

ZHEJIANG UNIVERSITY
UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN INSTITUTE

ECE 445

SENIOR DESIGN PROJECT

FINAL REPORT

Desktop-sized Environment-controlled Greenhouse

Team #2

ZHIMIN WANG

(zhiminw2@illinois.edu)

ZE YANG (zeyang2@illinois.edu)

TAORAN LI (taoranl2@illinois.edu)

HAOYU QIU (haoyuq2@illinois.edu)

TA: Qi Wang

Sponsor: Professor Wee-Liat Ong

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Abstract

Greenhouse plays an essential role in modern agriculture. It has been proven that greenhouse environmental conditions are efficient and essential for crop yield, pest prevention, and energy saving. However, the size and energy consumption of a traditional greenhouse makes it not likely to be used as an ornamental product in people's rooms. To solve this problem, we designed a desktop-sized greenhouse with several controlling systems to adjust the environmental conditions inside the greenhouse. We integrate sensors and control units that can monitor and adjust the environment parameters including temperature, humidity, light wavelength, light intensity, and air conditions, etc. Also, we develop a cloud server for remote monitoring and a mobile app for remote control and monitoring. There are three advantages of our design. First, we use a cloud server as a transfer to implement the remote control of the whole product instead of using Bluetooth. As long as the PCB board and the mobile phone have access to the internet, users can control the greenhouse remotely with very low latency. Second, to control the other subsystems, the PCB board has provided three relays. These relays play as automatic switchers, using small currents to control large currents in other circuits. Third, we use a semiconductor to decrease the temperature of the chip on the PCB board. The surface temperature of the chip can be quickly reduced through this design. The experiment shows that the remote-controlling system works well and efficiently, achieving the desired effect.

Keywords: Cloud server, Printed circuit board, Semiconductor, Light conditions

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1 Introduction

A greenhouse (also called a glasshouse) is a structure with walls and a roof made chiefly of transparent material, such as glass, in which plants requiring regulated climatic conditions are grown [1]. These structures range in size from small sheds to industrial-sized buildings, according to various purposes. Although greenhouse technology has shown its value in different uses, people who live in apartments in urban areas have not enjoyed such techniques yet. There are still several obstacles and gaps that remain to be solved for such kinds of products.

1.1 Background and Problem

Greenhouse plays a significant role in modern agriculture, especially in densely populated areas such as eastern China. Greenhouse environmental conditions have proven efficient and essential for crop yield, pest prevention, and energy saving [2]. As a productive system, the large-scale and medium-scale greenhouses allow us to respond to the growing global demand for fresh and healthy crops throughout the year, which is widely applied in agricultural production [3]. Traditionally, small-scale greenhouses are used in agricultural experiments. Researchers cultivate their plants in a modular environment-controlled greenhouse, to gather data on the state of crop growth in a highly specified and optimized environment.

In most cases, these greenhouses are not intended for ordinary consumers. Even those greenhouse products marked for home use, are mainly for those customers who live in houses with gardens. It is not likely for a user who lived in an apartment to enjoy a greenhouse for ornamental use. In fact, several obstacles remain to be solved for a customer greenhouse product. First, traditional greenhouses are usually too large in their size. The most common glasshouse size for growers is 8 to 10 feet wide, while the large greenhouses for sale may range from 12 to 20 feet in width [4]. Secondly, the greenhouse industry's current practices require considerable energy to power lighting to maintain plant growth on overcast days[5]. Excessive energy consumption also makes it not applicable for household use. Considering the above two factors, it is very inconvenient for the customers to install and carry away. The main cause for the large size and the high energy consumption is that the greenhouse environment is not easily controlled [3]. As its climate parameters are interrelated, a specific amount of sensors should be installed in a comparably small model, which is the third problem. Another problem is that current products on the market do not have fully-featured applets to support the use of the greenhouse. Since customers nowadays are more likely to be accustomed to using their phones to control devices in their homes [6], there is still much room for improvement in this area.

1.2 Overview of the Solution

In an attempt to solve the problems mentioned above, we plan to design a desktop-size environment-controlled greenhouse that can be used for ordinary customers. To reduce

its size and energy consumption, only the necessary components would be kept in the product. The product is a cuboid space with an environment-controlling system. All the advanced control functions will be implemented through the applet on the mobile phone. The whole product's dimension is strictly controlled to be the desktop size. The energy consumption should be similar to general household appliances.

1.3 Components List and Visual Aid

1.3.1 Components List

1. A Tencent light cloud server:
 - (a) CPU: 2 cores of Intel(R) Xeon(R) Gold 6133 CPU @ 2.5 GHz
 - (b) RAM: 2 GB
 - (c) ROM: 40 GB
 - (d) System: Windows Server 2012 R2 Datacenter
2. A PCB board with:
 - (a) ESP32-WROOM-32E
 - (b) plots for DHT11
 - (c) Two HDR-1x5
 - (d) plots for Light (Light sensor)
 - (e) plots for MQ-135 (Air sensor)
 - (f) plots for A2541WV-2x7P (OV2640 camera)
 - (g) 5V Power
 - (h) Three resistors: 10 K Ω
 - (i) Three relays
3. A semiconductor cooler
4. Light source
5. Two fans can input and output the air according to the demands.
6. A mobile phone app that can receive the data and adjust the settings.
7. The main planting cube. The model should be able to hold a fully functional environment-controlling system.

1.3.2 Visual Aid

As shown in Fig. 1, the whole model consists of three parts: a main growing space with a water tank and a control board, a cloud server, and a mobile phone. The detailed 3D

model version of the growing space is shown in Fig. 2, according to the design draft in Fig. 3.

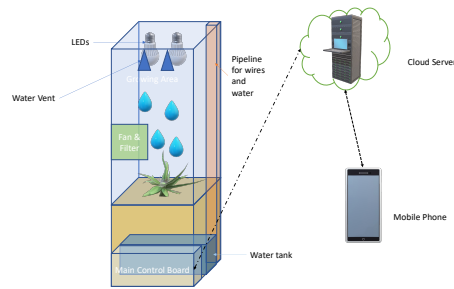


Figure 1: Overview of the model

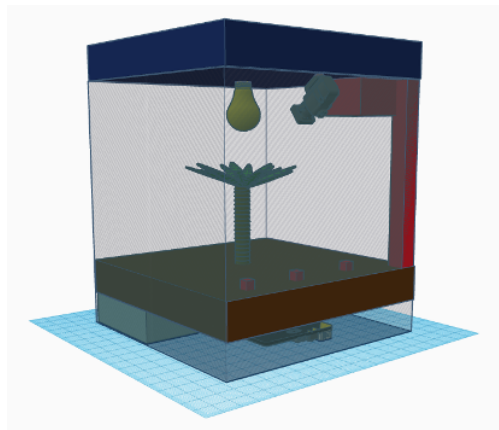


Figure 2: 3D Model draft

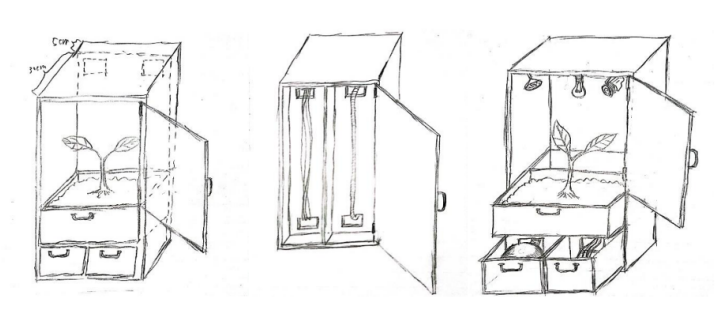


Figure 3: Design draft

The graphic flat design for the upper level of the model is shown in Fig. 4. Its 3D model version is shown in Fig. 5. The graphic design for the lower levels is shown in Fig. 6 and Fig. 7

