ECE 445
SENIOR DESIGN LABORATORY
FINAL PAPER

Bike Theft Lock & Chain Detector

Team 74
Natasha Sherlock, Jonathan Lee, Zhuoyuan Li
Spring 2024
Professor: Arne Fliflet
TA: Tianxiang Zheng

Abstract

This paper details the motivation, design, development, and verification of the Bike Theft Lock & Chain Detector. We will first cover the statistics and history of bike theft in the Champaign-Urbana area, which first raised the need for this project. We will then detail each subsystem in-depth, discussing the functional requirements for the camera module and the theft detector module to work as intended. We will show the evolution of the product in development, and explain the software and hardware design considerations and hurdles that influenced the final product. Finally, we will outline the verification methods and process. Overall, the final design met most functional requirements and the PCB was successfully integrated into the product.

Contents

1. Introduction

1.1 Problem

1.2 Solution

1.3 Visual Aid

1.4 High-level Requirements

2. Design

2.1 Introduction

2.2 Block Diagram

2.3 Subsystem Overview

2.3.1 Theft Detection Subsystem

2.3.2 Camera Subsystem

2.4 Design Description and Justification

2.4.1 Theft Detection System PCB

3. Cost Analysis

3.1 Labor Costs

3.2 Parts Costs

4 Design Verification

5 Conclusion

5.1 Accomplishments

5.2 Uncertainties, Alternatives and Future Work

5.3 Ethics and Safety

5.4 Broader Impact

6. Reference

Appendix A

Appendix B

1 Introduction

1.1 Problem

In the Champaign-Urbana area, an estimated 856-1070 bikes are stolen each year [1], with most perpetrators going unapprehended and missing bikes seldom recovered. A mere 5-10% of bike theft cases are solved in the campus area [2]. Bike theft often goes unnoticed when locks are cut, particularly during nighttime or with limited witnesses. The situation is only getting worse, with the number of bikes reported stolen on campus surging from about 51 bikes in 2021 to 148 bikes in 2023 [2].

1.2 Solution

In order to alert the bike user swiftly and provide important information about the thief, the proposed solution is a cable bike lock that detects when the cable is cut. A voltage is connected via a wire running through the cable and an open circuit will be detected by the microcontroller if the cable is cut. When the cable is cut, the camera positioned on the bike will record images that may potentially identify the criminal. The microcontroller will also send out a signal to trigger an alarm, as well as relay all this information to the user via Wi-Fi. The entire system serves to provide multiple layers of safeguards for the user’s bike. First, it deters theft attempts. Second, it alerts the public to a crime. Third, it captures evidence that can enable bike recovery.

1.3 Visual Aid

Figure 1. Visual aid

1.4 High-level requirements list

- Our system must achieve a 95% (± 3%) accuracy in detecting when a cable is cut, minimizing instances of false alarms.
- The system should capture and transmit images within 5 seconds (± 3 seconds) of detecting an open circuit. This will ensure that detection is prompt and evidence is collected in a timely manner.
- The system should set off an alarm within 5 seconds (± 3 seconds) of the cable being cut.
- The batteries should last for about 3.0 hours (± 0.5 hours) for the main control subsystem and the camera control subsystem.

2 Design

2.1 Introduction

Our product consists of two main systems. The first system is the Theft Detection System, which is powered with a 9V battery, stepped down by the voltage regulator in our power system to supply the required 3.3V to power the master microcontroller. This system sits on the bike lock, with a wire running through the bike lock and connecting to the master microcontroller. When the chain is cut, the microcontroller powers the alarms and sends a Bluetooth signal to the Wireless Camera System that is placed elsewhere on the bike, in a position that the user can set but ideally where an image of the thief can be taken. The Wireless Camera System is also powered by a 9V battery that is stepped down to 5V via voltage regulator, and upon receiving the signal from the master, the slave microcontroller takes an image with the camera and sends the image to the Telegram app on the user's phone via a Wi-Fi connection between the user's phone and the Wireless Camera System.

