Remote Controlled Smart Socket

ECE 445 Design Document
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10/01/17

1 Introduction

1.1 Objective

Nowadays, with the development of science and technology, electricity becomes such an essential part that we cannot live without it and thus there are many accompanied problems being induced. For example, many people get annoyed at work when they realize they forget to turn off the household appliances. It is not only money-consuming and wasting energy but also dangerous if the appliance is overheated by long time power-on. Only from January 2017 to September 2017, there are 32 civilian home fire fatalities reported by U.S. news media, which are caused by electrical malfunction or appliances [1]. Moreover, in many laboratories or hospitals electric security is a really important part. Many equipment is precision and has very strict requirements for the power supply system. Uncautious using electricity may cause a lot of problems such as damage of equipment, fire and hurt people. On January 22, 2017, an electrical worker died in Lubbock Hospital when he tested the new equipment because of the overflow current [2]. If we can monitor the power supply of the socket and alert the user in advance, we can avoid these accidents.

Our goal is to build a smart socket, which can protect the equipment by checking the power supply automatically or remote controlling by people. It can be analyzed by the core microcontroller in power and other parameters and send these data to the computer. Depending on the value of the parameters, the computer would send the signal back if something goes wrong and shut down the power to protect the socket and devices. In addition, user can manually send back the signal by computer if they want to turn off an appliance when they are absence.

1.2 Background

Internet of Things develops based on the computer and Internet, which utilize sensor, RFID and other technologies to realize the communication between physical objects. Nowadays, people's lives are already around by electronic devices and with more focus on the daily life's quality and detail, Internet of Things gets more and more attention. Based on this technology, we put almost everything in our pocket and construct a smart world [3]. Among it, smart home is a very important field and there are already series of products which can control the power supply system. But most of those products' functionality is simplex and does not fit industrial demands. Also, the smart socket will become more popular and necessary in the future. "Coming era of smart grids has implications for domestic DC distribution concepts with smarts sockets" [4].

Our goal is to fit for both household and industry use. Therefore, our socket must overcome the problems and implement multiple functions including control system, monitoring system and protection system. Also, taking account of universal practicability, the socket needs to be portable and not too expensive.

1.3 High-level Requirements

- The data of voltage and current can be send to the microcontroller once per second.
- At least two abnormal data have to be detected before send a warning message. At least five abnormal data have to be detected before automatically shut down the device.
- Switch of the socket can be controlled by computer, in order to turn on and off remotely.

2 Design

The whole system needs five sections: power transformation, data collection, control system, WIFI module and the software feedback system.
In United States, the wall power is 110v. In our design, we want a small, stable DC voltage, so we design a power transfer module to transfer the 110v AC to 5v DC or smaller. For data collection, we focus on measuring the voltage and current and send the data to the microcontroller and then the microcontroller will send the data through WIFI module to the computer. The control system contains one microcontroller to analyze the data and transfer them to the computer. For the WIFI module, we will use ESP8266 to connect the microcontroller to a standard WIFI network. For software part, we will use C language to modify the program based on Linux or Windows.

