Multi-Functional Shoe Cabinet

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1 Introduction

1.1 objective

Traditional household shoe cabinets are limited in terms of functioning: they only act for the placement and storage of shoes. Being closed and unventilated in most cases, such cabinet is a breeding ground for bacteria since it is usually also the dark and damp environment. We understand cabinets like those fail to meet the basic needs for foot health care.

Therefore, we develop our objective of building a multi-functional shoe cabinet, which consists of the control module, temperature and humidity detection module, combination key module, the dynamic display module, alarm module, and sterilization module.
The control module takes STC15 microcontroller as the core unit to realize the control of temperature and humidity sensor, liquid crystal display LCD, dryer and Ozonator. It monitors the temperature and humidity of the cabinet in real time, starts the dryer when the humidity exceeds the limit, and sterilizes the cabinet regularly. A Wifi module is designed for remote controls of the cabinet.

1.2 background

A study which investigated germs collected on footwear, by Dr. Charles Gerba[1], microbiologist and professor at the University of Arizona, and The Rockport® Company, found large numbers of bacteria both on the bottom and inside of shoes; averaging 421,000 units of bacteria on the outside of the shoe and 2,887 on the inside. Some of the bacteria found on the shoes included: Escherichia coli, known to cause intestinal and urinary tract infections, meningitis and diarrheal disease; Klebsiella pneumoniae, a common source for wound and bloodstream infections as well as pneumonia; and Serratia ficaria, a rare cause of infections in the respiratory tract and wounds.

By the time of writing, shoe cabinet with these multi-function has not been found yet. We think there may be a chance to develop a more functional cabinet for the customers. [2]In 2017, there were about 126.22 million households in the United States. According to the U.S. Census Bureau, a household consists of all the people who occupy a housing unit. If only 10 percent of them update cabinet, there is a huge potential market.

1.3 High-level requirement

- Cabinet must display and adjust humidity and temperature accord to 4 key combinations.
- Alarm module must work if the cabinet is open within 30 mins after ozone generated.
- A remote display must be completed through WIFI.

2. Design

The multi-functional shoe cabinet system consists of a control module, temperature, and humidity detection module, connect button module, dynamic display module, alarm module, in-home HVAC module, WIFI module, and sterilization module. A power supply will also include ensuring the system could continuously work for all day with 5V.

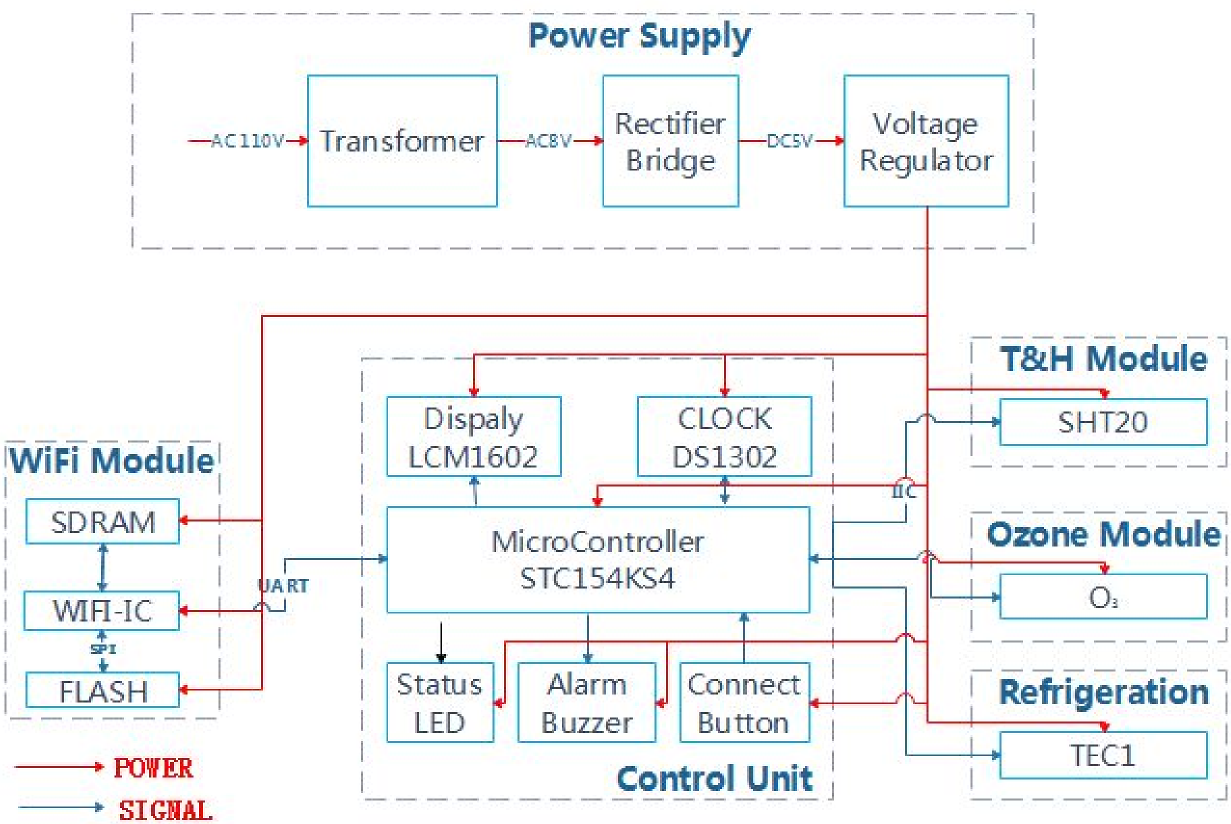

Figure 1. Block Diagram

The physical design, shown in Figure 2, will include a shoe cabinet (40cm*30cm*18cm) with water tank, the condenser inside.