2.2 Block Diagram

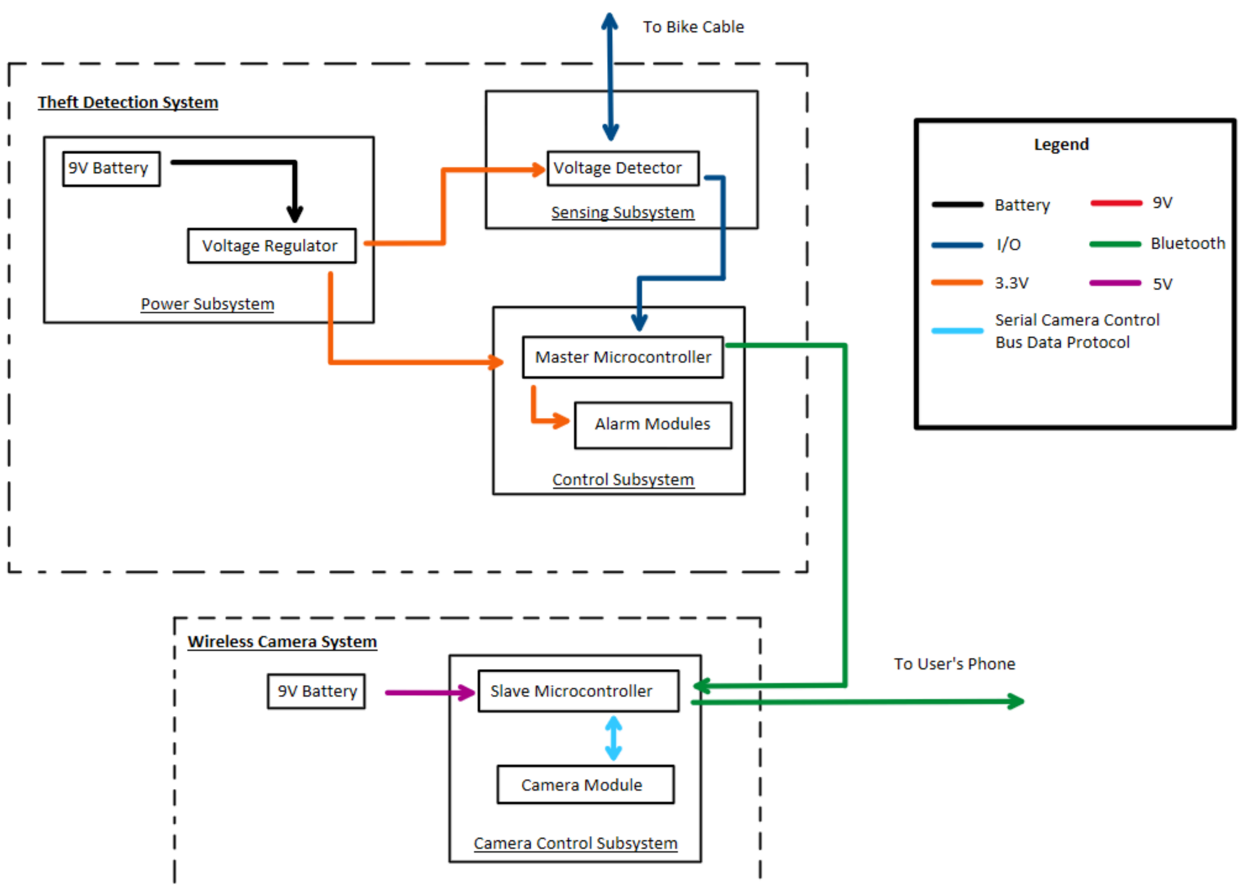

Figure 2. Block Diagram

2.3 Subsystem Overview

2.3.1 Theft Detection System

Sensing subsystem:

The sensing subsystem is the wire running throughout the bike lock which is connected to the output of the voltage regulator and the master microcontroller. The constant 3.3V from the regulator allows a GPIO pin on the microcontroller to read HIGH. If the chain is cut, the GPIO pin will then read a low signal or 0V and the microcontroller will then power the alarms and send a signal to the camera control subsystem.

Design Alternatives:

The original idea was to create a current detection circuit with a BJT and other surface mount components, however, by using the regulator's output to provide a HIGH signal falling within the range of the GPIO pin specifications and the pin to read this signal, we no longer needed to construct the current detection circuit, saving time and money.

Power subsystem:

The power subsystem uses a linear voltage regulator to step down the voltage from a 9V alkaline battery to 3.26V, providing adequate power for the master microcontroller and the sensing subsystem. To achieve this specific output voltage, Equation 1 from the LM317 datasheet [6] is used and simplified to Equation 2 due to the I_{ADJ} current being a negligible 50 µA. With V_{ref} set to 1.25V and Vout as 3.3V, the resistors that we chose to best achieve this output were 3.3kΩ for R_2 and 2.2kΩ for R_1.

$$V_O = V_{REF}\,(1 + R2 / R1) + (I_{ADJ} \times R2) \tag{1}$$

$$Vout = Vref * \left(1 + \frac{R_2}{R_1}\right) \tag{2}$$

Design Alternatives:

Although we had planned on using AA batteries to power our theft detection system, we stepped away from this due to the abundance of 9V battery jacks provided by the department to avoid difficulties with replacing AA batteries connected via solder to terminals throughout testing. The main worry that caused the proposal of AA batteries was the battery life. While not disputing that AA batteries would have provided more battery life, the battery life of the master microcontroller due to 9V batteries surpassed the high level requirement of 3 hours, depicted in Requirements and Verification.

Control subsystem:

The control subsystem in the theft detection system consists of an ESP32-S3-WROOM, a microcontroller with Wi-Fi + Bluetooth capabilities. With 3.3V supplied by the power subsystem, it uses a GPIO pin to constantly read the voltage through the wire from the sensing subsystem. When the chain is cut, the wire will also be cut and the GPIO pin will read 0V, immediately sounding the alarms and sending a signal via Bluetooth to the camera control subsystem to take an image.

Design Alternatives:

The ESP32 in the control subsystem serves as the server for the Bluetooth BLE communication with the ESP32-CAM, which is the client. A characteristic with value is constantly notified to the client by the server. A characteristic consists of a boolean value, a property and a descriptor. We programmed it such that the value sent in the characteristic is 0 when the wire isn't cut, and 1 when the wire is cut. An interrupt is used to trigger the alarm by output digitalwrite HIGH whenever the chain is cut.

During the debugging, when we restart the camera module to test it multiple times, we found bugs that the server triggered the alarm and sent value 1 in characteristic even though the wire isn't cut. After debugging, we found out that once the server disconnect from the client due to the client restart, we didn't manually set the characteristic value to 0, the chain1.cut, which is a boolean value that indicate if the chain is detected to be cut, to false, and the digitalWrite(buzzer1.PIN, LOW), which gives a LOW output to the alarm. By failing to reset these parameters, the chain 1.cut is still 1, causing the server to mistakenly believe the chain is cut, and the HIGH output in digitalWrite causes the alarm to trigger. This problem is solved after changing the code for disconnection.

```
// disconnecting
if (!deviceConnected && oldDeviceConnected) {
    value = 0;
    chain1.cut = false;
    digitalWrite(buzzer1.PIN, LOW);
    delay(500); // give the bluetooth stack the chance to get things ready
    pServer->startAdvertising(); // restart advertising
    Serial.println("start advertising");
    oldDeviceConnected = deviceConnected;
}
```

Figure 3. Disconnect code of the server after debugging

2.3.2 Wireless Camera Systems

Power subsystem:

Since the wireless camera system is separate from the theft detection system, a separate power system will be used to power the camera system. Another 9V battery will be connected to an LM317 voltage regulator to step the voltage down to 5V as per the ESP32-CAM datasheet [5]. To output 5V from the voltage regulator, Equation 2 was used in the same manner, with the closest resistor ratio being R_2 with 10kΩ and R_1 as 3.3kΩ.

