Self-check Mailbox

ECE 445 Design Document

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1 Introduction

1.1 Objective

The prototype of the mailbox was patented in 1858 by Albert Potts; it was only a letterbox that collects letters.[1] In 2020, the use of mailboxes is still prevalent in the world. Nowadays mailboxes can collect flyers, bills or small packages. Even though our delivery service has been greatly expanded and developed over the past 150 years, the mailbox is still the same compared with the ones in the old days: they are just a box with a lock. Users don't know when their mailbox would have new mail; they cannot tell what is in their mailbox without opening it. Most mailing services and online shopping websites only guarantee 2-8 days delivery and thus it is common to have delayed mails or delivery.[2] As a result, people have to open the mailbox regularly to check if there's anything new, especially while waiting for something important to be delivered.

Our team thinks that this job is completely repetitive and can be replaced by a system with self-checking ability. Our system's goal is to detect new mails, take a picture of the mailbox's contents and notify users with the information collected by the system. The notification system will push to the user's phone or email address within 2 minutes of a new delivery. It will also attach a photo of the mailbox's inside to let users know what has been delivered. In addition, our design is incorporated with solar powering so this system can have self-sustained green energy for outdoor use.

1.2 Background

There's no product on the market now that has the exact same functionalities as our system does, but there are several similar ideas. The most similar one is the Amazon Locker, which could be found at the bookstore on the U of I campus. People could pick up their packages using QR code and get notified from Amazon App. However, the Amazon Lockers are not perfect; this hub is under the commercial operation of Amazon.com Inc; it's for Amazon users only. Also, people still have to go to the pickup location to pick their packages up. [9]Another similar idea could be the smart doorbell, where there are plenty of choices on the market already. A smart doorbell usually includes a notification system and camera system; the main difference between our project and smart doorbell, however, is that we will automatically detect new delivery rather than let someone ring the bell for you. Also, we will use solar energy so that people don't have to replace the battery occasionally.

Hence, our goal is to build a personal and affordable system for home mailbox, which allows all deliveries to be easily checked, and users can have real-time notification from their mailbox within minutes.

1.3 Physical Design

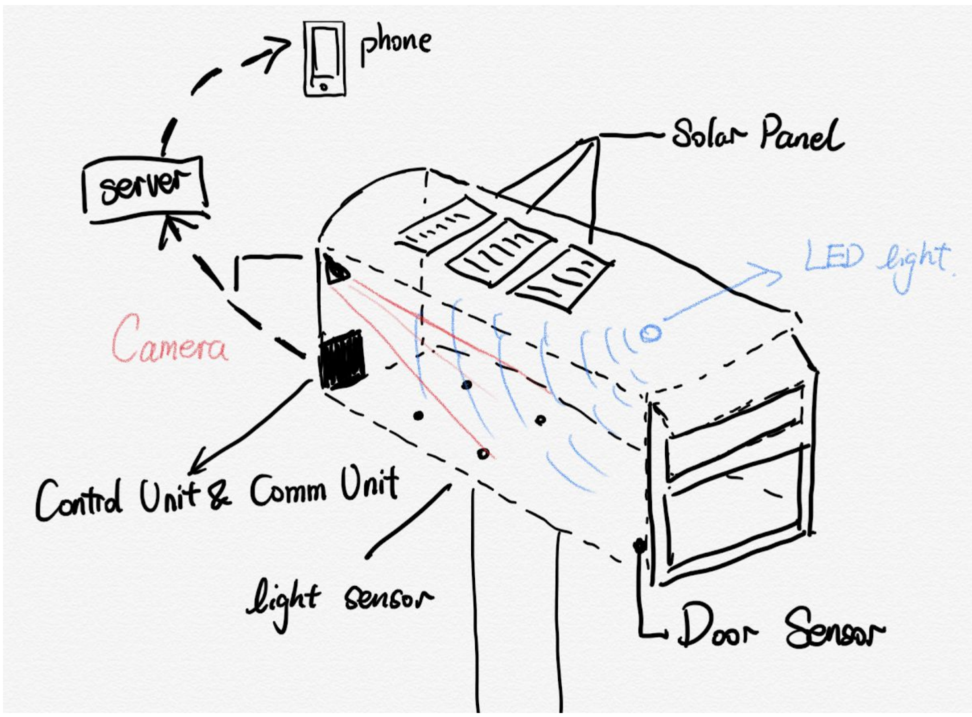


Figure 1. Physical Design

1.4 High-level Requirements

- The sensing system is real-time sensing and immediately responding; it can take pictures and send emails containing photos of inside to users once new mail has been delivered within 2 minutes.
- The mailbox should withstand different weather conditions and prevent electronic components from being damaged.
- The battery unit can support the system to operate for at least 20 hours without solar panel charging.

