ECE 445
SENIOR DESIGN LABORATORY
DESIGN DOCUMENT

Bike Theft Lock & Chain Detector

Team 74
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Spring 2024
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6. Reference

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 current will be passed through the cable and an open circuit will be detected by the microcontroller if the cable is cut. When the cable is cut, our cameras positioned on the cable and 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 bluetooth connection. 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 of Bike Theft Lock & Chain Detector

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 of the device should last for about 3.0± 0.5 hours.

Design

2.1 Block Diagram

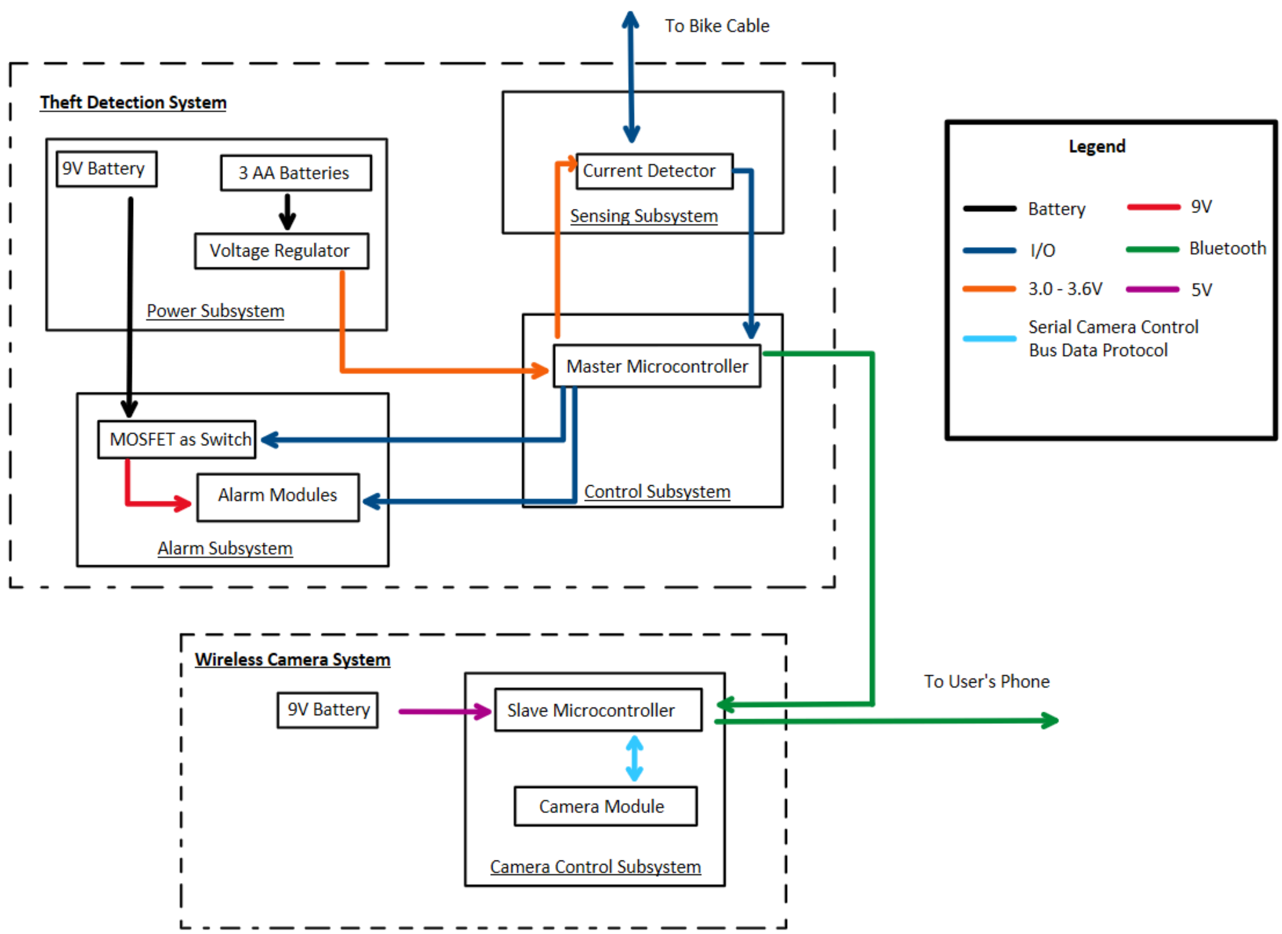

Figure 2. Block diagram

2.1.1 Physical Design

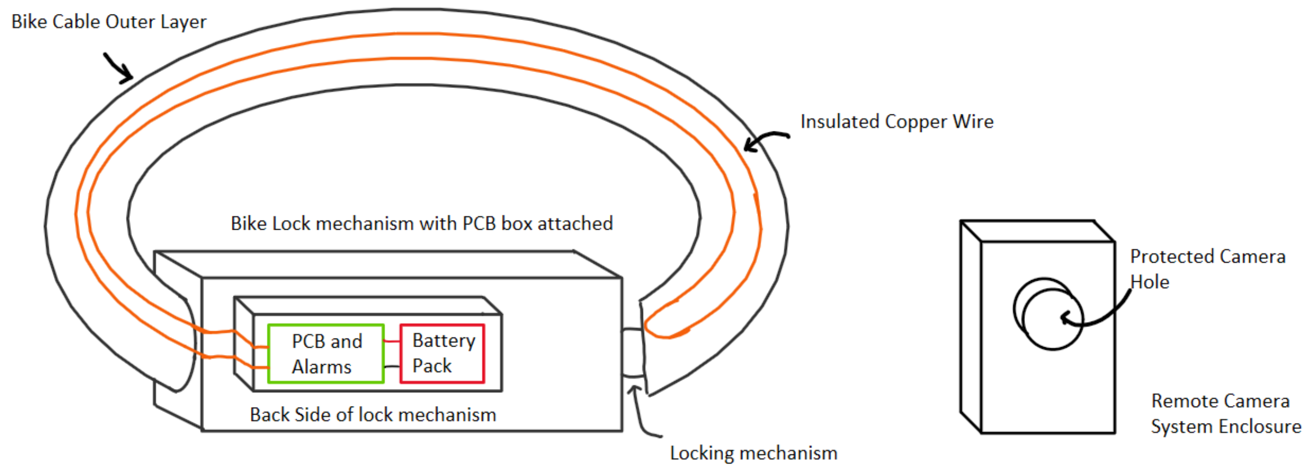

Figure 3. Design Sketch

A box enclosing our main subsystem would be physically attached to the bike lock as shown above, with an insulated copper wire running through the entirety of the cable length as part of the current detection system. The copper wire will be bent at the end by the locking mechanism and return back to the side it came from, connecting into a different pin on our microcontroller. This will help ensure that any cuts through the bike cable will set off an alarm, while still being able to lock and unlock without setting an alarm off.

The box enclosing our main system will need to include the PCB which would be at most 100x100 millimeters, the alarm modules, and the battery pack powering our system. The layout of batteries is still subject to change, but assuming a 2x2 formation while keeping the batteries serially connected, the enclosure box must account for the extra 100x28 millimeter battery pack. The remotely connected camera subsystem must also be enclosed with a hole to fit the 5.8x6.3 millimeter camera.