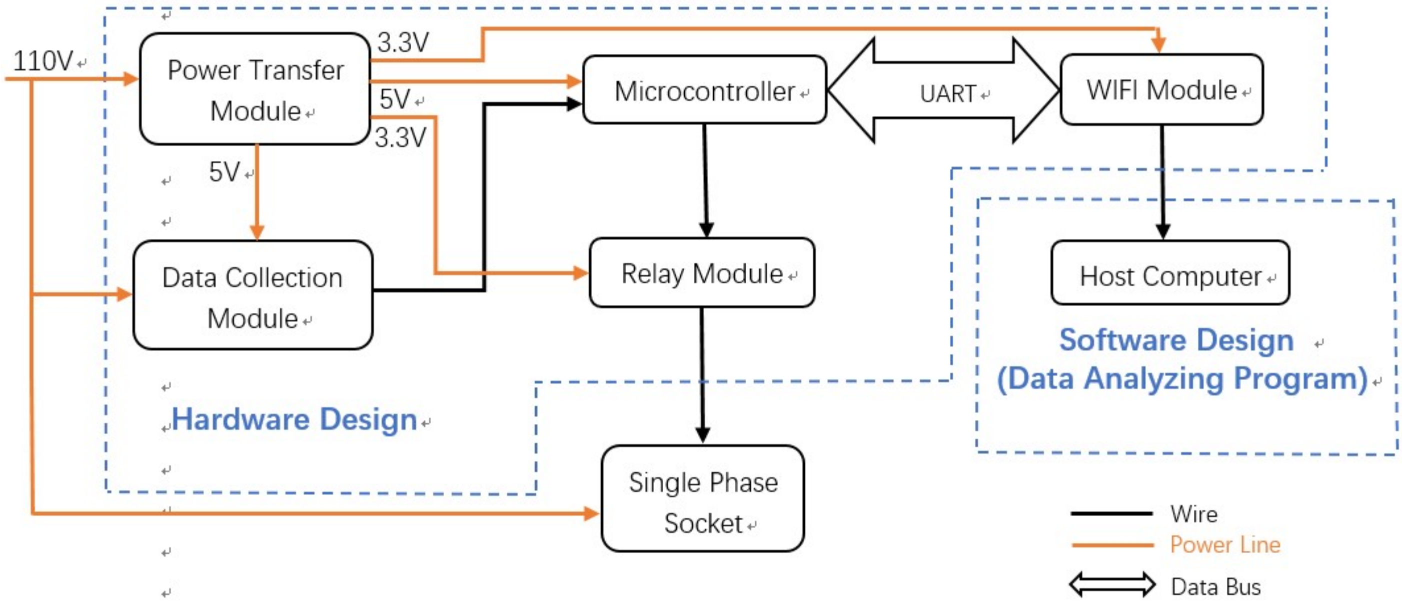


Figure 1 Block Diagram

2.1 Power Transfer

Our power will be used to power 5 modules. For microcontroller and data collection module, the power is 5V. For the relay and the WIFI module, the voltage should be 3.3V. We will use the wall power 110V AC and build a resistor circuit to transfer the wall power to DC voltage and use the transferred DC voltage to supply the modules and the chips. We will use a transformer chip and several resistors to achieve this task.

First, we use a potential transformer to transfer 110V AC to 9V AC which is small enough for the resistor circuit to get an output of 5V DC. To implement this task we use LM7805. LM78xx family can produce a stable DC voltage according to the last two number. For example, LM7815 will produce 15V DC. This family is one of the most commonly used in many TTL. For this project, we only need LM7805 which deliver 5V for the microcontroller and the data collection module.

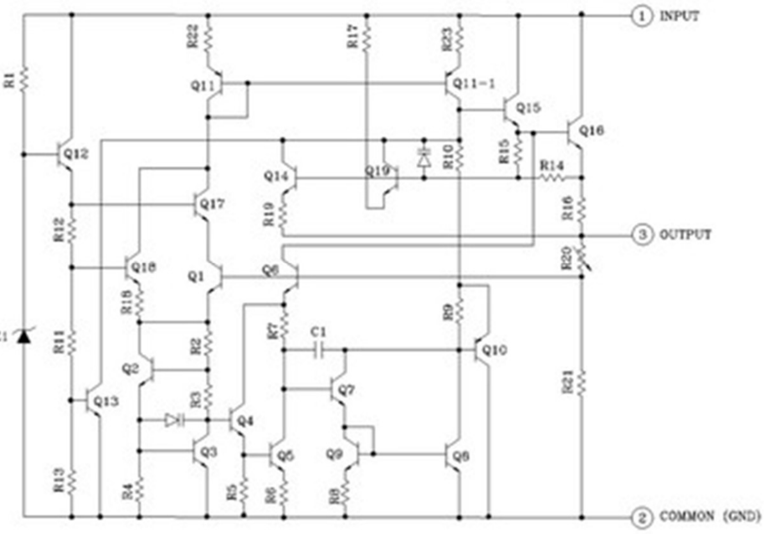


Figure 2 LM7805 Schematic

In order to get a 5V DC, first we add a bridge rectifier to rectificate the current and make the resistor to deliver a DC voltage, second, we will add a large value capacitor to wave filter the current and third we will add this voltage to the input of LM7805 pin and the output will be a stable 5V DC.

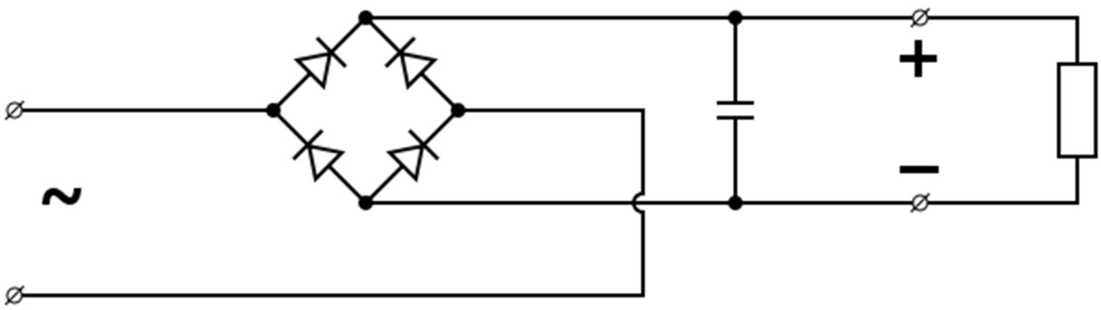


Figure 3 Bridge Rectifier Schematic

The capacitor we choose is 0.33uF which is large enough to filter the wave provided from the datasheet and the resistor we choose is 1Kohm which is also a large value to lower the current.