2 Design

For our design, it requires five parts for the success of operation: a Power Unit, a Sensing Unit, a Camera Unit, a Communication Unit and a Control Unit, as shown in the diagram below. The Power Unit has the battery as well as solar panels; the battery will guarantee our system to run for at least 20 hours without charging and the solar panel can provide enough current to charge the battery while sunlight is sufficient. The Sensing Unit is responsible for detecting new actions in the mailbox, including new mails' arrivals and door's behavior. It will also send signals to the Control Unit for further logic. The Camera Unit is used to take a photo of the mail inside the mailbox when new mails have arrived, and the images will later be pushed to users' phones. Communication Unit is responsible for transferring data between our system and the remote server via WiFi.

Block Diagram

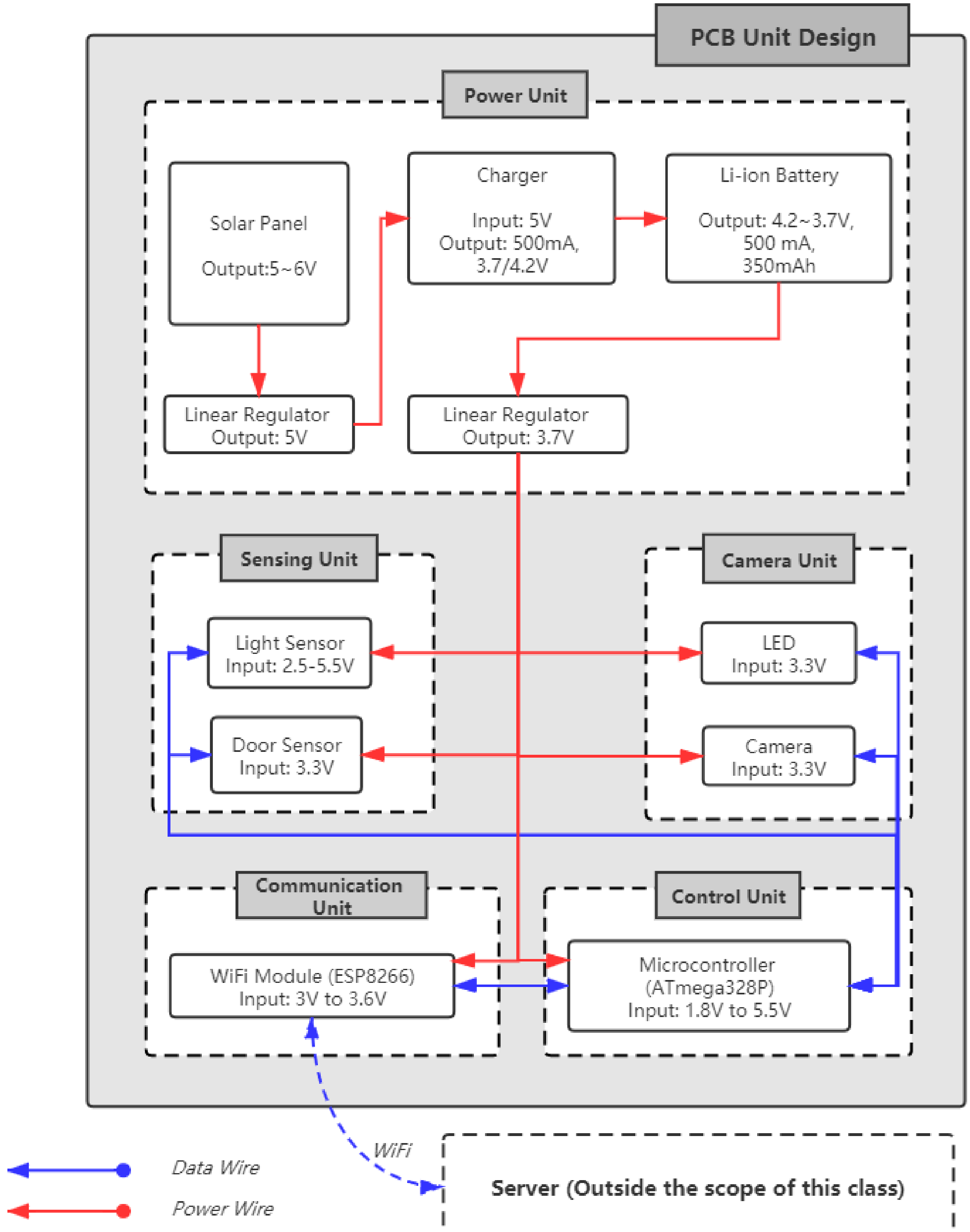


Figure 2. Block Diagram for Self-Check Mailbox

2.1 Power Unit

Green energy will be used to power the functionality of the PCB board. We will charge a Li-Po battery using a solar panel and employ some voltage regulators to ensure stability and safety. This power unit will provide enough power to drive our system to run at least 20 hours without solar panel charging.

2.1.1 Solar Panel

As the most abundant energy resource outside, sunlight will be collected through a solar panel to charge the Li-ion battery, providing a voltage output to the voltage regulator and then get through the battery charger.

Requirement	Verification
~0.5W minimum is required and we want to output around ~6V, ~330mA. Must be able to rewire with a mini-B USB driven connector to the battery charger.	**Step 1**: Measure the output voltage and current while charging using an oscilloscope, ensuring that the error within 5%. **Step 2**: Rewire and adjust the solar panel to connect with mini-B USB input power management to measure the charging voltage is around 3.7V-4.2V.

2.1.2 Voltage Regulator

Two linear voltage regulators will be used. One will regulate the voltage coming from the solar panel since the generated voltage will be fluctuating based on the sunlight intensity. As a result, we need to make sure that it won't exceed a certain maximum voltage. Another regulator will be deployed between the Li-ion battery and other units for stable voltage safeguards.

Requirement	Verification