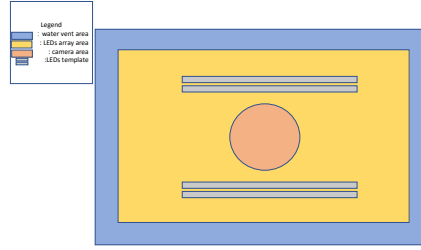


Figure 4: Model's upper platform design

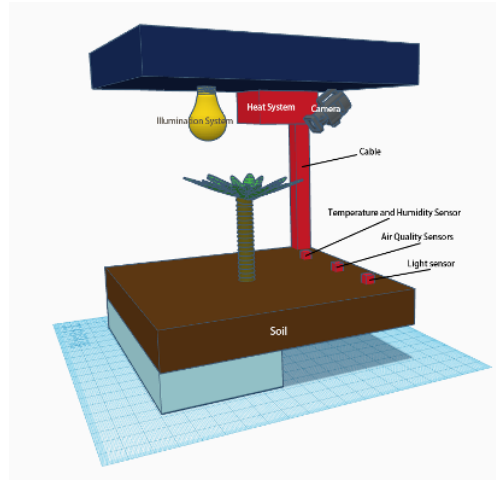


Figure 5: Model's upper platform design (3D version)

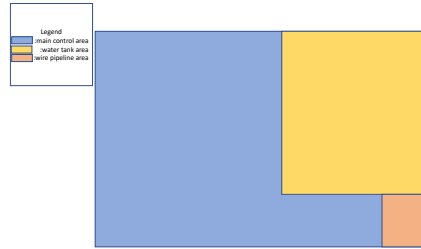


Figure 6: Model's lower platform design

1.4 Environment-controlling systems overview

1. Temperature system: Our heater can produce hot wind to heat up the greenhouse and the water pipe cooler can produce cold air to cool the greenhouse. We can manually open the heater and water pipe cooler. Components of Temperature system:
 - (a) DHT11: The DHT11 sensor detects the environment temperature and sends out the temperature value.
 - (b) Water Circulation System: This system will pump up the cold water, and cold

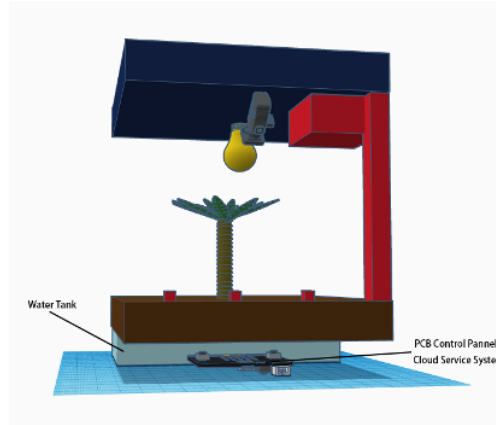


Figure 7: Model's lower platform design (3D version)

water with the greenhouse internal plumbing flow over to take away the heat, and finally the water will return to the water tank.

- (c) Heating wire: We use a USB-powered heating wire to heat up the internal temperature of the greenhouse. The temperature can be heated up to 60 degrees Celsius.
- 2. Air Circulation System: Air Circulation System is designed to purify the air inside the greenhouse and help the temperature control when the temperature system is on. It could bring cold or hot air into the greenhouse. Components of Air Circulation System:
 - (a) MQ-135: The MQ-135 is the sensor to detect air quality in the greenhouse and sends out the air quality value.
 - (b) Fans: We have two fans to circulate the air in the greenhouse. And we can both manually and remotely turn it on and turn it off.
- 3. Humidity Control System: The system needs to increase the environment humidity and to keep the plants with good growing humidity.
 - (a) DHT11: The DHT11 is the sensor to detect environment humidity and sends out the humidity value.
 - (b) Water Pump and spray-head: When the humidity is low, the user can use the mobile phone to turn the water pump on and the spray-head will spray the water and increase the humidity.

1.5 High-Level Requirement List

1. The whole model's size should be controlled under 40cm (width) * 40cm (length) * 90cm (height).

2. The temperature controlling system should be able to control the temperature in the main planting area from 18° to 24°C (64°F – 75°F) [7].
3. The humidity controlling system should be able to adjust the humidity in the growing space from 70% to 90%, as it is a relative humidity setpoint for most plants [7].

2 Design Requirement Verification

2.1 Block Diagram

The design's block diagram overview is shown in Fig. 8. In order to decrease the size of the accessories in the model, leaving more space for the growing area, only the necessary sensors and a chip microcontroller would be left in the model. There will be a default environmental setting for the model to maintain the temperature and humidity. The information collected by the sensors will be packaged and sent to a cloud server. The server will then process these data, sending them to the mobile phone. The users can view this information directly on their mobile phones, and adjust the environmental settings.

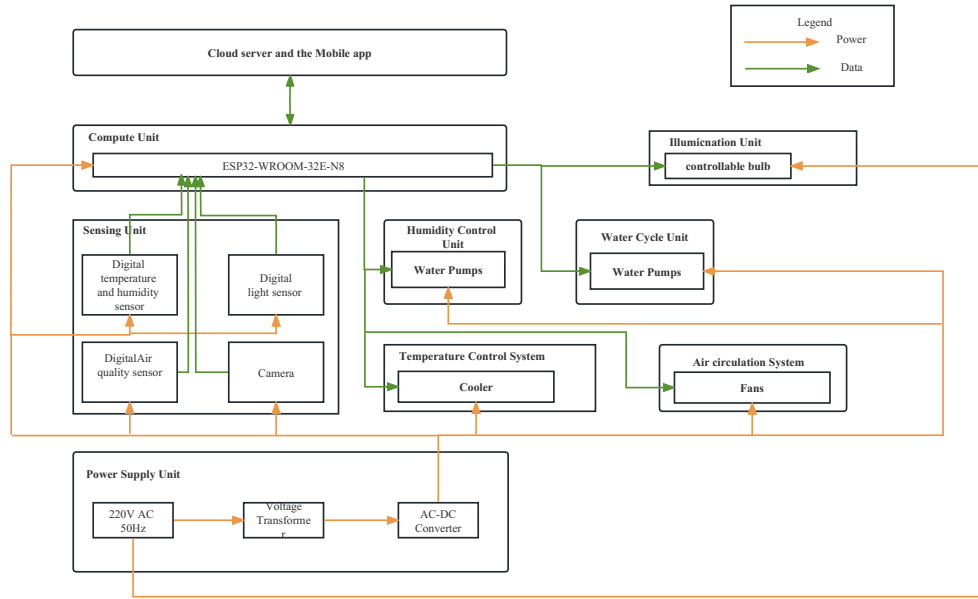


Figure 8: Overview of block diagram

2.2 Temperature Regulation System

The temperature regulation subsystem is one of the crucial parts of the whole design of the system. The temperature regulation system monitors and controls the temperature in the main growing space. Temperature sensors are used to monitor the temperature data.