Vdc = 2*Vmax/Pi = 0.9Vrms

Vrms = Vp/sqrt(2) = 9V/1.414 = 6.36V DC and Vdc = 0.9 * 6.36 = 5.73V DC

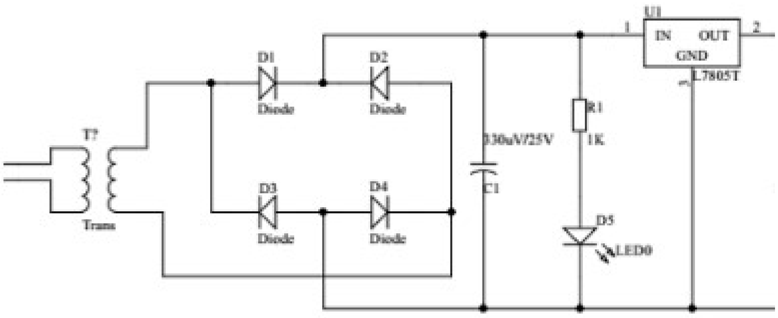


Figure 4 Power Transfer Basic Schematic

So the input on pin1 is 5.73V which is good for LM7805 to output a DC voltage close to 5V at pin2.
Moreover, we need another chip called AMS1117-3.3 to get a 3.3V DC from the 5V. AMS1117 is a common family for DC-DC transformation. We use AMS1117-3.3 to get a stable 3.3V DC to power up relay and wifi module.

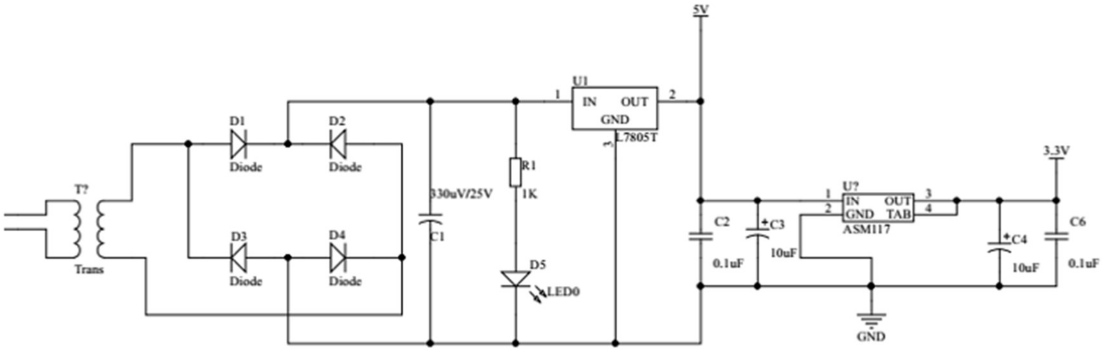


Figure 5 Power Transfer Module Schematic

Here is the final power circuit design for the power module. We get constant 5V and 3.3V DC to power up the rest four modules.

Requirement	Verification
Able to deliver 5V to the microcontroller and data collection module and 3.3 V to the relay and WIFI module. The error should be less than +/- 1 V.	1.Use multimeter to measure the output voltage for microcontroller and data collection module and ensure it is in the range of [4,6]V. 2.Use multimeter to measure the output voltage for relay and WIFI module and ensure it is in the range of [2.3,4.3]V.

2.2 Data Collection

Data collection module is to measure and calculate the circuit parameters and send the data to microcontroller to analyze. In order to realize it, we will use the CS5463 power metering chip. This chip can measure small DC voltage and current accurately enough for this project. This sensor can collect the data from the current connected device. Combined with voltage divider and current divider, CS5463 can sample voltage and current and calculate the power. We will weld this chip on the PCB. Moreover, the data collected by the sensor will be sent to the microcontroller. The safety voltage for this sensor is 5V DC. Besides, CS5463 has an internal temperature sensor so it can also measure the temperature for future use.

By CS5463 datasheet [5], we know that due to the input voltage limitation, the chip cannot connect to 110V circuit directly, so we need sample circuit first.

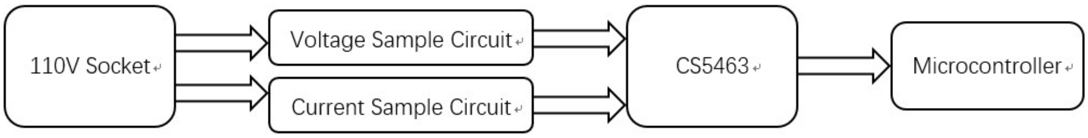


Figure 6 Data Collection Block Diagram

There are two common sampling methods. One is direct sampling and the other is mutual inductance sampling. Direct sampling utilizes voltage divider and shunt resistor to sample voltage and current respectively. Mutual inductance sampling utilizes voltage transformer and current transformer. But compare to direct sampling, it has large error, large size and poor linearity so we will use direct sampling.

