Greenhouse Environmental Analyzer of Blue to Red Light, Humidity, Temperature, & CO_2

Maya Sosa, Paul Weiner, Leiner Suarez Colome, and Raul Graterol Medina

Dept. of Electrical Engineering and Computer Science, University of Central Florida, Orlando, Florida, 32816-2450

***Abstract* — This paper presents a new multifunctional device capable of measuring the overall light intensity (lux), the ratio of blue and red light, humidity, temperature, and carbon dioxide within the confines of a greenhouse, which is known as the Greenhouse Environmental Analyzer of Blue to Red Light, Humidity, Temperature, & CO_2 (G.E.A.). In addition to measurement, this device can remotely adjust blue and red LEDs to fit a user's desired ratio. The purpose of the device is to allow greenhouses to have more direct control over how their plants grow.**

***Index Terms* — Semiconductor Diodes, Vegetation**

I. INTRODUCTION

Greenhouses are used across the planet to grow plants and supply food to an unfathomable number of people across the planet. Despite the prevalence, there has not yet been an all-inclusive device capable of measuring the most important parameters within a greenhouse at the same time: light intensity, temperature, and carbon dioxide, and temperature. In addition to these parameters, there is none that measures the ratio of blue to red light.

The ratio of red and blue light is important, as red light is primarily responsible for the flowering and fruiting of plants, and blue light is primarily responsible for the stem and leaf strength. [1]Therefore, how much red or blue light a plant receives is directly correlated to the plant's overall health. As such, our device provides greenhouse owners with a device controlled by a mobile app, that allows users to not only measure overall light intensity, humidity, temperature, carbon dioxide, and the ratio of blue and red light, but it also provides them with the opportunity to choose the light ratio that best fits the needs of their plants.

II. SYSTEM COMPONENTS

The whole device will consist of three main modules that will interact with each other for the application's purpose. Two hardware modules: The Main PCB and The LEDs Panel PCB, and one software module: the mobile app. We will describe the main components of the hardware modules.

A.The Main PCB

This is the heart of the project. It contains an MCU that is powered by batteries. The Microcontroller reads data from four sensors and sends the information through wifi/internet connection to a remote server.

*A1. The Microcontroller **

The brain of the PCB is the ESP32-S3- wroom-1. The main reason is its embedded Wi-Fi antenna, and a flash memory ,which made it easier and feasible to design and implement. and save real estate on the PCB. It has dedicated pins for USB and any GPIO pin can be used for I2C, which makes it the ideal microprocessor for our application since we have multiple sensors that communicate through I2C. It also has a 40 MHz crystal oscillator and supports temperatures in the range of -40 to 85 °C.[2]

A2. Photodiode Sensors

The VEML6030 is the main light-sensing hardware on the project. The dynamic range and impressive top value of 120,000 lux make it easily reach what can be seen in a greenhouse, as the lux value seen in direct sunlight is 100,000 lux [3], which is unlikely to be reached. Also, the sensitivity range for this sensor is exactly that of photosynthesis [4], and it also expands that sensitivity with its algorithm. Also, it was the cheapest option. [5] Three of them are used in the project, one for blue light, one for red light, and another for ambient light.

A3.CO2, Humidity and Temperature sensor

We need to measure CO2, humidity, and temperature to properly monitor a greenhouse. We found a sensor which measures all, it is the SCD-40. It detects CO_2 levels from 400 ppm to 5000 ppm using the photoacoustic effect, with an accuracy of ±40 ppm + 5% at 25°C and 50% relative humidity. The CO_2 measurement response time is 60 seconds, making it suitable for applications like greenhouse monitoring. The sensor also measures relative humidity with ±9% accuracy over a temperature range of -10°C to 60°C and humidity levels from 0% to 100%, with a response time of 90 seconds. Temperature readings have an accuracy of ±0.8°C from 15°C to 35°C and ±1.5°C for -10°C to 60°C, with a response time of 120 seconds. The unit is cost-effective at $49.95, making it a viable option for environmental monitoring applications. [6], [7]

A4. I2C Splitter

The project is using four sensors in one PCB, in which all the light sensors are the same which means we have three identical I2C addresses. The sensors have the option to change their hardware I2C address to another one, but even that will leave us with 2 redundant I2C addresses .Here is where we decided to implement an I2C splitter: TCA9546ADR. It receives the main I2C signal from the microcontroller and then splits to 4 I2C lines all of them with their own which goes through each sensor.