The regulator of the power management will regulate the voltage to 3.3V +/- 0.5% from the 3.7V-4.2V input Li-Po battery to control units. Maintain thermal stability below 125°C.	**Step 1**: Measure the output voltage and current while discharging using an oscilloscope, ensuring that the error within 5% of 3.3V.

2.1.3 Li-Po battery

Our design of inbox energy consumption is small and Li-Po battery is generally safer than Li-ion. On the other hand, although Li-Po has a shorter lifespan, the solar panel will consistently provide sufficient energy while Li-ion batteries will suffer from aging problems, which we don't want users to change the battery very often.[3] Hence, we will use a rechargeable Li-Po battery to power our circuit.

Requirement	Verification
The battery will provide around 300mAh and power the circuit without charging up to 20 hrs. 3.7~4.2V and ~500mA at least are required for charging or discharging.	**Step 1**:Fully charging the battery and discharging it at a constant rate to record the durability. Double check with numerical calculations.

2.1.4 Li-Po battery management

The charger is specifically designed for Li batteries. We want to use a USB-driven charger to charge the Li-Po battery. We will redesign the configuration between the charger and our solar panel and put Voltage regulators in between to adjust the input and output. Based on our PCB's power consumption, around 0.7 hour will be enough to charge the battery.

Requirement	Verification
The input voltage from the solar panel should be in range of 4.35V ~ 6.6V and input current maximum is ~1.5A. The output current maximum is ~4.5A. Maintain thermal stability below 125°C.	**Step 1:** Measure the input voltage and current while charging using an oscilloscope, ensuring that the error within 5%. **Step 2:** Measure the output ßvoltage and current while charging using an oscilloscope, ensuring that the error within 5%.

2.2 Sensing Unit

2.2.1 Light Sensor

This is the major sensor we will use for sensing new things in the mailbox. It must be able to receive light from LED in the Camera Unit, detecting the light condition inside the mailbox. If the condition has been changed, it means that a new delivery has arrived and should send a signal to the microcontroller.

Requirement	Verification

The light sensor must be able to detect the light with the luminance of 130-170 lm from the LED.	**Step 1:** Use the voltmeter to test the voltage of the output of the sensor when the LED is turned on. **Step 2:** Use the voltmeter to test the voltage of the output of the sensor when the LED is turned off. **Step 3:** Compare the results and make sure there is an obvious difference.

