University of Central Florida

Divide and Conquer
EEL 4914 & OSE 4951
Senior Design I
Group 1

Greenhouse Environmental Ratio Analyzer of Blue to Red Light, Humidity, Temperature, and CO2

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1. Description of Project

1.1 Background

In this high-tech and technology-dependent world, it is easy to forget the source of our foods and how important simple things like farming and the agricultural industry are in our lives. For our Senior Design project, our team aims to focus on improving this industry and coming up with an idea to aid and advance this field. We plan to create a greenhouse monitoring system utilizing photonics sensors to measure and report on key environmental factors such as relative light intensity, the ratio of blue to red light, temperature, humidity, and CO_2 levels. Our system will ideally be placed in the center of a greenhouse environment, at the canopy level of plants, and be able to monitor these parameters in real-time. The device will be capable of wireless communication and feature an accompanying mobile app that allows for remote data analysis and real-time updates. The system will also prioritize energy efficiency to ensure long-term usability. In essence, our project aims to progress the capability of environmental sensing devices and further the efficiency of greenhouses.

When choosing an idea, we needed to select a project that was going to make a positive impact on an industry and the world, as well as be challenging enough to allow us to put in a large amount of time and effort. However, the project must also not be too expensive or unrealistic for a senior design project, provided the fact that we did not secure sponsorship for our project. Our original plan was to make a portable, handheld device that would function both indoors and outdoors, but we quickly realized that we wanted our device to have a more specific use. Hence, we chose the greenhouse idea. We also realized that designing a handheld device with mounted optics would be virtually impossible for a device of this nature and that we needed plenty of optical design, which simply buying sensors would not provide. Therefore, after much research, we decided that designing both an overall light intensity sensor, designing a sensor that would quantitatively show the ratio of red to blue light, and buying a sensor that measured the humidity, temperature, and CO2 levels would be the most reasonable. Our reasoning for building the red and blue light sensor involves our background research into the importance of these wavelengths in plant health and growth.

Specific wavelengths of light such as blue (400–500 nm) and red (600–700 nm) have been shown to positively impact morphogenesis, metabolism, and the capacity for plants to photosynthesize [1]. With our optical light sensor, we can detect the ratio of blue and red light within the greenhouse to see when optimal light for the plants is achieved. For the future of this device, there is potential to even suggest or automatically change the lighting within the greenhouse to remotely adjust to optimal conditions.

Our project requires sufficient optical design, as one optics student needs to design a light sensor that will feed into a spectrometer, which the other optics student will build and will detect the wavelengths of the light. In conjunction with the optics students, the EE needs to design a PCB and ensure all electronic components function properly, and the CPE needs to integrate all the components with an application.

1.2 Motivation

In the very sensitive and necessarily stable environment of greenhouses, there is an increased need for reliable and easy-to-use greenhouse monitoring systems. There are many ways to define the environment of a greenhouse, but for the sake of simplicity, it is the general space in which plants would grow. Instead of measuring on a plant-by-plant basis, the "environment" described here is a broad generalization and categorization of some of the most important parameters that can be measured through the air, which will be listed later. While not a one-to-one comparison, this idea can be compared to the difference between measuring the average temperature of a single city versus measuring the temperature of the whole earth. For this project, we are focused on the "global" measurement. Keeping that in mind, modern solutions lack the combination of durability and comprehensive data collection, which is important for real-time environmental monitoring. A lot of devices tend to measure a few of these metrics at a single time. This leads to inconvenience and the purchase of multiple devices to measure metrics such as relative white light intensity, the ratio of blue to red light, temperature, humidity, and CO_2 levels. Our project aims to address these gaps by creating an all-inclusive device that not only provides accurate environmental data but is also user-friendly and adaptable to various conditions. To conclude, this project aligns with the goal of advancing greenhouse monitoring technology by making it simpler, faster, and more complete.

1.3 Goals and Objectives

1.3.1 Basic Goals

- The device will be capable of detecting temperature, humidity, $CO_{2,}$ and blue/red light ratio.
- The measurements of these parameters will be determined and wirelessly sent to be displayed through an application.
- This device must be able to continuously collect data and update the application in real-time.

1.3.2 Advanced Goals

- The CO_2 measurement will be accurate within ±50 ppm.
- The temperature measurement will be accurate within ±1°C.
- The red and blue light ratio measurement will be accurate within ±5% of the intensity of each wavelength.
- The relative humidity measurement will be accurate within ±10% RH.
- The total dimensions of the device will not exceed 15”x15”x10”.

1.3.3 Stretch Goals

- The data collected through this device will be used to predict greenhouse status dependent upon the type of plants inside
- The application will be able to analyze the data and determine parameters that must change for optimal plant health
- The data gathered by the device will be able to physically adjust to the environmental needs of the greenhouse

1.3.4 Objectives

- Successfully calibrate light sensors with lenses and other optical elements to ensure overall white light intensity measurement and the ratio of blue to red light is accurate.
- Determine the elements used and combined voltage to satisfy voltage requirements of 5V.
- Establish a firmware/hardware that allows the dispositive to understand the data and analyze it.
- Create a software structure, such as an app, where the readings from the sensor are updated in real-time and are user-friendly

1.4 PSE Diagrams

1.4.1 Optical Diagram (Physical path of light)

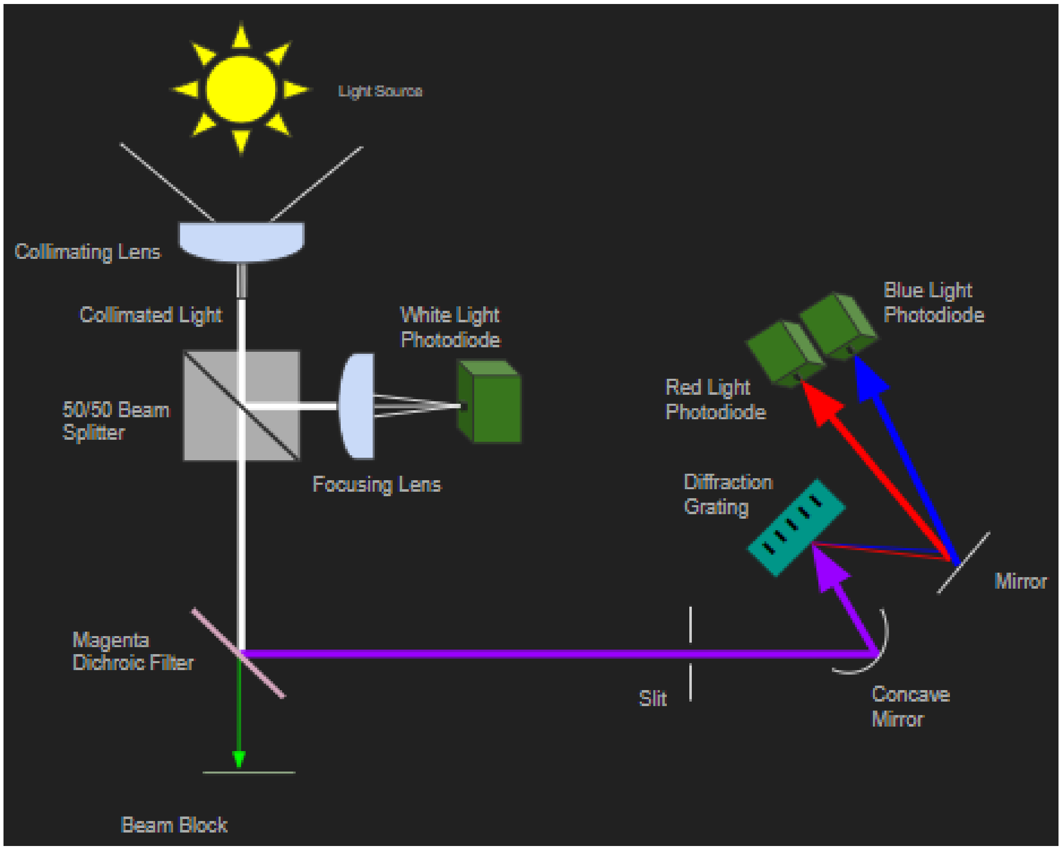


Figure 1: Diagram showing optical setup of device

1.5 Features and Functions

1.5.1 Software and UI

The software and user interface (UI) components are important to the functionality and usability of our environmental monitoring system. This section covers the data collection process, including how the sensors will interact with the system's machine learning processor for weather predictions, as well as the design and features of the mobile app that users will interact with to access real-time and historical environmental data.

1.5.2 Data Collection

- Our sensors will collect data and send it to our database.
- Feed this data into our machine-learning processor.
- Then that data will be used for potential daily weather predictions.

1.5.3 UI/APP

- The app will have to be user-friendly and easily accessible.
- Real-time notifications, such as air quality, temperature, humidity, and UV.
- Show data from previous dates and compare them.

1.5.4 Wireless Connection

- The device must support wireless communication to collect and send all data.
- The device will be able to support app requests.

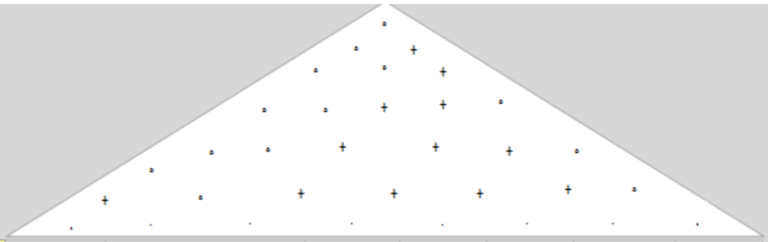
1.6 Related Work

1.6.1 Related Products

The market for greenhouse monitoring systems includes separate sensors that usually measure either temperature, humidity, CO_2, or light levels.