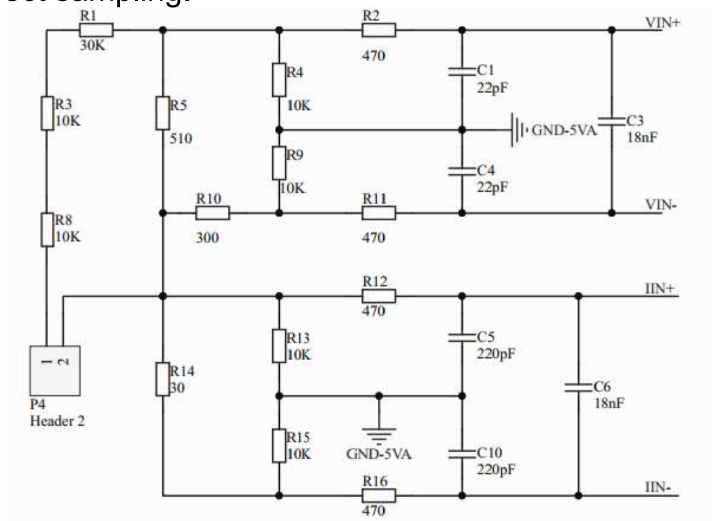


Figure 7 Sample Circuit Schematic

Voltage sample circuit is the top part of the schematic. R1, R3, R5 and R8 build the voltage divider circuit. R5 is the sampling resistor. R10 is to limit current. R4 and R9 are to control the differential voltage signal. R2, C1, R11 and C4 build a simple low pass filter. Then C3 filters the differential voltage signal again. The full-scale differential input voltage for the voltage channel is $\pm$250mV [5], so the maximum RMS voltage is $250□□ \div \sqrt{2} = 176.78□□$. In our circuit, the output voltage after voltage divider is $\frac{1□□}{300□□*3+1□□} * 110□ = 122\ □□$. So it is not beyond the voltage range. But we have a gain factor K, where K=$\frac{1□□}{300□□*3+1□□} = \frac{1}{901}$.

The bottom part of the schematic is current sampling circuit, which is similar to voltage part. We use a shunt resistor to get the sampling voltage and calculate the current.

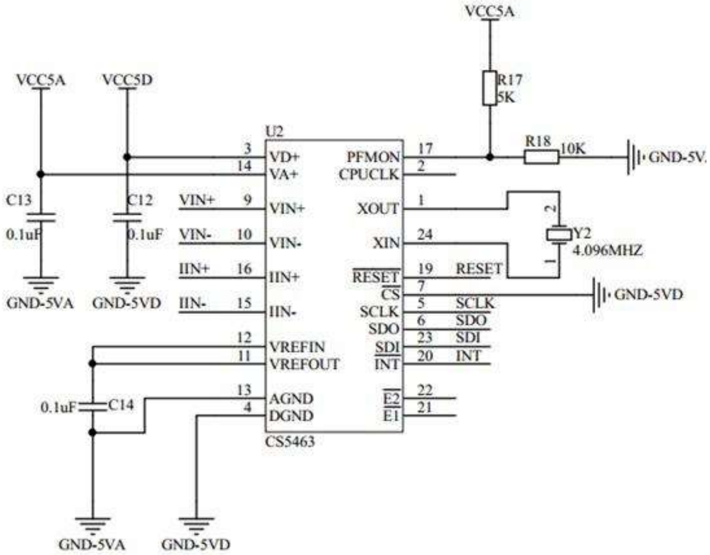
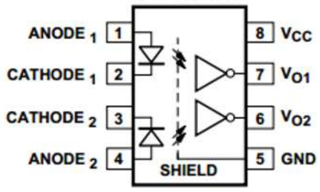


Figure 8 CS5463 Connection Diagram

VIN+/VIN- and IIN+/IIN- are connected to the output of the sampling circuit respectively. RESET, SCLK, SDI, SDO and INT are used to communicate with microcontroller.

CS5463's input signal is operated on the 110V voltage and this will result in that the common-mode level of the CS5463 is referenced to the line side of the power line [5]. It may lead to severe common mode interference, even destroy the devices. Thus, in order to ensure efficient communication between microcontroller and power metering IC, we are thinking about add an isolation circuit. We choose HCPL2631 to build the isolation circuit. It is LSTTL/TTL compatible and has very superior common-mode rejection so it can provide maximum ac and dc circuit isolation [6].



LED	OUTPUT
ON	L
OFF	H

Figure 9 HCPL2631 Functional Diagram and Truth Table

HCPL2631's operating voltage Vcc is 5V and the forward input current I_F range is 3mA to 10mA. We assume that the built-in potential of diode is 0.7V, so we can get the current-limiting resistor $R = \frac{VCC - VDD}{IF} \in [430,1433]\Omega$ and we choose 1KΩ. The pull-up resistor range is 330Ω to 4KΩ and we choose 350Ω. Besides, the Vcc supply to each optoisolator must be bypassed by a 0.1uF capacitor or larger [6].

