Automatic Secure Locker

ECE 445 Design Document

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1 Introduction

1.1 Objective and Background

With the rapidly growing e-commerce industry and the increasingly mature logistics system, more people choose to shop online for their daily needs. However, although shopping online spares people the inconvenience of going to physical stores, the risk of package being stolen by random thieves also becomes rampant. Such a problem is more pervasive in apartments that are not equipped with package lockers or package receptionists. In this case, packages are usually left at the residents' front doors, which greatly increases the risk of package being stolen by people walking by.

In order to eliminate this kind of package thefts, we want to design an affordable automatic secure locker which can effectively help people securely store their packages and can be put right next to their front doors. This system is constituted by an electrically controlled locker, a control panel with an LCD display, a camera and a piezo buzzer, a control unit that wirelessly connects to the internet and coordinates the operation of every other modules, a server and a power supply. When there is no package stored inside, this secure locker normally remains unlocked until a courier puts a package inside and closes the door. During this process, the LCD display will give the courier instructions on how to use the locker. Once the door is closed by the courier, the locker will relock itself to prevent someone else from accessing the package inside. To retrieve the package in the locker, the owner can unlock the locker remotely from his/her cell phone or PC. Although the mechanical lock is secure enough in most cases to keep the package inside safe, in order to prevent anyone from violently damaging the locker to steal the package inside, the security module of the locker will be triggered if the locker is open when the locker is supposed to be locked. The camera will automatically take a picture of the intruder and send it to the user via the internet; the piezo buzzer will make a loud noise to scare the intruder away.

1.2 High-Level Requirements

- The locker must remain locked until the microcontroller receives an instruction from the owner to open the locker.
- If the hall effect sensor detects a door opening when the servo is supposed to be locked, the buzzer will sound and the camera will take a picture of the potential intruder and send it to the user over the local WiFi connection.
- The rechargeable Li ion batteries must provide power to the system for at least 13 hours without the need of solar energy.
- The microcontroller (WiFi module) must be able to wirelessly send data to the server and receive data from the server with a speed of at least 5 Mbps.

2 Design

The entire automatic secure locker is constituted by a server, a power supply, a locker module, a control panel, and a control unit. A block diagram showing the interconnection between different modules is provided below.