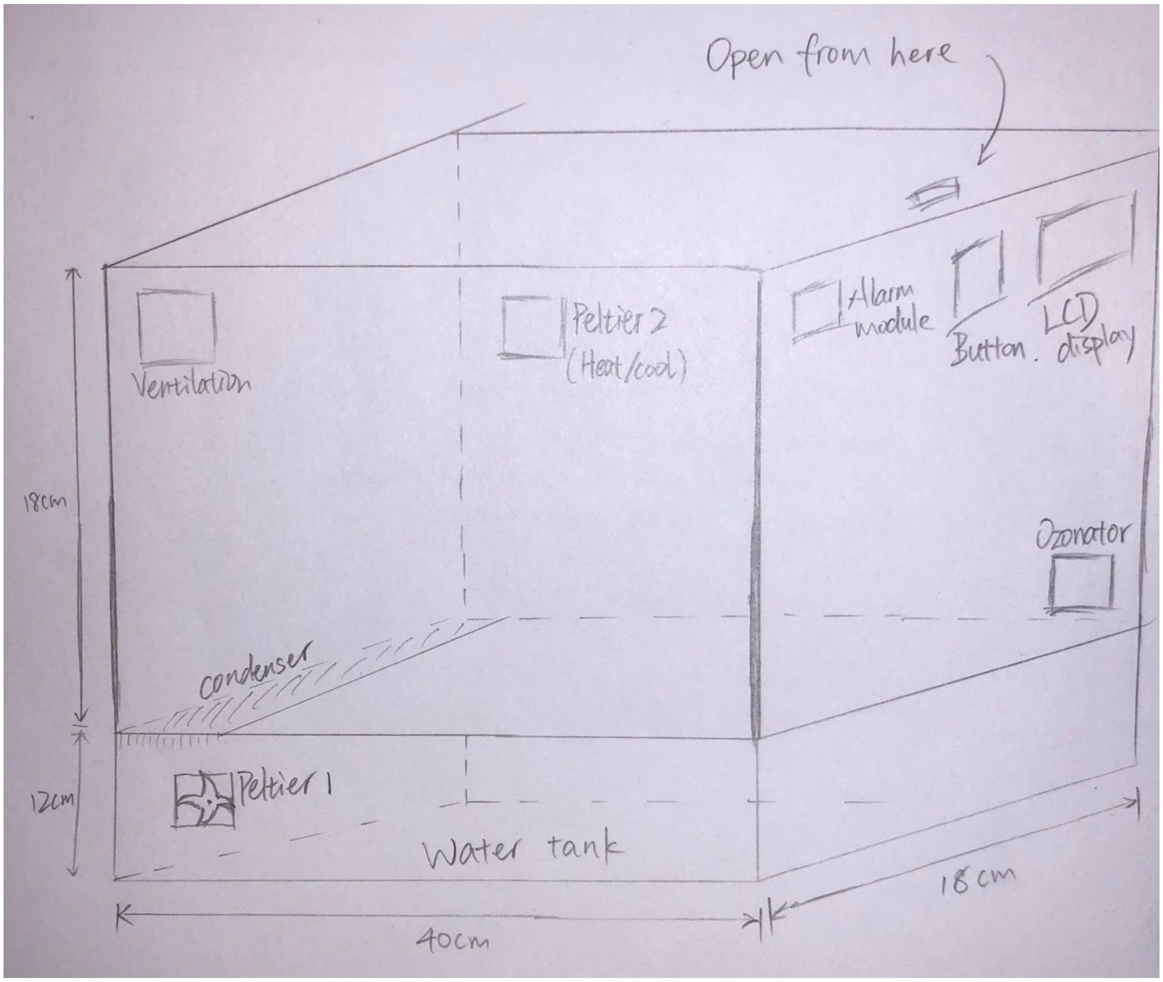

Figure 2. Physical design sketch

2.1 Power Supply

The power supply part we used should convert 110V AC to around 5V DC continuously, which will fulfill the requirement of voltage for all parts in the design.

2.1.1 Voltage Transformer

Our voltage transformer will be used to transfer voltage from 110V AC to around 8V AC.

Requirement	Verification
Voltage should transform from 110V to around 8V+/- 5%	Use an oscilloscope to measure the output voltage, ensuring that the output voltage stays within 5% of 8V

2.1.2 Rectifier Bridge

By using rectifier bridge to filter the voltage change from AC to DC.

Requirement	Verification
Voltage should change from AC to DC	Use an oscilloscope to test outflow current, and make sure is DC

2.1.3 Voltage Regulator

As there exist ripples in DC supply, we need to use LM7805 as three terminal regulators to smoothing the supply voltage to around 5V DC. Also, another voltage regulator should be used to smoothing the voltage from 5V to 3.3V for using WIFI module and SHT20 module.