Design Alternatives:

While connecting the resistor values labeled above, the actual output ended up being 5.5V which was over what ESP32-CAM could safely handle. To bring the output down, an extra 380Ω resistor had to be added in series with the 3.3kΩ resistor, successfully providing a new output of 5.19V.

Camera control subsystem:

This is the slave microcontroller to the control subsystem in the theft detection system. A ESP32-CAM microcontroller is used for this control system. Using its Bluetooth, it receives the signal from the theft detection system. Then it sends a signal from its camera module, informing the camera to start shooting images. After the recording, the microcontroller receives the photos the camera captured and sends them to the user's phone via WIFI.

Design Alternatives:

To design the PCB for the camera control system, an ESP32 could be used with a camera module, however, understanding and implementing the Serial Camera Control Bus protocol in addition to debugging time appeared detrimental to our schedule and finishing the product on time, and so the ESP32-CAM devkit was chosen to eliminate the unnecessary challenge.

The WIFI module is coded such that the ESP32-CAM communicates with telegram bot by sending pictures it captured.

During the coding, we met failure to connect to the user phone using the Wi-Fi module. After researching, we realized that the Wi-Fi and bluetooth module cannot work at the same time since they share the same antenna; thus, we modified the code such that the ESP32-CAM disconnects from the the bluetooth server, or the ESP32 in detecting module, and switches to Wi-Fi after the signal from the detection system is received.

2.4 Design Description and Justification

2.4.1 Theft Detection System PCB

The first rendition of our product's PCB is shown below in Figure 4. The power system is the same as described above but the alarm system includes a MOSFET which we bypass in our final product due to issues with the alarm sounding as long as the battery is connected, even before the microcontroller gives the proper signal. Instead, the alarms are connected to mounting holes H5 and H9. The power system is the same as described, and the sensing subsystem is the wire that connects to TP2 and H6 for 3.3V and the microcontroller's GPIO pin respectively.

Although we had multiple renditions ordered after this, the final product was achieved with the first rendition of the PCB due to unwanted trace connections made regarding the voltage regulator in our smaller and final PCB renditions, which resulted in higher regulator output voltages that rendered one of our microcontrollers useless.

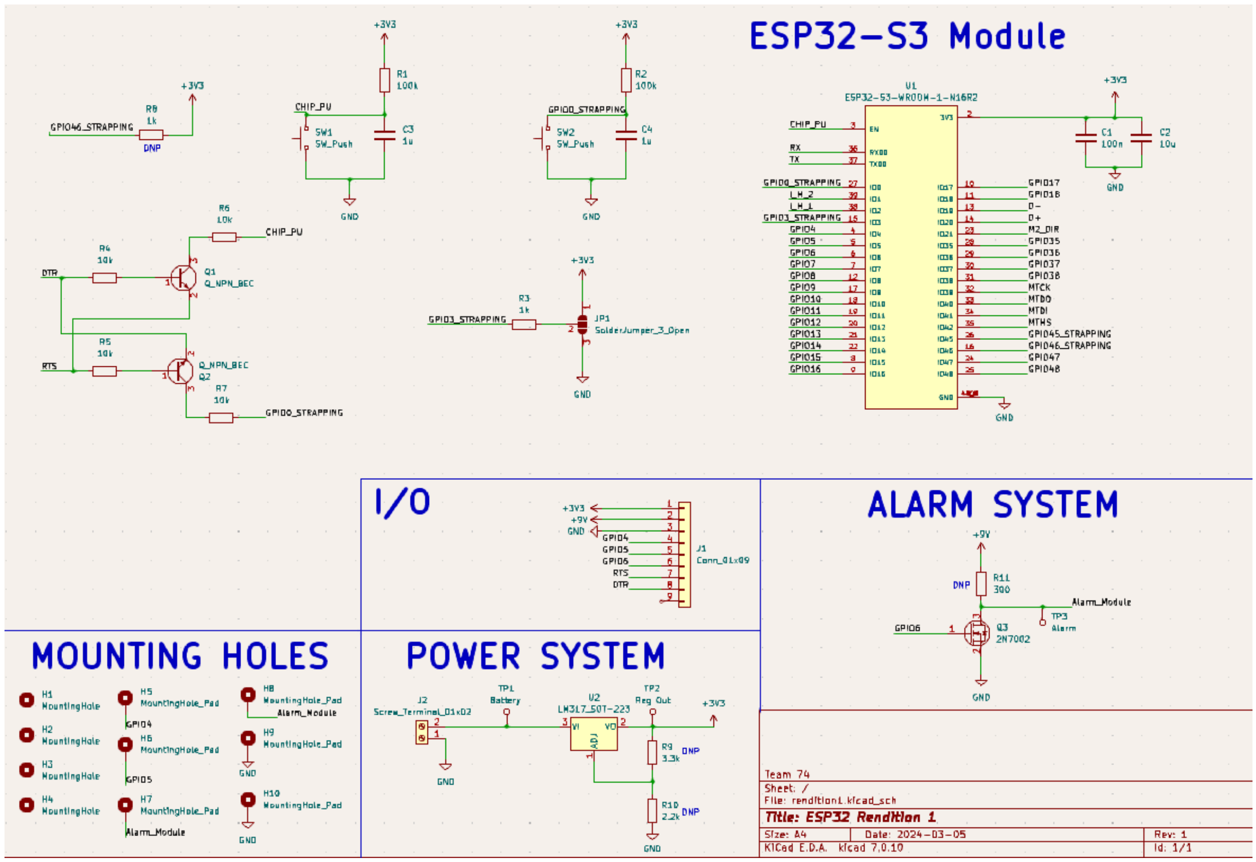

Figure 4. Theft Detection System Schematic

Figure 5 shows the actual model of the PCB, where there are airwires from R8, R9, and R6. While the airwire from R8 is intended to keep the default strapping pin values for the microcontroller, the airwires from R9 and R6 were not. Soldering wire to R9 allowed the PCB to receive the 3.3V, but soldering wire to R6 did nothing. R6 is part of the circuit that automatically sets the strapping pins and chip enable pins on the ESP32, but since the TX and RX pins were not connected to any pins in the I/O section of the schematic, we could not use the FTDI USB programming method to upload code, and instead had to use the data pins on the ESP32.

