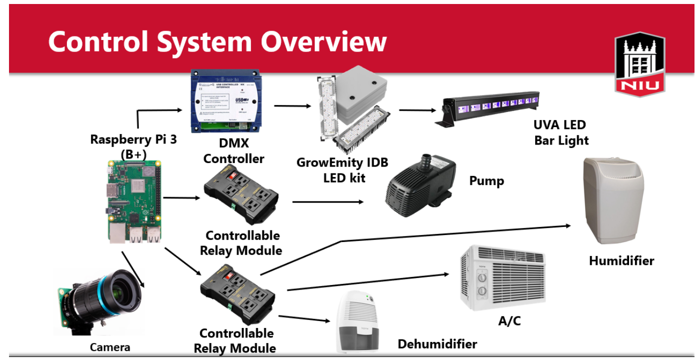

Fig. 5. Components of the System

VII. Technical Methodology and Solution Approach

In this section we will bridge the gap between theory and our design objectives and how they have been implemented into the system. Included in the already implemented features of the system we will describe our improvements to these features. Finally, we will discuss and describe our continued plan to meet our design objectives. The Vertical Farm System is split into four core subsystems: Climate, Irrigation, Camera and Lighting. These four subsystems are enclosed within a mylar lined tent. This enclosure provides the tent with thermal insulation. It also provides us with isolation from external light pollution. Referencing back to the theory section, the elements of interest with regards to climate are temperature, humidity, and CO2 concentration. For this sub-system we employ two independent closed-loop control systems to control temperature and humidity. Each control system is fitted with a Raspberry Pi (RPi) single board computer. By using an RPi we are allowed flexibility and versatility when it comes to implementation. The feedback element is a dual temperature and humidity sensor that takes both temperature and humidity measurements from one sensor, simplifying the system. Temperature and humidity readings are processed into the RPi using a program written in Python. This program compares the sensed values against the upper and lower thresholds derived from the optimal climate conditions. For example, if the temperature sensed by the sensors exceeds a value of 24°C the program reacts by sending a signal to turn on the Air Conditioning (AC) unit. This air condition is capable of 5,000 BTU cooling which will allow us to quickly return within the optimal temperature range. The same process applies to the humidity but with one caveat. In certain situations, the humidity of the tent can exceed the optimal range. In the region above 60%, the likelihood that mold can begin to grow increases exponentially. Therefore, the system utilizes a dehumidifier to remove excess moisture from the air to maintain optimal humidity levels. CO2 concentration is not something we can safely control in any meaningful way to be beneficial to the system. Although, atmospheric levels of CO2, in the tent measure around 400 ppm which falls within optimal range. For this reason, we are simply monitoring the concentration within the tent and CO2 enrichment is not a consideration. Irrigation encompasses a vast set of parameters that need to be tracked and controlled. It also consists of the methods and techniques to deliver water to our plants. As stated in the irrigation theory section, main parameters to track are power of hydrogen (pH), dissolved oxygen (DO), electrical conductivity, and temperature. The system utilizes an ebb and flow technique for water delivery. The water supply is stored within two 50-gallon reservoirs that sit underneath each grow rack. Inside each reservoir are two submersible pumps. These pumps connect to flexible tubing that run vertically up the shelf and into flood tables that sit above on shelves within each grow rack. It is imperative that we have water-tight seals between the flood table and tubing to eliminate any leaking and waste. Our seedlings sit on top of a coconut fiber growth medium within a precision cut plant tray. Typically fit 3 plant trays side by side within the flood table. Like the environmental system, a Python program running on a dedicated RPi controls the pumps. Every day at a predefined time the RPi sends a signal to turn on the pumps. Our project predecessors determined a sufficient pumping time of 5 minutes ensures that the coconut fiber and seedlings are properly saturated. To avoid the flood table overflowing, a conical outlet is installed at a set height above the inlet. The height difference ensures that the water can fully saturate the coconut mat. The outlet returns water to the reservoir through more flexible tubing. The water control system is controlled by a single GUI that uses 2 sub programs. The first is the water control system overview, which provides the current setup (illustrating start date, growth cycle length, occurrences, the current mode [germination or farm], the water cycle start time, and duration), and options to create a new setup, modify the existing setup, make a live adjustment, or exit the menu.