Requirement	Verification
Should output around 5V +/- 5% DC voltage from 6~8V source	Use an oscilloscope to measure the output voltage, by connecting pin3 & pin2 (figure 4) , to ensure that the output voltage stays within 5% of 5V
Should output 3.3V +/- 5% DC voltage from 6~8V source	Use an oscilloscope to measure the output voltage, by connecting pin2 & pin1 (figure 4), to ensure that the output voltage stays within 5% of 3.3V

2.2 Control Unit

Control unit manages the signal send from temperature/humidity sensors, control the in-home HVAC, the alarm, the Sterilizing device and prepares data that is later sent to the WIFI module.

2.2.1 Microcontroller

STC15W4K56S4 is a microcontroller belonging to the series of STC15W4K56S4. It is a system based on 8-bit MCU processing chip STC15. The single clock/machine cycle (1T) single-chip microcomputer that is compatible with 8051 core, has a new pipeline / reduced instruction set structure and an internal integrated MAX810 special reset circuit.

Requirement	Verification

Working voltage should be 5V +/- 5%	Use an oscilloscope to measure the output voltage, connect pin 40 and GND (figure 3) to ensure that the output voltage stays within 5% of 5V

2.3 Dynamic Display Module

An LCM1602 dynamic display module located on the shoe cabinet serves to display the current temperature/humidity in the shoe cabinet, the threshold and trigger value of our in-home HVAC system. It will also display the date and time on the screen.

Requirement	Verification
Display temperature/humidity, date and time	Combinate it with a microcontroller to test the rightfulness of display
LCD display should work under 5V +/- 5%	According to figure 12, test the voltage of LCD by connect oscilloscope with pin1 & pin2, check the working voltage is within the desired voltage range

2.4 Clock Chip

A clock chip DS1302 will be also contained in the design and is able to collect time and date.

Requirement	Verification
Clock chip should collect currently time and date	If it works properly, LCD will display correct time and date, and use the voltmeter to test both ends of the voltage transformer, make sure voltage matched with desire value
Clock chip should work under around 5V +/- 5%	Connect oscilloscope to pin8 & pin4 (figure 10)to measure the voltage of clock chip, make sure the working voltage is in desired voltage range

2.5 Connect Button Module

The connect button module will have two parts; one part is used to select options, the other is used to set up the system.

2.5.1 Shoe Type Button

Four buttons on the outside of the cabinet, each represents one kind of shoes. The system should be managed by pressing buttons or mobile phone application. For different kinds of shoes, the system will provide a temperature range and humidity range, in order to provide the best environment for the shoes.

Requirement	Verification
The button should be pressed easily	Press the button with little force to check if it works
Button needs to be debounced and allows only one input per press	Connect pin to the button and measure the voltage, should be active -low signal when pressed or released.

2.5.2 System Setting Button

For the second part of the button, four buttons located outside the shoe cabinet could be used to adjust temperature range and humidity range for the system. This could make the system to achieve the specific request from the user.

Requirement	Verification
The button should be pressed easily	Press the button with little force to check if it works
Button to be debounced and allows only one input per press	Connect pin to the button and measure the voltage, should be active -low signal when pressed or released.

2.6 Temperature and Humidity Detection Module

As for the sensors, our group plans to use SHT20 humidity/temperature sensors to detect the humidity and the temperature, and to send all the information to the microcontroller.

Requirement: The sensor should keep the precision within decimal digit.

Requirement	Verification
Humidity and temperature must be display on the screen with the correct value with +/-3% RH and +/-0.3 ℃	By apply different humidity and temperature to test the correctness of sensors.
SHT20 sensor should work under 3.3V +/- 5%	Use an oscilloscope to measure the output voltage, by connecting pin5 & pin4 (figure 5),

	to ensure that the output voltage stays within 5% of 3.3V

2.7 Function output module

Considering the health protection and maintenance benefits to the foot, the functional output module consists of two sub-functional modules: in-home HVAC module and sterilization module. Each executable sub-module can be single, multi-use and full use according to the user's needs.

2.7.1 In-home HVAC Module

Heating, ventilation, and air conditioning (HVAC) is the technology of indoor and vehicular environmental comfort.

2.7.1.1 Heating/Cooling

In our design, we plan to use two Peltier coolers, put them on both of the cabinets, and provide them with different DC current flow direction by using H-bridge circuit, so they will act as heater and cooler individually. By the temperature and humidity sensors provide on-time information to the microcontroller, it could be used to change the temperature into the set range and could also be changed by system setting button locate outside of the shoe cabinet.

Requirement	Verification
Only one Peltier cooler (far to the condenser) work during heating/cooling process	Use an oscilloscope to test outflow current, and make sure the other Peltier cooler is power off
Peltier cooler (far to the condenser) should be provided by H-bridge circuit and should first act as “heater” during the dehumidification process, then change mode if needed after 5 minutes	Count for 5 minutes and make sure H-bridge circuit will only work after 5 minutes

2.7.1.2 Dehumidification

By inserting a condenser between two Peltier coolers and next to "cool" side, after providing voltage, the vapor in the cabinet will start liquidation on the condenser next to "cool" side, and water will flow out into the water tank thus to dehumidify the cabinet while at the same time the other side Peltier cooler will act as a heater in order to temperature complementation. This function is controlled by the microcontroller and work with the humidity sensor to keep the best environment for shoes. It could also allow the user to adjust the humidity in the cabinet by setting buttons.