All these lines have to be pulled high since I2C is open-drain and we use 3.3V same as the microcontroller. We also have the RST signal that is good to use for controlling this IC.[8]

A5. Fisheye Lenses

Since our device is meant to be placed in a greenhouse environment, we had to make many considerations when figuring out how our optical design was going to be. Initial considerations and tests were performed with plano-convex lenses, which turned out to be fruitful when considering a light source that is directly overhead the sensors. Otherwise, we found that the lenses did not focus the light onto the sensors. Considering that our device is meant to be placed in a greenhouse, as the sun moves, it would be very likely that the most intense light, which would come from the sun itself, would be missed by the sensors. That would be far from ideal.

After pondering how to fix this problem and consulting professors, we landed on using fisheye lenses. Since fisheye lenses typically capture light from a wide field, usually 180 degrees, they were the perfect candidate for a lens.

While the idea seemed good in theory, we had to back it up with math.

The first equation that we considered was for a 180 degree projection from a fisheye lens. This equation essentially relates the beam size leaving the lens (r) to the focal length (f) and field of view(θ) of the lens in radians. [9]

$$r = f\theta \tag{1}$$

By plugging the desired beam radius, which is half the size of the active area of the sensor (25mm) and the field of view of 180 degrees, or π, we found that we would need a focal length of 0.31mm, which essentially means that the lens would need to have a very large power and is not feasible.

This did tell us, though, that we most likely needed our lenses to at least be as close as possible to our sensors, which makes sense, as the further away a lens is from the image plane, the more distance the image will move if the source moves.

Another method we used to determine how far away from the sensors our lenses would have to be with trigonometry. While this is a much simpler approach, many optical equations come from trigonometric relations, so this seemed like a valid way to approach this. Unlike the previous equation, which took the lens' field of view into account, we used the sensor's field of view of 110 degrees into consideration and assumed that the maximum size of the beam that exits the fisheye lens is the diameter of the backside of the fisheye lens itself . We were able to do this, since we figured out that the lens would need to be as close as possible to the sensor to fully cover it. Ideally, most of the light would be focused directly onto the sensor, but since the sensor itself has a large FOV, it's okay if the beam is larger than the diameter of the sensor, as long as the sensor is able to collect all the light leaving the lens. This is also okay since we are not imaging, only measuring.

The equation that we used to calculate the distance between the sensor and the lens is seen below, and is visually shown in Figure 1 with the numbers from the lens that we chose:

$$\frac{Opposite}{Adjacent} = \frac{Lens\ Back\ Diameter}{Dist.between\ Lens\ \&\ Sensor} = tan(\frac{FOV\ Sensor}{2}) \tag{2}$$

We can see that the larger the backend of the lens, the larger the distance from the sensor our lenses needed to be for the sensors to detect all of the light.

For these reasons, picking a fisheye lens to do the job was much simpler than expected. Instead of worrying about focal lengths, we just had to worry about the quality of the lens and where to buy it from. While there were many different options online, there were practically no reasonably-priced options that came from manufacturers like Edmund Optics or Thorlabs. This makes sense, as fisheye lenses are typically used for photography for a desired fisheye effect, and photography equipment can get very expensive if looking for professional equipment.

Thankfully, there are many alternatives to these expensive lenses online which are much smaller and cheaper. Doing a quick search on Amazon brought up fisheye lenses meant to be mounted on a phone camera, which we thought were the perfect candidate considering the fact that we aren't concerned about image quality or focal length, and we wanted to have something that would fit well with our sensor.

Out of those options, we chose the ALILUSO 180° Fisheye Lens since it was the cheapest option, and it had the 180 degree field of view that we required. While there is vignetting, it is something that we were willing to deal with, as the lens fit our requirements in every other possible way. Additionally, during testing later on, this didn't prove to be a huge issue.

The next thing we had to do was measure the diameter of the back lens so that we could use Equation (2) and find the distance needed between the back of the fisheye lens and the sensor. The back lens of the fisheye lens was measured to be ~11mm.