- *Govee Hygrometer Thermometer H5075* - A humidity and temperature sensor complete with a Bluetooth-connected app. Temperature accuracy: ±0.3°C. Relative humidity: ±3%. Measurement refresh rate: 2s.
- *AIROASIS Air Quality Monitor Indoor* - Small screen display monitoring CO_2, TVOC, HCHO, humidity, and temperature. Used for indoors only.
- *Reed LM-8000, Environmental Meter* - A handheld relative humidity, air temperature, contact temperature, and light intensity sensor. Temperature accuracy: ±1.2°C. Relative humidity ±5.2% for RH > 70% & ±4% for RH < 70%. Light intensity: ±5% reading. Response time: 1s.
- *Temp Stick* - Small temperature and humidity sensor that can be placed anywhere and links with application. Temperature accuracy: ±0.15°C. Humidity accuracy: ±2.0% RH.

1.7 House of Quality



	Desired direction of improvement (▲,▼)	▼	▼	▲	▲	▲	▼	▲	▲
	Engineering Requirements → Customer Requirements ↓	Size	Weight	Wireless Communication	Real-time Data Monitoring	Sensor Accuracy	Cost	Rechargeable Power Supply	Diffraction Grating
1	Affordability	↑↑	↓	↓↓	↑↑	↑↑	↑↑	↑↑	↑
2	Durability	↑	↓	↓↓	↓	↓	↑↑	↑↑	↓
3	Energy Efficiency	↑	↓↓	↑↑	↑↑	↑↑	↑↑	↑↑	↓
4	Ease of Maintenance	↑	↓	↑	↑	↑↑	↑	↓	↑
5	Communication Range	↓	↓↓	↑↑	↑↑	↑	↑	↓	↓↓
6	User Safety	↑↑	↑↑	↓↓	↓↓	↓↓	↓	↓↓	↑
7	Mobile App	↓↓	↓↓	↑↑	↑↑	↑↑	↑	↓↓	↓↓
8	Product Efficiency	↓↓	↓↓	↑↑	↑↑	↑↑	↑	↑	↑↑
9	Installation Ease	↑↑	↑↑	↑	↑	↑	↓	↓	↑
10	Portabily	↑↑	↑↑	↓↓	↓↓	↓↓	↑	↑	↑
11	User-Friendly	↑	↑	↑	↑↑	↑↑	↓↓	↓↓	↓↓
	Target	15"x15"x10"	15 lbs	100%	40 Seconds	>95%	≈$600	≈48hrs	100%

Improvement:

▲	▼
High	Low

Correlation:

+	o	-
Positive	No correlation	Negative

Relationships:

↑↑	↑	↓	↓↓
Strong	Moderate	Weak	None

Figure 2: House of Quality diagram showing correlation between engineering and customer requirements.

1.8 ECE Diagrams

1.8.1 Hardware Diagram

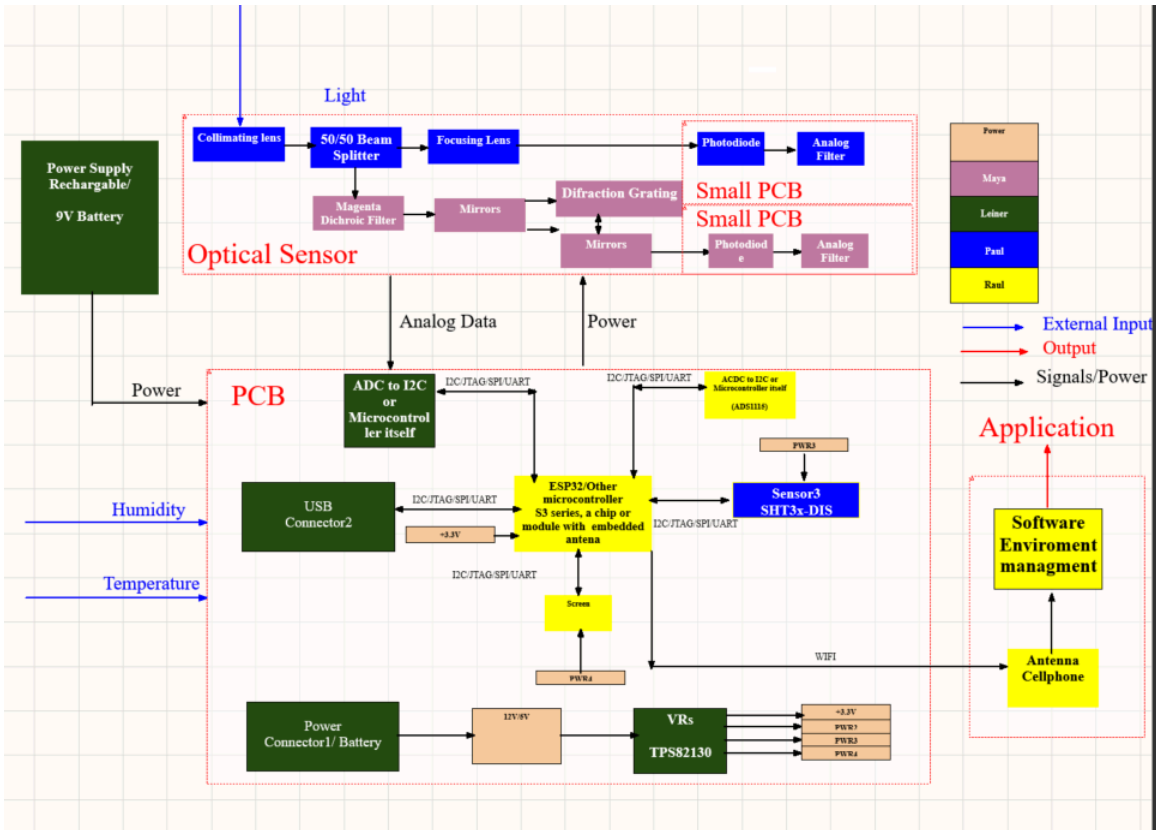


Figure 3: Hardware diagram showing responsibilities of each team member.

<table>
<tr><td rowspan="2">Engineer</td><td colspan="8">Main Assignments Tasks</td></tr>
<tr><td colspan="2">PCB design</td><td colspan="2">Application/Website</td><td colspan="2">Red and Blue Sensor/Diffraction Grating</td><td colspan="2">White light sensor, Hum;Temp,CO2 Sensor</td></tr>
<tr><td>Lead</td><td colspan="2">Leiner</td><td colspan="2">Raul</td><td colspan="2">Maya</td><td colspan="2">Paul</td></tr>
<tr><td>Secondary</td><td colspan="2">Raul</td><td colspan="2">Leiner</td><td colspan="2">Paul</td><td colspan="2">Maya</td></tr>
<tr><td>//////////////</td><td colspan="4">ECE specific Tasks</td><td colspan="4">PSE specific Tasks</td></tr>
<tr><td></td><td>Schematic Design</td><td>PCB layout</td><td>Microcontroller code</td><td>Application functionality</td><td>Optics Design</td><td>Optic Signal Translation</td><td>Sensor Research</td><td>Sensor Programming</td></tr>
<tr><td>Lead</td><td>Leiner</td><td>Leiner</td><td>Raul</td><td>Raul</td><td>Paul</td><td>Paul</td><td>Maya</td><td>Maya</td></tr>
<tr><td>Secondary</td><td>Raul</td><td>Raul</td><td>Leiner/Paul</td><td>Maya</td><td>Maya</td><td>Maya/Leiner</td><td>Paul/Leiner</td><td>Raul/Paul</td></tr>
</table>

Table 1: Tasks divided up between team members.

1.8.2 Software Diagram

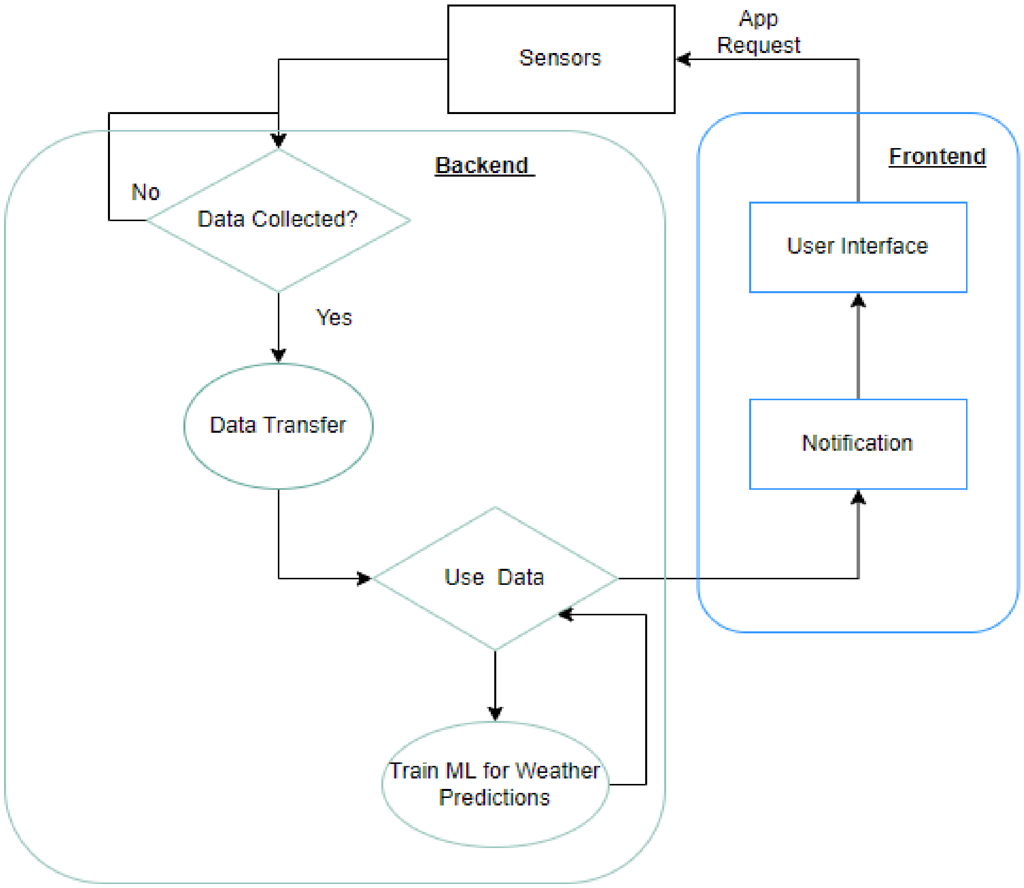


Figure 4: Software Diagram showing data flow within the device.