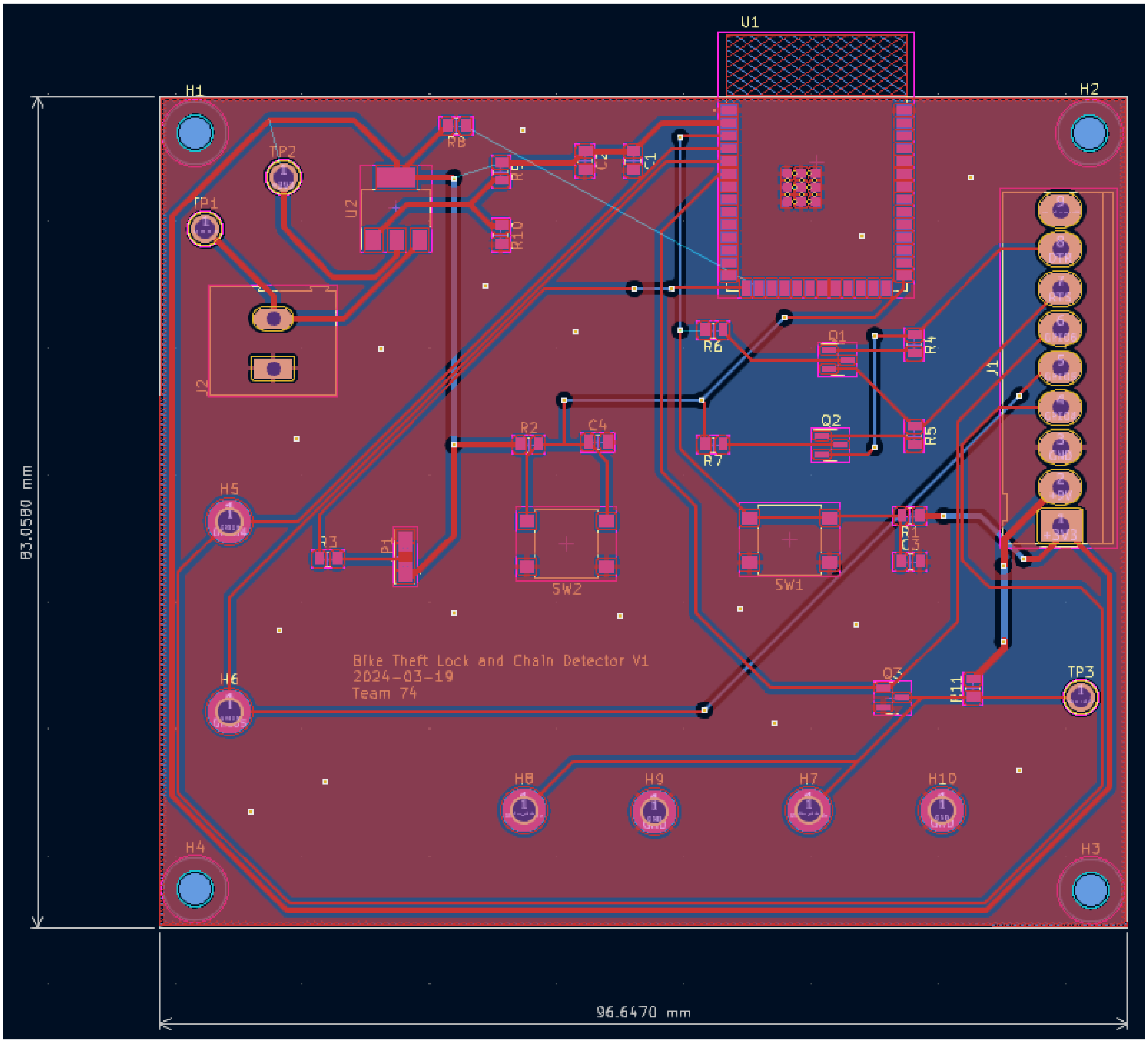

Figure 5. Theft Detection System PCB

3 Cost Analysis

3.1 Labor Costs

The average salaries of electrical engineering and computer engineering graduates from the University of Illinois at Urbana-Champaign $87,769 and $109,176 respectively. Estimated salaries of $98,000 each, our team members would make $47.12/hour.

Labor: $47.12/hour*2.5*80 hours = **$3,769.60 per person**

$3769.60/person * 3 people = **$11,308.80 total**

3.2 Parts cast

Parts	Quantity	Total Cost ($)
9V Batteries	1	12.59
Bipolar (BJT) Transistor NPN 45 V 500 mA 100MHz 300 mW Surface Mount	20	2.04
25V Ceramic Capacitor X7R 0805 (2012 Metric)	20	1.12
Linear Voltage Regulator IC Positive Adjustable 1 Output 1.5A	10	6.06
Tactile Switch SPST-NO Top Actuated Surface Mount	20	12.94
Connector Header Through Hole 9 position	10	5.87
2 Position Wire to Board Terminal Block Horizontal with Board 0.200" (5.08mm) Through Hole	10	6.07
16V Ceramic Capacitor X5R 0805 (2012 Metric)	10	0.64
RES SMD 100K OHM 0.1% 1/8W 0805	20	1.80
RES SMD 10K OHM 0.1% 1/8W 0805	40	3.60
RES SMD 3.3K OHM 0.1% 1/8W 0805	10	0.90
RES SMD 2.2K OHM 0.1% 1/8W 0805	10	0.90

RES SMD 1K OHM 0.1% 1/8W 0805	20	1.80
RES SMD 300 OHM 0.1% 1/8W 0805	10	0.90
25V Ceramic Capacitor X7R 0805 (2012 Metric)	20	1.28
50V Ceramic Capacitor X7R 0805 (2012 Metric)	10	0.63
Bike Lock	1	35.87
DC 3-24V Electronic Buzzer Alarm 10 Pcs	1	9.89
Small junction box	1	6.99
Big junction box	1	8.49
ESP 32 CAM module	1	18.99

Table 1. Parts cost

The listed parts cost above are purchased through UIUC. Moreover, we purchased the ESP32 cam and the enclosure of the design ourselves. The cost of these are listed below:

The total sum of labor and parts cost:

Labor cost + parts cost = $11,308.80 + $141.25 = $11,449.25

4 Design Verification

Please refer to Appendix A for detailed requirements and verification table and refer to Appendix B for photos evidence for verification.