2.2.1 Temperature Sensors

We use DHT11 as a Temperature sensor. DHT11 Temperature Humidity Sensor features a temperature humidity sensor complex with a calibrated digital signal output. By using the exclusive digital signal acquisition technique and temperature humidity sensing technology, it ensures high reliability and excellent long-term stability. This sensor includes a resistive-type humidity measurement component and an NTC temperature measurement

component, and connects to a high-performance 8-bit microcontroller, offering excellent quality, fast response, anti-interference ability, and cost-effectiveness.

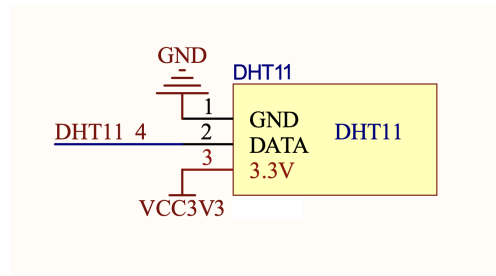


Figure 9: Schematics of DHT11

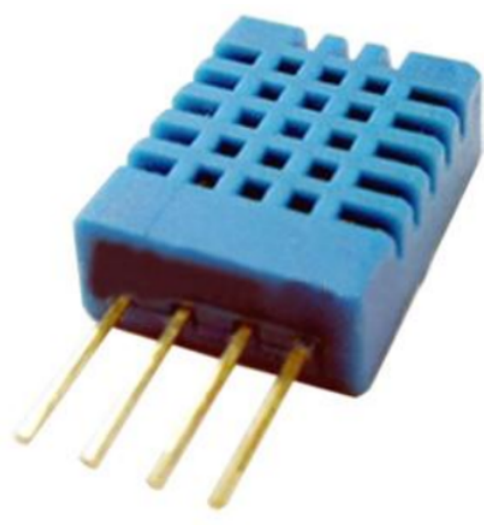


Figure 10: DHT11

2.2.2 Heater

We use a USB-powered heating wire, shown in Fig. 11, as the heater. The heating wire can be heated up to 60 degrees Celsius, which is enough for the heating requirement of the greenhouse. In Fig. 12, We also add a fan above the heating wire to bring hot air into the greenhouse to speed up the heating process. The fan is also a part of the air circulation system and can be controlled remotely.

2.2.3 Cooler

We design a water circulation system to cool the system. This is inspired by the computer water-cooling radiator. The cool system will pump up the cold water, and cold water with the greenhouse's internal plumbing flow over to take away the heat, and finally, the water will return to the water tank. We also add a fan above the internal plumbing to bring cold air into the greenhouse to speed up the cooling process. The fan is also a part of the air circulation system and can be controlled remotely.



Figure 11: USB-powered heating wire

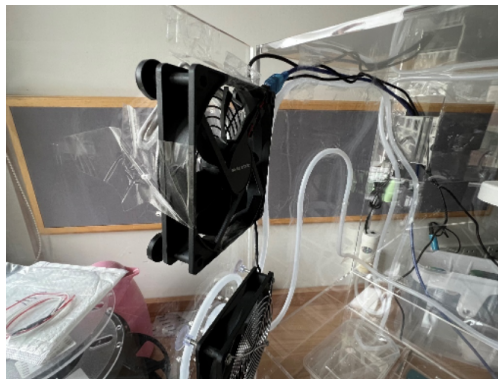


Figure 12: The fan above the heating wire

2.3 Air Circulation System

The air circulation subsystem works with a temperature system and mobile app system. The air circulation system monitors and controls the air quality in the main growing space. Two fans are installed to pump the air in and out. MQ135 gas sensor is used to monitor the temperature data. Also, air circulation system also helps the temperature

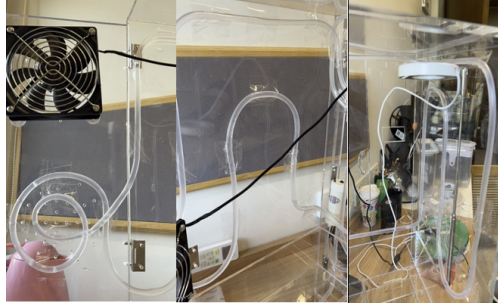


Figure 13: Internal water plumbing



Figure 14: The fan above the water plumbing

system work well.

2.3.1 Air Quality Sensors

We use MQ135, shown in Fig. 15 and Fig. 16, as an air quality sensor. The sensitive material of the MQ135 gas sensor is SnO_2 , which with lower conductivity in clean air. When target pollution gas exists, the sensor's conductivity gets higher along with the gas concentration rising. Users can convert the change of conductivity to the corresponding output signal of gas concentration through a simple circuit. MQ135 gas sensor has a high sensitivity to ammonia gas, sulfide, and benzene series steam, and also can monitor smoke and other toxic gases well. It can detect kinds of toxic gases and is a kind of low-cost sensor for kinds of applications.

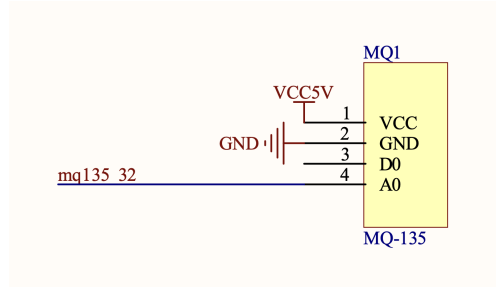


Figure 15: Schematics of MQ-135



Figure 16: MQ-135

2.3.2 Fans for Air Circulation

We installed two USB-powered fans on the ventilator of the greenhouse. When these two fans work, the fresh air will be brought into the greenhouse and the bad air will be pumped out. Also, these two fans will help the temperature system to control the internal temperature. These two fans can be both controlled remotely and manually controlled.



Figure 17: Fans for Air Circulation

2.4 Humidity Control System

This system is used to provide plants with the right humidity environment for growth by adjusting the supply of water. We use a moisture Sensor to detect the humidity condition of the air around plants. Underneath the device, we are equipped with a water tank,

which can be pumped and sprayed into the internal environment regularly through the mobile app's remote control.