TABLE 1
COMPARISON OF FISHEYE LENSES

Lens	Cost	Vignetting	FOV	Focal Length
ALILUSO 180° Fisheye Lens [10]	$12.99	Yes	180°	7.5mm
Xenvo Pro Lens [11]	$39.99	No	<180°	4.1mm
Edmund Optics 2/3" Format C-Mount Fisheye Lens [12]	$835	No	185°	1.8mm

Fig. #1. shows the calculation of the required distance, which was found to be 3.5mm. While this was still very small, it was much more attainable than the 0.31mm that the previous equation suggested. Additionally, this turned out to be perfect, as the distance from the active area of the sensors and the physical distance that the lenses physically could be placed, given other structures on the sensor, was about this.

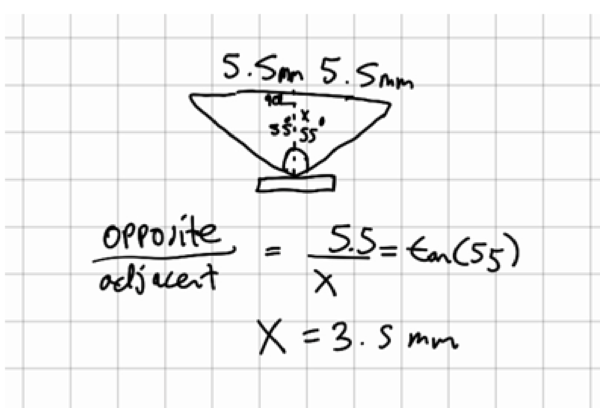

Fig. #1. Trigonometric Calculation for Lens Distance from Sensor.

A6. Blue and Red Light Filters

Since a large portion of our project focuses on measuring the ratio of blue to red light, we needed a way to filter the ambient light before it hit the blue and red sensors, respectively.

After researching the different types of filter technologies, we landed on using an absorption-based filter because they are not angle dependent, which is important since the sun is a moving light source and are generally cheaper than dichroic filters.

Finding a suitable filter was time-consuming. There are many different blue and red absorption filters online, but the ones from reliable companies are expensive, and filters on websites like Amazon don't tend to specify wavelength cutoffs or transmission factors.

Eventually, we found a company called LEE Filters Direct USA which specializes in making filters for photography. These filters were cheap, and they had options which were suitable for our project.

TABLE 2
FILTER CHOICES

Filter	Wavelength Range >6% Transmission	Wavelength Peak	Transmission % at Wavelength Peak
713 J.Winter Blue [13]	405nm-490nm	450nm	~25%
027 Medium Red [14]	610nm-700nm	700nm	~80%

After looking at all the different red and blue filters on the website, we landed on the choices seen above in Table 2. These filters were the only ones that did not leak any red or any blue, respectively. You may notice that the transmission ranges aren't a perfect 400nm to 700nm. However, these wavelength ranges are still very good for the price and type of filter, and the table above only shows the wavelength ranges where the transmission percentage is over 6%, so we were okay with this.

As you may also notice, the blue filters have a much lower peak transmission percentage than the red filters. This was something that we had to take into consideration when calibrating our sensors with the filters.

B1. The LED Panel PCB

The LEDs PCB follow the same design as the Main PCB but instead of having sensors it has LEDs. We need as many LEDs as possible to properly control the greenhouse blue to red ratio. We decided to implement 10 LEDs of each color: 10 Blues and 10 Reds. A total of 20 LEDs was the best our microcontroller could handle due to pin limitations and power consumption. Since we were already on Senior Design 2, we did not want to change the microcontroller and implement a whole new design. Time constraints may not allow this big change.

B2. Transistors

Let's take a closer look at the transistor plus LED circuit.

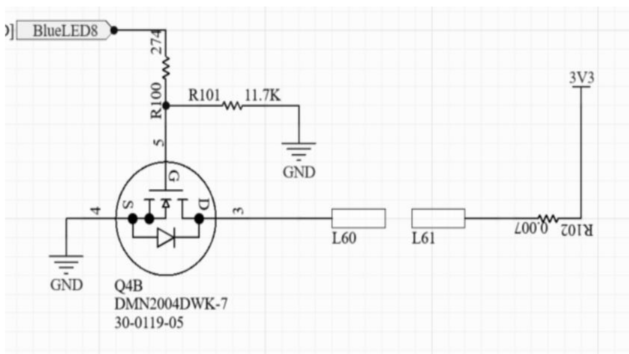

Fig. #2. Transistors as Switches to Light Up the LEDs.