2.2 Subsystem Overview

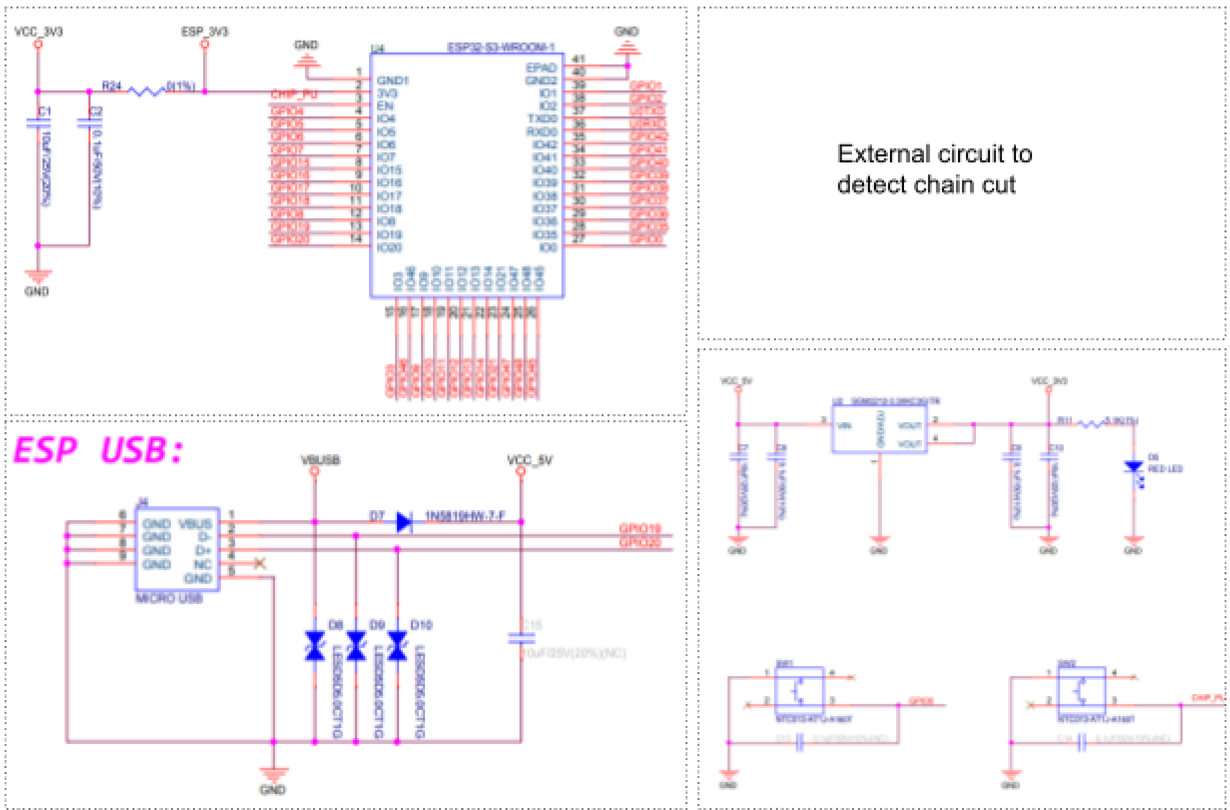

Figure 4. Draft of Schematic (Source: Espressif) [9]

2.2.1 Theft Detection System

<u>Sensing subsystem:</u>

The sensing system, or open circuit detection subsystem, is used to detect if the lock chain of the bike is cut and send signals to the microcontroller when the chain is cut. The system with its circuit is powered by the power system. The open circuit detection subsystem consists of a circuit along the lock chain and a current detector used to detect if such circuit is open. A signal will be sent to the microcontroller indicating that the circuit is open.

<u>Alarm subsystem:</u>

The alarm subsystem guarantees that the alarm will be triggered within 5±3sec after the lock is cut. It consists of a voltage boost converter and an alarm module. The voltage boost converter serves to boost up the voltage received from the power supply subsystem so that the alarm module, with a higher voltage, can make a larger sound.

Power subsystem:

The power supply system is used to supply power to our whole system. An alkaline 9V battery will be used to power the alarm system. Four 1.5V AA Alkaline batteries in series will be connected to an LM317 voltage regulator to supply 3.0 ~ 3.6 V to the ESP32-S3-WROOM microcontroller, and less than 10mA to the circuit cable in the open circuit detection subsystem. The power supply system will additionally use a 9V battery to power the speaker in the sound alarm subsystem.