2.4.1 Humidity Sensors

We use DHT11 as a Humidity sensor. DHT11 Temperature Humidity Sensor features a temperature humidity sensor complex with a calibrated digital signal output. By using the exclusive digital signal acquisition technique and temperature humidity sensing technology, it ensures high reliability and excellent long-term stability. This sensor includes a resistive-type humidity measurement component and an NTC temperature measurement component, and connects to a high-performance 8-bit microcontroller, offering excellent quality, fast response, anti-interference ability, and cost-effectiveness. And figure 2 shows the DHT11 sensor.

2.4.2 Water Pump and spray-head

We installed a water pump and spray head to spray water into the greenhouse and increase the humidity. And we remotely control the water pump to control the water spray.

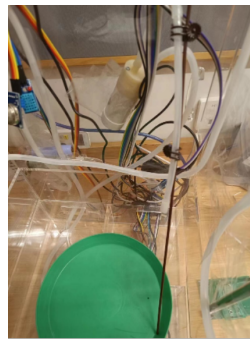


Figure 18: Water pump and the spray-head

2.5 Remote-controlling System

The remote-controlling system is composed of a PCB with ESP32[8] (in Subsection 2.5.1), a Tencent Cloud Server (in Subsection 2.5.2), and a mobile phone app (in Subsection ??). All the sensors' information should be first sent to ESP32 to process and packaging. These data should then be pushed into the cloud server. The mobile phone app can receive the information from the server and feed it back to the user. At the same time, the applet can also remotely control the light, temperature, humidity, and air quality as it will send requests to the server.

2.5.1 PCB

I use ESP32-WROOM-32E-N8, shown in Fig. 19 and Fig. 20, as the control center of the whole system. ESP32 has relatively high stability and security. It also has a Wi-Fi module,

with a network API named SmartConfig. The SmartConfig is a provisioning technology to connect a new Wi-Fi device to a Wi-Fi network. It uses a mobile app to broadcast the network credentials from a smartphone, or a tablet, to an unprovisioned Wi-Fi device [9]. Digital temperature and humidity sensor (DHT11), camera (OV2640), light sensor, and air quality sensor (MQ-135) will collect environment data and send it to the control center for further processing (shipping to the server and activating parts according to the signal from server). These data will also be displayed on the screen of Greenhouse. Three relays are provided to connect to other subsystems' circuits in a way shown in Fig. 21 and Fig. 22. The power supply of the whole PCB board is 5V. The requirements and verification can be found in Table 1. The final PCB layout and circuit schematic is shown in Appendix A.

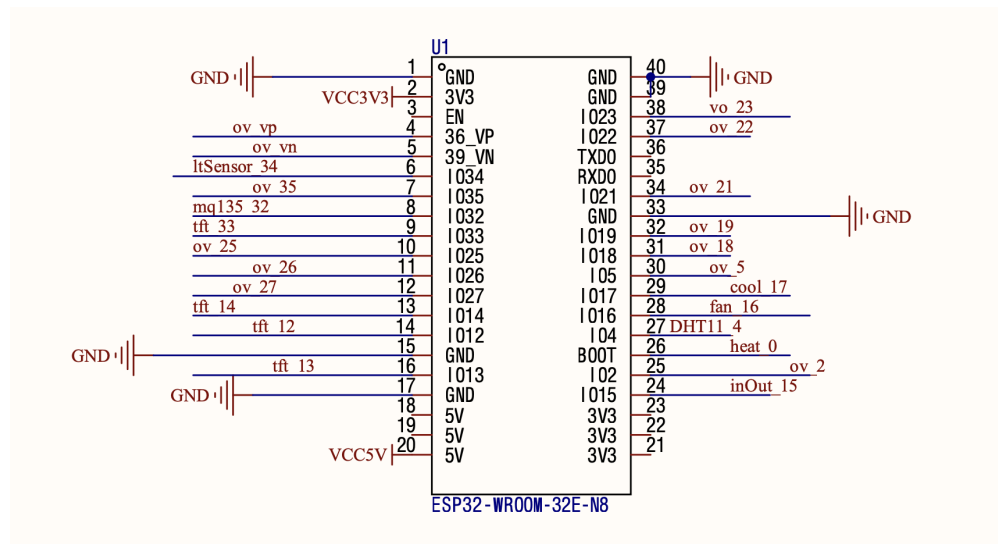


Figure 19: Schematics of ESP32



Figure 20: ESP32

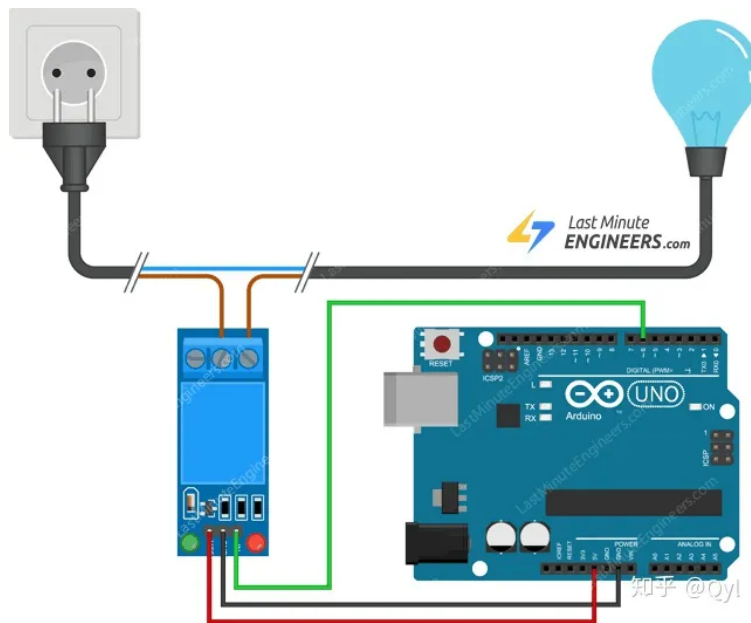


Figure 21: Connection schematic of relays [10]