Requirement	Verification
Two Peltier coolers should work under the same power during the dehumidification process	The temperature detected during the dehumidification process should maintain ±4℃, check by LCD screen
Humidity should decrease to under 30RH within 10 minutes of the dehumidification process	Humidity sensor should return humidity lower than 30RH after dehumidification process after 10 minutes.
Water tank should locate under the cabinet and could collect water from the condenser	Check water tank contains water after the dehumidification process completed

2.7.1.3 Ventilation

A ventilator will be used to accomplish the ventilation function and will work every 10 mins following the signal from the clock.

Requirement	Verification
should be 2 inches * 2 inches, small enough to fit inside the cabinet	Locate the ventilator on the left up corner of the cabinet, should smaller enough and work every 10 minutes after 30 minutes of dehumidification process

2.7.2 Sterilization module

Ozonator is used as sterilizing module, it is a device that can be used to generate ozone which is widely used to kill the bacteria, and Ozonators are widely used in drinking water, industrial oxidation, sewage, pharmaceutical synthesis, food processing and preservation, and space sterilization. The sterilization module will work only one time during the first 30 mins[6] and should close when the alarm system started.

Requirement	Verification
Ozone Concentration must be designed carefully to due to safety reason.	The maximum ppm for a human to stay close to ozone is 0.1, our ozone generator can generate 350mg /h. By control the time of generation time we can guarantee that dosage

	of ozone won't do harm to users.
Ozonator should work under 5V +/- 5%	Use an oscilloscope to measure the output voltage, by connecting pin1 & GND (figure 9), to ensure that the output voltage stays within 5% of 5V

2.8 WIFI module

Wifi module will be used to connect the shoe cabinet to the phone APP, it's function include real-time information of the cabinet environment, adjust button for temperature/humidity and also include alarm module to warn the user.

2.8.1 WIFI microchip

We chose ESP8266 32-bit microchip for our UART-WiFi module. ESP8266 supports standard IEEE 802.11 b/g/n specification. It has a relatively low price and has standby power of as low as 1.0mW.

ESP8266 supports Smart Config function for Android and iOS products, which we will use for mobile control.

Since ESP8266 has a working voltage of 3.3V, we will implement a voltage divider to circuit of the chip.

Requirement	Verification
The Wifi microchip must be capable of sending signals following IEEE 802.11b/g/n specification	Use Arduino IDE AT command to Detect and Connect to Wifi Network. If Wifi microchip is IEEE 802.11b/g/n- compatible, it will be successfully connected.
Wifi module ESP8226 holds a service voltage from 3V~3.6V, here we use 3.3V and should make sure within range of 3.3V +/- 5%	Use an oscilloscope to measure the output voltage, by connecting pin8 & GND (figure 6), to ensure that the output voltage stays within 5% of 3.3V

2.9 Alarm Module

An alarm module will be included in the design as O3 is harmful to the human body during the first 30 minutes as it is expelled to the air, after which it fully decomposes. We will build a alarm system in order to protect shoe cabinet and user.

2.9.1 Status LED

A status LED will be displayed to signal if sterilization completes, and will, in collaboration with alarm buzzer, turn red to warn the user that O3 has not decomposed fully.

Requirement	Verification
Should be yellow during the first 30 minutes after Ozonator works	Yellow LED is lit up after Ozonator and will remain 30 minutes
Should turn red when the cabinet is opened during first 30 minutes after Ozonator works	LED color changes from yellow to red when the cabinet is opened during first 30 minutes after Ozonator works

2.9.2 Alarm Buzzer

An alarm buzzer will also be used and connected in series to the status LED, and will work with Status LED to function as the sound-light alarm system.

Requirement	Verification
The volume of the buzzer should be maintained at 70 decibels for awareness	Use decibel meter to measure the alarm buzzer to be above 70 decibel.
Should buzzing when cabinet is opened during first 30 minutes after Ozonator works	Alarm buzzer will work when cabinet first 30 minutes after Ozonator works, at the same time LED turns from yellow to red.
Alarm Buzzer should work under 5V +/- 5%	Use an oscilloscope to measure the output voltage, by connecting pin1 & GND (figure 7), to ensure that the output voltage stays within 5% of 5V

2.9.3 APP alarm

When cabinet lid is opened before sterilization completes, an alarm signal will also be sent through ESP8266 wifi module to the registered mobile device. A notification is prompted to user's phone screen.

Requirement	Verification
The volume of the alarm should be maintained at 70 for awareness	Use decibel meter to measure the alarm buzzer to be above 70 decibels.

Should warning when the cabinet is opened during first 30 minutes after Ozonator works	App alarm, alarm buzzer will work when cabinet first 30 minutes after Ozonator works, at the same time LED turns from yellow to red.

2.10 Risk Analysis

In order to make Peltier coolers to work properly, the time difference between providing different direction of current should be longer than five minutes. We need to provide a clock signal to the heating/cooling system as well as dehumidification part.

For the sterilization module, as O3 is harmful to the human body and it will be decomposed in the air after 30 minutes, for safety proposes, we will install the Ozone generator instead of building one, and will make certain it works under control by the microcomputer, clock and alarm system all the time.