Control subsystem:

The control subsystem in the theft detection system consists of a master microcontroller that controls the device. The system is powered by the power system. From the sensing subsystem, the microcontroller's IO receives the signal that indicates the lock has been cut, and sends signals using its IO to the alarm subsystem, informing the alarm to sound. Meanwhile, the microcontroller sends signals via bluetooth to the remote camera control subsystem, which controls the wireless camera system. The ESP32-S3-WROOM, a generic Wi-Fi + Bluetooth LE MCU module, is used as the microcontroller.

2.2.2 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. Four 1.5V AA Alkaline batteries will be connected in series to an LM317 voltage regulator to get a lower voltage for the camera microcontroller. The power supply system is hardwired to our subsystems to supply 5V and 500mA to the ESP32-S in the camera controller subsystem.

Camera control subsystem:

This is the slave microcontroller to the control subsystem in the theft detection system. A ESP32-S microcontroller is used for this control system. Using its bluetooth 4, it receives the signal from the theft detection system. Then it sends a signal from its IO to the 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 bluetooth.

2.3 Subsystem Requirements

2.3.1 Theft Detection System

Sensing Subsystem:

Requirement	Verification
Within 7±3mA current runs through the circuit.	Use a small ammeter to detect current value.
Within 3.0V to 3.6V voltage to power the detector.	Use a multimeter to measure DC voltage.
Successful detection whether the current is lower than 5mA.	Detects whether the signal is high using an LED in the absence of the <5mA that should run through the cable.

Alarm Subsystem:

Requirement	Verification
65±15dB sound recorded from within 5 feet of alarm module	Use a microphone to capture alarm sound and measure dB.
Alarm will be triggered within 5±3sec after the lock is cut	Use a timer to detect the time the alarm triggered after the lock is cut.
Alarm signal from the microcontroller is received within 2±0.5sec.	Use a timer to detect the time when the alarm signal from the microcontroller is high at the end of the alarm subsystem.

Power Subsystem:

Requirement	Verification
The used battery provides constant DC voltage of 9±0.6V to the speaker in the sound alarm subsystem.	Use a multimeter to measure DC voltage.
Voltage regulator steps down the voltage from 6V to 3.3±0.3V to power the detector.	Use a multimeter to measure DC voltage.
Supply a 7±3mA current to the sensing subsystem.	Use a small ammeter to detect current value.

Control Subsystem:

Requirement	Verification
The control subsystem sends an alarm signal to the alarm subsystem after receiving the open circuit signal from the sensing subsystem within 0.5±0.1sec.	Check the time between the high open circuit signal and the high alarm subsystem.
The signal to the camera slave microcontroller is sent within 0.5±0.1sec after receiving the open circuit signal via bluetooth.	Check the time when the open circuit signal is high and the time when the bluetooth signal is sent by the microcontroller.
The subsystem provides a constant 3.3±0.3V voltage with a 15±3mA DC current to the sensing subsystem.	Use a small ammeter and multimeter to detect current and voltage value.

2.3.2 Wireless Camera System

Power Subsystem:

Requirement	Verification

Voltage regulator steps down the voltage from 6V to 3.0±0.3V to power the camera control subsystem.	Use a multimeter to measure DC voltage at the power pin of the microcontroller.
Ensure the maximum DC current provided to the camera subsystem is within 500mA±100mA	Use an ammeter to detect current value at the output of the LM317.
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

Camera Control Subsystem:

Requirement	Verification
The bluetooth module of the camera control subsystem successfully received the camera signal from its master microcontroller after 10±0.5 sec.	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.
Ensure the camera-consent-signal is sent to the camera subsystem through the serial control bus within 5±3 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 transmitter send to the receiver of the slave microcontroller
Ensure the microcontroller starts to send the image to the user's phone 10±5 sec after it receives the image data from the camera module.	Check the code and ensure that proper Bluetooth 2 way communication protocols are set up properly, and test by attempting to find the module on a phone, and connecting to said module.