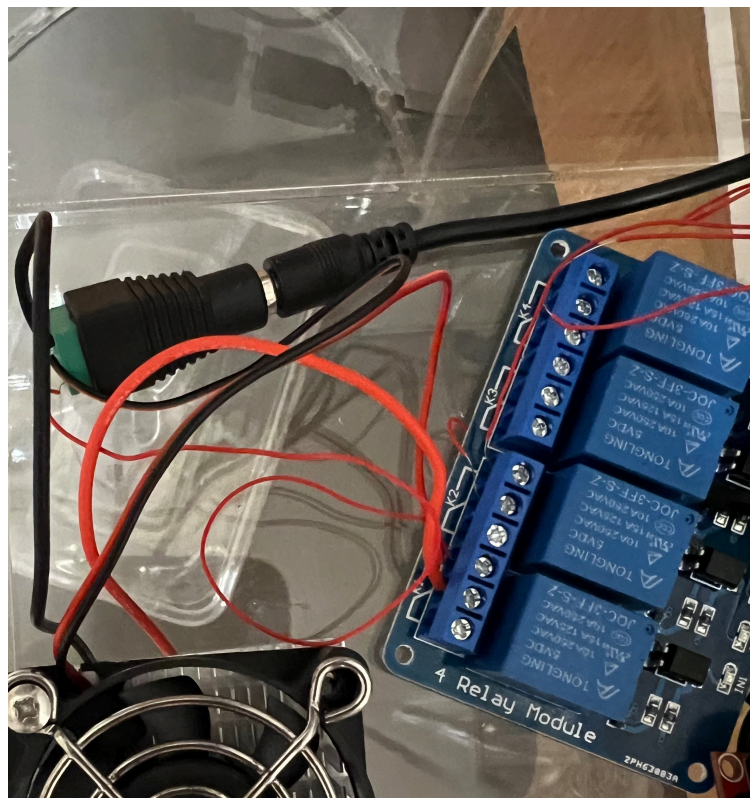


Figure 22: Connection examples of relays

Requirement	Verification
<ol style="list-style-type: none"> 1. The microcontroller needs to receive multiple data inputs, process all the data, and produce multiple data outputs. 2. The data processing part needs to process various data relatively quickly to ensure our system can work properly. 	<ol style="list-style-type: none"> 1. Connect all sensors to the PCB, then turn on the power of the PCB. The LCD screen should be turned on first. Then the temperature, humidity, illuminance, and air quality should be displayed on the screen. The environmental changes would be displayed on the screen immediately. The status of 2. When the environmental factors change, the changed value should be displayed on the screen in 5 seconds.

Table 1: PCB

ESP32's chip will be quite hot after working for 5 minutes. To reduce the risk of burning the module, I employed a semiconductor made of bismuth telluride in Fig. 23 as thermoelectric cooling. It uses the Peltier effect to create a heat flux at the junction of two different types of materials [11]. Using a small fan to release the heat generated by the hot side, this module can decrease the temperature of the ESP32 chip quickly.

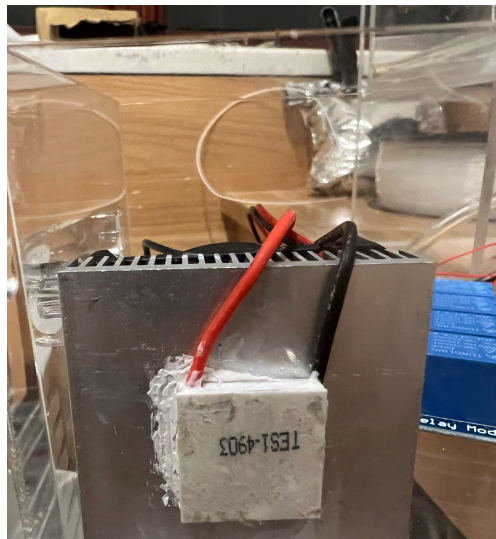


Figure 23: Semiconductor cooling module

2.5.2 Cloud Server System

I choose to rent a cloud server as a transfer. This system will interact with ESP32 and the smartphone app for data transmission. It works like a bridge connecting ESP32 and the smartphone app, letting the user activate parts on ESP32. The cloud server system is a 2-core Tencent cloud server, with Windows Server 2012 R2 Datacenter. Port 10000 is turned

on with User Datagram Protocol (UDP). This port is used to transfer data between the server and PCB. UDP can transfer data quickly. Although UDP is not very reliable, the ESP32 will send the updates of the status in a quite short period, the server still can receive the changes. Port 7777 is turned on with Transmission Control Protocol (TCP). This port is used to transfer data between the PCB and mobile applet. TCP is more reliable compared to UDP. Since I need to make sure that every request from the applet is received by the server, using TCP is a better choice as it tracks the packages and resends them if packages are lost. The cloud server program's panel is shown in Fig. 24. Despite the environmental conditions and the relays' status, the mobile phone's IP address will be shown on the program. The requirements and verification can be found in Table 2.

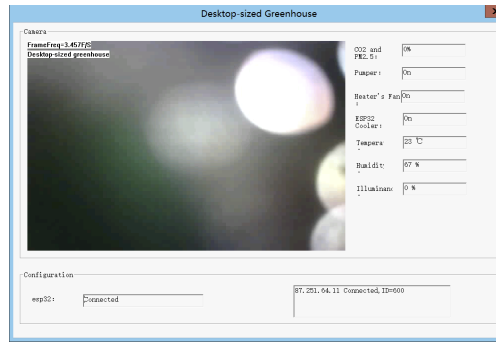


Figure 24: Cloud server program

Requirement	Verification
1. The system must receive from and transfer data to the phone and esp32. We need several ports for the phone app and esp32.	1. Connect the mobile applet, the server, and the ESP32. The data can be synced among these three.
2. The data processing part should be done relatively quickly to ensure our system can work properly.	2. When the environmental factors change, all the data should be synced among these 3 platforms in 5 seconds.

Table 2: Tencent Cloud Server

2.5.3 Mobile Applet

This system is used to provide remote control and monitoring. We design and implemented the app to control parts in the greenhouse, like opening the water pump and opening the fan. Also, we can monitor the environment remotely.

We build the TCP connection between the cloud server and the mobile app. The cloud server will send data of sensors to the mobile applet, and the mobile applet will display them to the user. The user can also click the button in the mobile app to send control signals to the cloud server, and the cloud server will route the signal to the esp32 (the control unit) to do the remote control.

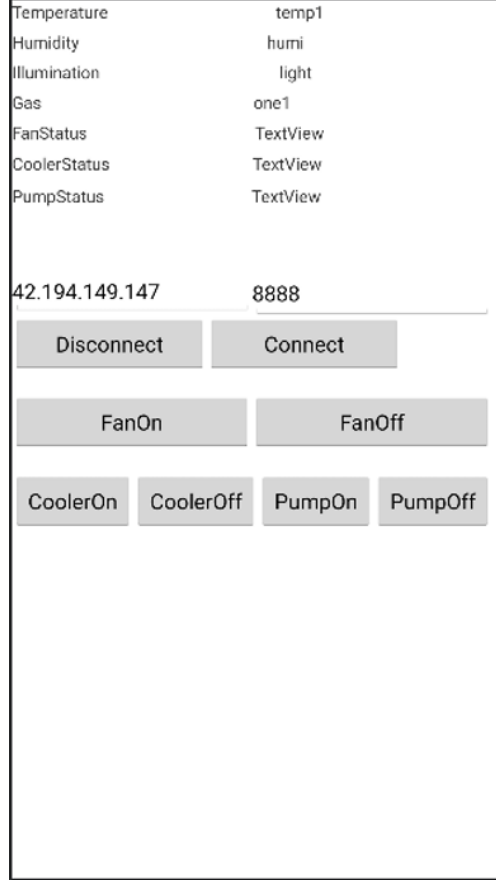


Figure 25: Mobile applet layout

2.6 Illumination Condition Tolerance

Light is an important environmental factor influencing plant growth, development, and secondary metabolism. All plants have their own optimal light intensity (illuminance) ranges for growth [12]. To meet the requirements for illumination, one important factor that we need to take into consideration is photosynthetic photon flux density (PPFD). PPFD can be regarded as the unit of photosynthetic active radiation (PAR). PAR light is the wavelengths of light within the visible range of 400 to 700 nanometers (nm) that drive photosynthesis. It defines the type of light needed to support photosynthesis [13].