2.2.2 Door sensor

This sensor is used to detect whether the door for the mailman is closed or opened. It will send a signal to the microcontroller, activating the camera to be used shortly after. By using a door sensor, we can reduce the usage of camera, only activating it while necessary (when there's new action on the mailbox).

Requirement	Verification
It should be able to change the output voltage to send the signal as soon as the door is closed by the mailman.	**Step 1:** Use the voltmeter to test the voltage of the output of the sensor when the door is closed. **Step 2:** Use the voltmeter to test the voltage of the output of the sensor when the door is opened. **Step 3:** Compare the results and make sure there is an obvious difference.

2.3 Camera Unit

2.3.1 LED

LED is implemented at the top inside the mailbox. It will be turned on for 5 seconds after the door(for mailman) is closed for both the light sensors to know if there's new mail delivered and for cameras to have enough illumination for capturing pictures.

Requirement	Verification
The luminance of the light should be strong enough to be sensed by the light sensor. Luminance: 162 lm/W, Voltage input 3.3 V.	**Step 1:** Use the voltmeter to test the voltage of the output of the sensor when the LED is turned on. **Step 2:** Use the voltmeter to test the voltage of the output of the sensor when the LED is turned off.

	Step 3: Compare the results and make sure there is an obvious difference.

2.3.2 Camera

The camera is implemented at the top inside the mailbox. It will take the picture of the mail when received the signal of the light sensor.

Requirement	Verification
1. It must be able to communicate with the microcontroller (ATmega328P) and be controlled by it. 2. The captured 640x480 image quality can show good details in the mailbox. 3. Maintain stability for thermal value under 60 °C.	**1A.** Connect the camera to the microcontroller via I2C and digital pins. **1B.** We can use the Arduino Development Board for testing driver codes' functionality. Upload the driver code to microcontroller to generate the images and download the image. **2A.** Repeat 1A and 1B to connect this module. **2B.** Examine the downloaded images. Make sure it shows a good level of detail. **3A.** During other verifications, use an IR thermometer to ensure the IC stays below 60°C.

2.4 Communication Unit

2.4.1 WiFi Module

The WiFi module should be capable of communicating with the server directly, taking the responsibility to send the photos taken to the server. To balance performance and cost in our design, we will use ESP8266 as our WiFi module for our microcontroller and communicate via 802.11b/g/n.

Requirement	Verification
1. The WiFi IC should be able to connect via WiFi IEEE 802.11b/g/n and exchange data with the server.	**1A.** Connect the WiFi module to the microcontroller via I2C module. **1B.** We can use the Arduino Development Board for testing driver codes' functionality. Upload the

2. The WiFi can connect to a server for a range of at least 10 meters (without blocking). 3. Maintain stability for thermal value under 60 °C.	driver code to microcontroller to set up the AP mode. **1C.** On other WiFi devices, we can set up a WiFi hotspot and connect the module to this WiFi. **1D.** We can use another driver script to try to communicate with our module over HTTP protocol. **2A.** Repeat the process 1A - 1D. **2B.** Try communications over the distance of 10 meters to see if it works. **3A.** During other verifications, use an IR thermometer to ensure the IC stays below 60°C.

2.5 Control Unit

2.5.1 Microcontroller

The microcontroller should be powerful enough to process images from the camera and provide a real-time response within a 2-minute period. To balance performance and cost in our design, we choose ATmega328P as our microcontroller.

Requirement	Verification
1. The microcontroller can communicate over I2C and SPI with the camera and WiFi module. 2. The microcontroller should finish image processing in less than 2 minutes. 3. Maintain stability for thermal value under 60 °C.	**1A.** These verifications can be done in other procedures as well. **2A.** We can use the Arduino Development Board for testing driver codes' functionality. The result should be given in 2 minutes. **3A.** During other verifications, use an IR thermometer to ensure the IC stays below 60°C.

2.5.2 Server

We will use a Raspberry Pi as our server to push notifications and send photos to users. This Raspberry Pi is connected to the internet. We will write scripts on it to do everything automatically. How to setup this device is not in the scope of this class.