2.1 Block Diagram

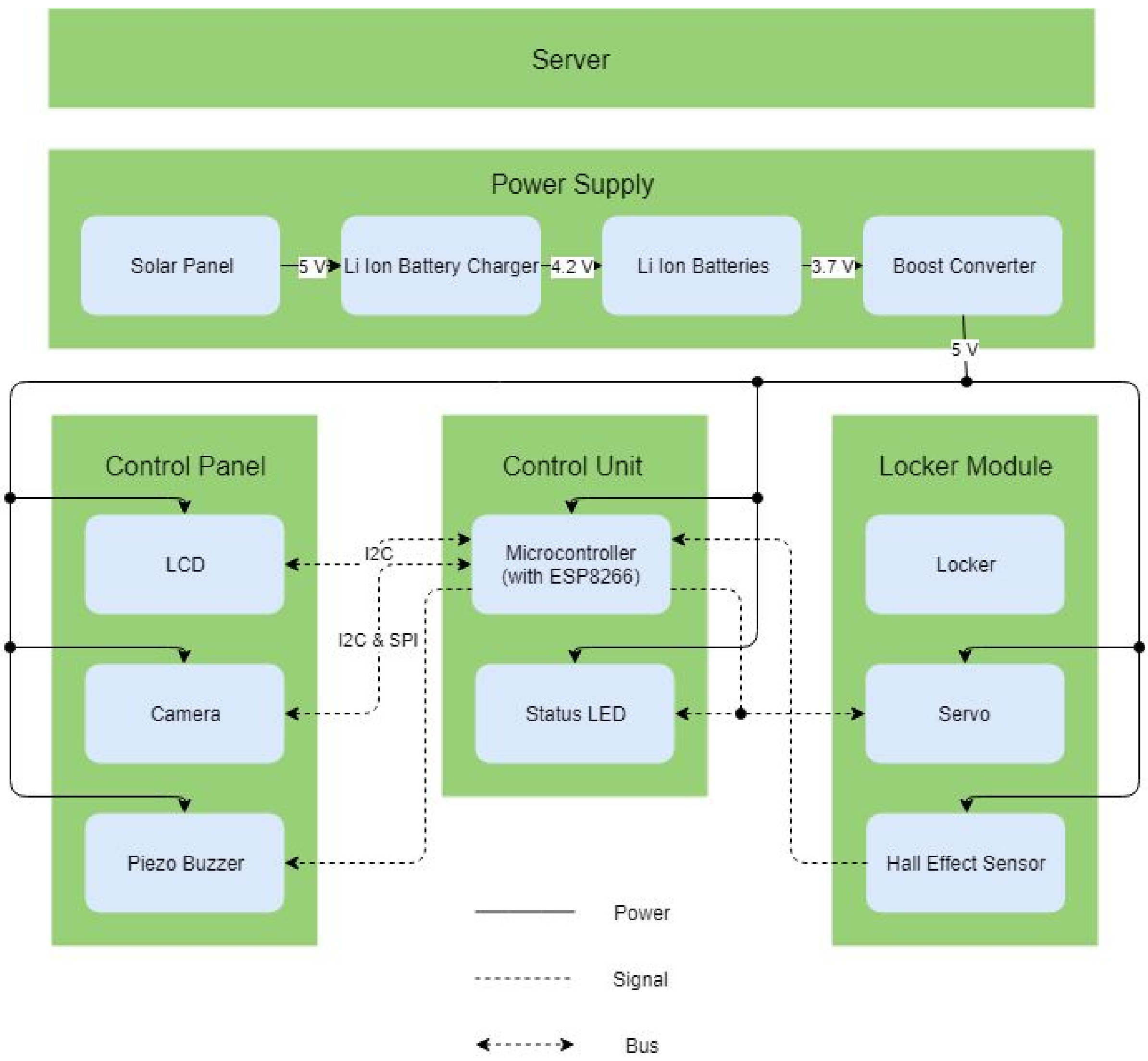

Fig. 1 Block Diagram of the Project

2.2 Physical Design

Fig. 2 shows the physical design of the automatic secure locker. The box on the locker is the control panel integrated with the security module. The left part of the control panel is a 130mm x 150mm solar panel that sustainably provides power to the system; the middle part of the control panel is a camera that captures the face of the user; the right part of the control panel is the LCD display and piezo buzzer. Most electronics of the project including the PCB will be placed inside this box. Underneath the box is the locker. The locking mechanism of the locker is implemented by a servo controlled by the microcontroller. When the locker is unlocked, the servo will be in its 0 degree position; while the locker is locked, the servo will be in its 90 degree position, latched with the hook on the locker door to prevent anyone from opening the door. The four circles on the edges of the locker and door are magnets that make sure the locker can be successfully locked after the door is closed. The one extra magnet that is placed near the hinge of the locker door is used to work with the hall effect sensor to detect whether the door is closed or not. This enables the locker to either lock itself after the door is shut by the user or trigger the alarm if an unexpected opening of the locker is detected. This physical design only serves as a prototype of our project design and certain modifications will be made during the process of assembling.