2.4 Tolerance Analysis

2.4.1 Voltage regulator

A key factor to the success of our project is the functionality of our power system. To properly power the rest of our project, we will need to apply the LM317 Voltage Regulator chip to step down the AA batteries in series from 6V to an appropriate voltage between 3.0V and 3.6V.

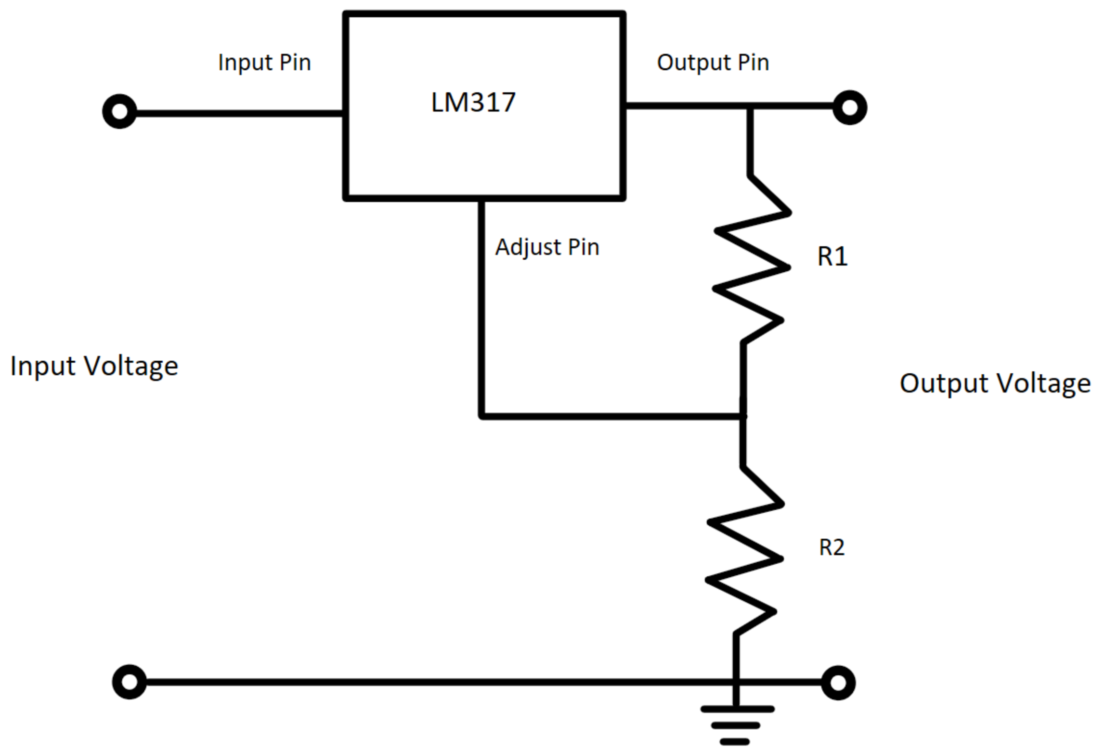

Figure 5. LM317 voltage regulator

While the equation for the output voltage given by the datasheet [6] is shown in Equation 1, the output current from the adjust pin is listed as 50 microamps, and will not interfere with our application, thus simplifying to Equation 2.

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

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

Since the regulator works by sourcing a current to output a voltage 1.25V higher than the voltage from the adjust pin, Vref will be set to 1.25. The equations can then be solved by picking an arbitrary output voltage between 1.25V and 37V by selecting physical resistors to create the ratio needed for the selected output voltage.

$$\frac{V_{\text{out}}}{1.25} - 1 = \frac{R_2}{R_1} \tag{3}$$

For both the main and slave microcontrollers, a safe operating voltage will be 3.3V. Using this value, the resistor ratio comes out to be 1.64. In order to provide the necessary 500mA to the microcontroller, the total resistance must add up to 6.6 ohms via Ohm's Law.