1.8.3 Prototype Idea

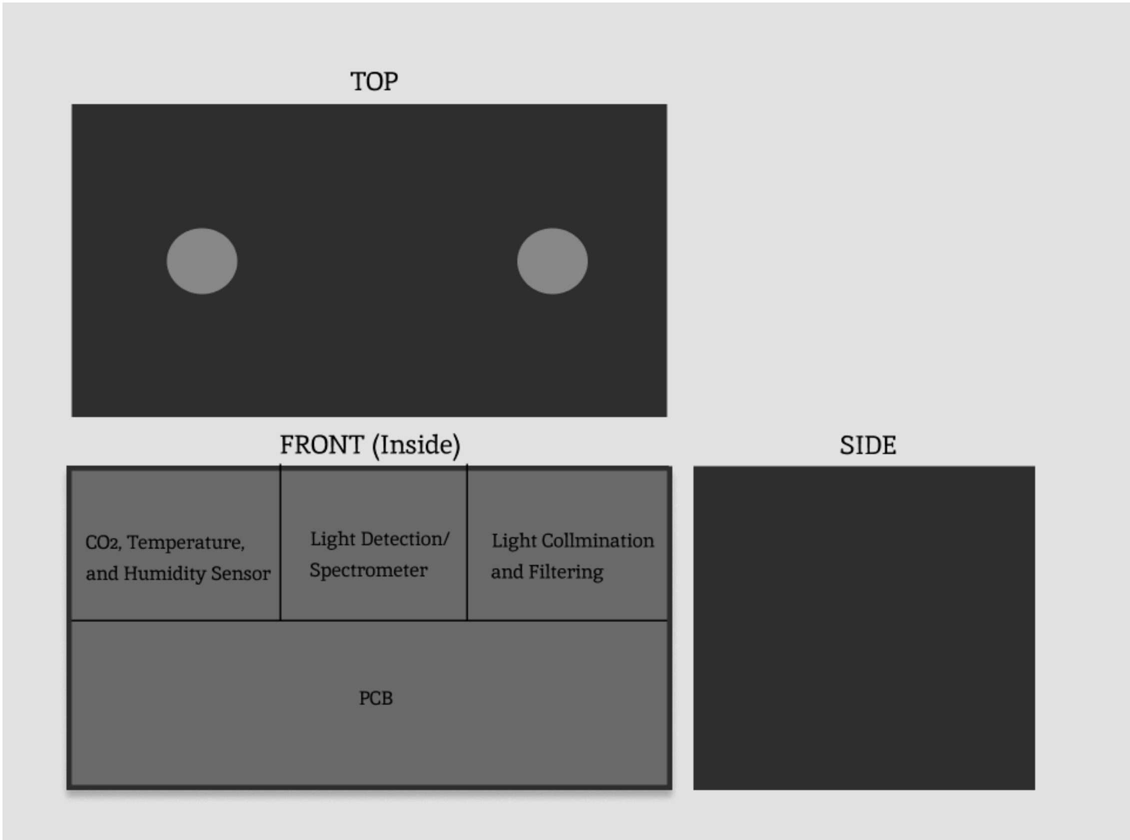


Figure 5: Diagram of first prototype idea showing top, front, and side views.

1.8.4. App Illustration

Figure 6: Illustration of potential app layout showing data collected from device.

2. Research and Investigation

2.1 Technology Comparison

2.1.1 Light Sensing Technologies

There are a variety of different light-sensing technologies, each with different pros and cons. For our project, we need light intensity sensors that are able to detect a wide range of light intensities across the entire visible spectrum. This is because our sensors will primarily be used in a greenhouse setting and there will be differing levels of light intensity as the day goes on. As the sun rises, the light intensity increases, and as the sun sets, the light intensity decreases. Three different technologies that can be compared for these purposes are photodiodes, phototransistors, and photoresistors.

2.1.1.1 Photodiodes

Photodiodes are a very common way to convert light energy into electrical energy. Photodiodes consist of P-N junction semiconductors, which have different properties, depending on the way they're biased. For light intensity sensing, the photodiode needs to be in the reverse-biased "photoconductive" mode.

One of the biggest problems that our team might have to solve when using any type of light-sensing device is the calibration and relationships between incident light and current. One of the largest benefits of using a photodiode in photoconductive mode is that the relationship between current and incident light is linear. This relationship would make the calibration and calculations on the software side much easier, as the analog signal of the current would be more easily converted into digital. If the relationships weren't linear, a more complex analysis of the signal would have to be performed.

Another one of the biggest benefits of using a photodiode is the fast response time. After a quick search on DigiKey, it was found that the response times ranged from 10 milliseconds to 16.67 picoseconds. This sort of response time, while not being the only factor to determine the overall speed of the system on the application side, is still an important factor.

While there are many benefits to using photodiodes, there are some very important disadvantages. Firstly, running a photodiode in a reverse-biased way causes something called a dark current, which is essentially noise added to the total current. Ideally, this current would not exist, but it is unavoidable. With the presence of this dark current, it is important to have an input light source with a high enough intensity to cause the overall current to increase by a readable amount. Now, that readable amount is determined by the sensitivity of the receiver. With a highly sensitive receiver, low-light-level conditions may be okay, but without one, it may be hard to distinguish between the noise and the current being produced. The dark current also increases with increasing bias, so that is something to take into account.

Below are some equations showing the relationship between the overall current and the dark current, and the relationship between the overall responsivity of the system, the generated current, and the input optical power. The responsivity essentially tells us how effective the photodiode is at generating a photocurrent at a specific wavelength, given an input optical power. The lower the input power, and the higher the photocurrent, the higher the responsivity.

$$I_{Out} = I_{Dark} + I_{Photo}$$

Equation 1: Relationship Between the Output Current, Dark Current, and the Photocurrent

$$R(\lambda) = \frac{I_{Photo}}{Power}$$

Equation 2: Relationship Between Responsivity, Photocurrent, and Input Power

Another issue is that the currents generated by the photodiode can be very small, even with light present. Because of this, amplifiers are typically used, which is yet another expense.

2.1.1.2 Phototransistors

The next technology for consideration is the phototransistor. Phototransistors are very similar to photodiodes. In fact, DigiKey compares it to a photodiode that has a current amplifier integrated into the part. While this sounds great in theory, it brings up some interesting issues that will be discussed further down. First, we'll take a look at the benefits of using a phototransistor.

As stated above, one of the biggest benefits of a phototransistor is its current gain. This gain is quite large, with the output current being 50 to 100 times that of a photodiode. This large gain would make any MCU processing much easier, as it would guarantee that there is a readable current. The equation for the current of phototransistors are different than those of a photodiode, as the current gain, collector current, base current, and emitter current all have relationships. In a phototransistor, the base current is the photocurrent, assuming an NPN transistor. These relations are seen below:

$$I_C = \boldsymbol{\beta} I_B$$

Equation 3: Relationship Between Collector Current, Base Current, and Current Gain

$$I_E = I_C + I_B$$

Equation 4: Relationship Between Emitter Current, Collector Current, and Base Current

The first of the potential downsides is that a current amplifier does not necessarily mean a better reading of the change in current. If the current is purely being amplified, it means that the noise of the dark current is being amplified as well. So, while the current would be easier to read, it would not necessarily get rid of the noise issue that comes from a low light level. Technically, the sensitivity of the phototransistor is greater than that of a photodiode, but that's only because of the internal processes that amplify the dark current.

The second potential downside of a phototransistor is that it has a slower response time compared to a photodiode. As stated earlier, any reduction of response time in one part will chain down to the response time of the final product.

The third potential downside is that phototransistors have slower response times compared to photodiodes. As mentioned earlier, the slower each part is, the slower the system will be overall. While the response time will likely be determined by how fast the MCU can process all the data, it would be better if change in light intensity was tracked as fast as possible, to have the most up-to-date and accurate information.

The fourth potential downside of phototransistors is that the response of a phototransistor is not as linear as a photodiode. For our project, we want to have clear relationships between variables and equations so that we can compare our outputs to what “should” be. A mostly linear response with a slight curve could still work, but it may take more calibration and testing to make sure that we’re getting the results we want.

Lastly, phototransistors are typically more expensive than photodiodes. Because of this, we’d need to justify the cost versus the benefits of this type of device.

2.1.1.3 Photoresistors

Photoresistors have a very different operating method than that of a photodiode or phototransistor. They are still semiconductor-based devices, but instead of the current and voltages changing with the increasing light intensity, the resistance and conductivity of the devices change. This change can be quite drastic, as it can go from operating with hundreds of thousands of mega-ohms to almost nothing.