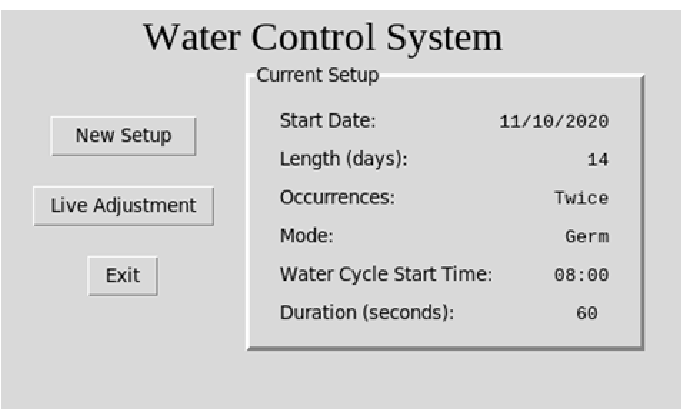

Fig. 6. Water control system main setup panel

The new setup menu allows you to create a new program for running either the farm or the germination system. In the new setup, you can adjust the grow cycle based upon the number of days it will run, a start date selected by the user, and occurrences (with options of once or twice daily watering).

The start time allows you to set what time the watering

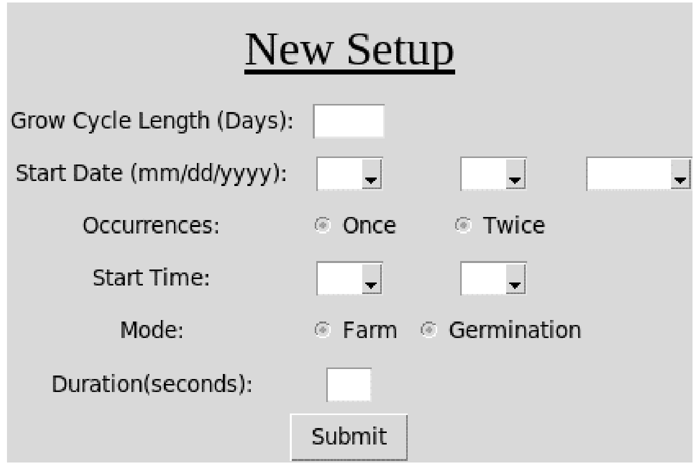

Fig. 7. New setup window

system turns on, while the mode allows you to select which system will run (main farm or germination). Finally, duration sets the length of time the watering system will run.

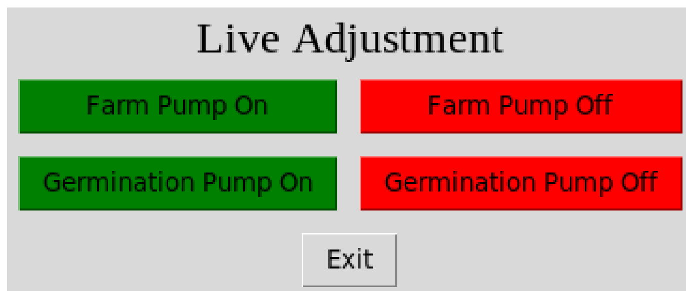

Fig. 8. Live adjustment window for rapid adjustments to watering system

Live adjustment allows for immediate user control of the watering systems of both the germination system and of the vertical farm. By clicking Farm pump on or germination pump on, the watering system will activate and run until the user decides to turn it off. To turn off either system, the Farm Pump Off and Germination Pump Off buttons will shut down the watering process. With the ebb and flow system that has been implemented, the same water source is reused constantly over time. This can cause the quality of the water to drift outside of optimal values.

VIII. Germination Testing

Germination is the process for providing the plants with adequate water. As per the given farm conditions plants were germinated twice per day so that they are moist enough during the growth process and get sufficient nutrients from water for better growth. Sprinklers were attached inside the tent which were operated via a germination python program that would automatically on/off the sprinklers at the mentioned time intervals during the growth cycle.

Fig. 9. Sprinkler's used for germinating the trays

Fig. 10. Trays placed under sprinklers during germination

IX. Lighting

The DMX controller functions acts as a passthrough between the lighting fixtures and the lighting RPi. This RPi contains all the programs used to setup and run the lights, including custom made software as well as open-source programs. To operate the lights and setup an experiment, we begin by running the Open Lighting Architecture (OLA) software. This allows the RPi to utilize the DMX connections to the lighting fixtures. Once the OLA software has been initialized when run our custom Lighting Control Graphical User Interface. From this menu (Figure below), the user can start a new cycle, import a cycle that they have already created, view the current growth cycle recipe, or modify the current growth cycle recipe.Vertical farming utilizes a controlled environment with the use of LED lighting, therefore it is not affected by climate change. This lighting system supports up to eight different wavelengths with the ability to simultaneously run four independent automated environmental control system for growing microgreens.