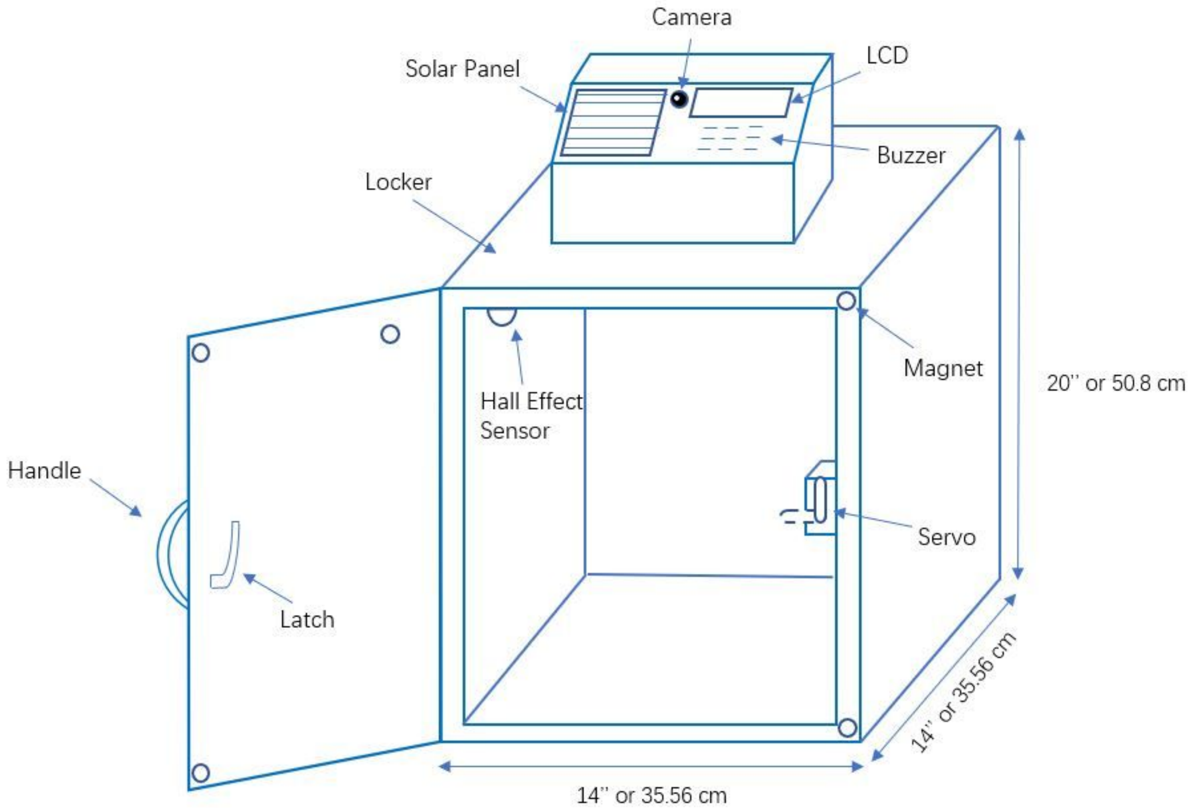

Fig. 2 Physical Design of the Locker

2.3 Power Supply

The power supply module consists of four parts: the solar panel, the Li ion battery charging circuit, the rechargeable Li ion batteries and the boost converter. The solar panel is used to convert sunlight to electric energy that can be used by the electronics in our design; the Li ion battery charger is used to regulate the unregulated voltage from the solar panel to the appropriate voltage level that the rechargeable Li ion battery needs; the Li ion batteries are used as a voltage supply that provide stable voltage to the locker; the boost converter is a switching voltage regulator that step up the 3.7 V from the Li ion battery to 5 V, which is the VCC of the microcontroller. Fig. 3 shows the connection of the four parts.

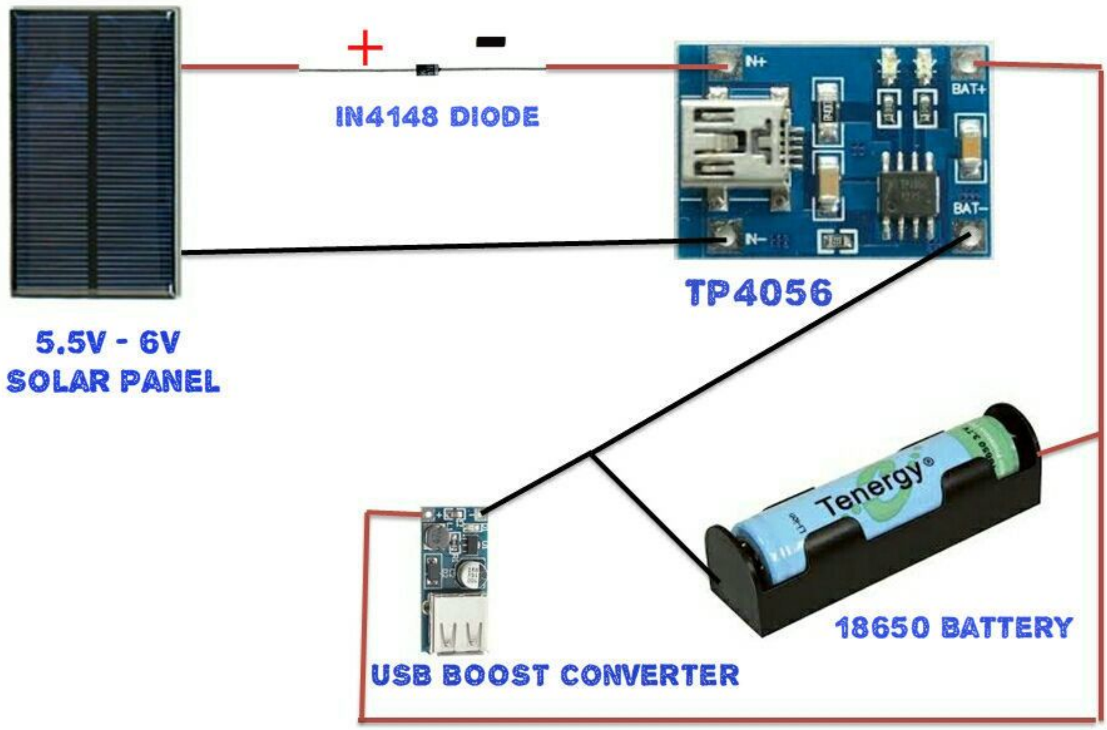

Fig. 3 Power Supply Module Connection [1]

2.3.1 Solar panel

A piece of 2.5 W 5 V/500 mAh solar panel is used to provide sustainable energy to the automatic secure locker. Considering the fact that our locker is designed to be placed outside the owner's apartment, using a power outlet to power the locker is not a reasonable option. Also, since we are using ESP8266 NodeMCU as the microcontroller of our design to do wireless communication, our locker design has a considerable power consumption which is not efficient for non-rechargeable batteries to handle. Therefore, adopting solar energy to be our energy source becomes the best solution for us. A 5 V solar panel is chosen due to the fact that the solar panel voltage should be 1.5x the battery voltage. Since we are using a 3.7 V Li ion battery, using a 5 V solar panel is the most recommended setting. In addition, the 5 V lies well within the battery charging circuit input voltage range (4.5 V - 5.5 V). Other than the voltage requirement, the maximum current rating of this solar panel is 500 mA, which is much higher than the current drawn by our locker (approximately 250 mA).

Requirement	Verification
1. The open circuit voltage of the solar panel when it is exposed under sunlight in a partly cloudy day should be at least 5 V. 2. The current drawn from the solar panel should be at least 250 mA when the voltage output under load of the solar panel is 5 V.	1. On a partly cloudy day, place the solar panel under sunlight, measure the voltage across the output terminals of the solar panel using a voltmeter to see if the voltage is higher than 5 V. 2. Terminate the solar panel with a resistive load such that the voltage across the load is 5 V. Measure the current through the resistive load with an ammeter to see if the current is higher than 250 mA.