Some of the benefits of photoresistors are that they do not need to be biased and that they are cheap. This may benefit projects that are tight on space and budget. Also, as stated, the resistance changes with light intensity. So, with projects that aim to determine whether light intensity is changing, this may be sufficient.

Now, there are many cons to using this technology. Firstly, photoresistors are very sensitive to changes in temperature, much more than phototransistors and photodiodes. These changes in temperature affect the resistance that the photoresistor exhibits. For projects that primarily need accurate light intensity readings, this is not ideal because of the chance that the change in ambient temperature messes up the readings.

The second disadvantage of using this technology is the fact that photoresistors have much slower response times to changes in light intensity than the other options. Whereas the other technologies have response times that are much smaller than a second, photoresistors can take as long as a second to react to a change in light intensity. This would not be sufficient for projects that need very fast measurements.

Lastly, the photoresistors do not have a linear light intensity to resistance relationship. This relationship exponentially decays, which makes the calculations and calibrations more complex than those of photodiodes and phototransistors.

Here is a table simplifying all the facts so we can have a clear comparison between the technologies:

Technology	**Cost**	**Response Time**	**Relationship**	**Measured**
Photodiode	$	Very Fast	Linear	Current
Phototransistor	$$	Fast	Linear	Current
Photoresistor	$	Slow	Non-linear	Resistance

Table 2: Comparisons between parameters of light sensing technologies.

2.1.1.4 Light Sensor Technology Choice

After analyzing the difference between photodiodes, phototransistors, and photoresistors, it’s clear that photoresistors are not a reasonable choice for a light-intensity sensor that needs specific and precise measurements. The response times are too slow and the sensitivity to temperature is a factor that we’d really have to worry about, since ambient temperature is something that changes, even by a small degree, and it’s hard to say how much that would affect the accuracy of readings.

The choice between photodiodes and phototransistors is a more difficult decision. While phototransistors have the benefit of not needing current amplifiers and essentially being upgraded photodiodes, their slower response times and not-quite-as-linear light intensity and current relation make them less valuable. Also, since they are more expensive than photodiodes, they would need to have much better properties to justify buying them, but they don’t.

Therefore, photodiodes will be the choice for the light-intensity sensors in our project.

2.1.2 Diffraction Gratings

Diffraction gratings, as the name suggests, use the principles of diffraction to reflect or transmit light at an angle determined by the wavelength. Reflective gratings are the most common, however, there are transmissive, concave, ruled, holographic, and echelle gratings as well. These gratings differ in their own ways and have their own benefits and drawbacks. We will dive deeper into the pros and cons of these different grating technologies in regard to our project.

2.1.2.1 Reflective Gratings

A plane, or flat, reflective grating is an optical element that contains periodic lines, or groves, that are made either mechanically or optically (refer to section *2.1.2.4 Ruled and Holographic Gratings*). Incident light hits these grooves and diffracts based on the light's wavelength. The reflected light then spreads due to the various angles of diffraction, allowing certain wavelengths to be captured by using a slit or other blocking device. This element provides a way to separate a light source into its components, a very useful tool in optical design.

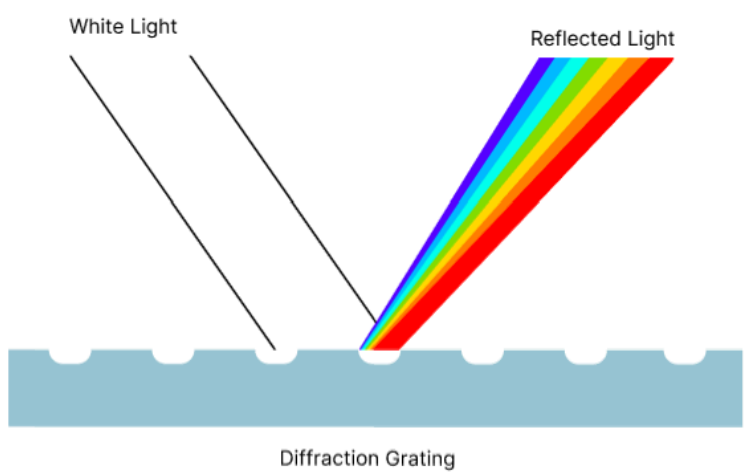


Figure 7: An illustration of a plane reflective refractive grating and how it works.

The distance (d) between the grooves decides the angle of the reflected light. As the governing variable, gratings are labeled based on the frequency of d, or the number of lines per millimeter on the grating ($\frac{1}{d\ (mm)}$). This is usually on the order of hundreds to thousands of lines per millimeter. We can see the dependency between the frequency, angle of incidence, angle of diffraction, and wavelength below in equation 5.

$$m\lambda = d(\sin\alpha + \sin\beta)$$

Equation 5: Diffraction Grating Equation

Following this formula, incident light coming in at angle α will reflect at angle β. Same wavelengths (λ) of light can reflect at various set angles based on the order (m) of the diffraction. Most of the light will diffract at the first order angle, less light at the second order angle, and so on until it is negligible [Edmund Optics].

Plane reflective diffraction gratings are useful due to their simple structure and lower price point. They are commonly used in applications where mirrors can be used to reflect the light back to where it needs to go. They are a solid choice in a simple optical system.

2.1.2.2 Transmissive Gratings

Transmissive gratings operate similarly to reflective gratings in regards to the equation and angle of diffraction of the light. However, the main difference comes from the fact that a transmissive grating allows the light through the element. Instead of the diffracted light being reflected, it is transmitted through.

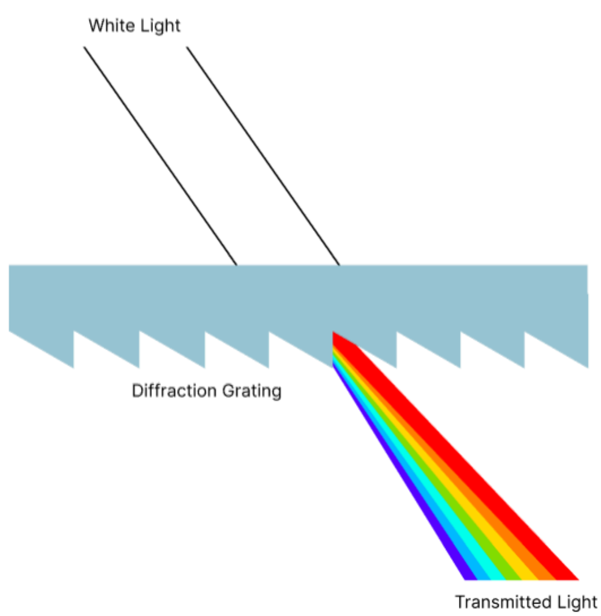


Figure 8: An illustration of a plane reflective refractive grating and how it works.

While more expensive, benefits of a transmissive grating include ease of set up. Rather than having to account for reflection and use mirrors to get the light back on track, using a transmissive grating won't disrupt the flow of the light assuming a straight line optical setup. This is useful in applications that require a more compact optical setup [ThorLabs].

2.1.2.3 Concave Gratings

A diffraction grating, whether reflective or transmissive, can be flat (plane) or concave. A concave grating will operate in the same way as the aforementioned two, dispersing the light based on incident angle and wavelength. However, the issues arise due to the shape. Concave gratings bring complexity that plane gratings don't by causing dispersion. The light will either converge or diverge after it has been diffracted [Edmund Optics]. This can be useful in an optical setup that needs this focusing from the dispersive element, but commonly it is not necessary when the focusing can be done by adding another lens. Plane gratings are the common choice not only due to the lower complexity, but due to the much lower price point as well. A reflective concave grating from Edmund Optics[1] that is 25mm in diameter is about $725 compared to a 25mm x 25mm reflective plane grating that is $134. Due to budgeting and simplicity, we will not be considering a concave grating.

2.1.2.4 Ruled and Holographic Gratings

When talking about gratings, 'Ruled' and 'Holographic' refer to the type of groove on the optic. Ruled gratings are created mechanically, usually cut out of the glass or copper element using a diamond forming tool [ThorLabs]. This creates a groove profile similar to the top element in figure 9. On the other hand, a holographic groove profile is created optically. This is done by projecting an interference pattern of two laser sources onto a material that is photosensitive. The material will then get the interference pattern of the sources "engraved" into it, resulting in a periodic groove structure similar to the bottom element in figure 9.

[1] Information found on Edmund Optics site, edmundoptics.com and prices are subject to change

Figure 9: The groove profile of a ruled diffraction grating (above) and a holographic diffraction grating (below).

In the past, ruled gratings were more efficient and lower in price. However, with advancements in technology, holographic gratings have now come out on top. They provide no irregularities in the grooves that the mechanically created ruled gratings have, resulting in less stray light and ‘ghosts’ (false spectral lines) while having comparable efficiencies [SSI]. Additionally, holographic gratings have become relatively low in cost and simple for industry creation. The cost difference is a negligible amount when compared to the ruled gratings. Also, the process to create them can create lower groove spacings, up to 3600 lines/mm, allowing more options of angle of light dispersion [ThorLabs].

2.1.2.5 Echelle

Echelle gratings are gratings with a low groove density, down to tens of grooves per millimeter. This higher groove spacing allows for higher diffractive orders (m) to be reached by using a high angle of incidence. This gives high dispersion, resolving power, and efficiency with a low dependence on polarization [Edmund Optics].