In order for the voltage regulator to function within the provided design margins, there is a specification known as the dropout voltage where the input voltage minus the output voltage must meet or exceed this value. The LM317 datasheet [6] recommends a minimum dropout voltage of 3V, however, more specifics are included in the datasheet [8] provided by the creator of the LM317, National Semiconductor.

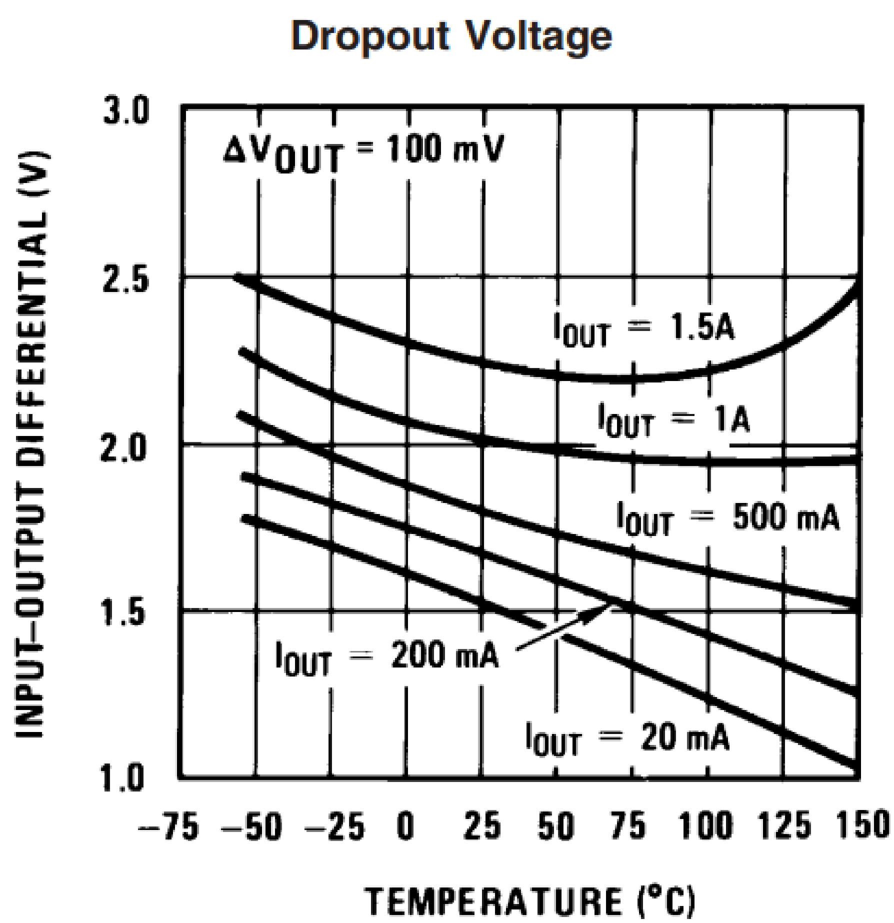

Figure 6. Temperature vs. Dropout Voltage at various load currents

Since our input voltage is 6V with 3.3V as the output, the dropout voltage we produce is 2.7V which is less than the recommended value of 3V, but at a load current of 500mA this is fine for any temperature in the graph. This means the regulator should provide the desired output for any weather conditions that our product may be exposed to.

2.4.2 Battery Life

The steps, formulas, and method of this LM317 voltage regulator are stated in 2.4.1 As discussed in the previous section, one of the pivotal steps of the design is to step down the voltage from the 6V to the microcontrollers' operating voltage. For both of the microcontrollers, a voltage regulator with a LM317 chip as indicated by Figure 5 is needed to step down the 6V voltage to 3.0V operating voltage with an operational current of 500mA.