2.3.2 Li ion battery charger

The Li ion battery charging circuit is essential to charge the Li ion battery because the battery requires a stable charging voltage of 4.2 V. Any voltage higher or lower can cause unwanted chemical reaction that leads to danger. Unfortunately, the output voltage of the solar panel is a variable value depending on the light intensity. Therefore, the charging circuit is needed to provide a steady 4.2 V to charge the battery. We plan to use MCP73831 chip as our battery charger and Fig. 4 shows the connection of the chip.

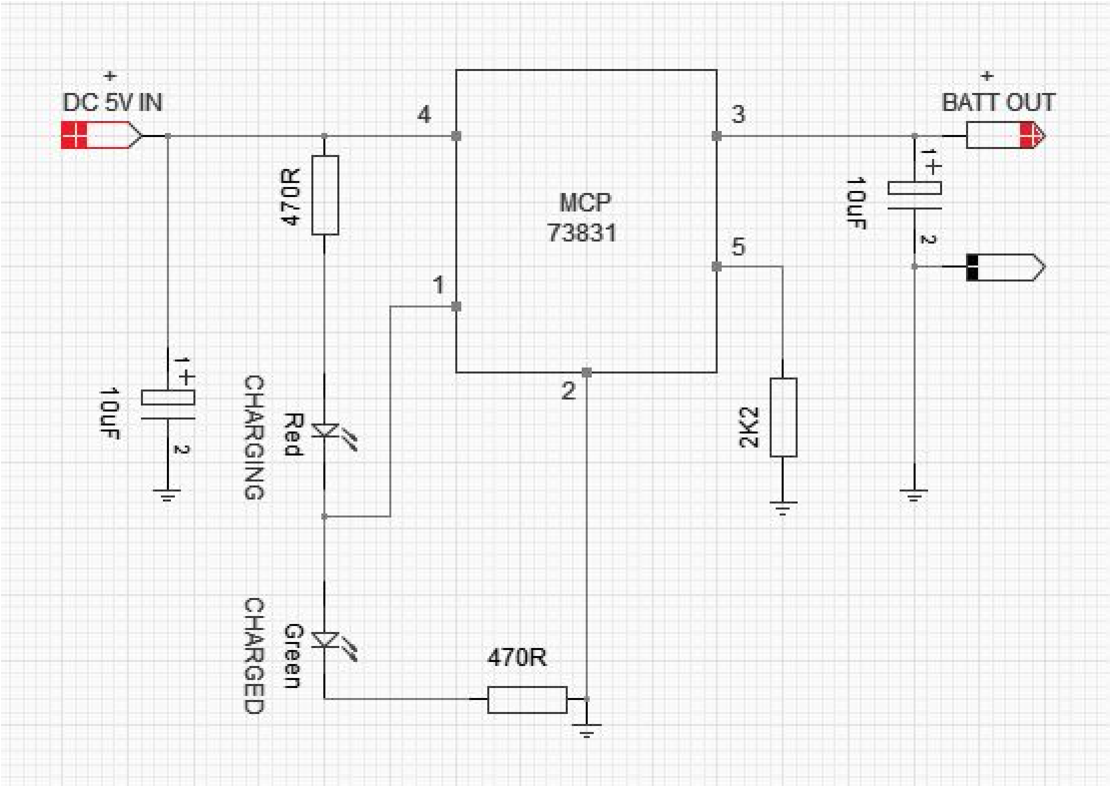

Fig. 4 MCP73831 Li Ion Battery Charger [2] [3]

Requirement	Verification
1. When the Li ion battery charger is connected to a not fully charged Li ion battery, the output voltage should be between 4.1 V and 4.3 V when an input voltage of 4.5 V - 5.5 V is applied.	1. Discharge a 3.7 V rechargeable Li ion battery to ⅔ of its capacity, connect it to the battery charging circuit. Apply a 5 V input voltage to the battery charger, use a voltmeter to measure if the output voltage of the charging circuit is between 4.1 V and 4.3 V.

2.3.3 3.7 V Li ion battery

The 3.7 V Li ion battery is the direct voltage source that powers the locker electronics. The battery capacity is chosen to be 3000 mAh to guarantee the electronics can be powered even when the solar panel is not charging the battery for 14 hours.

Requirement	Verification
1. The Li ion battery should has an output voltage between 3.6 V and 3.8 V when it is not depleted.	1. Measure the voltage across a fully charged Li ion battery using a voltmeter to see if the voltage is around 3.7 V. 2. Discharge the battery at a rate of 150 mA for 14 hours, then measure the voltage across it again, check if the voltage is still around 3.7 V.

2.3.2 Boost converter

The boost converter circuit is used to step up the 3.7 V from the battery to 5 V to satisfy the power supply voltage requirement of the electronics we use. The switching regulator is chosen to maximize the power efficiency (typically > 90%). The following schematic shows the boost converter circuit. The npn MOSFET will be used as a switch to control the duty cycle of the converter. The gate of the MOSFET will be connected to a PWM generator to turn the switch on and off. Since the input voltage of the boost converter is a constant 3.7 V from the lithium ion battery, only open-loop control will be used to control the output voltage.