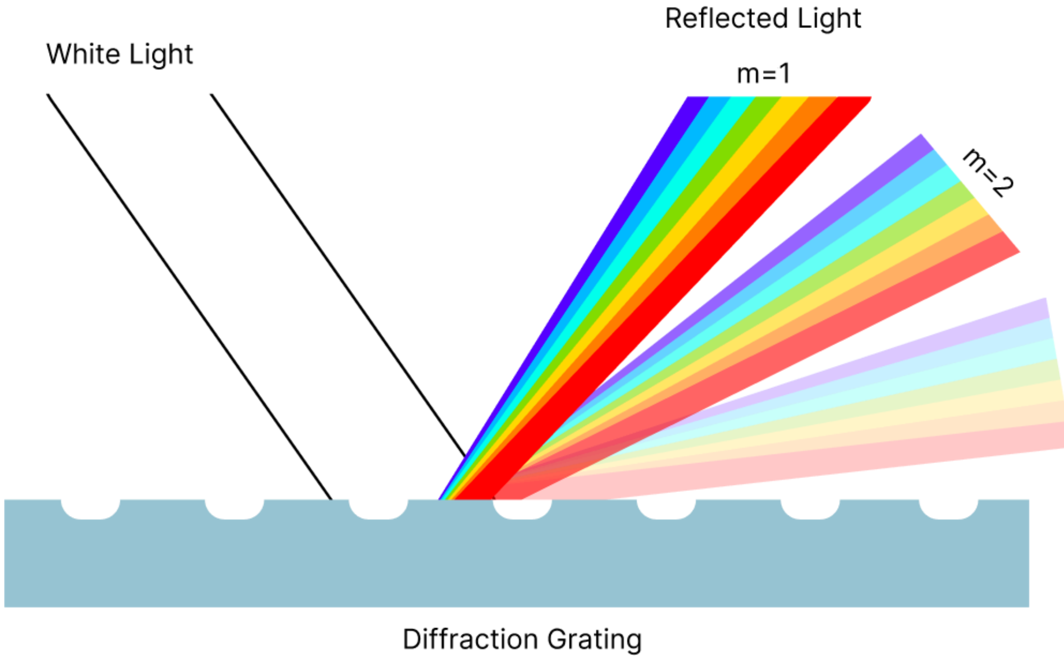


Figure 10: Different modes (m) of a reflective diffraction grating.

At about $100 more than a plane reflective grating, echelle gratings are more expensive. For our purposes, an echelle grating would only be needed if the dispersion we get from our chosen grating is not high enough to be able to isolate the blue and red wavelengths.

2.1.2.6 Diffraction Grating Technology Choice

Our research into the various types of diffraction gratings allows us to make an educated choice for our device. Based on multiple factors including price, efficiency, frequency of grooves, etc, we will compare these technologies and decide. For ruled and holographic gratings, they are similar enough in price and efficiency that we will not include them in the comparison but instead once the type of grating is decided, we will see what is available on the market.

Technology	**Cost**	**Pros**	**Cons**
Plane Reflective	$	Simple	Need to use mirrors to keep light on track
Plane Transmissive	$$	Can make optical system more compact	More expensive for similar experience of reflective grating
Concave	$$$	Can converge or	Very expensive

		diverge the light	Can make system more complicated
Echelle	$$$	Can create higher diffractive orders, higher dispersion	Very expensive Not necessary for our needs

Table 3: Comparisons of different types of diffraction gratings.

2.1.3 Data Transmission

The Greenhouse Environmental Ratio Analyzer will require a communication system to effectively transmit real time environmental data from the greenhouse to the user. The device is intended to be placed in the center of the greenhouse, where it will continuously monitor key environmental factors, such as the ratio of blue to red light, humidity, temperature, and CO2 levels, which are essential for optimizing plant growth. These environmental conditions can vary throughout the day, and manually checking them could be disruptive, time consuming, and impractical, especially in larger greenhouses.

2.1.3.1 Wireless Connectivity

To address data transmission protocol, we considered incorporating wireless communication technology, allowing for seamless, real-time updates to be transmitted directly to a user's mobile app. This would enable growers to remotely monitor and make adjustments as necessary, without physically disturbing the greenhouse environment. Additionally, the communication setup could potentially offer alerts and notifications for critical conditions, such as out of range environmental parameters. These features are intended to enhance decision-making, improving greenhouse management precision.

As we continue our research, the finalized communication system will also aim to enable automation of certain processes, making operations more efficient. The following sections will discuss various communication technologies under consideration, examining the strengths and limitations of each. This analysis will take into account factors like signal range, energy efficiency, data transmission reliability, and scalability, ultimately guiding us toward the most suitable option for ensuring optimal performance in varying greenhouse conditions.

2.1.3.2 Wired Connectivity

While wireless communication is often used in remote monitoring, we also considered a wired solution for its reliability, especially in environments where interference might compromise signal quality. Using a wired connection would guarantee uninterrupted data flow, unaffected by signal interference or range limitations. However, it requires careful consideration of installation logistics, as laying cables could limit the flexibility of the system's placement. In the following sections, we will further analyze these wired communication technologies, examining their respective benefits in terms of reliability,guiding our final decision on the best approach for greenhouse monitoring.

2.1.3.3 Comparing Wireless and Wired Communication

When choosing between wired and wireless technologies for The Greenhouse Environmental Ratio Analyzer, we considered several factors. Wired connections offer a high level of reliability and security, providing a stable and consistent data transmission with a low risk of interference. Wired connections also support higher bandwidth and lower latency, which can be beneficial for real time data processing. However, installation of wired connections systems would require extensive cabling that can disrupt greenhouses' environment and complicate the ease of maintenance.

In contrast, wireless technology provides notable advantages in terms of installation and flexibility. Wireless systems eliminate the need for physical cables, which simplifies the setup process. This ease of installation is particularly advantageous in a dynamic environment where running cables could be disruptive. Additionally, wireless systems are more scalable, making it easier to add or move sensors as needed without extensive modifications. Furthermore, the incorporation of a mobile app into the greenhouse monitoring system necessitates wireless communication. The mobile app requires wireless connectivity to facilitate real-time data access and interaction from any location, which wired connections would restrict.

While wireless connections do face challenges such as potential interference, security risks, and bandwidth limitations, these can be mitigated through careful design and implementation of encryption and signal optimization strategies. Given these considerations, wireless technology emerges as the preferred choice for the greenhouse monitoring system. Its benefits in terms of ease of installation, flexibility, and support for mobile app functionality align well with the project's requirements for a practical and adaptable solution. Despite the potential drawbacks, wireless technology ensures that the system remains reliable and secure, meeting the needs of modern, remote monitoring.

2.1.3.4 Exploring Wireless Communication Alternatives

After determining that wireless technologies is the optimal choice for our project, we now turn our focus to exploring and analyzing the various wireless communication alternatives available. This section will provide a comprehensive evaluation of different wireless technologies assessing their suitability in terms of range, data transfer rates, reliability, and compatibility with our system's requirements. By examining these alternatives, we aim to select the most effective wireless solution to ensure seamless integration with the mobile app and to meet the needs of real-time monitoring and data accessibility within the greenhouse environment.

2.1.3.5 Bluetooth 5.0

In evaluating communication options for our greenhouse monitoring system, Bluetooth was considered due to its low power consumption and ease of device pairing. Operating on the 2.4 GHz frequency band, Bluetooth is designed for short-range communication, typically effective up to 10 meters. This makes it suitable for connecting devices that are in close proximity, such as linking sensors to a central hub within the greenhouse. While Bluetooth offers limited range and lower data transfer rates compared to other technologies, its efficiency and simplicity in establishing connections could be advantageous for specific applications where extensive coverage is not required. With this being said, as we are implementing a mobile app with extensive coverage, Bluetooth would not be the most suitable option for this project due to its limited range and lower data transfer rates.

2.1.3.6 Wi-Fi

Wi-Fi is another significant communication option for our project, offering high-speed internet and network connectivity over greater distances. Wi-Fi operates on two primary frequency bands 2.4 GHz and 5 GHz. It uses a technology called Orthogonal Frequency-Division Multiplexing (OFDM) to transmit data, which divides the signal into multiple smaller sub-signals that are transmitted simultaneously at different frequencies. This method helps to manage higher data rates and reduce interference. Wi-Fi provides extended coverage, making it ideal for larger areas like greenhouses, and supports high data transfer rates, which is essential for real-time data streaming and integration with mobile apps. Additionally, Wi-Fi networks can accommodate multiple devices simultaneously and offer seamless internet connectivity, facilitating remote monitoring and cloud-based data management. Given the need for reliable, long-range communication and the ability to handle large amounts of real-time data, Wi-Fi might be the most suitable option for our greenhouse monitoring system, ensuring that the mobile app can function effectively and provide continuous access to critical environmental data from any location.

2.1.3.7 Infrared

Infrared (IR) communication has also been considered as a potential solution for our project. IR communication uses infrared light waves to transmit data between devices. This technology operates in the infrared spectrum, which is invisible to the human eye and involves wavelengths longer than visible light. IR communication requires a direct line of sight between the transmitter and receiver, as it relies on the direct propagation of infrared light. It generally supports lower data transfer rates and operates effectively within short ranges, typically up to a few meters. This makes it suitable just for applications where devices are fixed and within close proximity, such as remote controls or basic point-to-point data exchange. With this being said, as we are implementing a mobile app, Infrared would not be the most suitable option for this project due to its line-of-sight requirement, limited range, and lower data transfer rates.

2.1.3.7 NFC (Near Field Communication)

Near Field Communication (NFC) has also been considered as a potential solution for our project. NFC uses radio frequency identification (RFID) technology to enable data exchange between devices over very short distances, typically within a few centimeters. Operating in the 13.56 MHz frequency band, NFC allows for close-proximity communication and is commonly used in contactless payment systems or device pairing. Due to its extremely short range, NFC requires devices to be brought into close contact, making it suitable for specific tasks such as secure data transfer or device configuration through a simple tap. However, its limited range and lower data transfer rates may restrict its suitability for ongoing, real-time monitoring over larger areas, such as a greenhouse, where remote sensor communication and broader coverage are required.