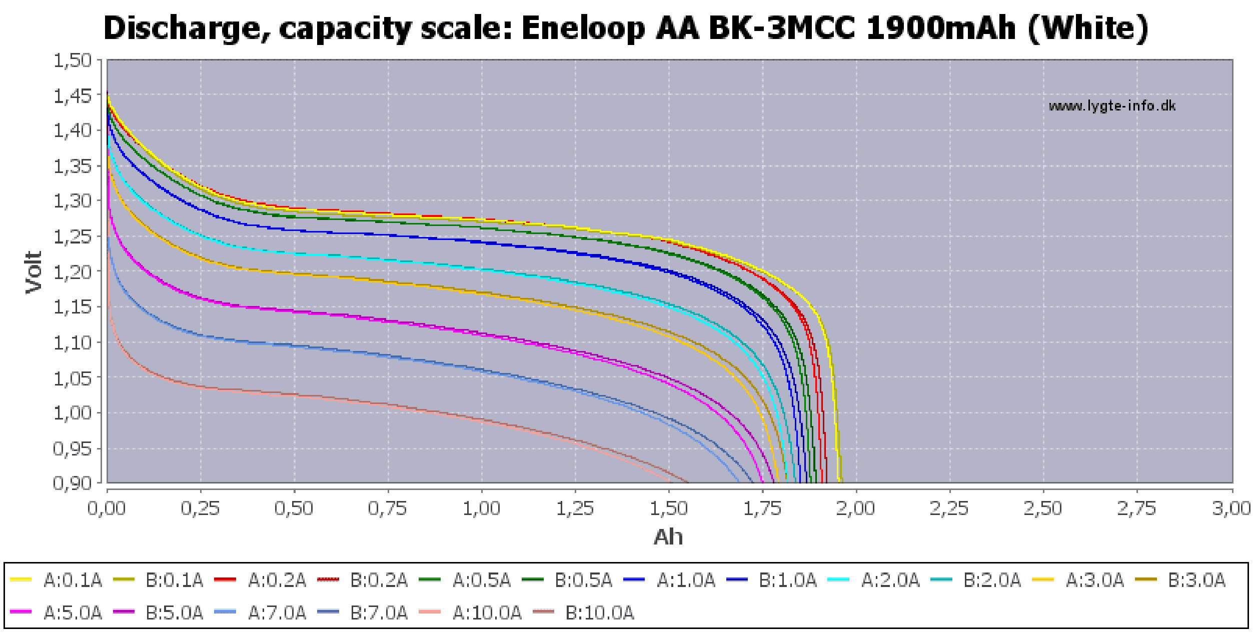

Figure 7. Discharge profile of 1.5V AA BK-3MCC battery

Taking the AA BK-3MCC as an example. For every AA battery, from the graph above, the average voltage input for a 1.5V AA battery with a current of 0.5A is about 1.27V. Thus, using the formula below, it's calculated that the efficiency of the regulator is

$$\eta = \frac{V_{out}}{V_{in}} = \frac{3V}{4\times1.27V} = 59.05\%$$

Although efficiency is just above 50%, this calculation makes sense as we are looking to bring a maximum of 6V input down to a minimum of 3V for the microcontroller to receive sufficient power. This also allows us to see how much power is dissipated as heat by the LM317.

Figure 7 indicates an average of 1.27V at our load of 500mA. Using 4 AA batteries in series at this voltage will result in a total input voltage of 5.08V. Looking back at the LM317, our calculations for the batteries at nominal voltage resulted in a sufficient dropout voltage, but the average value of battery voltage brings this down to 1.78V if the regulator output is 3.3V, causing the regulator to be extremely close to failure. The simple solution would be to bring the output voltage down to 3V, which is still enough to power our microcontroller, and may require changes in resistor values.

If we take dropout voltage at room temperature as 1.8V from Figure 6, assuming best case scenario and the rated capacity of 1900mAh, 4 AA batteries in series would provide power to our circuit until they reach 1.2V, resulting in an actual capacity of 1.625Ah. If the microcontroller were to draw a continuous 500mA, our batteries would last for 3.25 hours. Despite this, the ESP32 in both main and remote systems will draw a different amount of current depending on if it is in work mode, deep sleep, modem sleep, etc. The datasheet [10] lists these values as ranging between 97µA and 355mA. Depending on the time that the device is in these modes, the battery life would overall increase, as a constant 500mA is not used and thus should not be drawn from the LM317.