For the Blue LEDs we designed this circuit which allows low current consumption in the MCU. This circuit is an LED driver utilizing an N-channel MOSFET (DMN2004DWK-7), controlled by an ESP32 via the BlueLED8 signal. The LED, with its cathode labeled L60 and anode L61, is powered by a 3.3V supply through R102 (0Ω). The MOSFET's drain (pin 3) is connected to the LED's cathode, while the source (pin 4) is grounded. The gate (pin 5) is driven by the ESP32 through R100 (274Ω), with a pull-down resistor R101 (11.7KΩ) ensuring the MOSFET stays off when the ESP32 output is LOW. When BlueLED8 is HIGH (3.3V), the MOSFET turns ON, allowing current to flow from 3.3V through the LED to ground, lighting it up. Given that the LED forward voltage (Vf) is 3.0V to 3.2, the voltage drop across it matches the supply voltage. For the red LEDs we just change the pull up resistor to reduce the voltage across the led diode since the Red LED requires only 2-2.2V. The diodes work with 20mA, which multiply by 68 ohm provide a voltage drop off around 1.3V which allows the red led to only see 2V which is what it requires. This implementation helps us no to have to design another voltage regulator to just provide power for the red LEDs.

**The Microcontroller is also used on The LEDs Panel PCB.*

III. CORRELATION DIAGRAM

To properly understand how the project interacts as a whole we pictured this diagram which shows all interactions between the modules.

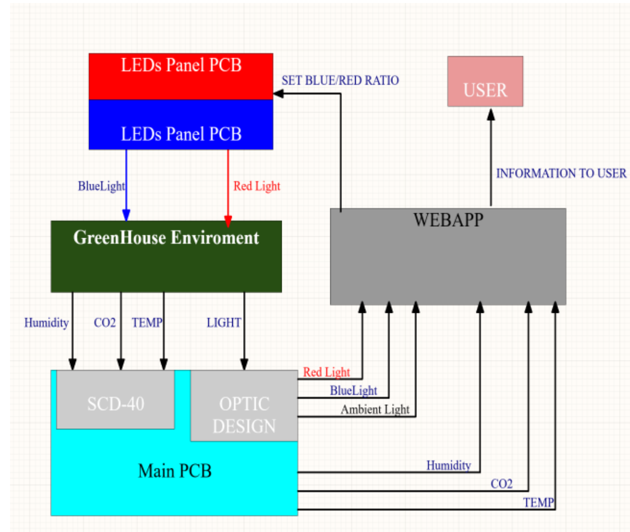

Fig. #3. Correlation Diagram.

The greenhouse environment is monitored by sensors measuring humidity, CO2, temperature, and light levels, with data processed by the Main PCB, which includes an SCD-40 sensor and an optical design module. The WebApp collects and displays this data, allowing the user to monitor conditions and adjust the blue/red light ratio to optimize plant growth. The LEDs Panel PCB provides red and blue light to the greenhouse environment to set up the ratio needed by the plant. The system ensures real-time environmental feedback, enhancing automated control and user interaction.

IV. POWER SUPPLY NETWORK

This device utilizes two power sources: a 9V battery held by a BC9VPC battery holder capable of providing 500 to 600 mAh, and the USB VBUS, which supplies a constant 5V. Users can select between these sources based on whether the device needs to be in a programmable or functional mode, controlled via a JS102011JCQN switch that supports a contact rating of 0.3A at 6VDC or 0.1A at 30VDC with an electrical life of 5,000 cycles. The switch features a maximum contact resistance of 70 mΩ and a minimum insulation resistance of 100 MΩ at 500V, ensuring reliability. The primary IC in the system, which operates over Wi-Fi and Bluetooth, consumes 240mA under full operation and 10μA in sleep mode. To indicate power status, a green LED (HSMS-C197) is used when the battery is active, operating at a DC forward current of