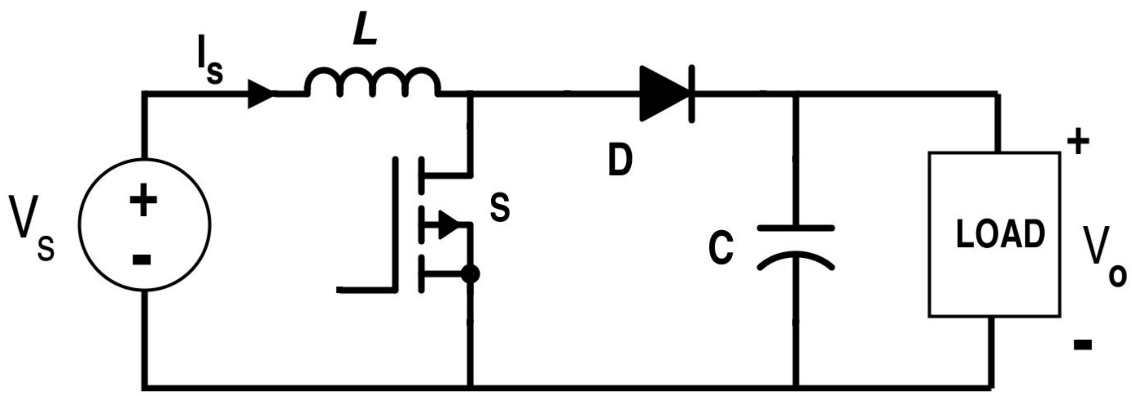

Fig. 5 Boost Converter

Requirement	Verification
1. The boost converter must output a steady 5 V voltage when it is connected to a 3.7 V Li ion battery.	1. Connect a 3.7 V Li ion battery to the input of the boost converter, measure the output voltage of the converter to see if the voltage is between 4.95 V and 5.05 V.

2.4 Control Unit

The control unit is the core of the entire design because it includes the microcontroller that controls the operation of all electronics used in our project. It is also responsible of sending data to and receiving data from the server via the WiFi chip. The ESP8266 NodeMCU will be used to take care of both the control and the WiFi communication. The status LED is used as an indicator to show whether the NodeMCU is sending or receiving data via WiFi.

2.4.1 Microcontroller

The microcontroller controls and coordinates the operation of every other electronic part in the project such that the locker operates as we expected. What is more, it sends information to the server and receives information back from the server over the local WiFi network to enable remote control of the locker. The microcontroller is constituted by an ATmega328p and an ESP8266 ESP-01 WiFi chip. The ATmega328p microcontroller is responsible of communicating with hardwares and sensors and the ESP8266 module is responsible of wireless communication over WiFi. Both ATmega328p and ESP8266 will be programmed with C++ under Arduino IDE. Fig. 6 shows the pinout of ESP8266 ESP-01 WiFi module. The RX and TX pins of ESP8266 will be connected to two digital pins on ATmega328p; the Vcc and RESET pins will be connected to the output of the 3.3 V voltage regulator and the GND pin will be connected to the ground. The two GPIO pins will not be used because we will mainly use the digital pins on ATmega328p chip.

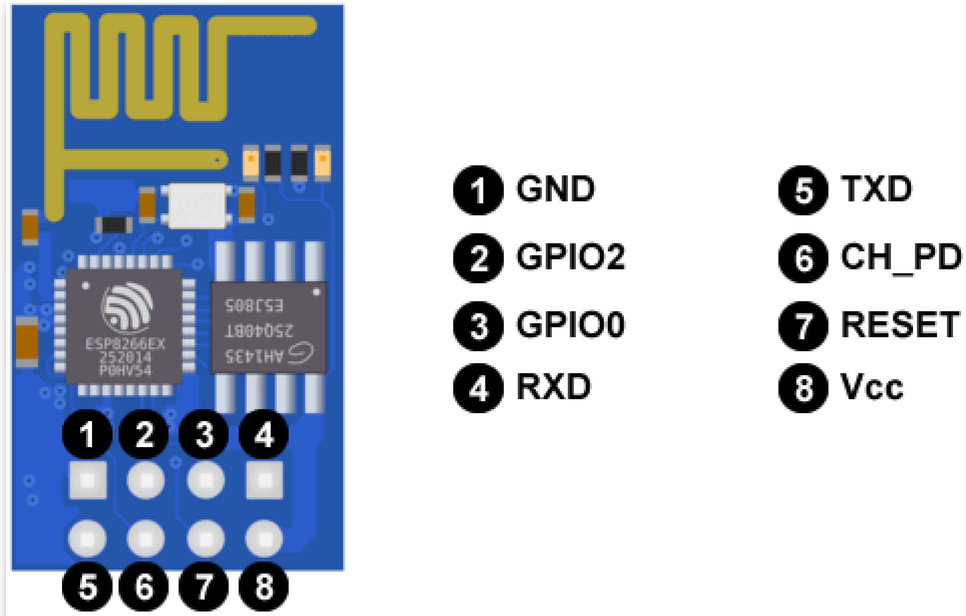

Fig. 6 ESP8266 Pinout [4]

As mentioned earlier, the ATmega328p needs to set up I2C and SPI interfaces to communicate with LCD and camera. The LCD and camera are going to share the I2C bus with different addresses. In addition, the piezoelectric buzzer is connected to one of digital I/Os of ATmega328p to generate certain alarm tone; the hall effect sensor output is connected to one of digital I/Os of ATmega328p to tell the controller whether the locker is closed; the servo is connected to one of digital I/Os of ATmega328p to either lock or unlock the locker.