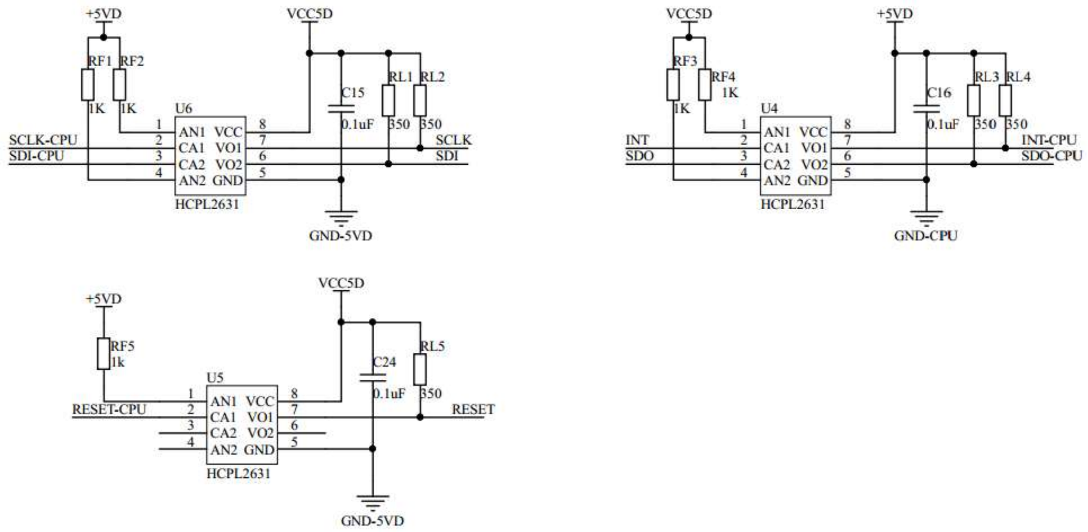


Figure 10 Isolation Circuit Schematic

Requirement	Verification
Able to collect the voltage and current values once per second and send the measured value to the microcontroller.	1. Adjust R and C in the sampling circuit and use multimeter to measure the sampling data to make sure it works. 2. Connect to the computer to ensure the data are sent already. 3. In one minute record 60 data on the computer .

2.3 Microcontroller

Microcontroller is the core of the socket. It manages the main logic function; sends signals to other modules and communicates with computer. The power transfer module, relay module, WIFI module and the data collection module are all connected to the microcontroller. It will received the data from the data collection module and analyze them and then send them to the computer through the wifi module. The microcontroller will qualify the data from the data collection sensor. All the modules are related by the microcontroller. We decide to use SPI or I2C to do the communication part for microcontroller. Both SPI or I2C will be tested in the circuit and the better performance way will be kept for the project. Our microcontroller will be powered by 5V from the power transformation module and send signal to both wifi module and relay module. The wifi module will adopt the UART as the tube to transfer the information and the data. If the voltage and current value seems to be abnormal, the microcontroller is able to receive the command from the users through the wifi module and control the relay to shut down the power.

We'll use STC12C5A60S2 chip, which has a high performance with an enhanced kernel. In addition, it has two extra I/O ports, a 10-sources, 4-priority-level interrupt structure, 10-bit ADC, two UARTs, on-chip crystal oscillator, a 2-channel PCA and PWM, SPI, a on-time enabled Watchdog Timer [7].

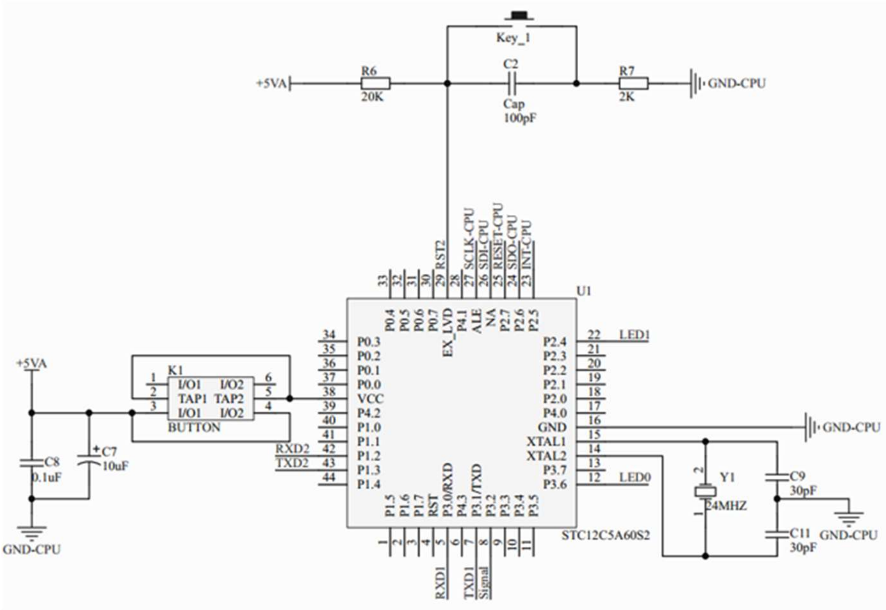


Figure 11 Microcontroller Schematic

Requirement	Verification
1.The work voltage is 5V. 2.Microcontroller can receive the data from the data collection module. 3.Microcontroller is able to analyze the collecting data and send them through WIFI module. 4.Microcontroller is able to control the relay module after receive the command from users.	1.Use multimeter to measure the work voltage and ensure it is 5V. 2.Connect the microcontroller to data collection module and computer and see the data on the computer. 3.Put the turn off button on the computer and then the relay is shut down.