Alarm module, including status LED, alarm buzzer and APP alarm, should work all the time in order to protect the user of the cabinet.

Ventilation module should only work after dehumidification process done after 30 minutes, this is because during first 30 minutes the concentration of O3 will harmful to human body, and after first 30 minutes ventilation module will work in a safe time period, bot help O3 to decompose and air exchange.

Heating/Cooling module should keep distance to the shoes inside the cabinet, make sure the temperature change will not affect on shoes.

2.11 Schematics

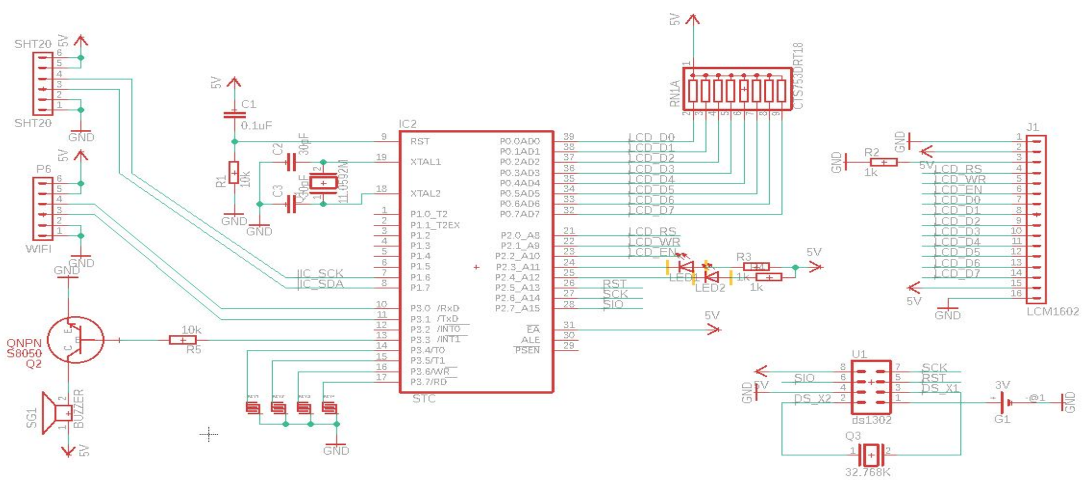

Figure 3. Control Unit Schematics

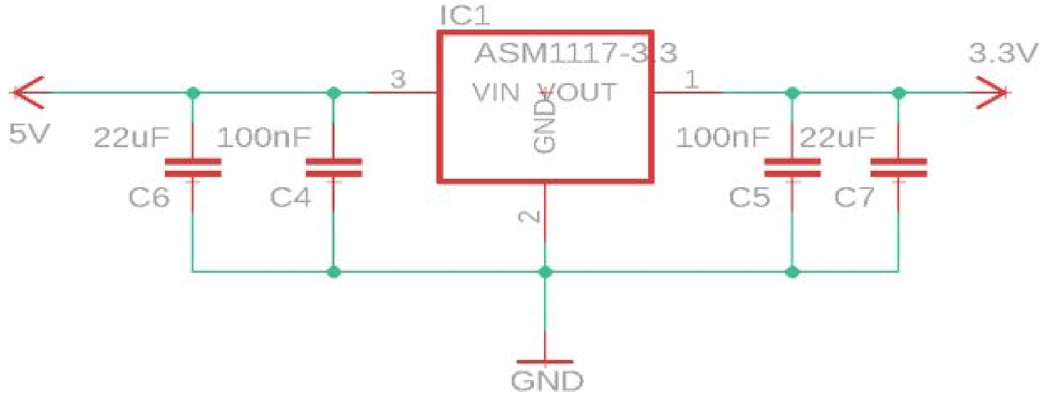

Figure 4. **Voltage Stabilization Module Schematics**

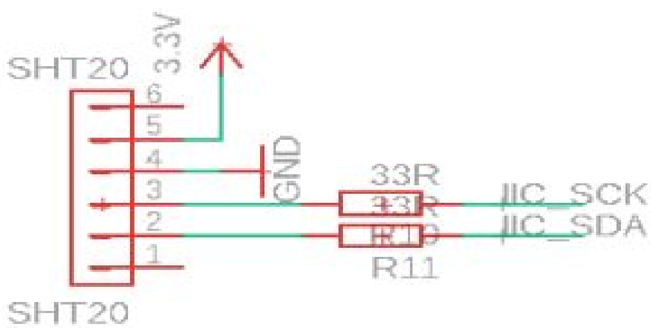

Figure 5. **SHT20 Module Schematics**

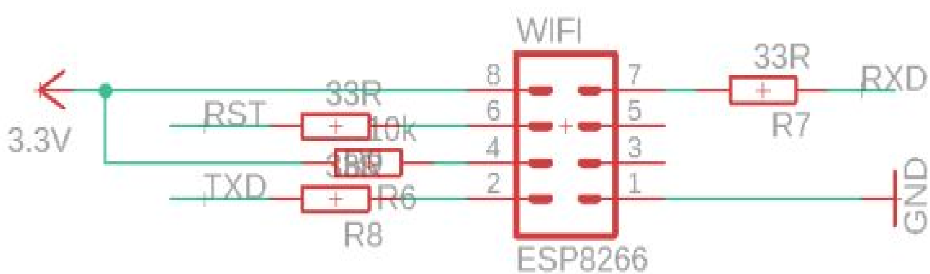

Figure 6. **WIFI Module Schematics**

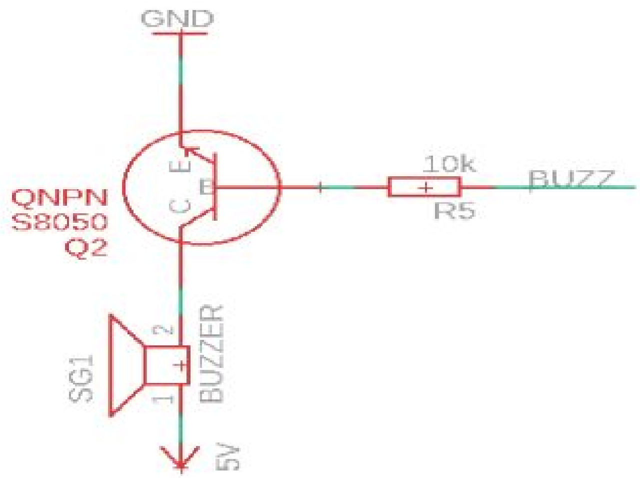