Requirement	Verification
1. The ATmega328p must transmit and receive data over I2C and SPI buses to control the operation of a certain I2C or SPI device . 2. The ESP8266 must transmit and receive data via local WiFi network.	1. Connect the OV2640 camera to the ATmega328p chip and upload code to the microcontroller over USB connection. If the an SPI interface can be setup between the microcontroller and the camera can be detected by the microcontroller, the I2C and SPI buses should work properly. 2. Connect the ESP8266 module to the local network. Connect an LED to one of the GPIOs of the ESP8266 module, control the output state of the GPIO from a web browser to see if the LED can be turned on and turned off via TCP remotely.

2.4.2 Status LED

The status LED is an indicator light that shows whether the ESP8266 is currently transmitting/receiving data via local WiFi network. When the LED is on, it means the ESP8266 is currently communicating over the WiFi; when the LED is off, it means the ESP8266 is not making any wireless communication.

Requirement	Verification
1. The LED must be turned on and off by a signal sent over the local WiFi network from a web browser.	1. Connect the LED in series with a 150 ohm resistor to one of the GPIOs of the ESP8266 module. Connect the ESP8266 to the local WiFi network, control the output of the LED GPIO from a web browser to see if the LED can be turned on and off wirelessly.

2.5 Control Panel

The control panel includes all the electronics visible to the user on the control panel box. It serves as a user interface for authorized people to easily and conveniently control the locker. The security module is also integrated into this panel. When a courier arrives, the LCD will instruct the user to place the package inside the locker. Once the courier does so, the camera will take a photo of the courier as a record and the LCD will notice the courier to shut the locker door. The piezo buzzer only sounds when the microcontroller detects an unexpected door opening when the servo should be in its locked position.

2.5.1 LCD

The 16x2 LCD with backlight visually provides the user with information necessary to operate the locker. Although a typical 16x2 LCD requires 16 pins on the microcontroller, with the help of I2C breakout board, only 4 pins of the microcontroller are needed to send data to the LCD to display.

Requirement	Verification
1. The LCD should communicate with the microcontroller over the I2C bus to display correct information to the user. 2. The contrast of the LCD should be set to an appropriate value to clearly display the characters. 3. The backlight of the LCD should be bright enough for the user to read during the night time.	1. Power the LCD by connecting VCC and GND pins to 5 V and ground pin of the ATmega328p, connect the two I2C pins SDA and SCL to corresponding pins of ATmega328p chip, use functions from LiquidCrystal_I2C.h library to send displayed data to the LCD to display. If all characters are displayed correctly and clearly, the LCD works. 2. Remove external light as much as possible to see if the characters on the LCD are still visible to the user.

2.5.2 Camera

The camera is an important part of the control panel to keep the security of the locker. When a courier is about to open the locker to place the package inside the locker, the camera will be turned on to take a picture of the courier as a record; when the locker is unexpectedly open (the IR sensor detects a door opening when the servo is in its locked position), the camera should be turned on and take pictures of the intruder to help identify his/her identity. The pictures taken by the camera will be automatically sent to the owner via the local network. The camera module communicates with the microcontroller over both I2C (sending configuration files) and SPI (sending commands and data) buses [5]. The default size and image type of the pictures taken is 800x600 JPG.

Requirement	Verification
1. The camera should remain idle to save power normally. When the locker is opened by a courier, the camera should take a picture of the courier to keep as a record; when the locker is opened unexpectedly, the camera should take 10 consecutive pictures of the intruder. The camera should be at least 2 megapixels to ensure the definition of the photos.	1. Connect power, I2C and SPI pins of the camera module to the ATmega328p. 2. Upload code from the Arduino IDE to ATmega328p over USB, open the host application provided by ArduCam to capture a photo with size 800x600. Check if the SPI interface can be set up and camera can be detected.

2.5.3 Piezo buzzer

The piezo buzzer on the control panel serves as an alarm that makes a certain tone specified by the microcontroller when the locker door is unexpectedly open to forces the intruder to leave the locker.

Requirement	Verification
1. The buzzer should make a tone controlled by the microcontroller with a loudness high enough to be heard 10 meters away from the buzzer.	1. Connect the buzzer to one of the digital I/Os of ATmega328p chip, upload code that makes the buzzer play a certain tone, gradually step back until we can no longer hear the sound played by the buzzer. Measure the distance with a ruler to make sure it is more than 10 meters.

2.6 Locker Module

The locker module is a physical implementation of the locker and electronics necessary to be placed in the locker to control the operation of the locker. The locker should be made of metal to resist external damage. Four magnets are placed at edges of the locker door to ensure the door can be shut without bouncing back. One additional magnet is placed near the hinge of the locker door. Once the door is properly closed by the user, the hall effect sensor will generate a higher voltage at its output due to an increasing magnetic flux density. The signal will be sent to the ATmega328p chip to indicate that the door is closed and the servo can start to lock the door. The servo is placed on the inner side of the locker and latch with the hook on the locker door to realize the locking mechanism. The size of the locker should be large enough to fit two large flat rate USPS boxes in order to meet the basic need of a normal family.