TABLE 3
PANEL LIGHT SOURCE COMPARISON

Light Source	Efficiency (lm/W)	Lifespan (hours)	Energy Consumption (W)	Heat Emission (W)	Cost (Initial)	Environmental Impact
LED	80-150	25,000-50,000	5-20	0.5-5	$2-$15	Low (No mercury, recyclable)
Incandescent	10-17	750-2,000	40-100	35-95	$1-$5	High (Energy waste, short lifespan)
Compact Fluorescent Lights (CFL)	50-100	8,000-15,000	8-30	3-10	$3-$10	Moderate (Contains mercury)
Halogen	16-25	2,000-4,000	30-120	30-90	$2-$10	High (Short lifespan, inefficient)
High-Intensity Discharge (HID)	75-125	6,000-20,000	150-400	100-400	$20-$200	Moderate (Contains mercury, high UV output)

20mA and a power dissipation of 65mW, with a reverse voltage rating of 5V at 100µA. The LED operates in a temperature range of -40°C to +85°C. A 1kΩ resistor is included to limit current through the diode to 9mV for the 9V battery and 5mV for USB, keeping it below the 20mA maximum threshold. Additionally, a red LED (HSMS-C197) is used for USB power indication to facilitate debugging.

The switch determines the active power source, which becomes PWR IN. The current through the diode follows:

$$\begin{gathered} \boldsymbol{PWR/1k} \\ \boldsymbol{Battery: 9V/1K \;=\; 9mA} \\ \boldsymbol{USB: 5V/1K \;=\; 1mA} \end{gathered} \quad (3)$$

The consumption in the standby mode by the major ICs:

$$\begin{gathered} 2 \times VrQ + ESP32\ SM + 4x(SensorsSM) + I2C\ SM \\ = 2 \times 20 + 10 + 4 \times 2.3 + 1.3\mu A \;=\; 60.5\,\mu A \end{gathered} \quad (4)$$

Assuming all small components consume 10 uA in the standby mode the device consumes 70.5uA.

$$\frac{Battery\ mAH}{SH\ consumption} = \frac{500}{0.0605} = 8264\ hours \quad (5)$$

Consumption while active mode:

$$\begin{aligned} &2\,x\,VrQ \;+\; ESP32\ AM \;+\; 4x(SensorsAM) + I2C\ AM \\ &= 2 * 0.02 \;+ 150mA + 0.0023 * 4 + 0.02 = 150.1mA \end{aligned} \quad (6)$$

Total time in active mode:

$$Battery\ mAH /\ AM\ consumption = 600/150.1 = 4\ \ hours \quad (7)$$

B2. Lighting Choice

Our decision to use LEDs for our lighting panel was based on our comparison of five main light source technologies. LEDs, incandescent, halogen, high-intensity discharge (HID), and compact fluorescent lights (CFL) are common lighting sources in greenhouses. Table 3 compares these various light sources based on parameters relating to a greenhouse.

Incandescent bulbs have been around since the mid-nineteenth century. They run on the principle of incandescence, which occurs when electricity passes through a filament, usually Tungsten, and on to a neutral wire which heats up and produces light. Incandescent bulbs have been a staple in many applications over the years, however they are overall very inefficient, with only about 3% of the electrical energy being converted into light, the rest becoming heat [15]. In Table 3 we can see that compared to LEDs, incandescent bulbs have a lower efficiency and lifespan and higher energy consumption and heat emission, which is not ideal for a greenhouse setting. Higher energy consumption means expensive bills and higher heat emission can be deadly to the plants and crops. This is why we did not choose incandescent.

Halogen, on the other hand, has a better lifespan and slightly higher energy efficiency; however, they are still no match for LEDs. For our project, halogen lighting is too broadband, covering the entire visible spectrum. We require specific red and blue wavelengths to precisely match the plant's needed light ratio, which LEDs can provide.

High intensity discharge (HID) lights produce light energy by creating an electric discharge through an ionised gas [16]. A strong option in the world of greenhouses, HID lights have a competitive energy efficiency and lifespan. However, they have extremely high heat emission (Table 3) and require cooling systems that can be expensive [17].