Figure 7. Alarm Buzzer Module Schematics

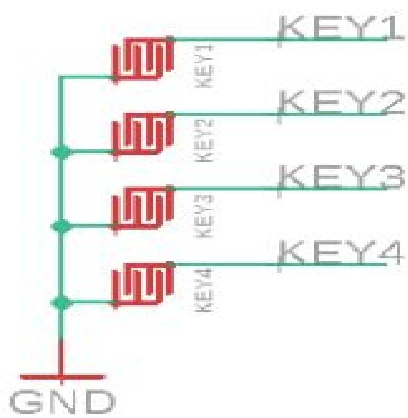

Figure 8. Connect Button Module Schematics

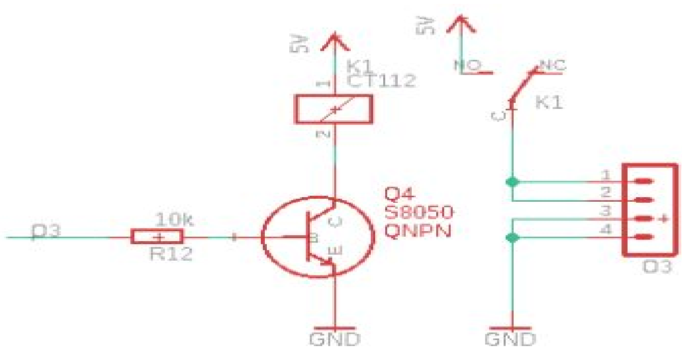

Figure 9. Sterilization Module Schematics

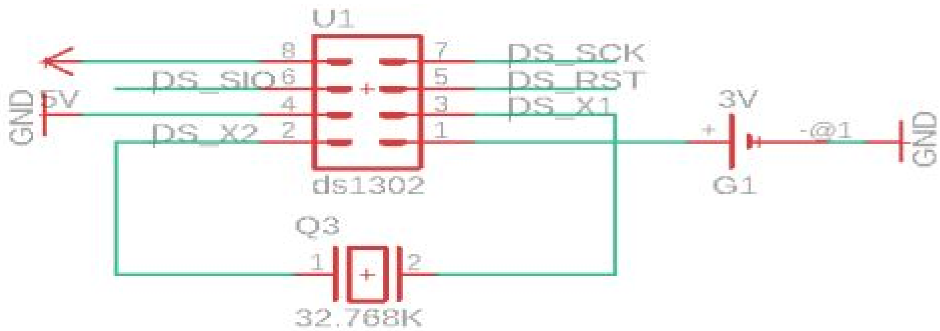

Figure 10. Clock Module Schematics

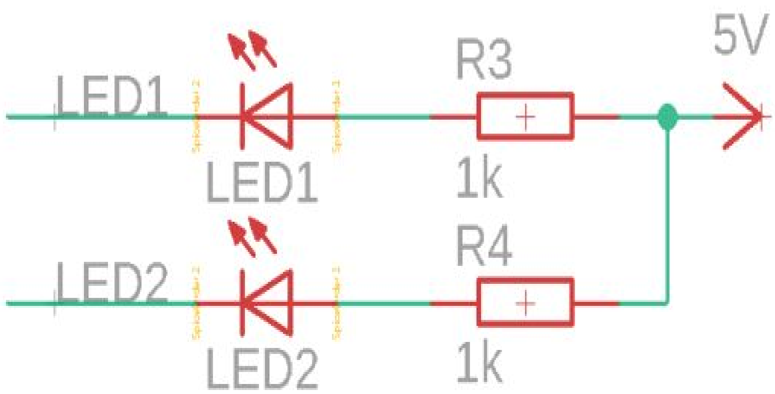

Figure 11. LED Module Schematics

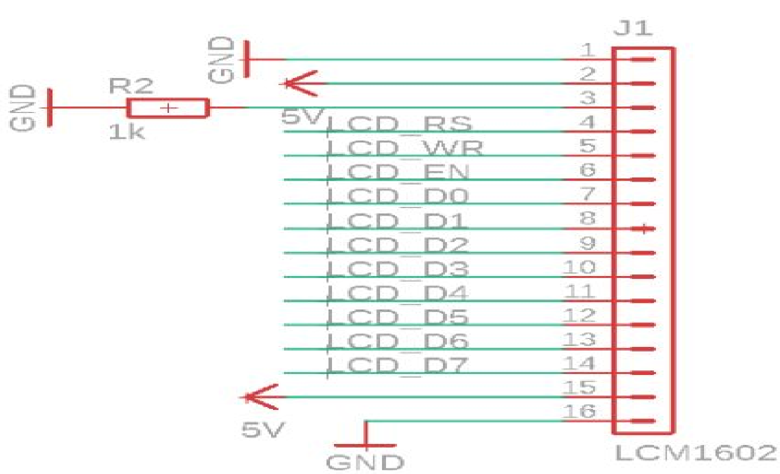

Figure 12. LCD Module Schematics

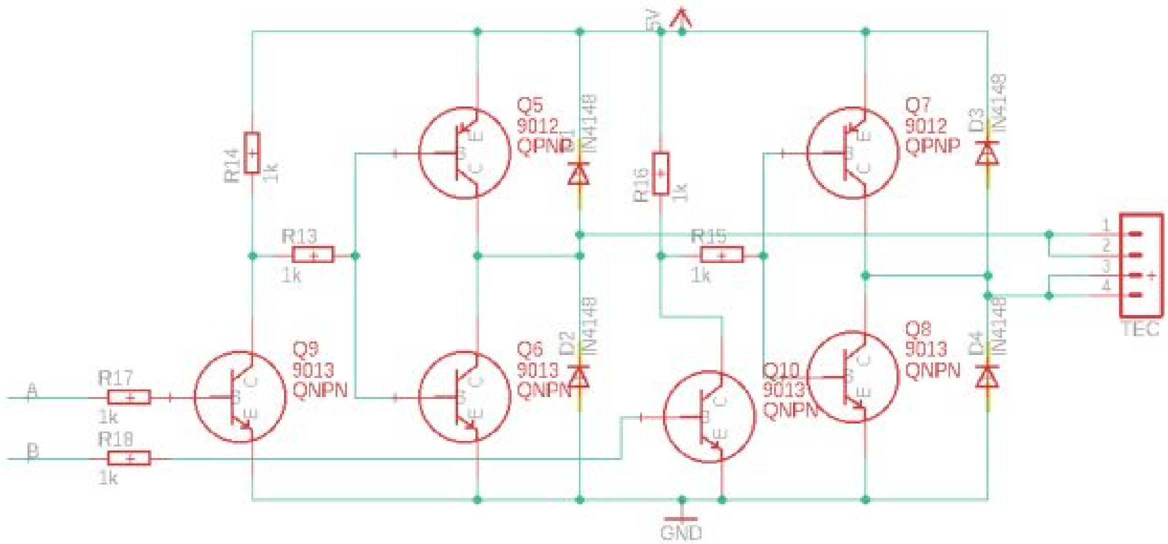

Figure 13. H-Bridge Circuit Schematics

2.12 Tolerance Analysis

One important tolerance we must contain is the readings of our sensor's value.To make sure our SHT20 sensor can work properly, we must analysis its tolerance. For SHT20, it has 6 pins,VDD,VSS,SDA,SCL, and 2 NC pins.VDD and VSS are supply voltage and ground voltage.

SCL is serial Clock , it's function is to synchronize the communication between our microcontroller.SDA pin is to transfer data in and out of sensor.SDA is valid on the rising edge of