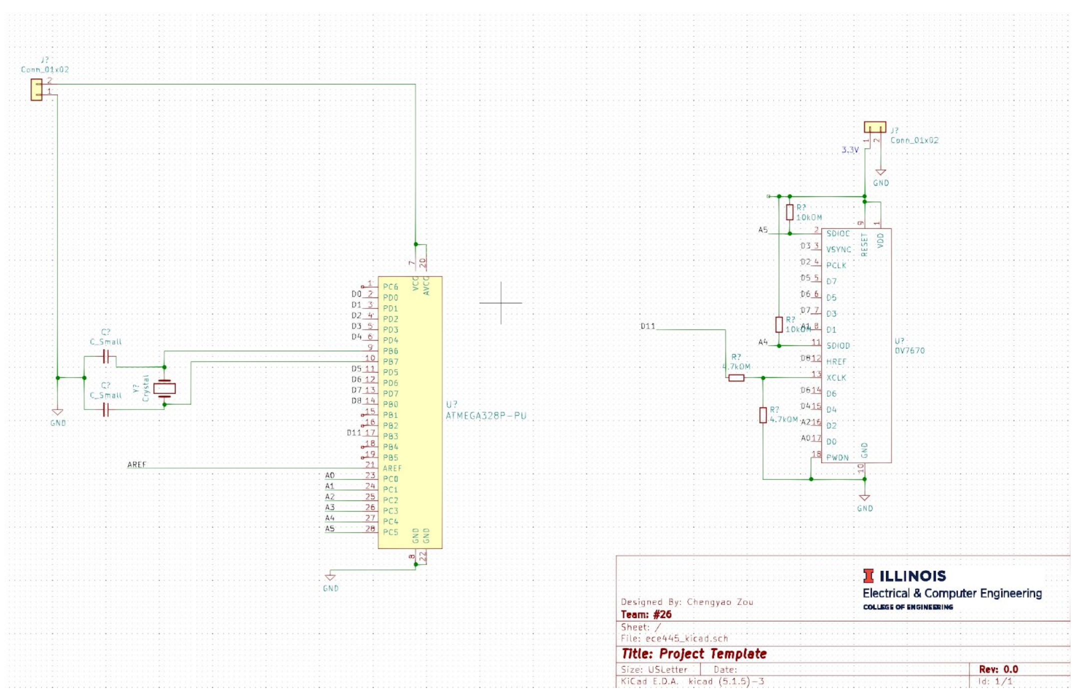
2.6 Schematics (one example)

Schematic for Control Unit & Camera Unit (ATmega328p & OV7670)

The connections among Control Unit, Camera Unit and WiFi Unit are driven by different protocols. The connections are designed as the following diagram:

Figure 3. WiFi & Camera & Microcontroller Connection Diagram

Connection between the WiFi module is via the I2C bus; connection between camera and the microcontroller is more complicated, since it involves parallel input data to be transferred and stored at one time. The detailed schematic of connection between microcontroller and Camera in KiCad is as follows:



2.7 Calculations (one example)

2.7.1 Labor Cost

Member	Hourly wage	Weekly hours	weeks	multiplier	Cost
Chengyao Zou	$50	12	12	2.5	$18,000
Peiming Wu	$50	12	12	2.5	$18,000
Haonan Wang	$50	12	12	2.5	$18,000

2.7.2 Parts Cost

Part	Cost (prototype)
Li-Po battery 3.7V 500mAh	$7.75
Li-Po battery management chip	$19.95
Solar Panel 6V 2W	$29.00
Light sensor(APDS-9007-020)	$10.00
LED(800008-00G4S012CL3-AI)	$3.50
Door sensor(P12961STR-ND)	$1.00
Microcontroller(ATmega328p)	$2.08
WiFi Module(ESP8266 WRL 13678)	$6.95
Camera (OV7670)	$4.98
Total:	***$85.21***
Grand Total:	$54,085.21