2.6.1 Locker

The locker is where the package and food is stored. A handle is on the outer side of the locker door and a latch is placed on the inner side of the locker door to hook up with the servo. To help the locker door locked in an easier and safer manner, the magnets are needed at both locker edge and door edge.

Requirement	Verification
1. The locker should be large enough to contain two USPS large boxes, therefore, the dimension of our locker should be at least 35.56 cm x 35.56 cm x 50.8 cm [6]. (However, for the demonstration purpose, the actual dimension of our locker may be smaller than expected.) 2. When the locker is closed, it should not be opened without at least 10 N of pulling force being applied to the handle.	1. Take two USPS large boxes and place it into the locker to see if the locker can fit the two boxes. 2. Hold a force gauge and place the hook of the force gauge to the door handle, pull the force gauge to open the door, record the force being applied at the moment when the door is open. Check if the force is at least greater than 10 N.

2.6.2 Servo

The servo is used to collaborate with the latch on the inner side of the locker door to lock the locker. In order to prevent the high current drawn from the servo from damaging the microcontroller, an additional 5 V power rail is needed to provide power to the servo.

Requirement	Verification
1. The servo should start at 0 degree position, and be able to rotate to the 90 degree position in about 1 second with no load applied.	1. Power the servo with a different 5 V power rail other than the one from the microcontroller, connect the servo signal input to one of the digital pins on a functioning Arduino Uno board. 2. With the help of Arduino Servo library, write code to set the initial position of the servo to 0 degree and then rotate it to 90 degree and upload the code to the board. If the operation is successfully done, the servo should be working.

2.6.3 Hall effect sensor

A hall effect sensor will be placed inside the locker to help determine whether the locker door is closed or not. As the door is closed by the user, the magnet sticked on the door becomes very close to the sensor and the increasing magnetic flux density increases the output voltage of the hall effect sensor. The microcontroller will receive the signal from the sensor and determine whether the door is locked based on the voltage level of the signal.

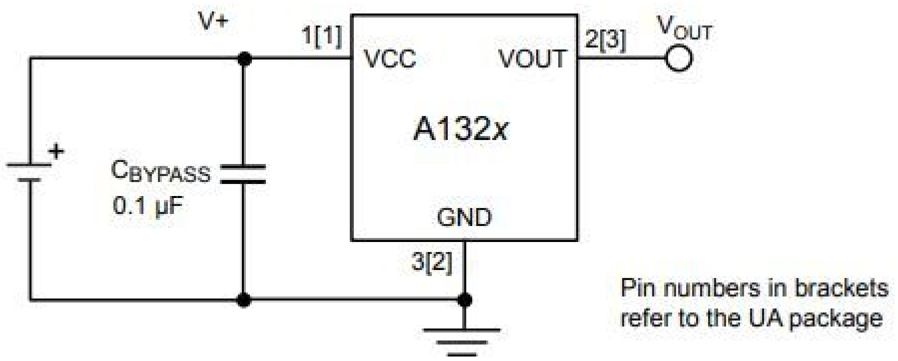

Fig. 7 Hall effect proximity sensing circuit [7]

Requirement	Verification
1. The hall effect sensor should send valid analog signal to the microcontroller based on how close the distance between the magnet and the sensor. There should be a distinguishable difference between the value we get when the door is closed and the value we get when the door is open.	1. Place the hall effect sensor on a breadboard such that it faces directly with a magnet. Set up the circuit in Fig. 6 and connect the output of the sensor one of the digital pin on a functioning Arduino Uno board. 2. Write code to use the serial monitor of Arduino IDE to check whether the Hall effect sensor returns signals that are proportional to the distance between the sensor and the magnet.

2.7 Server

Although the server design is beyond the scope of this course, it is necessary to realize certain functions of our locker. The server should communicate with the ESP8266 module to receive photos taken by the camera and send data to let the NodeMCU open the locker door.

2.8 Tolerance Analysis

The main source for powering the ESP8266 module is the solar panel, so it must be able to provide current for powering the ESP8266 NodeMCU as well as current to charge the battery pack during the day. According to some research online, the voltage of the solar panel is recommended to be 1.5 times the battery we want to charge. Since the battery we are using is a 3000 mAh 3.7 V Li ion battery, the approximate solar panel voltage requirement can be calculated by:

$$3.7 \times 1.5 = 5.55V$$

Next, we should calculate what amount of current must the solar panel provide to the microcontroller. On average, the ESP8266 module drains no more than 100 mA of current, the camera module drains 20 mA in idle state and the 1602 LCD drains 120 mA when the backlight is on and only a few mA when the backlight is off. Therefore, we can assume the electronics we are using draw no more than 200 mA on average. In addition, charging the battery requires about 100 mA of current. In conclusion, our solar panel