For different plants, as shown in Fig. 26, the PAR requirements are different. To achieve the required types of light, given an illuminance value (lux or footcandles), we need to calculate the PPFD in micromoles per second per square meter ($\mu\text{mol} \cdot \text{s}^{-1} \cdot \text{m}^{-2}$) for the given light source.

According to CIE 1931 luminous efficiency function $V(\lambda)$ [15], we can then get the total luminous flux in a source of light:

$$\Phi_v = 683.002(\text{lm}/\text{W}) \cdot \int_0^{+\infty} V(\lambda)(\lambda) \Phi_{e,\lambda}(\lambda) d\lambda, \quad (1)$$

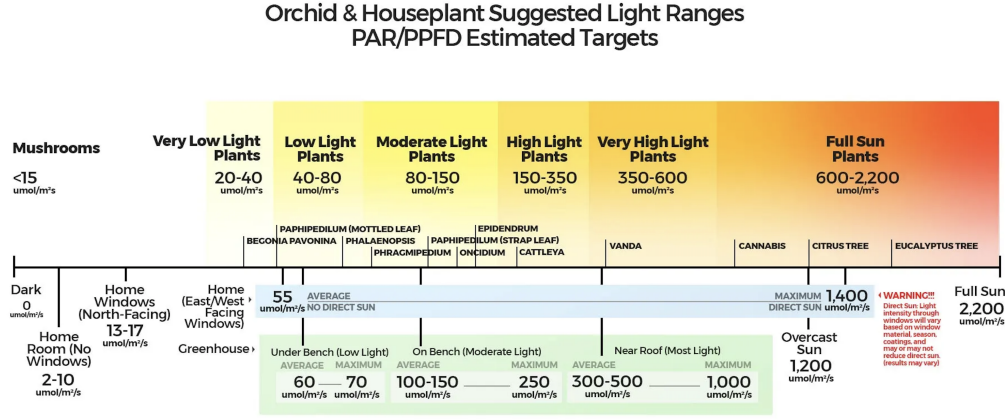


Figure 26: Suggested light ranges[14]

where Φ_v is the luminous flux in lumens, $\Phi_{e,\lambda}$ is the spectral radiant flux in watts per nanometre, $V(\lambda)$ is the CIE 1931 luminous efficiency function at wavelength λ in nanometres.

According to eq. 1, if the source light is across the relevant wavelengths (400-700 nm), then for each lumen, we can calculate the spectral radiant flux $\Phi(\lambda)$ for plants in watts per nanometer:

$$\Phi(\lambda)/lumen = [W_{rel}(\lambda)]/[683.002(lm/W) \cdot \sum_{400}^{700} V(\lambda)(\lambda)\Phi_{e,\lambda}(\lambda)d\lambda], \quad (2)$$

where $W_{rel}(\lambda)$ is the relative spectral power distribution.

We can get the photosynthetic photon flux (PPF):

$$PPF/nm = 10^{-3} \cdot [\lambda\Phi(\lambda)]/(N_a h c), \quad (3)$$

where N_a is Avogadro's constant, h is Planck's constant, and c is the speed of the light.

Thus, we get the PPF equals to $8.359 \times 10^{-3} \cdot \sum_{400}^{700} [\lambda\Phi(\lambda)\Delta\lambda]$. Once the wavelength of the LEDs has been decided, within the PPF calculated, we can then calculate the PPFD for the given light source.

The distance between the light and the plants will affect the PPF and PPFD heavily, as the area covered by the light is increasing when the distance is increasing.

As a rough calculation, assuming the PAR provided by the LEDs is 150 PPF, we can have an equation:

$$PPFD = \frac{PPF}{r \cdot x^2}, \quad (4)$$

where r is the conversion factor depending on different LED products. If r is 14.6 [5000K white light LED (Philips Luxeon Rebel LXW8-PW50) [16]], we can get Fig. 27, where the y-axis represents the PPFD, and the x-axis represents the distance between the light source and the plants.

Thus, the LEDs should provide at least 250 PPF, while the distance should be controlled under 0.46 m.

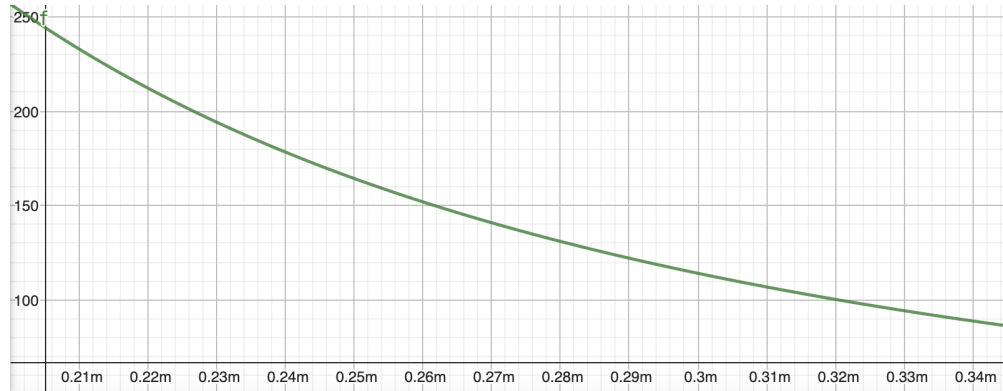


Figure 27: PPFD on different distances (LEDs: 150 PPF)

2.7 Real-time Monitoring System

The detection system can detect the growing space in real time, and this is detected by the installed camera. I use OV2640, which is shown in Fig. 28 and Fig. 29, as the camera. This module can produce an image array capable of operating at up to 15 frames per second (fps) in UXGA resolution with complete user control over image quality, formatting, and output data transfer [17]. At the same time, we can monitor the situation inside the server. FPC cable with the same direction and 0.5 mm interval is used to connect the OV2640 and PCB. The requirements and verification can be found in Table 3.

Requirement	Verification
1. When the user turns ESP32 on, it should send the live video to the ESP32, which can be transferred to the server.	1. Turn on the power, when the ESP32 is connected to the server, the videos are transferred to the server.