2.4 Relay Module

Relay module is to control the socket power supply. The relay we choose is electromagnetic controlled. It can detect the abnormal behavior of the circuit and cut off automatically. It can also be controlled remotely by the users. The output current may not strong enough to control the Relay module directly, so we will build an amplifier to strength the output current. We will use an integrated circuit to connect between the relay and the microcontroller.
In our project, the relay is controlled by the microcontroller. Because the output current from the microcontroller is too small to open and close the relay, we need to add a bipolar junction transistor to enlarge the output current.

Requirement	Verification
1. When the current flow through the coil is larger than 50mA, relay turns on; When it’s smaller than 50mA, relay turns off. 2. The output current from the pin of microcontroller is strong enough to control the relay. 3. The voltage is no larger than 3.3V.	1.Connect the relay directly to a 100mA current source and the relay shut down. 2.Connect the relay directly to a 20mA current source and the relay keeps working. 3.Connect the relay to microcontroller and control it by computer. Then use multimeter measure the pin of microcontroller to ensure it is larger than 50mA. 4.Use multimeter to measure the operating voltage and ensure it is less than 3.3V.

2.5 Wifi Module

WIFI module is used to transfer the data from the microcontroller to the main program. We use ESP8266 which is a low energy cost UART-wifi connection module. There are three work modes for ESP8266, softAp, station and softAp-station. We use “softAp-station” which makes the ESP8266 to connect the wifi automatically. There are 8 pins on ESP8266:

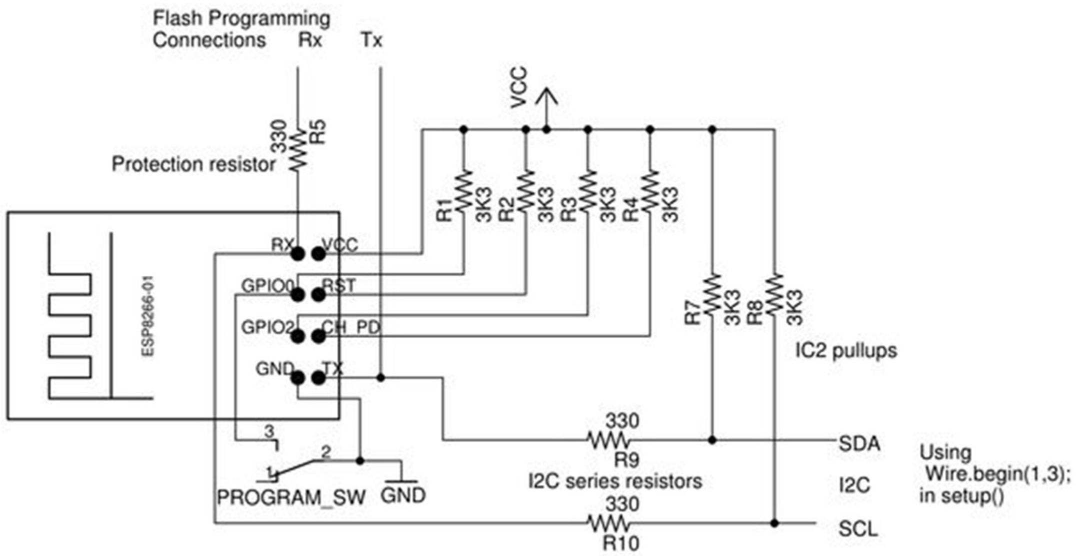


Figure 12 ESP8266 Schematic

The eight pins function is listed below:

Table ESP8266 Eight Pins

PIN	Function	Description
1	RX	UART_RX. receive data
2	GPIO0	a.)WIFI status: When WIFI is working, the LED b.)Working Mode Choose c.)Flash Boot, working mode d.)UART download, download mode
3	GPIO2	a.)High voltage work mode, hardware is not allowed pull down b.)Pull up inside
4	GND	GND
5	VCC	3.3V, power module
6	RST	Reset signal, low part reset, high part work mode
7	CH_PD	High voltage, work mode, low voltage, module shutdown
8	TX	a.)UART_TX, transfer signal b.)Forbidden pull down when start

ESP8266 and STC12C5A60S2 are communicated by UART, so we only need URXD, UTXD, GND, VCC and CH_PD to accomplish our project.