Theft detection system

Sensing Subsystem: We test the voltage ESP32 used to supply the wire is 3.26V using a multimeter as seen in the Figure B1 of Appendix B, so the voltage across the wire is 3.26V. This voltage is much lower than 50V, ensuring human safety when touching. We also test the voltage supplied to the ESP32 is 3.26V, which is within the 3.0V±0.3V operational voltage range, as seen in the Figure B2 of Appendix B.

Power Subsystem: For the detection system, we tested the battery voltage drop per hour is 0.57V as seen in Figure B3 of Appendix B. Since the drop out voltage is 2V for the regulator that steps down the voltage to 3.3V and a 9V battery is used to power the detection system, the battery life is expected to be $\frac{9V-(3.3+2)V}{0.57V} \approx 6\ hours$, which is much higher than our expectation of 3 hours. The battery is 9V, and since the voltage supplied to the ESP32 in the detection system is 3,26 as seen in Figure B2 of Appendix B, the regulator successfully steps down the voltage to operation voltage and supplies the microcontroller.

Control subsystem: We use an online app and detect 91dB at around 5 feet when the alarm is triggered by the control subsystem, as shown in Figure B4 of Appendix B. During the testing, the alarm is recorded to trigger around 1.0 second after wire cut. The ESP32 is supplying a voltage of 3.26V to the wire in the sensing subsystem shown in the Figure B1 of Appendix B.

Wireless camera system

Power system: We use a 9V battery to power the system. The operational voltage of the ESP32-CAM is around 5V. We use a LED light to indicate when voltage drops below 4.26V when a button is pressed, as shown in Figure B5 of Appendix B. As shown in Figure B6, the voltage supplied to the ESP32-CAM is 5.19V, which is around 5V. We failed to verify that the battery can last for around 3 hours however. Since the operational voltage of ESP32-CAM is 5V, it consumes more power than expected, and the battery is tested to last for around 2 hours. This unsatisfied requirement is described more detailedly in the conclusion section. We can confirm that the battery is expected to last for 2 hours.

Camera Control Subsystem: We use a timer together with code to detect the time ESP32-CAM needs to receive a bluetooth signal from the detection system. The signal is fast in transfer, and about 1 second (avg 1.84) is needed for the ESP32-CAM to indicate the signal is received. The tolerance was changed to ± 1 second to account for user error, as we manually timed the bluetooth signal response for testing. The camera-consent-signal is observed to be sent instantly after the bluetooth signal is received (observed through serial monitor display), so the timing data is the same as the previous requirement's verification. These requirements verify that both our code and the ESP32-CAM are fully functional. The timing between camera capture and cell phone notification is measured manually by observing camera flash and Telegram app notification. This timing averages to 3.52 seconds, meeting timing requirements. Despite the requirements being restrictive, the numbers are overall practical for application.

5 Conclusion

5.1 Accomplishments

The chain & lock detector now manages to accomplish the functionality we planned in the proposal; detecting system is capable of detecting the open circuit by a sudden voltage drop when the chain is cut, triggers and alarm to deter the theft, and communicate with the Camera system indicating the chain is cut via bluetooth BLE. The camera system can use the camera system to capture photos of the criminal with flashlight and send pictures to the user phone through WIFI module.

Most of the high level requirements of our design are met. The batteries that supply the detection system are tested to last for about 6 hours, longer than what we presumed in the high level requirement. The alarm triggers within 1.5 seconds after the wire is cut, and the first image is captured within 4.5 seconds after the wire is cut. The accuracy of detecting an open circuit is almost 100%. Its performance is overall better than what is described in the proposal for high level requirements.

5.2 Uncertainties, Alternatives and Future Work

One of the requirements that we failed to accomplish is the 3.0 hours (± 0.5 hours) for the camera control subsystem. We planned to use 3.3V operation voltage for the ESP32 cam, a method when the battery can last for around 6 hours; yet, when using 3.3V operation voltage, bugs are met when we try to program it. We searched online and found it was a common fact that many people reported errors when powering the ESP32-CAM with 3.3V. We decided to switch to 5V operating voltage instead, but this resulted in a higher power consumption and our battery life can only last for 2 hours before the camera system stops. A 5V battery instead of a 9V battery with a regulator can better power the camera module and increase its operational time.

During the process of designing, we met certain problems that hinder our design. Listed as below:

- Voltage regulator not working as intended.
- Wires disconnecting inside camera enclosure.
- ESP32 disconnecting and reconnecting constantly due to capacitors by the switches.

- Shorting components while testing with a multimeter.
- FTDI USB programming failure.
- Using Wi-Fi and Bluetooth in parallel.

We figured out all of these problems, and solved most of them.

The voltage regulator of our previous PCB design doesn't work as intended due to incorrect resistor placement. This was solved after adjusting the resistors.

The container of the camera system we purchased is small for the design. Our camera enclosure is indeed a little messy due to the limited space of the container and multiple components and resistors used for the linear voltage regulator to power the ESP32-CAM. When the box is closed, sometimes the wire disconnects due to the pressure. A larger container in the future can solve this problem.