Compact fluorescent lights (CFLs) have previously been limited by their brightness, however, there have been advancements that have made them suited for indoor growing [17]. They are comparable in efficiency to HID lights but produce less heat. They are about 75% more energy efficient than incandescent bulbs and are generally cheap [18]. Even so, CFLs pale in comparison to LED technology

Light emitting diodes, or LEDs, are one of the fastest developing technologies in the world of lighting. LEDs use semiconductors to convert electricity into directional light. They can be wavelength specific, and are small yet powerful ([18]). For all the parameters we have considered, LEDs come out on top for all of them. This is why for our lighting panel; we chose to go with LED lighting.

V. OPTICAL DIAGRAM

Now that we’ve covered all of our components, we can show you the optical diagram, which essentially visualizes everything that is physically happening in the system.

A quick summary of this design is that we will have the LED panel above the fisheye lenses, but open sides, so that both ambient light and the light from the LEDs affect the readings from the sensors. The readings from the sensors will then be able to change the intensity or the on/off state of the LEDs depending on the user’s desired ratio. This would run in a feedback loop.

We are aware of the fact that in our small-scale demo, the LED PCB will be very close to our lenses, which may bring up some questions. Firstly, because of the maximum number of LEDs that our PCB could handle, we had to put it close so that our sensors could measure a change in the ratio of light at all. The idea is that in practice, the LEDs would be placed far above the plants like you would see in a typical greenhouse. This would work with our design in theory, it’s just that we didn’t have the scale, money, or time to make that occur.

Still, we believe that the sensing aspect of our design would hold up despite a change in the scale of the LED panel.

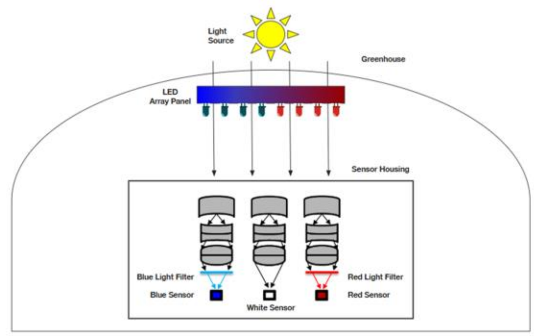

Fig. #4. G.E.A. Optical Layout

VI. SOFTWARE SYSTEM

The software system brings together two interconnected subsystems to handle both environmental monitoring and dynamic light control. On one side, using Arduino libraries like Wire, SensirionI2cScd4x, WiFi, and HTTPClient to communicate with the light sensors. Each sensor is set up on its designated I2C channel, and data is collected every five seconds with built in retry routines to ensure accuracy. Once gathered, this sensor data is preprocessed, packed into JSON payloads, and securely transmitted over Wi-Fi to specific Heroku endpoints for further analysis and real time monitoring of the greenhouse environment. Simultaneously, a separate PCB, also powered by an ESP32 and using the WiFi, HTTPClient, and ArduinoJson libraries, manages an array of 20 LEDs. This subsystem plays a critical role in controlling the blue-to-red light ratio captured by the sensors. It initializes the LED pins as outputs, connects to the network using preset credentials, and polls a Heroku server every second to retrieve the latest LED state information via HTTP GET requests. The JSON response is parsed to update each LED.

VII. TESTING

To make sure proper functionality we need to check that all hardware is behaving as expected and run some tests.

A1. PCB Testing

First after receiving the PCBs we check voltage points, Wi-Fi connectivity and response time, battery life, LEDs circuit consumption and behavior.

The 9.54 and 5 voltage source was within 1% tolerance. while the main voltage reel used by the MCU was 3.36 out of 3.3V which is at 1.12% tolerance while using a voltage regulator with an integrated inductor. If an integrated inductor was used we have to test 3.52V which still works but it is not preferred, this makes us take the decision to use the first option. Later we found that the percentage change on the embedded inductor voltage regulator was that JPL used a higher resistance than what was planned in the design. This was due to a shortage of stock and not paying close attention to substitute parts.

The Wifi response was working properly since the first try and we did not need to modify it since the communication time was within our specification.

Battery life was tested by having the device on for a week and then testing. It barely spent 1% of the battery life while Idle.

The LEDs PCB was a challenge from the beginning because of the high-power consumption from all the twenty LEDs, but we could test that all LEDs can be ON at the same time and also the MCU can communicate by WiFi without problem. Only interesting thing, we found while testing was that to power up the LEDs and the Wi-Fi module on the MCU it needs current from the Battery and only USB connection is not enough, we found that the length of the USB cable also affects.