has to provide a current no less than 300 mA. In our case, we are using a 5 V/500 mAh solar panel, which satisfies both the voltage and current requirements.
Another calculation that is important to our design is to calculate whether the battery capacity is sufficient to provide power to the locker when during the nighttime. According to our research, the average day length of Illinois is about 11 hours. Therefore, the battery must be able to sustain 13 hours without sufficient sunlight. The average power consumption of our locker can be calculated by multiply the average current drawn with the 5 V VCC:

$$P_{avg} = V_{CC} \times I_{avg} = 5 \times 150m = 0.75W$$

The total energy stored in the 3000 mAh 3.7 V battery is:

$$C = 3.7 \times 3000 = 11100mWh$$

By dividing the total energy of the battery by the average power consumption of our locker, we can calculate how many hours the battery can sustain without solar panel providing power:

$$T = C/P_{avg} = 14.8h$$

Since 14.8 hours is larger than 13 hours, this 3.7 V 3000 mAh battery can meet our need to power the locker when the sunlight is not present.

3 Cost and Labor

3.1 Cost Analysis

3.1.1 Labor Cost

Total labor cost = (2 x 40 $/hr) x 2.5 x 10 hr/wk x 12 wk = $ 24,000

3.1.2 Parts Cost

Description	Part #	Quantity	Cost
Microcontroller	ATmega328p	1	$1.80
WiFi module	ESP8266 ESP-01	1	$6.50
5 V Linear Regulator	UA7805CKCS	1	$1.56
3.3 V Linear Regulator	LM1117T-3.3	1	$1.54
1602 LCD with backlight	SunFounder LCD1602	1	$6.49
Camera	ArduCam Mini	1	$25.99

	OV2640		
LCD I^2C breakout board	HiLetgo 3-01-0080	1	$2.99
Solar Panel	ALLPOWERS 2.5W 5V/500mAh	1	$8.99
Li+ Battery Charger IC	MCP73831	1	$0.58
3.7 V Li Ion Battery	EBL 18650	1	$6.50
5 V Boost Converter	SenMod TE110	1	$1.46
Hall Effect Sensor	A1326LUA-T	1	$2.10
Passive Components	-	-	~$10.00
PCBs	-	2	$6.26
Metal Locker	-	1	$80
Total	-	-	**$162.76**

3.1.3 Total Cost

Total Cost = $162.76 + $24,000 = $24162.76

3.2 Schedule

Week	Jiaxuan Liu	Yanlin Chen
2/4/19	Buy parts and simulate electronics online (TinkerCAD)	Design the state machine to implement the system logic
2/11/19	Determine pin assignment, work on the custom microcontroller design	Programme LCD and servo
2/18/19	Work on Hall effect sensor pair	Programme buzzer and camera module
2/25/19	Assemble the custom microcontroller board	Programme the second microcontroller as a slave

3/4/19	Design and prototype power supply module	Develop PCB schematic
3/11/19	Prototype all electronics with microcontroller	Finalize PCB design and order it
3/18/19	Spring Break	Spring Break
3/25/19	Assemble the PCB and solder	Test PCB
4/4/19	Fit the design into the mechanical locker	Optimize the code to improve efficiency
4/11/19	Prepare for the mock demo	Prepare for the mock demo
4/18/19	Demo	Demo
4/25/19	Final presentation	Final presentation

4 Ethics and Safety

4.1 Ethics

As engineers who build projects for the welfare of the entire human community, we force ourselves to strictly follow the IEEE Code of Ethics [8]. First of all, this secure locker project is designed to help protect people's property, which corresponds to code 1 of the IEEE code of ethics:

- *to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, and to disclose promptly factors that might endanger the public or the environment;*

In addition, the project is designed for the use of all groups of people, with no discrimination either religiously or racially, etc. Therefore, it corresponds to code 8 of IEEE code of ethics:

- *to treat fairly all persons and to not engage in acts of discrimination based on race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression;*

However, due to the limitation of the design, this locker is not recommended to use by people with blindness. We hope that we could provide more accessible versions of this product in the future.

Another thing to be aware of is that when a package is placed in the locker or the security system of the locker is triggered, the camera needs to take pictures of the person standing in front of the locker. This might offend the person's right. Therefore, it violates code 9 of IEEE code of ethics in some ways:

- *to avoid injuring others, their property, reputation, or employment by false or malicious action;*

In order to minimize the negative impact of the camera module as much as possible, a notice will be labeled in a conspicuous position of the locker to tell the users that their actions might be recorded if they intend to open the locker without permission.

4.2 Safety

The general safety of our design can be guaranteed because no hazardous or volatile material is used in our design. The mechanical design of our product is also benign to the users.

One safety concern might come from the overheating of some electronic components. In order to reduce such a possibility as much as possible, an additional temperature sensor can be placed inside the control panel box (where most electronics are placed) to monitor the temperature inside the box. If the temperature goes unexpectedly high (higher than the maximum temperature rating of any component used), the power should be immediately shut off to avoid possible burning of any component.

In addition to that, in order to prevent inexperienced users from opening the control panel box to access the electronics parts inside, the mechanical design of the box will guarantee that it is difficult to open without specific tools and a warning will be labeled on the box to discourage users to open the box.

5 References

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