The ESP32 disconnects and reconnects constantly due to capacitors by the switches. We fixed the problem by removing capacitors C4 and C3 shown in Figure 4.

There was a time when we shorted components when debugging with a multimeter. We had to use our backup component and ensure we tested the design more carefully.

There was a FTDI USB programming failure, and we had to cut a USB cable open and manually solder the data pins onto the ESP32 to program it.

Some of the potential future improvements include supporting rechargeable batteries or 9V batteries in parallel, the design of the user's ability to remotely stop the alarm from the phone, integrating an LTE chip with the ESP32 cam for greater range, improving our battery life indicator so that it not only shows whether the battery can still ensure operating voltage to the ESP32cam and ESP32, but also shows how much power is still left in the battery. The alarm is supplied by the ESP32, and its sound now is 91dB, but a larger alarm sound supplied by another source with higher voltage can be included in the future to produce a larger sound and increase the chance that the theft will be deterred from stealing the bike.

5.3 Ethics and Safety

Our project is guided by the IEEE Code of Ethics and the ACM Code of Ethics and strives to comply with all ethical standards. As our project involves capturing evidence of an alleged crime, we ensured that we are complying with Section II of the IEEE Code of Ethics, which outlines the responsibilities of engineers to “avoid injuring others, their [...] reputation or employment by false or malicious actions [or] rumors”[3]. In accordance with Illinois privacy laws, a person may not be secretly recorded in certain private spaces, but public areas like bike racks and outside of university buildings do not fall under this prohibition. The purpose of this system is to alert and collect evidence, not to incriminate any individual.

In accordance with Section 1.2 of the ACM Code of Ethics, we ensured that the voltage that applied to our system to detect bike lock tampering will not be significant enough to cause any harm to an individual (less than 50V) [4].

The safety of all users who interact with the Bike Theft Lock & Chain Detector and the security of the users’ bike are of utmost importance.

5.4 Broader Impact

The project is accurate in capturing criminal pictures and deterring criminals. It’s highly portable and can be used on all kinds of bikes that can be seen in the market. The implication of this device on bike chains can further reduce the chance of bike theft. Mass usage of such design in a society can not only decrease the amount of stolen bikes, but also improve the chance of stolen bike recovery rate in a community.

References

[1] “Bike Theft in Champaign-Urbana,” Bikelab, Sep. 12, 2014. [Online]. Available: https://bikelab.shop/blog/bike-theft-champaign-urbana [Accessed Feb. 9, 2024].

[2] B Crane, “Bike Theft Surges on University of Illinois Campus, but Online Reporting System Aids Police Investigations,” January 4 2024. [Online]. Available: CU-CitizenAccess, https://cu-citizenaccess.org/2024/01/bike-thefts-surge-on-university-of-illinois-campus-but-online-reporting-system-aids-police-investigations/. [Accessed Feb. 9, 2024]

[3] IEEE, “IEEE Code of Ethics,” ieee.org, Jun. 2020. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html [Accessed Feb. 10, 2024]

[4] ACM, “ACM Code of Ethics and Professional Conduct,” Association for Computing Machinery, Jun. 22, 2018. [Online]. Available: https://www.acm.org/code-of-ethics [Accessed Feb. 10, 2024]

[5]“Handson Technology Datasheet ESP32-CAM WiFi+Bluetooth+Camera Module.” [Online] Available: https://www.handsontec.com/dataspecs/module/ESP32-CAM.pdf [Accessed Feb. 10, 2024]

[6] Texas Instruments, "LM317 3-Terminal Adjustable Regulator," Texas Instruments, 2020, [Online]. Available: https://www.ti.com/lit/ds/symlink/lm317.pdf. [Accessed: Feb. 10, 2024]

Appendix A Requirement and Verification table

Theft Detection System

Sensing Subsystem:

Requirement	Verification	Verification status (N or Y)
Use 3.0±0.3V to supply the current in the wire	Use a small multimeter to detect voltage value.	Y
Within 3.0V to 3.6V voltage to power the ESP32	Use a multimeter to measure DC voltage.	Y
According to the OSHA, voltage should be lower than 50V for no harm to human safety.	Use a multimeter to measure DC voltage.	Y

Power Subsystem:

Requirement	Verification	Verification status (N or Y)
The used battery can last for 3.0h±30 mins	Measurement from multimeter	Y
Voltage regulator steps down the voltage to 3.0±0.3V to power the detector.	Use a multimeter to measure DC voltage.	Y
Supply a 3.0±0.3V voltage to the sensing subsystem.	Use a multimeter to measure DC voltage.	Y

Control Subsystem:

Requirement	Verification	Verification status (N or Y)

65±15dB sound recorded from within 5 feet of alarm module	Use a microphone to capture alarm sound and measure dB.	Y
Alarm signal from the microcontroller is received within 1±0.25sec.	Use a timer to detect the time when the alarm signal from the microcontroller is high at the end of the alarm subsystem.	Y
The subsystem provides a constant 3.3±0.3V voltage to the sensing subsystem.	Use a small multimeter to detect current and voltage value.	Y

Wireless Camera System requirement

Power Subsystem:

Requirement	Verification	Verification status (N or Y)
Voltage regulator steps down the voltage to 5±0.5V to power the camera control subsystem.	Use a multimeter to measure DC voltage at the power pin of the microcontroller.	Y
Indicate when the power supplied to the camera has reduced below 4.3V.	Use an indicator light connected to VCC to determine battery life.	Y
Ensure battery life of 3 hours ± 30 minutes	Use a multimeter to test the DC voltage of the battery supplies before using it in the system. When the batteries are connected to the system, read voltages at the input of the LM317, ensuring it is above 4.8V±0.2V	N

Camera Control Subsystem:

Requirement	Verification	Verification status

		(N or Y)
The bluetooth module of the camera control subsystem successfully received the camera signal from its master microcontroller 1±0.2 sec after the signal was sent.	Connect LEDs to the receiver pin of the ESP32-S, and have a GPIO pin connected to another LED. Write code to power the LED via the GPIO pin on any signal received from the master microcontroller.	Y
Ensure the camera-consent-signal is sent to the camera subsystem through the serial control bus within 3±0.5 sec after the camera signal from its master is received.	Connect the main microcontroller to the computer and ensure that proper protocols are written to have the transmitter sent to the receiver of the slave microcontroller.	Y
Ensure the microcontroller starts to send the image to the user's phone 3±0.5 sec after it receives the image data from the camera module.	Check the code and ensure that proper WIFI communication protocols are set up properly, and test by attempting to see the time between the camera flashlight and the time when serial monitor pops transmitting photo	Y

Appendix B Figures for verification

Figure B1. Voltage ESP32 supply to wire is 3.26V

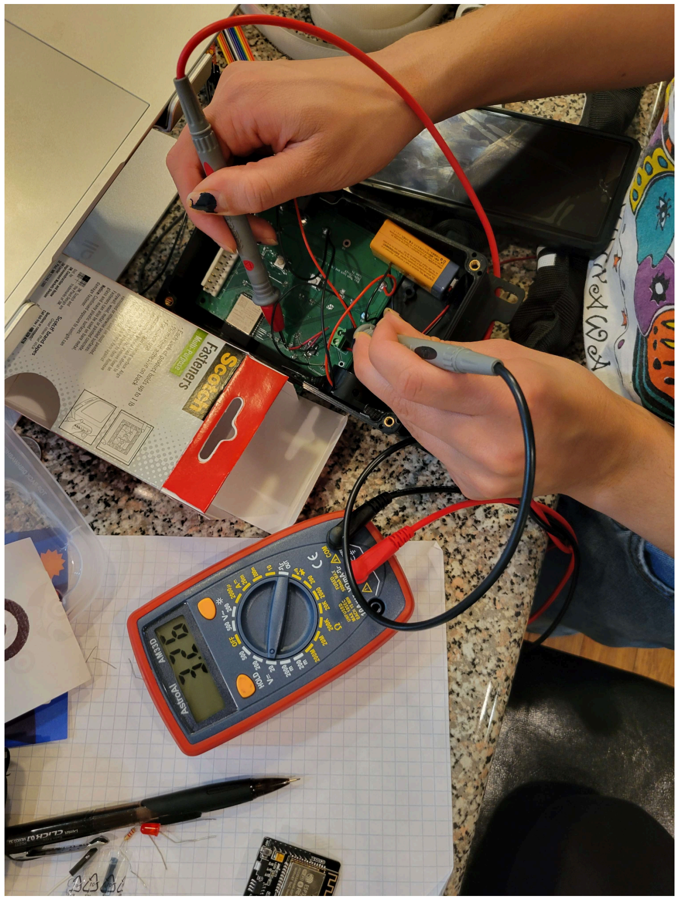

Figure B2. Voltage used to power ESP32 is 3.26V.

0.57V average drop per hour for chain cut detector module.

1.33V average drop per hour for camera.