A2. Optical Testing

Our optical testing includes experimenting with our photodiode sensors in order to find the correct calibration coefficients. These calibration coefficients must take into account the filter transmittance and error of the photodiode in order for our readings to be accurate within our lux accuracy specification. We conducted tests at 3 different light levels which we simply called “Low Light Level” (<200 lux), “Medium Light Level” (200-1000 lux), and “High Light Level” (>1000 lux). The following is a summary of our collected data.

TABLE 4
DATA COLLECTED FROM TESTING AT LOW LIGHT LEVELS (< 200 LUX)

Low Light Level			
Test Run	App Reading	Lux Meter Reading	Percent Error
1	158	130	21.54%
2	142	126	12.70%
3	142	118	20.34%
		Mean	18.19%
		Standard Deviation	4.80%

Our device is meant for a greenhouse with 10,000+ lux measured on average. Our initial testing did not have measured lux that high as we are using indoor lighting conditions due to the nature of our showcase location. Our device is less accurate at lower light levels, as seen with our mean percentage error of 18.19%. Our standard deviation was also high at 4.8%. Again, this is due to the nature of the lower lux values having a higher effect on the percent error.

TABLE 5
DATA COLLECTED FROM TESTING AT MEDIUM LIGHT LEVELS (200-1000 LUX)

Medium Light Level			
Test Run	App Reading	Lux Meter Reading	Percent Error
1	584	500	16.80%
2	521	484	7.64%
3	537	500	7.40%
		Mean	10.61%
		Standard Deviation	5.36%

Moving on to the testing at medium light levels, we see a decrease in the percentage error. With a mean percent error of 10.61% and a better standard deviation than at low light levels of 5.61%, we can see an improvement from the previous test. However, the mean percent error is still outside our desired accuracy of within 10%.

TABLE 6
DATA COLLECTED FROM TESTING AT HIGH LIGHT LEVELS (>1000 LUX)

High Light Level			
Test Run	App Reading	Lux Meter Reading	Percent Error
1	4078	3744	8.92%
2	4000	3675	8.84%
3	3934	3694	6.50%
		Mean	8.09%
		Standard Deviation	1.38%

At the higher light levels, our percent error fell into our engineering specification. Our standard deviation was lower, which ensures higher accuracy.

In order to be more accurate in calibration, the raw lux values were gathered against a handheld sensor and plotted. Doing this allowed us to create a line of best fit for all sensors and determine equations for calibration like seen below.

Fig. #5. Line of Best Fit Used to Calibrate White Lux Meter

VIII. CONCLUSION

This project will allow for a more well-rounded measurement device for a greenhouse. With our feature of the measurement of the ratio of blue to red light, along with our self-adjusting LEDs, greenhouse operators will have more direct control over their greenhouse environment. While the greenhouse environment for our project is not to scale, we proved that this idea is possible.

THE ENGINEERS

Maya Sosa is 22 years old and pursuing her Bachelor's in Optics. Her experience has been in the roles of opto-electronic test engineer and research fellow at Everix Optical Filters, Molex, and the National Energy Technology Laboratory.

Paul Weiner is a 22 year old Optics major. He did research with the Astrophotonics group at UCF and is considering going back for his MS one day.

Leiner Suarez is a 28 years old Electrical Engineer Major. Working for Eizo Rugged Solution as a Hardware Design Engineer, previously worked for companies such as Lockheed Martin, Luminar Technology and Kaman Aerospace. Interested in electrical design either high or low voltage.

Raul Graterol is a 26 year old Computer Engineering major. With experience as a Data Scientist Intern at Planet Home Lending. He was also selected as a Northrop Grumman research fellow and did research at The Draco Lab.

ACKNOWLEDGEMENT

We would like to give a big thank you to our professors who taught us over our time at UCF. We would not have made it this far without your instruction. We would especially like to thank Dr. Peter Delfyett, Dr. Suboh Suboh, and Dr. Mike Borowczak for taking the time to review our project.