2.8 Schedule

Week	**Chengyao Zou**	**Peiming Wu**	**Haonan Wang**
2/13	Finalize Draft Design	Finalize Draft Design	Finalize Draft design
2/29	Complete verification tests for camera / WiFi / Microcontroller	Complete R/V	Complete verification tests for sensing unit
3/7	Complete PCB prototype design & order PCB	Draw PCB prototype Parts order	Draw all the schematic of sensing part and do test on power unit
3/14	Complete coding for microcontrollers	Complete Charging parts Implement temperature tests	Complete PCB about sensing unit part and order PCB
3/27	Finish PCB board test	Complete discharging parts	Finished PCB board test
4/6	Connect with other units (Powering, Sensing)	Put all together with other two subsystems	Connect with other units (Powering, Sensing)
4/15	Test the system's high level requirement and debug	Test and optimize	Optimize the sensing system
4/21	Conduct environmental Testing	Test and optimize	Test if there is situation that sensing unit will not work as normal
4/28	Prepare for the final presentation	Prepare for the final presentation	Prepare for the final

2.8 Tolerance Analysis

2.8.1 Solar Panel

One of the most important features of our project is that we are using a solar panel to power our entire project. Solar panel output varies with the cell operating temperature. The output power of a typical solar panel will change by ~2.5% for about every 5 degrees variations in temperature. [9] Also, at relatively low temperature, say below 25 °C is usually low compared to that of high temperature. Therefore, it's necessary to analyze the power efficiency at different temperatures.

The Power efficiency of a solar panel is computed as follows:

$$\textbf{\textit{Efficiency}} = \frac{Power\ of\ solar\ panel * 100\%}{Area\ of\ solar\ panel * 100W/m^2}$$

The power of the solar panel is computed by multiplying the voltage across the panel with the current.

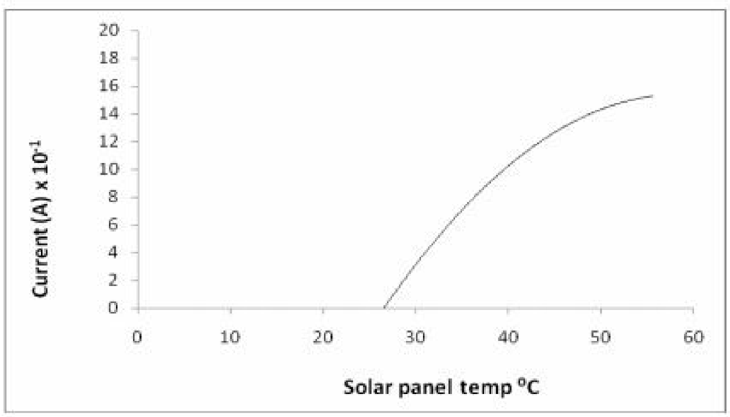


Figure 3. Output Current vs Solar panel temperature[10]

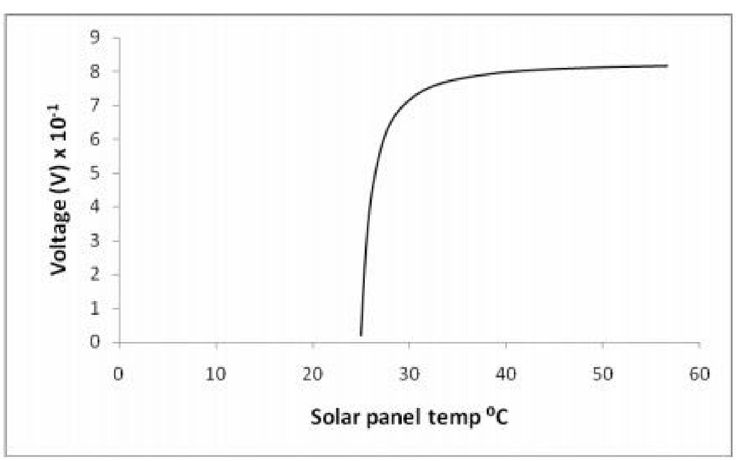


Figure 4. Output Voltage vs Solar panel temperature[10]

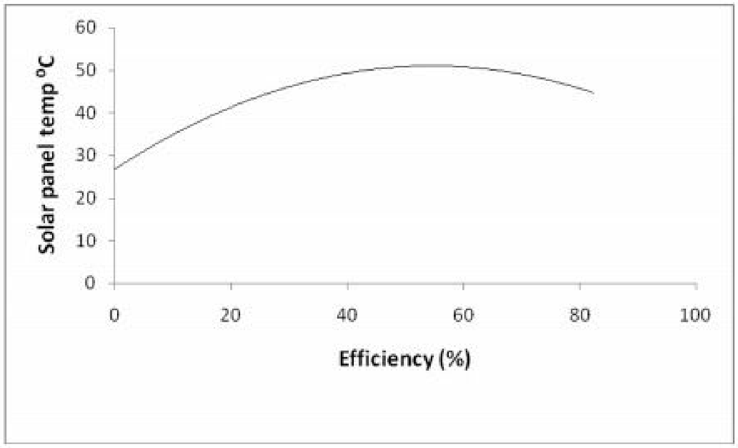


Figure 5. Solar panel temperature vs Efficiency[10]