2.1.3.8 Wireless Table Comparison

Feature	***Bluetooth***	***Wi-Fi***	***Infrared***	***NFC***
Range	< 10 meters	< 100 meters	1–5 meters	< 10 cm
Frequency	2.4 GHz	2.4 GHz-5 GHz	Infrared light spectrum	13.56 MHz
Data Transfer Rate	Up to 3 Mbps	Up to 1 Gbps	< 4 Mbps	< 424 kbps

Power Consumption	Low	Moderate to High	Low	Low
Security	Moderate	High	Low	High
Connection complexity	Easy pairing	Requires network setup	Line of sight must be maintained	Tap/close proximity
Scalability	Limited	High (supports multiple device)	Limited	Very limited

Table 4: Comparison of wireless data transfer technologies.

2.1.3.9 Final Wireless Technology Decision

After evaluating the available wireless communication options, we have decided to use Wi-Fi for our greenhouse monitoring system. Wi-Fi provides an excellent range, covering distances that are suitable for large environments like greenhouses. Its dual frequency bands (2.4 GHz and 5 GHz) help manage interference while offering higher data transfer rates, which are crucial for real-time monitoring and integration with the mobile app.

While Wi-Fi consumes more power compared to alternatives like Bluetooth or Infrared, and NFC, its benefits, such as wide coverage and faster data speeds, make it a suitable choice for continuous data transmission. Wi-Fi also offers strong security encryption, such as WPA3, which protects data from unauthorized access, ensuring that the data transmitted from the sensors remains secure.

Although the connection complexity of Wi-Fi is higher than simpler technologies, once set up, it provides a reliable and stable connection. Additionally, its scalability allows for easy expansion, enabling the integration of more sensors and devices in the future. Given these advantages, Wi-Fi is the most practical and robust option for our project.

2.2 Part Comparison

2.2.1 Photodiodes

Now that we have chosen the specific technologies behind our project, we are ready to choose the exact parts. Now, there are many different ways to go about choosing our light intensity sensors. We can buy packs of photodiodes for very cheap or buy dedicated photodiode light intensity sensors. The benefit of buying photodiodes as individual entities is that we'd have total control over the circuitry and how the photodiodes react. The downside would be that we'd have no real way of being able to calibrate our light intensities accurately. We would have to use commercial products to confirm the accuracy of our data, which we do not have the budget for. There are specifications for the photodiodes, sure, but they are not calibrated to any sort of absolute.

We also have to keep in mind that we'd still have to calibrate the sensors, even if we bought the photodiode light intensity sensors because of the presence of the lenses. The inclusion of lenses intrinsically changes the way that the sensors read measurements. Determination of how much light the lenses collect, how they focus it, and how the intensity changes would still need to be determined. Not to mention how other elements in the system would affect the accuracy of the readings from the sensor. Hand calculations and programs like Zemax will be necessary to ensure that all factors are taken into account and the readings are accurate. Therefore, the amount of optical design would remain the same if a photodiode sensor was bought, it would just ensure that the conversion from the electrical signal to the light intensity reading means something.

2.2.1.1 SparkFun Ambient Light Sensor - VEML6030

This evaluation board has a Vishay VEML6030 ambient light sensor integration. The VEML6030 is a 2mm x 2mm x 0.87mm sensor. The evaluation board itself is slightly bigger than a quarter. This product can read a lux range of 0 lux to 120,000 lux and boasts a 16-bit resolution. The photodiode itself can read a wavelength range of approximately 400 nm to 700 nm (assuming 25°C temperature). The nice thing about this technology is that it has a fit curve that adapts to human vision. This fit curve has a wavelength range from approximately 250 nm to 1000 nm. The center of these curves is approximately 550 nm to 600 nm. This range will ensure that we get a good measurement of the intensity of the white light. Since red and blue colors fall within this range, these sensors will also be able to be used for the ratio of the two. This sensor also includes temperature compensation and will be able to be integrated into the existing PCB and MCU. With a cost of $5.95, this sensor is much more affordable than some of the photodiodes found on websites like Thorlabs.

Unfortunately, there is some important information missing from the spec sheets and websites that leaves some doubt. For example, there is no exact specification for the temperature range or even the dimensions of the development board itself.

2.2.1.2 Adafruit TSL2591 High Dynamic Range Digital Light Sensor

This photodiode sensor can detect intensities from 188 µLux to 88,000 Lux. This is a smaller dynamic range than the Sparkfun sensor. The sensor picks up both IR and visible spectrums and operates within temperatures of -30°C to 80°C. The physical size of the entire unit is 19mm x 16mm x 1mm. It would also be able to be integrated directly with our PCB and MCU. The data transfer rate also approaches speeds of up to 400kbits/second. The spectral response peaks around 650nm and the wavelength range goes from around 430nm to 1100nm.

There are some ways in which this sensor falls short. The responsivity curve is not as bell-shaped as the Sparkfun sensor, so it may be more difficult to calibrate the blue and red sensors for the ratio analysis. Also, the cost of the unit is $6.95, which is more expensive, and the detectable intensities are also less.

2.2.2 CO2, Humidity, Temperature Sensors

2.2.2.1 Adafruit SCD-41 - True CO2 Temperature and Humidity Sensor

This three-in-one sensor claims to measure CO2, humidity, and temperature at the same time. According to the specifications given, it can measure 400 ppm to 5000 ppm of carbon dioxide with an accuracy of ±40 ppm + 5% of the actual reading at 25 degrees Celsius and 50% relative humidity. The way that the carbon dioxide sensing works is by the photoacoustic effect. This effect is a physical effect, where the interaction of photons with a material causes the creation of very tiny sound waves. In this specific case, there is most likely infrared light present in the sensor that gets absorbed by the CO2 molecules. This photon absorption would lead to a rise in the pressure and temperature of the gas, which would cause the sound waves to be formed. The response time for this aspect of the sensor is 60 seconds, which is not fast, but should be okay for a greenhouse.

The sensor can measure with an accuracy of ±9% relative humidity in temperatures ranging from -10 degrees to 60 degrees Celsius and from 0% to 100% relative humidity. This is not perfect, but it is still reasonable. The response time of this aspect is 90 seconds.

The sensor can also measure the temperature with an accuracy of ±0.8 degrees Celcius from temperatures spanning from 15 degrees to 35 degrees Celcius and with an accuracy of ±1.5 degrees Celcius from temperatures of -10 degrees to 60 degrees Celcius. This should be fine, especially since it’s unlikely anywhere near the lower end in temperature, at least in Florida. The response time for this aspect of the sensor is 120 seconds.

The overall cost of this unit is $49.95.

2.2.3 Diffraction Gratings

Diffraction Grating	**Company**	**Comparison**
Holographic Diffraction Grating Film	Edmund Optics	More options
Diffraction Grating Slide	Rainbow Symphony	● Cheapest option ● Only one option of 1000 lines/mm ● Fast shipping
Plane Ruled Diffraction Gratings	Newport	● Most expensive

Table 5: Diffraction Grating Comparison

3. Standards and Design Constraints

3.1 Specifications

Engineering specifications are crucial in the industry to explain how a product functions and what universal standards it may follow. During our research, we looked for industry standards in similar products and came up with specifications for our project. Throughout the process of prototyping and designing, our specifications may change. Currently, our project will adhere to the following engineering specifications.

Product Requirement	Specification	Units
The device will have sensors that measure accurately within a certain range.	±1	Celsius
	±50	ppm
	±10%	RH
	>0 & <100,000	lux
The time between updates of the measurements in the app will be realistic but not too much	<40	Seconds
The device shall not be so heavy that one person cannot lift it.	<15	Pounds

The device shall use the specified voltage.	9	Volts
The maximum frequency shall not exceed the specified amount.	2.4 or 5	GHz
Operating System	IOS/Android	
The idle power consumption shall not exceed the specified amount.	<1	Watt
The protective housing material for the sensors will be resistant to temperature and humidity.	PETG (polyethylene terephthalate glycol)	
The dimensions of the device shall not be excessive and be portable.	<15”x15”x10”	Inches

Table 6: Engineering Specifications Table

4. Hardware Design

Power Supply Structure 1:

This product will have 3 different power supplies which will allow the device to work properly in different situations. Only one will provide power if more than one supplier is being used. It will follow the logic structure in picture XXX.