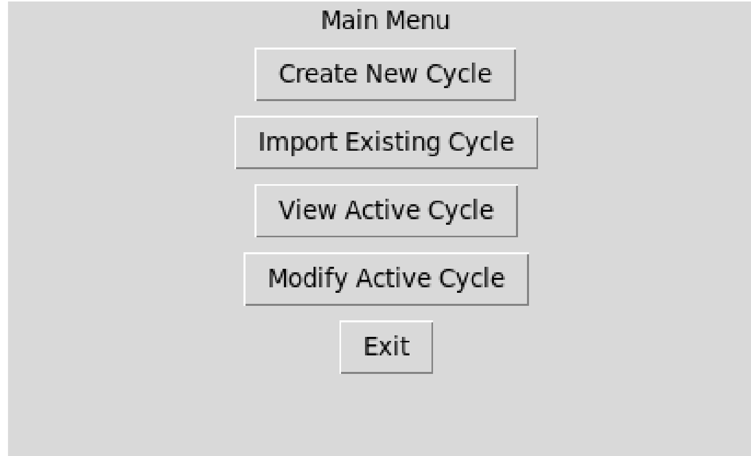

Fig. 11. Main Menu for the Lighting Control GUI

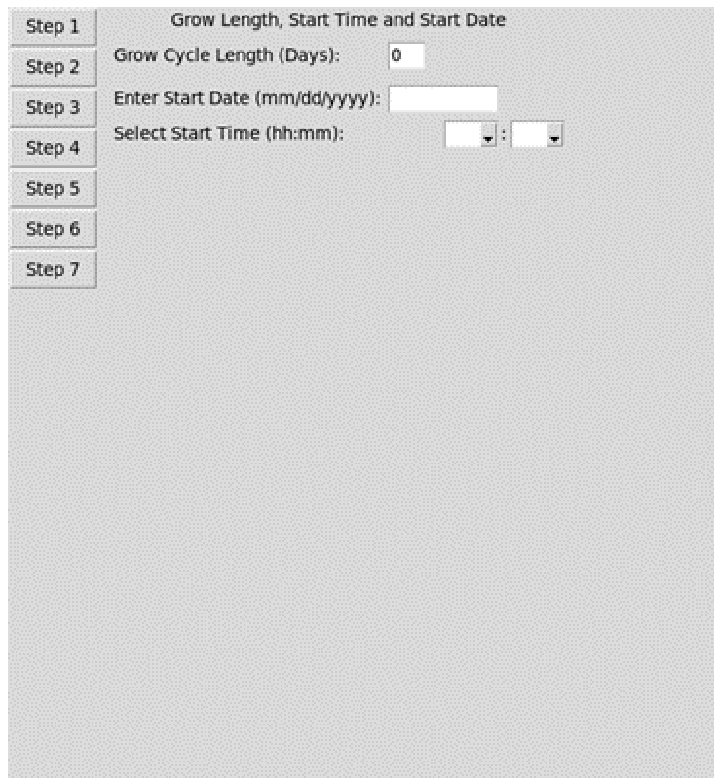

Fig. 12. Growth Length, Growth Start time and Date

With step 1, we establish the total growth cycle length in days. Next, the start date of the growth cycle is specified. Finally, the specific time of day for the growth cycle is established. Finally, the specific time of day for the growth cycle is established.

In steps 2-5, the user will input the specific lighting ranges for each of the lighting spectrum options, specifying its intensity. Below 50, the specific lighting option will not activate. This will be established by the user for each individual farm (4 in total).

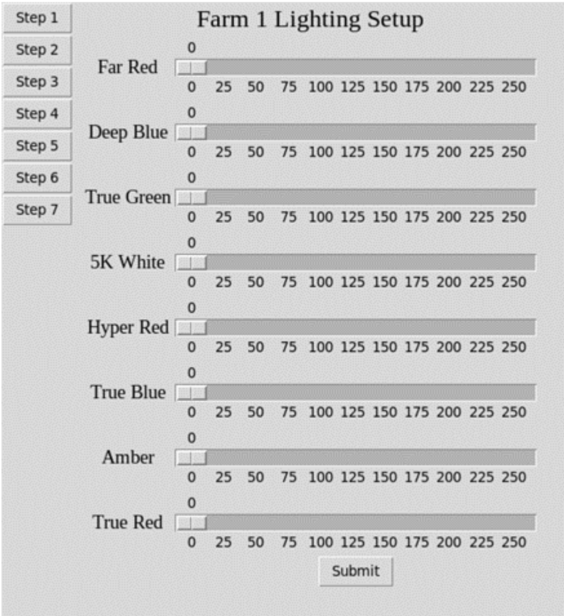

Fig. 13. Lighting Condition Setup for Farms 1-4

In the overview, the user can see the specific lighting settings for each farm on a single screen. By clicking any of the previous steps, they can return to that specific farm or step to adjust their values if they do not match what the user intended.