As we can observe from plots from above, both output current and voltage will increase as the temperature of solar panel increases whereas there's a peak output voltage ~8V for the example. On the other side, the solar panel efficiency reaches its maximum at ~45°C.
The solar panel we are planning to use right now has a peak output with 6V at 378mA and 2.27Watts. Therefore, for the purpose of recording the efficiency of our solar panel. We will record the output current and voltage of our piece of solar panel under high temperature conditions from 25°C to ~50°C. From that, we would have an idea of the maximum output power and based on that we will see the average efficiency to have a better picture of how long it takes to fully charge our Li-Po battery.

2.8.2 Led and light sensor

The forward voltage of LED is 2.7 - 3.5 V, we want to make sure that the output from the battery should satisfy this to prevent LED from burning out. To simplify the design, it is convenient to set the input voltage to be 3.3V which is the same as other components like light sensor and door sensor. We need to pay attention that 3.3 is very close to the max voltage. The temperature tolerance of LED and light sensors has a wide range so it is not necessary to take temperature into consideration.

2.9 Risk Analysis

The solar power unit is a major risk for our system's completion. It is the most crucial part of our design, as it provides the only power source for our system. If this part fails, then our whole system will fail. There are a lot of real-world problems we have to take into consideration, including safe use and operating conditions.

Solar panel charging ability is largely affected by uncertainties, so we have to design this part as robust as possible. Considering that light intensities change will vary the output of the solar panel, it's necessary to regulate the output voltage to be stable and strictly under 5V. Similarly, the regulation between the Li-Po battery and our PCB also has to be consistent. Otherwise, our PCB will be broken. Other problems like safety use are also important because batteries could be dangerous under wild use. We will put extra safeguards on our system such as linear regulators to ensure its safety.

3 Safety and Ethics

Our project's paramount goal is to provide users with a safe and reliable system. As a result, we will specifically focus on designing our system with many safety guarantees.

First, since the whole system is built for outdoor use, we have to consider some outdoor conditions including extreme weather, high moisture level, etc.. Scenarios like pouring rain and sultry weather are common these days that we have to deal with. These real-world factors could potentially interrupt our system's operation or reduce its lifetime reliability. To accomplish that, we will test that our system can work under harsh conditions varying from -15°C to 45°C and it can achieve at least IP66 water resistance level (resist to pouring rain).

Second, we will take special care with our battery. Scenarios like puncture, overcharge, overheating, etc. are everywhere. Li-ion batteries are generally more dangerous than Li-Po batteries in terms of accidents like leaking electrolytes and the most reported incidents occurred while the battery was charging. Hence our design of power supply will stay with Li-Po rechargeable battery.[4][5]

Safety is our paramount goal in our design, as the IEEE Code of Ethics says, "hold paramount the safety, health, and welfare of the public"[6]. Apart from safety, privacy is also our top concern. Our project involves collecting the privacy of users, including taking photos of the mailbox's content. In the IEEE Codes of Ethics, it says that "to avoid injuring others, their property, reputation, or employment by false or malicious action"[6], and we are strictly following that. The camera usage is also strictly limited to the content of the mailbox. Without infringing the delivery person's privacy, the camera should only keep record of the inside of the mailbox. In our design, we will not utilize these data for any other use; data will be kept locally, and only shared with the user himself/herself. Once a new record is sent to the user, our system will delete it permanently from the flash drive. However, even though we will try our best to keep the user's privacy safe, these data are still vulnerable if the server is being hacked or stolen. To avoid potential privacy issues, users shouldn't put the server in a risky environment.

This project will be developed under the BSD License 2.0[7]. As in the IEEE Code of Ethics, "to assist colleagues and co-workers in their professional development and to support them in following this code of ethics"[6], we will have minimal restrictions toward the usage of our design and code, and we encourage sharing and learning our project.

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