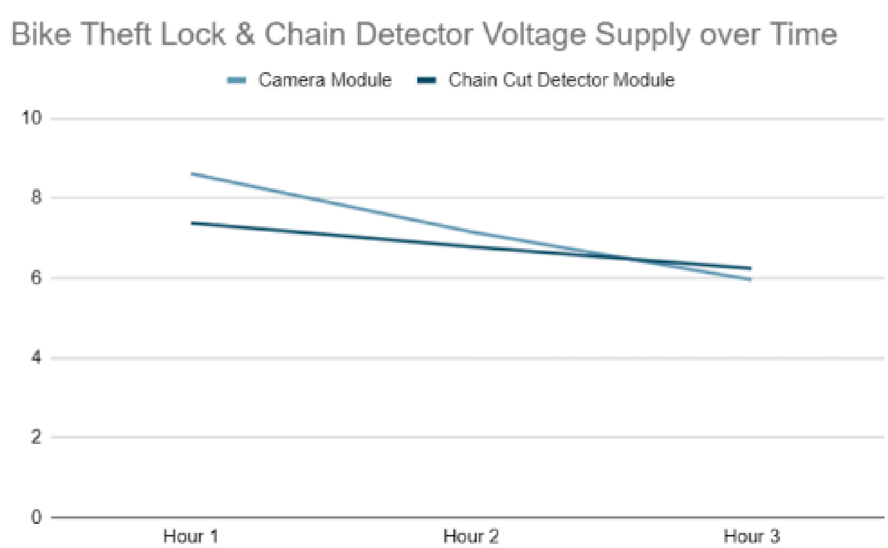

Figure B3. Voltage drop her hour

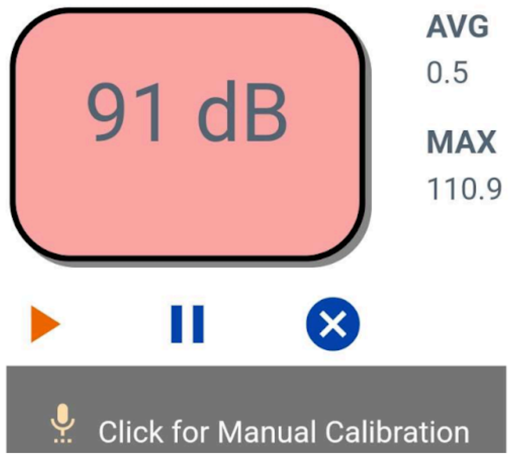

Figure B4. Decibel reading of alarm in 5 feet

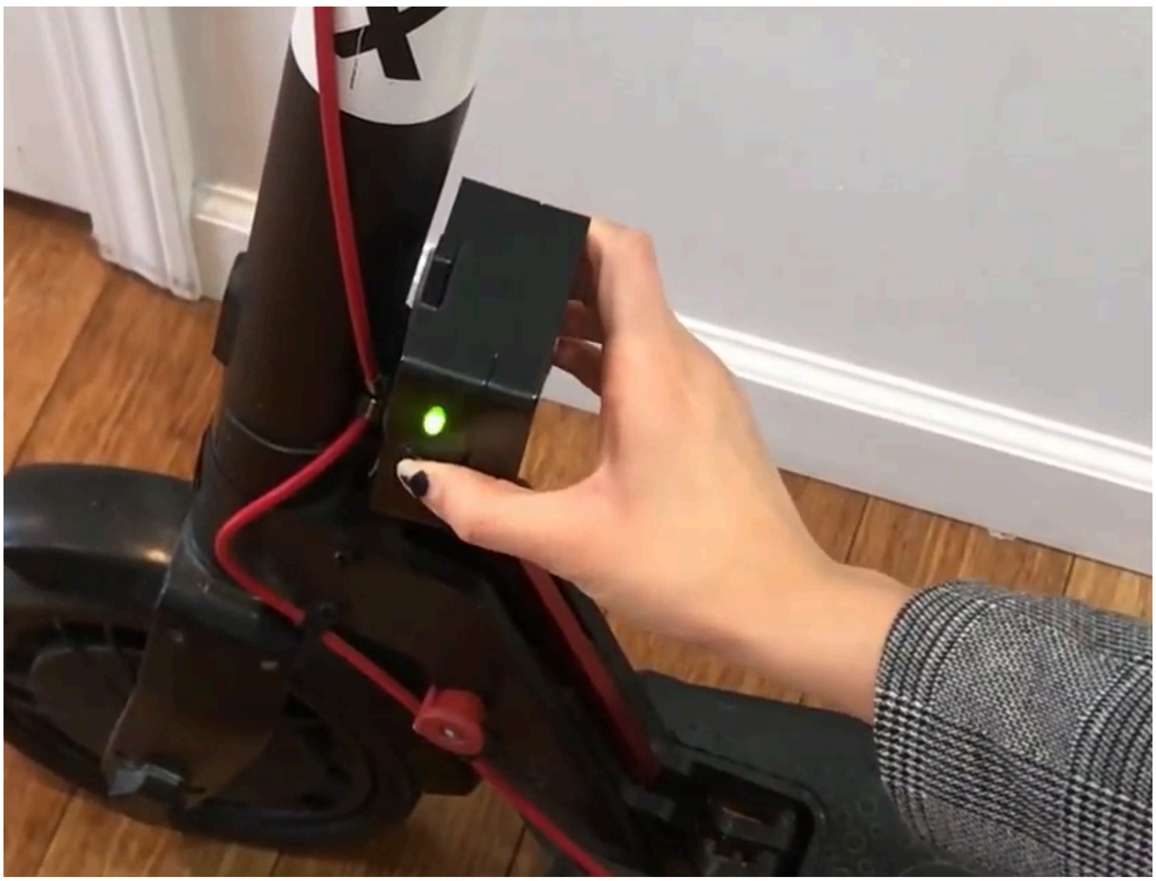

Figure B5. The LED that indicate whether the voltage for ESP32-CAM is below 4.26V

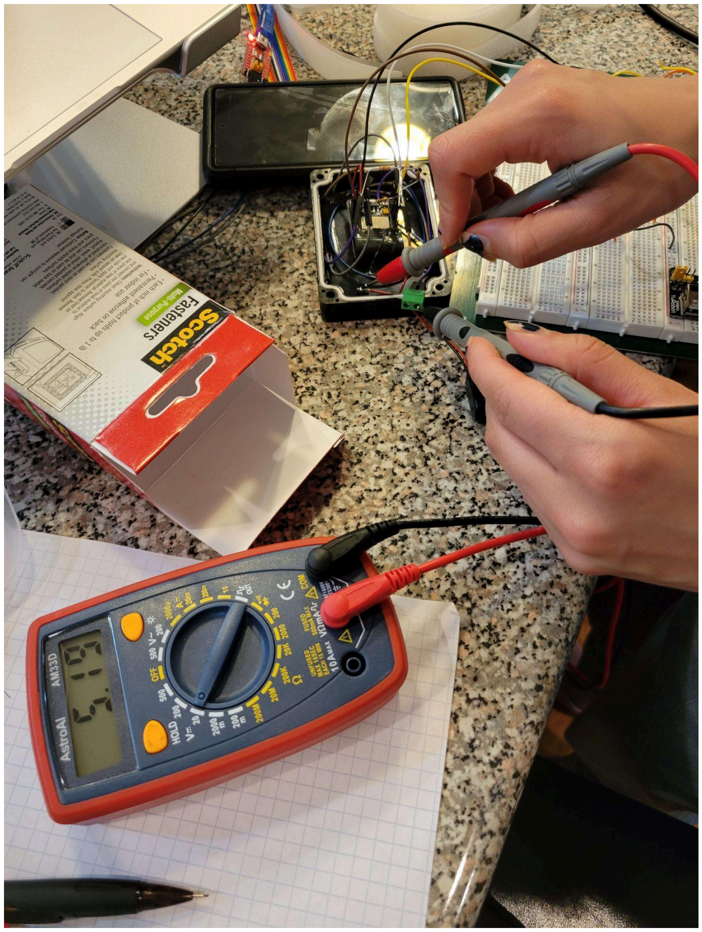

Figure B6. The voltage supplied to the ESP32-CAM

Trial 1	Trial 2	Trial 3	Trial 4
2.26 seconds	1.91 seconds	1.85 seconds	1.34 seconds

Figure B7. Timing recorded between cable cut and bluetooth signal received on ESP32-CAM

Trial 1	Trial 2	Trial 3	Trial 4
2.26 seconds	1.91 seconds	1.85 seconds	1.34 seconds

Figure B8. Timing recorded between cable cut and bluetooth camera consent signal to master microcontroller

Trial 1	Trial 2	Trial 3	Trial 4
4.28 seconds	3.01 seconds	2.92 seconds	3.87 seconds

Figure B9. Timing recorded between observed camera capture flash and Telegram cellphone notification