We will have AC/DC Voltage, Battery and USB. Direct input voltage is the highest hierarchy , if it is in the other suppliers will be in open circuit and they will not provide power to the system. Second is the Battery and the last is the USB port. This is to make sure that the device can work for unlimited time if connected to a standard AC 110V source. It also can work for a limited time by a battery without the need of a standard AC 110V source .And it can work through USB connections for technical and troubleshooting reasons

AC/DC Voltage:

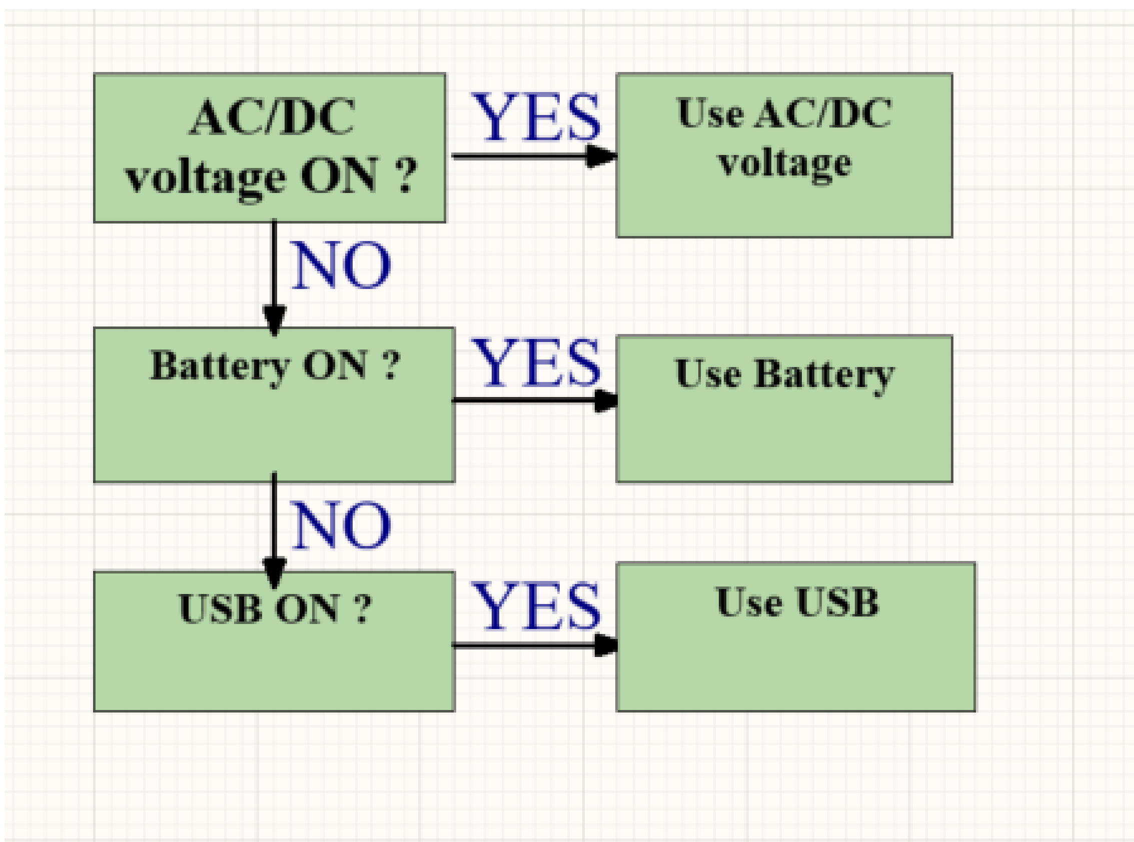
It will be 12 volts provided by a transformer, in amazon or walmart there are many and we will use connector PJ-002BH**.** This connector will be used because it can hold 24VDC and support 5A which is enough for our application. Also its datasheet, footprint and schematic are easily accessible.

Battery:

The battery will be a standard 9V that will use as a supporter a BC9VPC. This connector will be used because its footprint is SMT and that provides better mechanical features.

USB TypeC:

A USB TypeC connector (2169900002) will be used on the board. We decided to use USB to program the microcontroller ESP32 because we are very familiar with ESP32 development boards and its USB provides 5 volts that can be used through a voltage regulator to originate the 3.3V that the microcontroller needs. Also USB is one of the most common interfaces and providing support through it will make the product more feasible.



Power Supply Structure 2:

This product will have 2 different sources of power which will allow the device to work properly in different situations. We will call it the programmable mode and the functional mode. It cannot be on both modes at the same time and the modes will be chosen through a mechanical switch.

Programmable mode:

This mode is implemented in order to program the device. When it is in this mode the power supply to the device will be through USB line (5V) and a RED LED will be on. The device should be completely functional. We will use Battery explained above.

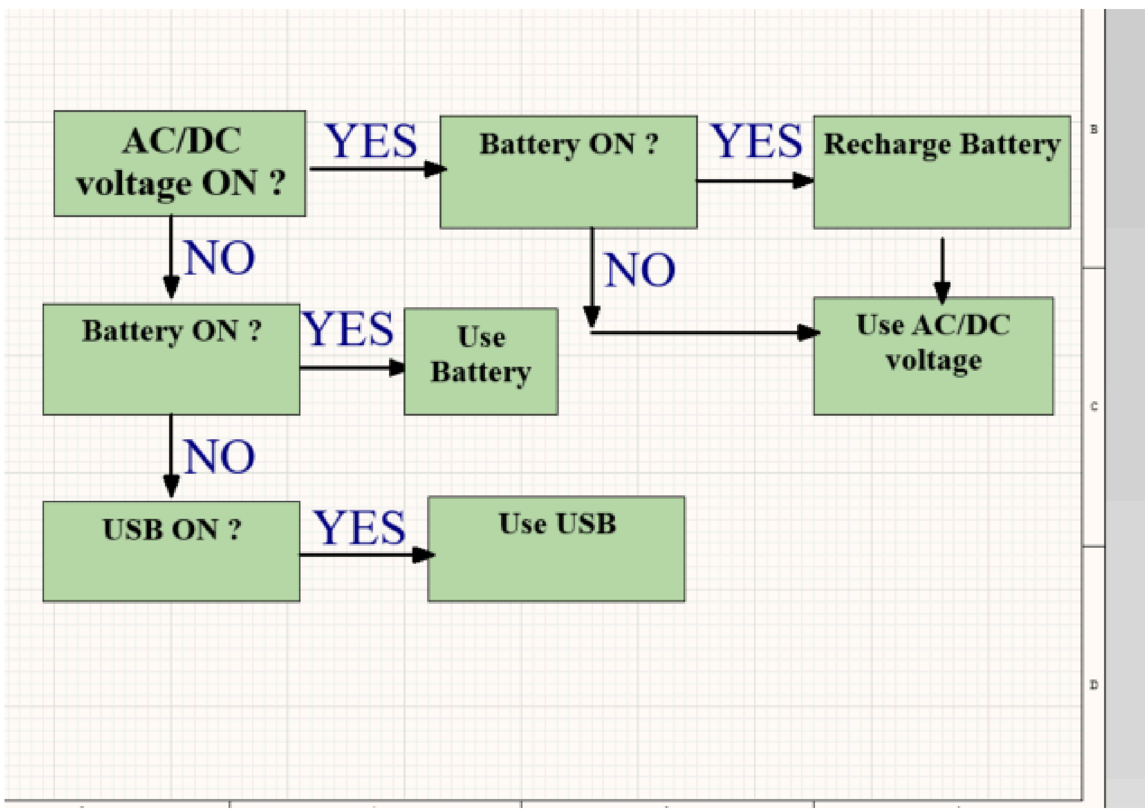
Functional mode:

This mode is implemented in order to use the battery power from the device (9V) and a GREEN LED will be on. The device should be completely functional. We will use USB Type C explained above.

Power Supply Structure 3:

This product will have 3 different power supplies which will allow the device to work properly in different situations. Only one will provide power if more than one supplier is being used. It will follow the logic structure in picture 4XXX.

We will have AC/DC Voltage, Battery and USB. This will consist in 2 modes functional and programmable that can be chosen by a mechanical switch.



Functional mode:

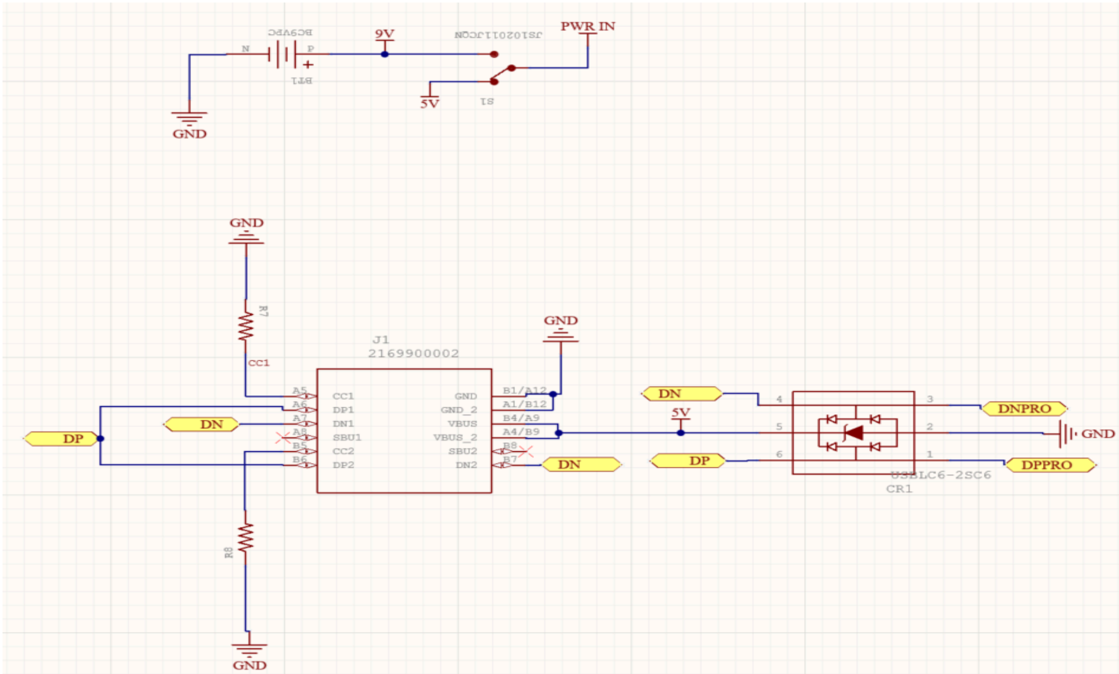
This mode is implemented in order to use the battery power from the device (9V) or the AC/DC connector. If there is a battery and AC/DC connector both connected, the battery will be charged and the power will be provided by the AC/DC source, if there is only one of them the circuit will work depending on the connected source and a GREEN LED will be on. We will use LTC4412 because it has a wide range for voltage in and for batteries capacities and also provides all the circuit logic, we will need to add a couple of extra electrical component.The device should be completely functional.