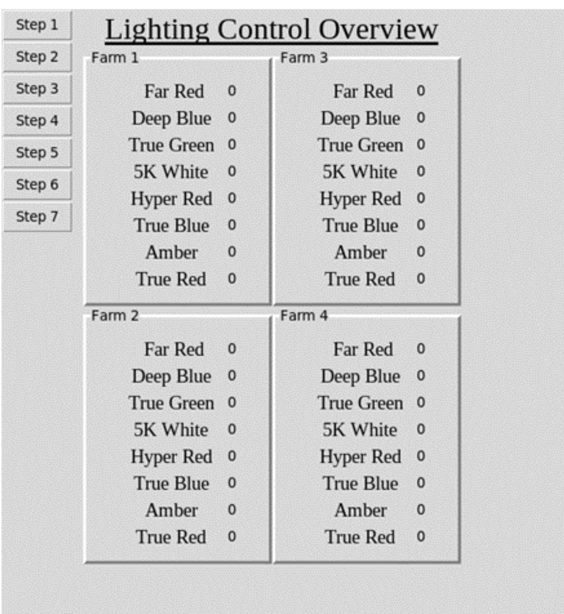

Fig. 14. Lighting Conditions Overview

Here, the user will be shown the current start date that they had specified. The user will be asked if they would like to apply this to the entire cycle and are then provided the option to enter an end date, at which point the growth cycle will complete.

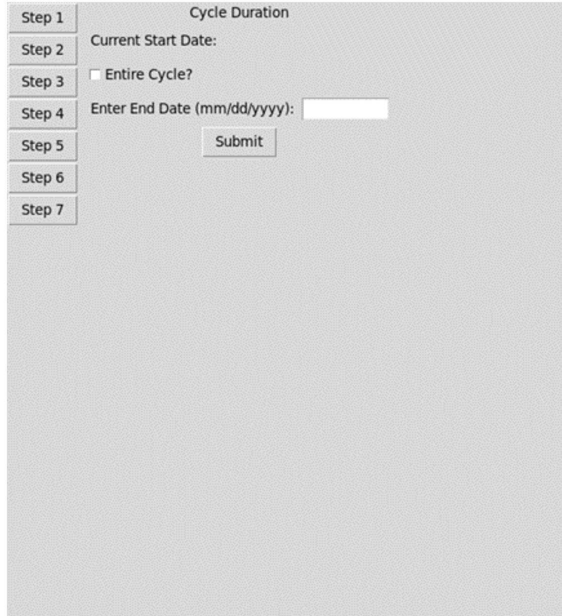

Fig. 15. Cycle Duration and Setup Completion

X. Camera Setup

Analysis of plant growth encompasses many different methods and practices from dry mass characterization to growth rate equations. We sought to implement a method that would allow us to analysis plant growth in a touchless manner that did not require physical labor or human intervention.

Fig. 16. View of the Farm Trays during growth phase

For this we have used 4 raspberry pi HQ camera one on each farm that can capture images of the 4 farms at regular intervals and store the images in the memory that can be used to apply Instance segmentation on the leaves. This workflow would use artificial intelligence to determine the plant boundary relative to the size of the growth tray. Using these parameters from a metadata text file, we could calculate the leaf area index to determine the effect lighting had on the plant growth.

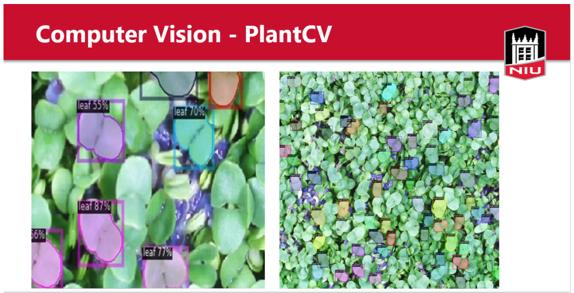

Fig. 17. PlantCV output image

XI. Conclusions and Recommendations

The overall goal of this project was to design a feedback-controlled lighting system that supports different wavelengths with the ability to simultaneously run four independent automated environmental control camera system for growing microgreens. Also, we wanted to implement multiple Graphical User Interfaces (GUI) for both the lighting and watering control systems to easily allow new users to set up a new growth cycle. The implementation of both GUI's was a very important step as this allows practically anyone, with no python experience, to easily setup the farm for use. Finally, to develop a system for characterizing the light inputs to plant growth outputs to optimize plant yields. Overall, the system was able to implement an automated growing environment that successfully produced microgreens. By using multiple Raspberry Pi microcomputers with both GUI's, we were able to develop an automated lighting, watering, temperature, camera, and humidity control system. Using the collected data, we were able to prove that our system operated as designed and will help further the project in the future.

XII. Acknowledgments

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