SCL and must remain stable while SCL is high. After the falling edge of SCL the SDA value may be changed.To avoid signal contention the MCU must only drive SDA and SCL low, which require a pull up resistor.

The max current goes into the sensor's pin is 100ma, and 20ma for MCU.Assume there is no pull up resistor inside MCU, we need at least R = V/I = 3.3 V/0.02A = 165 ohm.

Considering that we are converting AC to DC, the signal are not smoothing, so we may also need to add a 0.1 uf decoupling capacitor to smoothing the signal between VCC and VSS(we can also build a net capacitor at the power supply so that we do not need to do it at every module.)

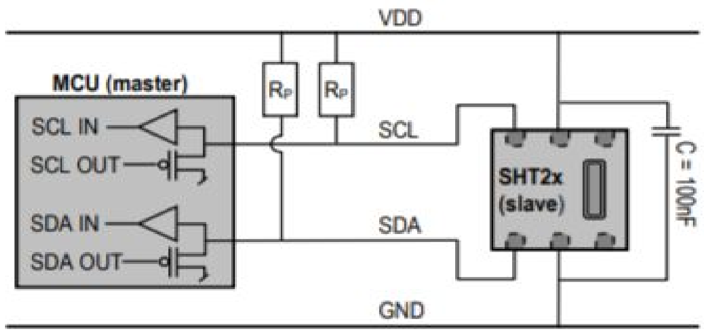

Figure 14. Typical application circuit

3. Cost and Schedule

3.1 Cost Analysis

Name	**Salary** ($/hour)	**Hours** (hrs/16 weeks)	**Total**	**Total** (2.5 multiplier)
Yupei Mao	35	200	7000	17500
Yuguang Chen	35	200	7000	17500
Haochuan Jiang	35	200	7000	17500
Total	105	600	21000	52500