Table 3: Real-time Monitoring System



Figure 28: OV2640

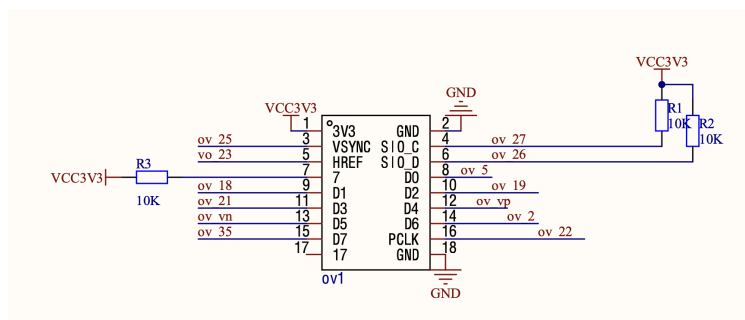


Figure 29: Schematic of OV2640

3 Costs and Schedule

3.1 Cost Analysis

1. Labor

According to UIUC's Computer Engineering average salary (\$105,325), the fixed development costs are estimated to be \$52/hour, 20 hours/week for everyone.

$$weeklycost = \frac{\$52}{hour} \cdot \frac{20hours}{week} \cdot 14weeks \cdot 4 \cdot 2.5 = \$145,600 \quad (5)$$

(a) Zhimin Wang: \$36,400

(b) Ze Yang: \$36,400

(c) Haoyu Qiu: \$36,400

(d) Taoran Li: \$36,400

2. Parts ¹

Part	Cost
ESP32-WROOM- 32E-N8 (Taobao)	¥21.8
DHT11 (Taobao)	¥7.9
DHT22 (Taobao)	¥25.8
MQ-135 (Taobao)	¥9.76
OV2640 (Taobao)	¥21.5
OV5640 (Taobao)	¥158+¥5 (delivery)
Manufacture of PCB (Taobao)	¥200+¥5 (delivery)
2-core Tencent Cloud Server (Tencent)	¥30
Acrylic shell	¥1200
FPC cable	¥17.30
DuPont Line	¥94.80
Total cost of parts	¥1818.66

Table 4: Part cost

3. Total cost estimated: ¥1818.66 + \$ 145,600

¹Noting: Costs spend as of 5/7/2023.

3.2 Schedule

WEEK	Zhimin Wang	Ze Yang	Taoran Li	Haoyu Qiu
2/13/2023	Form the team.	Form the team.	Form the team.	Form the team.
2/20/2023	Request for Approval (RFA) and contract writing.	Modified RFA.	/	/
2/27/2023	Writing all the remaining part of the proposal.	Proposal's subsystem description.	Proposal's subsystem description.	Proposal's subsystem description.
3/6/2023	Keep writing the proposal; draft model design; contact modules' manufacturer	Contact modules' manufacturer; Proposal's subsystem description	Proposal's subsystem description; block diagram draft	Proposal's subsystem description; block diagram draft
3/13/2023	Ordering the modules; Design Document (DD) writing; weekly meeting ppt modification; PCB designing	DD subsystem parts: esp32, cloud server, mobile app; weekly meeting ppt drafting; PCB designing	DD subsystem parts: model shell, temperature, humidity	DD subsystem parts: illumination, air circulation camera
3/20/2023	Keeps working on DD; delivery should be arrived by this week	DD subsystem parts: esp32, cloud server, mobile app;	DD subsystem parts: model shell, temperature, humidity	DD subsystem parts: illumination, air circulation camera
3/27/2023	Cloud Server environment testing.	Android Applet developing.	Model shell design for PCB.	Sensor testing and enhance features.
4/3/2023	Connect the cloud server to the ESP32; feature developing	Connect Applet to the cloud server; feature developing	Model analyzing and designing.	Connect the ESP32 to the server.
4/10/2023	Connect the cloud server to the applet; feature developing	Help test the communication among esp32, server, and applet; feature developing	Model analyzing and model producing.	Model analyzing and model producing.
4/17/2023	Finish the connection among esp32, server, and applet; feature testing	Finish the connection among esp32, server, and applet; feature testing	Model producing; installing hardware.	Model producing; installing hardware.
4/24/2023	Final testing; Final report writing.	Final testing; Final report writing.	Final testing; Final report writing.	Final testing; Final report writing.
5/1/2023	Final testing; Final report writing.	Final testing; Final report writing.	Final testing; Final report writing.	Final testing; Final report writing.
5/8/2023	Mock Demo; Final report	Mock Demo; Final report	Mock Demo; Final report	Mock Demo; Final report
5/15/2023	Enhance the performance; Final report.	Enhance the performance; Final report.	Enhance the performance; Final report.	Enhance the performance; Final report.
5/22/2023	Demo	Demo	Demo	Demo

4 Conclusion

4.1 Accomplishments

In this report, a fully featured remote-controlling system is designed and produced. The designed PCB with ESP32 can receive the data collected by all sensors. The Wi-Fi module on the ESP32 works and can connect to the internet to send data to the server. The cloud server can receive and handle the requests from the mobile applet. Users can also monitor the plants through the server. The mobile applet's instructions can be correctly executed by the PCB, controlling other environmental-related subsystems through relays, which act like switchers. A semiconductor cooling module is employed to decrease the surface temperature of ESP32's chip. The requirements of the illumination system are carefully calculated and provide a reference for the project's design. The heating wire with the fan can output hot temperature air. And the same for the water cooler part. We assemble the water pump and the spray head, they could work properly. The humidity sensors could collect values of the humidity. Multiple subsystems are integrated. The whole system works well to achieve environmental control, manual and remote control, and monitoring.

4.2 Uncertainties

There are still some problems that remained to be solved with this design. First, due to design flaws at the beginning, there are only three relays for the other subsystems to connect. If these modules are originally controlled by electronic switchers, then the relays may not work. Second, the relays' circuits are not fully packaged with insulation materials. There are risks in the leakage of electricity. Third, the camera OV2640's pixel is quite low. The video's quality is not good enough to play as a monitor for the plants. Besides, the video quality will be worse if I use an FPC cable to connect the camera and PCB, which means we cannot put the camera on the top of the model to monitor the plants.

4.3 Ethical consideration

According to IEEE codes of ethics [18], there are a few potential safety and ethics concerns we need to take into consideration during the development process.

The first safety-related is that it must not hurt people, which is corresponding to the IEEE Code of Ethics, #1: "to hold paramount the safety, health, and welfare of the public" [18]. Traditionally, the main concern on house-use electrical products is the leaking of electricity. Considering that our product incorporates many precision electronic components, while the working space is quite wet, moisture could do damage to the nodes, causing a short circuit. Since the ESP32's working space is near the water tank, a closed waterproof design is needed for the work area. Meanwhile, the ESP32 board should never be charged over a safe voltage (3.0 to 3.6 V) [19]. The temperature should also be controlled between -40 and 85 °C [19].

Despite the risk in the circuit, there is also a risk that users may use this product for drug-related plant planting, which is against the IEEE Code of Ethics, #1: "to hold paramount the safety, health, and welfare of the public" [18]. We do not want to see our product being used to feed drug abuse. Since cannabis is one of the few plants which flourish under more than 950 to 1,200 photosynthetic photon flux density (PPFD) [20], our product should not choose the LEDs that support this working power.