REFERENCES

[1] "How the Lighting Color Spectrum Affects Plant Growth," vol. 2024, no. September 5. SpecGrade LED. [Online]. Available: https://www.specgradeled.com/news/how-the-lighting-color-spectrum-affects-plant-growth/

[2] "ESP HTTP Client." Bluetooth SIG, Inc. [Online]. Available: https://docs.espressif.com/projects/esp-idf/en/latest/esp32/api-reference/protocols/esp_http_client.html

[3] "Lux, Lumens and Watts: Our Guide." ATB Industrial Ltd. [Online]. Available: https://greenbusinesslight.com/resources/lighting-lux-lumens-watts/

[4] A. Trivellini Alice, Toscano, Stefania, Romano, Daniela, &. Ferrante, "The Role of Blue and Red Light in the Orchestration of Secondary Metabolites, Nutrient Transport and Plant Quality,"

Plants, vol. 2024, no. Light and Plant Nutrition. 2023. doi: https://doi.org/10.3390/plants12102026.
[5] "veml6030-2490104.pdf." Accessed: Mar. 27, 2025. [Online]. Available: https://www.mouser.com/datasheet/2/813/veml6030-2490104.pdf
[6] K. Rembor, "Adafruit SCD-30 - NDIR CO2 Temperature and Humidity Sensor." Adafruit Industries, 2024. [Online]. Available: https://cdn-learn.adafruit.com/downloads/pdf/adafruit-scd30.pdf
[7] "SCD4X Data Sheet." Sensirion, 2024. [Online]. Available: https://sensirion.com/media/documents/48C4B7FB/66E05452/CD_DS_SCD4x_Datasheet_D1.pdf
[8] J. Wu, "A Basic Guide to I2C." 2022. [Online]. Available: https://www.ti.com/lit/an/sbaa565/sbaa565.pdf?ts=1728587678545&ref_url=https%253A%252F%252Fwww.google.com%252F#:~:text=I2C%20is%20a%20two%2Dwire,and%20receive%20commands%20and%20data.
[9] "Pre-distorted and special charts for Fisheye Lenses," imatest. Accessed: Mar. 27, 2025. [Online]. Available: https://www.imatest.com/support/docs/23-1/pre-distorted-charts/
[10] "180° fisheye Lens for iPhone Samsung Google Android Smartphone,with Clip,Cell Phone Lens,anamorphic Lens,Funny Pictures : Cell Phones & Accessories," Amazon. Accessed: Mar. 27, 2025. [Online]. Available: https://www.amazon.com/fisheye-Samsung-BlackBerry-anamorphic-Pictures/dp/B08NSGWNTX
[11] "Xenvo Pro Lens Kit for iPhone and Android, Macro and Wide Angle Lens with LED Light and Travel Case Black." Accessed: Mar. 27, 2025. [Online]. Available: https://www.amazon.com/Xenvo-iPhone-Camera-Lens-Clip/dp/B01A6D2JVI
[12] "2/3" Format C-Mount Fisheye Lens 1.8mm FL," Edmund Optics. Accessed: Mar. 27, 2025. [Online]. Available: https://www.edmundoptics.com/p/23quot-format-c-mount-fisheye-lens-18mm-fl/16922/
[13] "713 J.Winter Blue," LEE Filters. Accessed: Mar. 27, 2025. [Online]. Available: https://leefilters.com/colour/713-j-winter-blue/
[14] "LEE 027 Medium Red," LEE Filters. Accessed: Mar. 27, 2025. [Online]. Available: https://leefilters.com/colour/027-medium-red/
[15] "How Does a Incandescent Light Bulb Work? [Step-by-Step]." Accessed: Mar. 27, 2025. [Online]. Available: https://lumenauthority.com/how-does-a-incandescent-light-bulb-work/
[16] "HID Lights for Beginners - High Intensity Discharge Lamps Explained | LEDwatcher." Accessed: Mar. 27, 2025. [Online]. Available: https://www.ledwatcher.com/high-intensity-discharge-lamps-explained/
[17] "LED Lights: A comparison to Incandescent, Fluorescent and HID." Accessed: Mar. 27, 2025. [Online]. Available: https://www.thermoline.com.au/blog/led-lights-in-comparison-to-incandescent-fluorescent-and-hid-lights
[18] "The History of the Light Bulb | Department of Energy." Accessed: Mar. 27, 2025. [Online]. Available: https://www.energy.gov/articles/history-light-bulb