Table 1. Labor costs

Description	**Manufacturer**	**Unit Cost($)**	**Quantity**	**Total Cost**
ASM1117 -3.3V	Advanced Monolithic Systems	0.79	2	1.58
SHT20-I2C Temperature & Humidity Sensor with waterproof probe	DFRobot	22.50	1	22.50
ESP8266 WiFi module	Speed Technology	6.95	1	6.95
Mini Push Button Switch	SparkFun(Retailer)	0.35	4	1.40
DS1302 Trickle-Charge Timekeeping Chip	Maxim Integrated	3.35	1	3.35
LED (Red, Yellow and Green)	YoungSun LED	0.35	3	1.05

Thermo-Electric Cooler Module	Peltier	34.95	2	69.90
LCM1602 LCD module	EONE	4.81	1	4.81
Total				190.12

Table 2. Hardware costs

Grand cost = Labor costs + Hardware costs = **$52690.12**

3.2 Schedule

Week	Task	Responsibility
9/17/2018	Complete Project Proposal	All
	Prepare **Eagle Assignment**	All
9/24/2018	Research Wifi module	Yupei
	Compare and choose hardware modules	Yuguang
	Prepare Mock Design Review	Haochuan
10/1/2018	**Mock Design Review & Finalize Design Document**	All
	Research on effects of temperature & humidity on leather	Yupei, Haochuan
	Purchase hardware	Yuguang
10/8/2018	Prepare Design Review	All
	Assemble airtight chamber and ozonator	Haochuan, Yuguang
10/15/2018	**Soldering Assignment**	All
	Learn microcontroller programming	Yupei
10/22/2018	Assemble temperature module & Test sensor accuracy	Haochuan
	Assemble humidity module & Design PCB	Yuguang
	Test Wifi module and microcontroller	Yupei
10/29/2018	Set up alarm module and timer	Haochuan
	Test PCB	Yuguang
11/5/2018	**Individual Progress Report**	All

	Design mobile device application	Yupei
11/12/2018	Test Wifi module - mobile device connection	Yupei
	Integrate cabinet prototype & Test individual module	Yuguang, Haochuan
11/19/2018	Test alarm and LED & Refine prototype	Haochuan
11/26/2018	**Mock Demonstration & Prepare for Final Paper**	All
12/3/2018	**Demonstration** and **Mock Presentation**	All
12/10/2018	**Final Paper** and **Lab Notebook**	All

Table 4. Schedule

4. Ethics and Safety

It is of paramount importance to address ethical and safety issues as we are obligated to devote ourselves to good conducts which positively affect our communities.

We acknowledge that some process of our project imposes potential safety challenges. For instance, ozone gas, used in the sterilization process here cause problems including shortness of breath and damage in the airways. [3] Therefore, even though it is impossible to design a completely airtight chamber since the cabinet needs to meet other requirements, we added special features to the cabinet so that the leakage of ozone gas, and thus damage to human health would be minimized. Additionally, people, while being completely safe if getting to close to the cabinet during the sterilization process, are still not suggested to do so for their safety concerns. It is calculated that the whole process of sterilization is 30 minutes, with 50mg of ozone gas produced. With our design of minimizing ozone leakage, we assume that there will be 5mg gas leakage during the working process, being not harmful to human health. We also suggest that people come around and open the door of the cabinet 30 minutes later than the sterilization process ends.
As indicated by the ACM Code of Ethics and Professional Conduct 1.2: “Avoid harm”[4], after all, ensuring physical safety is top one consideration we will always have in mind.

Temperature regulator can burn shoes and circuits, leading to irrevocable consequences. After detecting a drop in temperature, the controller can order an amplified power to the heater. To prevent this, we will set upper and lower temperature thresholds to be 28.5°C and 18.5°C respectively. Also, the heater device will be isolated from the rest of the circuit to meet higher safety standard.

We are accountable for stating correct data of relevant variables in our project, such as temperature and humidity. In rare cases, unexpected feedback from temperature sensor may be monitored. Regardless, we will be truthful in disclosing it, as honesty is more valued than desirable results. This is in accordance to the IEEE Code of Ethics, #3: “To be honest and realistic in stating claims or estimates based on available data”[6].

While it feels satisfying to be recognized for contributing thoughts and hard work towards our project, we should invariably remain humble to accept constructive feedback and to admit and rectify errors. Proper compliments should be awarded towards insightful contributions, as we adhere to #7 of the IEEE Code of Ethics: “to seek, accept, and offer honest criticism of technical work…”[6]. For instance, when one group member finds out that one dehydrant poses better control over moisture, he should not hesitate to ask for testing and renewal, even though it means replacement of other members’ work.

It is inevitable to find out there exist the enormous amount of gendered products on the market. Some are optionally made for men or one race only, while others are labeled with higher prices against women[7]. This kind of merchandise goes against gender and racial equality and places women and minorities at an inferior level. As the IEEE Code of Ethics indicates: “to treat fairly all persons and to not engage in acts of discrimination…” we promote equality by fully designing shoe cabinets. In addition to loafers, options of heel shoes and sandals will be added with more adjustments. Dryer module will be turned on for longer period if moisture sensor detects more sweat residues on these shoes.

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