Cost Analysis

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**

Parts Costs

Description	Manufacturer	Part #	Quantity	Total Cost ($)	Purchase Link
WiFi+Bluetooth+Camera Module	OmniVision	Product name: ESP32-CAM WiFi+Bluetooth module: ESP-32S. Camera Module: OV2640 2MP.	3	18.99	Link
80dB Electronic Buzzer Alarm Sounder with Continuous Beep	Tatoko	Tatoko DC 3-24V	10 pack	9.99	Link
9V Disposable Alkaline Battery	Amazon Basics	N/A	8 pack	12.45	Link
AA Disposable Alkaline Battery	Amazon Basics	N/A	20 pack	8.87	Link
8mm Chain Key Chain Bicycle Lock	Kryptonite	N/A	1	19.96	Link
LM317 Voltage Regulator	Texas Instruments	LM317 chip	2	1.90	Link
MOSFET (NMOS)	Diodes Incorporated	2N7002	1	0.20	Link
Miscellaneous Resistors	N/A	N/A	~20	~5.00	N/A

Miscellaneous Capacitors	N/A	N/A	~30	~10.00	N/A
Spare Components	N/A	N/A	N/A	~10.00	N/A
Estimated Taxes & Delivery Fees (12% of above)	N/A	N/A	N/A	~15.00	N/A
Total				$112.36	

The total cost is the sum of the cost of labor and of parts:

$11,308.80 + $112.36 = **$11,421.16**

Schedule

Week	**Task**	**Person**
2/18 - 2/24	Design Review sign-up	All
	Order Hardware Parts	All
	Design and Build switching circuit for alarms	Jonathan
	Research Bluetooth Protocol with Microcontroller	Zhuoyuan and Natasha
	Research ESP32-S3-WROOM Programming	Natasha
3/2 - 3/9	Finalize PCB design and Order PCB	All
	Teamwork Evaluation	All
	Order PCB parts	Natasha
	Test battery setup with voltage regulator	Jonathan

	Work on Bluetooth protocol between camera and ESP32-S3-WROOM microcontroller on dev kit	Zhuoyuan and Natasha
3/10 - 3/16 (Spring Break)		
3/14 - 3/23	Test PCB design	Jonathan
	Work on Bluetooth protocol between ESP32-S3-WROOM microcontroller on dev kit and phone	Zhuoyuan and Natasha
	Work on smartphone application	Zhuoyuan and Natasha
3/24 - 3/30	Individual Progress Reports	All
	Work on GPIO driver for alarm buzzer with dev kit	Natasha
	Work on GPIO camera driver with dev kit	Zhuoyuan
	Continue smartphone application development	Natasha and Zhuoyuan
	Refine PCB Design (if necessary)	Jonathan
3/31 - 4/6	Assemble PCB and Bike Lock system	All
	Test GPIO driver for alarm buzzer with PCB	Natasha and Jonathan
	Test GPIO camera driver with PCB	Zhuoyuan and Jonathan
	Test smartphone bluetooth communication with ESP32-S3-WROOM microcontroller on PCB	All
4/7 - 4/13	Assemble and integrate all components	All
	Test functionality	All
4/14- 4/20	Mock Demo	All
	Begin Final Paper	All
	Team contract fulfillment	All
4/21 - 4/27	Final Demo	All
	Mock Presentation	All

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 must ensure 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 will ensure that the current that will run through our system to detect bike lock tampering will not be significant enough to cause any harm to an individual [4]. According to OSHA, a current of less than 10mA allows an individual to maintain control of their hand, but a current in the range of 0-5mA, is the safest without causing the individual pain [11]. We will ensure the current running through the chain is in the safe range by adding significant resistance to the system.

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. If an active electrical wire comes in contact with water, it can cause electrical fires or electric shock to the user. To prevent this issue in the case of rain, we will ensure that all electrical equipment is waterproofed and protected from the environment.

References

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