Figure 13 Four Important Pin of ESP8266

For ESP8266, the work progress is “Module reset” → WIFI connection → Signal transit and receive. In our project, we use AT orders for design the program. ESP8266 can be controlled by several AT orders.
AT+CWMODE = 3 which set the ESP8266 to be “SoftAp-Station”
AT-CWJAP= ssid, password makes it connects to the wifi
AT+CIPSTART = TCP, IP makes it connects to the main server
AT+CIPMODE = 1 starts the chip to be signal processing mode
AT+CIPSEND, the chip starts to send the signal.

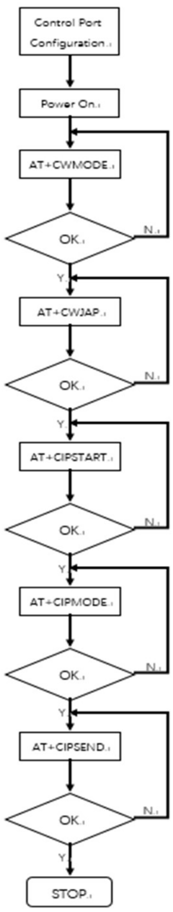


Figure 14 WIFI Module Flowchart

Requirement	Verification
It can send a stable signal between the computer and the microcontroller.	Connect the module to computer and see the data.

2.6 Software

The software is to mainly deal with the wireless communication task. When the program start, the computer can monitor the socket and if it detects there is client coming, it will open the connection thread and begin to receive data. When it is done, the program will start a new monitor cycle.

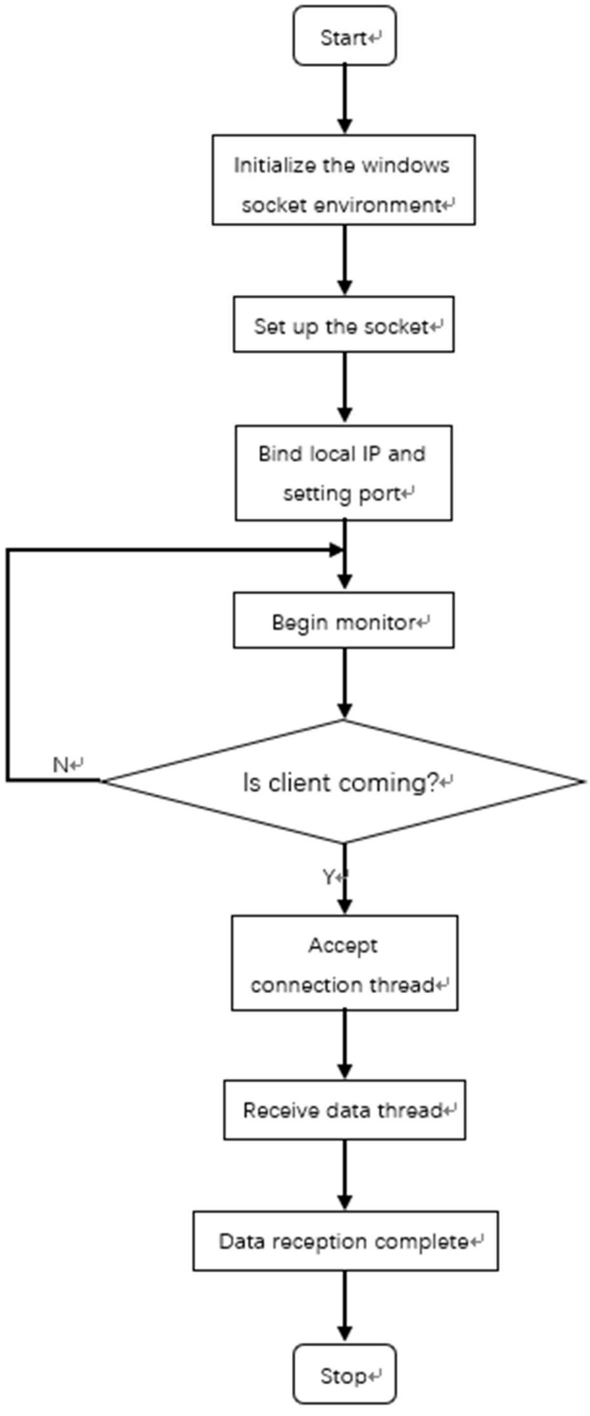
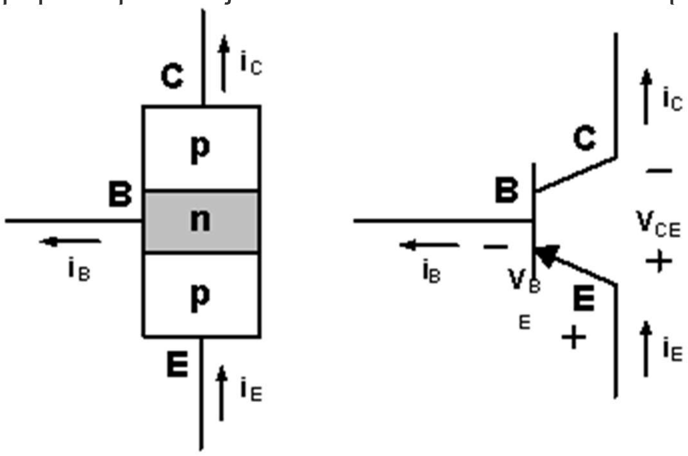