Programmable mode:
Same as explained in power structure 2.

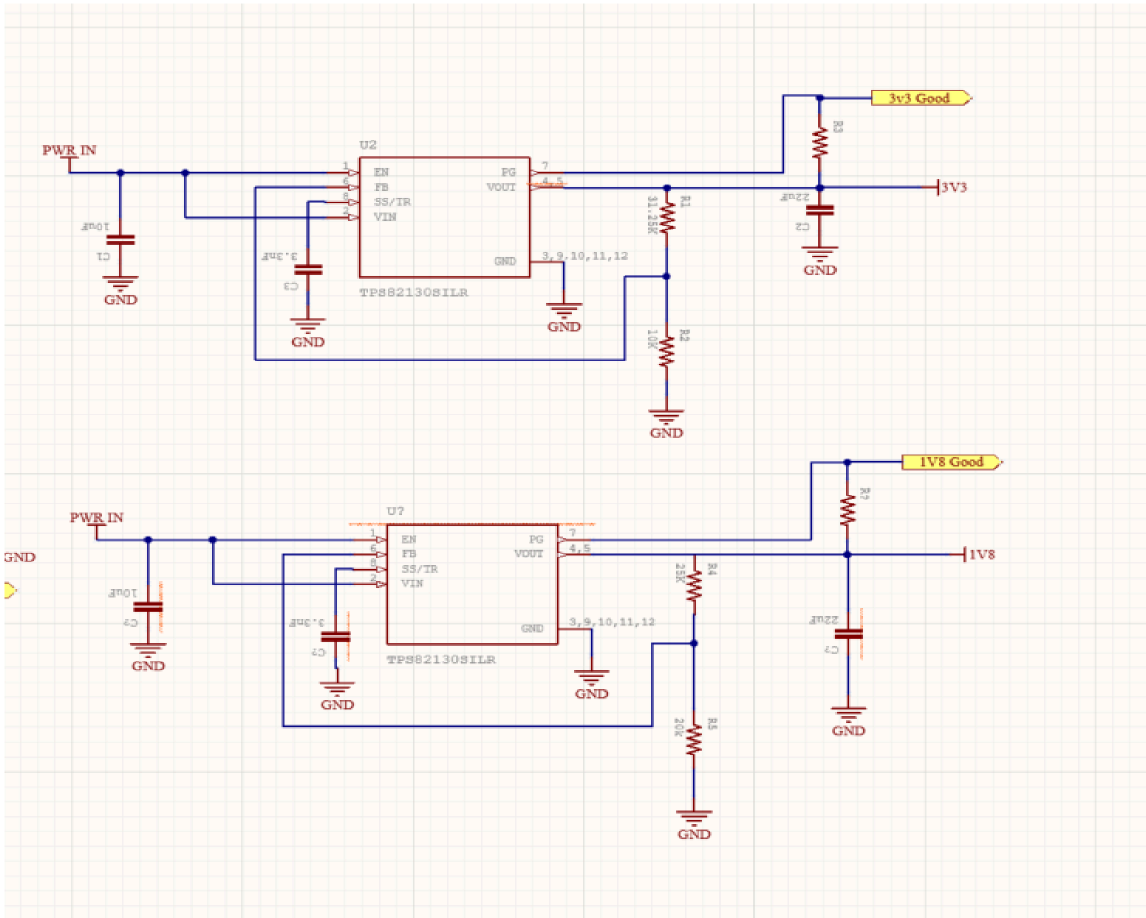
Conclusion:
The preferable power structure is number 3 which is a mix of number 2 and number 1. It is capable of providing 3 different power sources and able to recharge the battery. This will be easy to sell in the market. But it is complicated to implement and most costly, it will also take more time while number 2 can be implemented in 30 minutes; 3 will take around 10 hours. Depending on the peace of Senior Design 2 we will consider. Number one we will keep it as a draft since it is really hard to implement without a mechanical switch and only by electric logic, but it can be another project in the future since I found that there is not an IC capable of multiplexing 3 input voltages without a voltage supply. For now we think number 2 is the right option.

Implementing Power Supply Structure 2:
Depending on the mode established by a mechanical switch the board will receive its main power supply PWR IN (9V or 5V). PWR IN will be stepped down by two voltage regulators to provide 3V3 which will be used by the microcontroller and peripherals and 1V8 which will be used for other peripherals.

Power Sources and Mechanical Switch



VRs:



Voltage regulator comparison:

TLV700 series:

This was the first one we took a look on because it is easy to implement, highly efficient, low cost and small size but was discarded because its input voltage is in a range which will not fit our battery application which provides 9 volts. We can use it for other peripherals and not for the main application.

LD29150DT18R :

This is also a fixed voltage regulator which provides 1.5A and works up to 30V vin.STMicroelectronics also has a configurable Vout version. It is relatively small in size and can be really efficient in our design. But we need to choose different part numbers for each of the series since they are fixed output voltage.

LMS1585A:

This is also a fixed voltage regulator which provides from 3A to 5A, which may be good but may be too much for our application and works up to 13V vin. They have adjustable modules and fixed ones that provide only 1.5V or 3.3V.

LTM4623:

This is an adjustable voltage regulator that can set up Vout in a range of 0.6 to 5.5V and accept Vin from 4 to 20V which really matches our application. Also it has Power Good indicator and CLKin and CLKout logic implementation which can help us with many different configurations in our application.We can also control rise time by hardware, It provides 3A which may be too much for our circuit and it is a little big.

TPS82130:
This is an adjustable voltage regulator that can set up Vout in a range of 0.9 to 6V and accept Vin from 3 to 17V which really matches our application.We can control rise time by hardware. It provides 3A that may be too much. It has a 100% duty cycle for lowest dropout and Power Good output. And I have used it before for other designs.

Conclusion:
The preferable power supply is TPS82130. It has a perfect Vin range and Vout range as LTM462 and 3LD29150DT18R. It is better than 3LD29150DT18R because we do not have to choose different part number and getting fix Vout, 3LD29150DT18R does not provide PGOOD capabilities and controllable rise time, however 3LD29150DT18R has a lower current output to the load which may be better for us .TPS82130 also overpass LTM462 because is smaller and has a 100% duty cycle for lowest dropout as we I have used it on other designs. For now we have decided to use TPS82130.

5. Administrative Content

5.1 Budget and Financing

Item	Price per unit	Quantity	Total Price
Server	$5	1	$5
Rechargeable Power Supply	$100	1	$100
MC (If ESP32 chip down(Mousser))	$3	1	$3
ADC (ADS1115)	$5	2	$10
Batteries	$15	1	$15
Mic (ESP32 s3 with antenna)	$10	1	$10

Voltage regulators (TPS82130)	$5	2-4	$20
Screen (NHD-C12864A1Z-FSW-FBW-HTT)	$25	1	$25
Humidity, temp, & CO2 Sensor (SCD-41)	$49	1	$49
Mirrors	$11	2	$22
Detector (Linear CCD)	$70	1	$70
Grating	$100	1	$100
Magenta Dichroic Filter	$73	1	$73
PCB manufacturing	$50	1	$50
Biconvex Lens	$31	1	$31
Total			$583

Table 7: Budget

Our current budget includes all the elements needed for the CPE, EE, and PSE sides of the project. While there are miscellaneous parts that will be needed, we put together a budget for the main components. As can be seen above, the estimated cost is $583. This price is a few hundred dollars more than the devices listed earlier in the document. However, as stated in the motivation behind this project, none of these devices carry all the features that our device aims to.

5.2 Project Milestones

5.2.1 Senior Design I Schedule

Week(s)	Milestone	Finish By
1	Brainstorming Project Idea and Forming Group	8/23/2024
2-3	Divide & Conquer Document/Committee Formation	9/6/2024
4-5	Individual Research & Finalize Idea	9/18/2024
5	Order Optical Components	9/20/2024
6-8	Continue Research/Prepare for Midterm Demo	10/7/2024
8	Midterm Demo (1 Optical Subsystem)	10/8/2024

7-10	Setting up and Testing Optical Sensor	10/25/2024
8	PCB Design and Ordering	10/18/2024
8-10	60-page Draft Report	10/25/2024
10-12	60-page Report Revision	11/8/2024
13-15	Mini Demo Video/Final Report	11/26/2024

5.2.2 Senior Design II Schedule

Week(s)	Milestone	Finish By
1	Finalize schematics	Beginning
2	Order the Rest of Materials	
3-5	Building Prototype	
6-7	Testing Prototype	
8-9	Evaluation/Redesign	About Midway
10-12	Building Final Prototype	
13-14	Final Testing	
15	SD Showcase	Showcase Day

6. Conclusion

Our chosen project aims to simplify the complications of monitoring and improving greenhouse systems. By making a remote, all-inclusive measurement system, the future of greenhouses stands to improve tremendously. Through our research, our team has been able to collect information about the background of this issue, similar products, the materials needed, and has begun the design process of our prototype. While the main idea of the project is concrete, there may come a time when we realize that some goals are hard to reach and we need to redefine the scope or specifications of our project. This is part of the engineering design process, and we must focus on the most important aspects of the project. By listing our mission, goals, specifications, proposed budget, hardware/software diagrams, and schedule, we can re-evaluate the realisticness of our project and make sure that we are on the road to success. As it stands, this project appears to be challenging, as there are multiple different measurements that need to be taken, sensors that need to be calibrated, electronics that need to be connected, and information that needs to be displayed. This will certainly take much effort and time, but our team is ready to face this challenge.

12. Appendix A

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