Another ethics-related problem is that since our product has a monitoring system, the data collected by the camera may include the user's privacy. According to the IEEE Code of Ethics, #1: "to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment" [18], we need to inform the users of the risk using it. On the other hand, these data should be carefully ciphered and saved on the server with necessary security protection. A leaking of information may lead to a severe problem.

Defects may always exist in our product, and sometimes we may accidentally overlook them due to various reasons. It is essential for us of being humble and ready to accept advice. This is also an implementation of the IEEE Code of Ethics, #5: "to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors" [18].

4.4 Future work

To improve the performance of this product, several potential works can be done and are shown as follows. First, increasing the number of relays for other subsystems to connect can help the whole product being more integrated. Second, a feedback system that can automatically adjust the greenhouse's environmental settings should be included in future generations of the product. Meanwhile, the real-time monitoring system can be updated by choosing a better camera module. More research should be done on how to prolong the connection between the PCB and the camera module, as the FPC cable can not provide a reliable transfer. For the mobile app, we can improve the layout and the reliability of the app. For the temperature regulation system, we need to measure the efficiency of the system and do improvements if the system works not well. For the humidity part, we also need to measure the efficiency of the system and do improvements if the system works not well. For the air circulation part, we need to strengthen the fixing of the fan, which currently falls off after a long run.

Appendix A PCB circuit schematic and layout

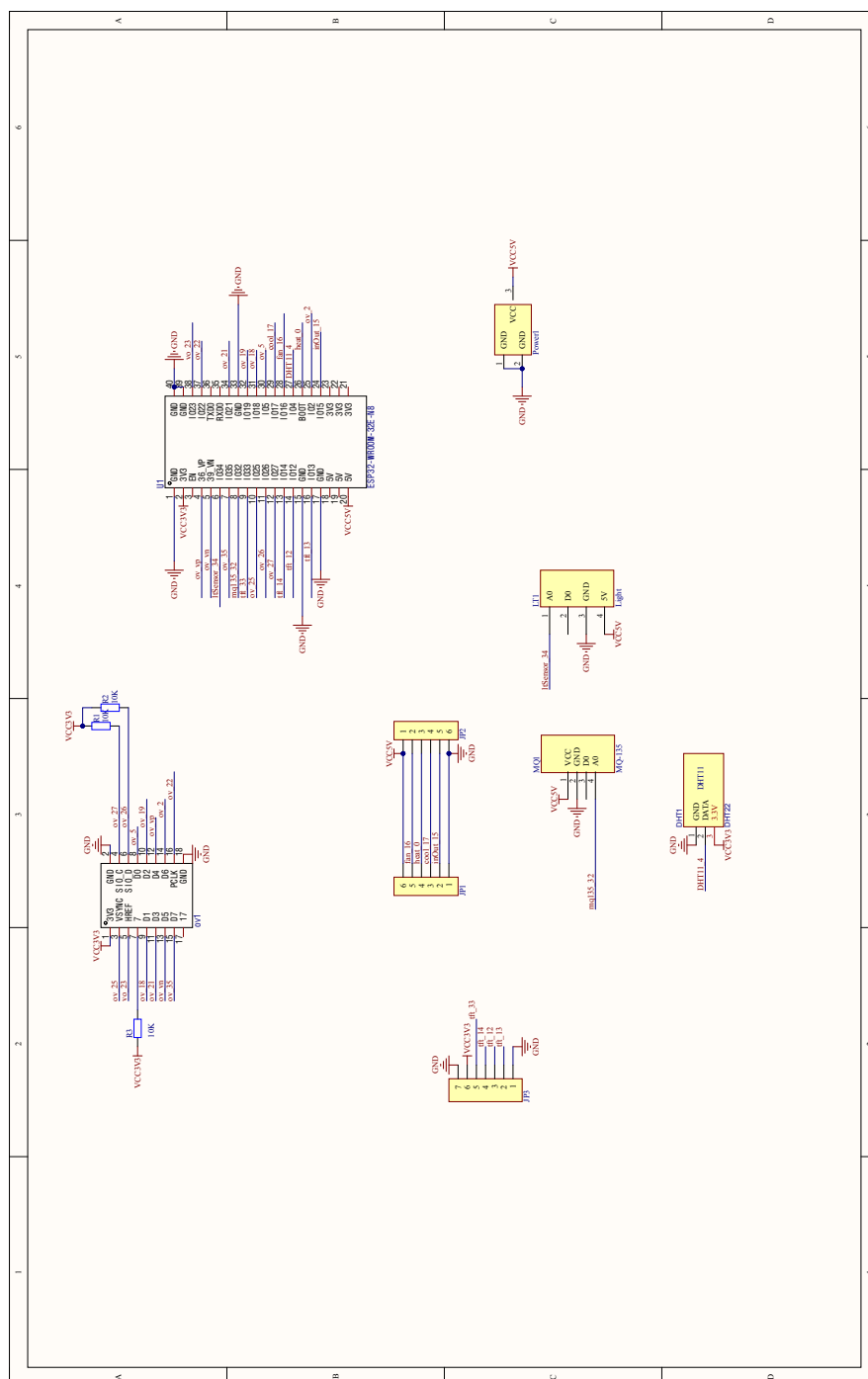
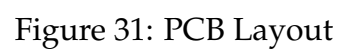


Figure 30: PCB circuit schematic



Appendix B R&V tables

Requirement	Verification	Verification status (Y or N)
Maintain a good range of the temperature inside the growing space for the plants to grow better.	We can turn on the temperature control system to cool the system. And the temperature should be controlled well.	Y
Report the temperature condition to the cloud server and mobile app. The user can know it in time and do adjustment.	The real-time data of temperature will be fed to the mobile app through the capacitive temperature and humidity sensors DHT11 built into the systems and the cloud system, and the user can adjust it through the app. Detect the system frequently at different times during the twenty-four hours.	Y

Requirement	Verification	Verification status (Y or N)
Report the data of the current air condition to the mobile app and cloud server. The user could monitor the condition and adjust it manually	The real-time data of air quality will be fed to the mobile app through the gas sensors placed in the growth space. The user can monitor the current air condition and adjust the air condition by turning on/off fans.	Y

Requirement	Verification	Verification status (Y or N)
The cloud server system must receive from and transfer data to the phone and esp32. We need several network ports set for the phone app and esp32.	We would plan and distribute the server ports for the phone app and ESP32. We should connect these three parts for the test and see if the phone app can receive the information from ESP32. ESP32 should follow the switcher's status on the phone (change the status of the switchers on the ESP32 in further developments)	Y
The data processing part should be done relatively quickly to ensure our system can work properly	We need to optimize the code as much as possible to speed up the processing. All data should be synced in 5 seconds and phone control operations must not have significant delays, like several minutes.	Y

Requirement	Verification	Verification status (Y or N)
Maintain a good range of the humidity for the plant growth	We can turn on the humidity control system to adjust the humidity.	Y
	The real-time data of humidity will be fed to the mobile app through the capacitive temperature and humidity sensors DHT11 built into the system and the cloud system, and the user can adjust it. Detect the system frequently at different times during the twenty-four hours.	Y

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