Figure 15 Communication and Data Transmission Flow Chart

2.7 Tolerance Analysis

One tolerance is that the output power from the power transfer circuit may not in the range to power on other modules or it may be too large to burn the chip. For our project, the voltage range for ESP8266 and microcontroller is 5+/-0.5V. As long as not destroy the whole system, we prefer the voltage to be little lower respectively. So by using LM7805 and large reference resister, the output voltage is supposed to be lower than 5V because of the resistance in the circuit. The output voltage is around 4.7V to 4.9V (measured by the voltmeter).

Another tolerance is the microcontroller and the relay connection. According to the datasheet of STC12C5A60S2, we found that the output current from microcontroller is too small to control the relay. Therefore, we need to add a pnp bipolar junction transmitter to help control the relay. The



IE= IC + IB, Vbc=Vbe-Vce

Figure 16 PNP Junction

output from the microcontroller is about 50mA which is big enough the turn on the BJT.

We should connect the C end to 5V from the power transfer module and E to the relay switch and B to the microcontroller pin. Therefore, since the current IB is big enough to turn on the BJT, the output current IE is also large enough to control the relay. The tolerance of IB in this part is 30mA to 50mA which is reasonable for the output current from microcontroller.

3.Cost and Schedule

3.1 Cost Analysis

Our fixed development costs are estimated to be $40/hour,10 hours/week for two people. The project will take approximately 16 weeks, so the total labor cost is 2*40*10*16=$12800.

The table below is our parts cost, which is $66.46. In total, our cost will be 66.46+12800=$12866.46.

Part	Cost (prototype)	Cost (bulk)
STC12C5A60S2	$14.35	$4.44
CS5463	$11.21	$2.95
HCPL2631	$11.98	$3.98
LM7805	$7.90	$1.50
AMS1117	$6.50	$1.36
Relay (SDC-03VDC-SL-C)	$2.77	$0.79
ESP8266	$1.75	$1.75
RCL	$10.00	$0.40
Total	$66.46	$17.17

3.2 Schedule

Week	Shiyuan	Yuqiao
10/9/17	Complete voltage and current measurement circuit	Complete power transfer circuit, pass the test.
10/16/17	Complete data collection module	Build the WIFI module, test the ESP8266
10/23/17	Program the microcontroller	Program the Microcontroller
10/30/17	PCB first version design	PCB first version design
11/06/17	Relay module design and construct	Software design, able to receive and analyze the data
11/13/17	Test the prototype and construct all the module together	Test the prototype and construct all the module together
11/20/17	PCB final design construct and test	PCB final design construct and test
11/27/17	Test the project	Test the project
12/04/17	Begin final report	Prepare final presentation

4.Safety and Ethics

4.1 Safety

Because our socket will deal with a high voltage of 110V, it is dangerous for us when we test our circuit. Especially for the power transfer module, the capacitors may not work or our circuit does not work very well as expect. At this time, some incautious acts could induce a serious outcome such as getting an electric shock. When we testing our project, we have to keep the circuit away from water, metal and anything which is conductive. Also, after every test, the connection should be turned off first before we modify our circuit. For the reason that our project is uncovered, the whole project could be dangerous as an electricity conductor, we need to wear an isolated glove every time and keep the other part of the body away from the circuit. Moreover, if the current is too large, the chips could be burned up. The best result is that the circuit is broken and we need to reconnect the whole system and the worst result is that something could be ignited. Therefore, we need to design the power transfer part first and make sure it is working before every test and connect it first before we add on more. Also, we need to make sure the fire extinguisher is in the laboratory and do not use water to extinguish the fire because it may be still powered on.

The finished product supposed to be covered by some isolated material so that the circuit is not exposed to the users. However, the customers should be careful about the environment. First, they need to make sure that no wire is out of the cover. Second, they need to keep the place clean, for example, there is no water around the socket. Third, they have to make sure that the wall power is no larger than 110V.

4.2 Ethics

Our socket is a remoted controlled electric device which connects the wifi in the room and has other control utilities. Violation usage includes stealing data, hack the devices, shut down the devices with illegal purposes and break the whole electrical circuit. Unfortunately, these possible actions are against #7 and #9 of the IEEE Code of Ethics[8]. So we want to reiterate our principle in a note while packaging, which is people are not allowed to use our product to undermine the privacy of others or use them for malignant business competition or other criminal act. We are responsible for making human's lives more safety and convenient. The main function of our socket is to control the power supply and protect both appliance and people from potential electrical fault. It stresses the importance of electronic security so it is an implementation of the IEEE Code of Ethics, #1:" to accept responsibility in making decisions consistent with the safety, health, and welfare of the public and to disclose promptly factors that might endanger the public or the environment" [8]. We want to build a safe electric environment.

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