Smart Bike Lock

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ECE 445 Second Design Document -- Spring 2020
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1 Introduction

1.1 Objective

According to Project 529, the world's largest bike registry, around 2 million bikes are stolen annually in North America which is a bike stolen every 30 seconds [10]. Bike locks provide a good first line of defense versus any opportunistic thieves that see unattended bikes. It is not uncommon though for those thieves to be equipped with cutting tools to remove those locks. Changing the material of the lock to not be cut is expensive and a lot of time just makes the lock too bulky or expensive and sometimes does not even work if they brought more heavy duty cutting tools. The idea of this project is to create a bike lock that lets the owner of the bike react to their bike being stolen if they're in the area or to retrieve it after if the owner is not. This GPS alternative would be cheaper than and easier to handle than alternatives. The lock will also be electronically unlocked to stop any thieves trying to pick the lock rather than using brute force. Since it is electronically controlled it is also more convenient to unlock with an app rather than a loose key.

1.2 Background Information

Locks have been getting more advanced with cutting resistant materials like the Tex-lock or electronic unlocks like the Bitlock [1]. There are also GPS trackers for bikes such as the Sherlock Bike Tracker, this however is not a lock. The past project that this is based off of used a wheel locking mechanism if the bike is moved without being unlocked properly. We see the front-locking mechanism as a weakness because if the thieves have cutting tools then the locking mechanism can be removed like any other normal lock. Our bike lock will incorporate multiple of these features like the GPS tracking, the app for unlocking, plus a lock that is difficult to remove improperly. Unlike the last attempt at this project, we are more focused on detection and recovery as our primary defense mechanism, as opposed to deterrence from the last project, since determined bike thieves will be able to bypass just about any lock.

1.3 High-Level Requirements

1. The lithium polymer battery must be able to power the device continuously for 48 hours of operation and be weather-proof.
2. The lock must be able to transmit a "cut-chain" notification signaling the owner that the lock has been cut with 100% accuracy, as long as the bike has a network connection the distance between the owner and the lock is irrelevant..
3. The device must be able to track GPS location continuously to the app while operating, giving updated location every minute with a location accuracy of at least 10 feet.

2 Design

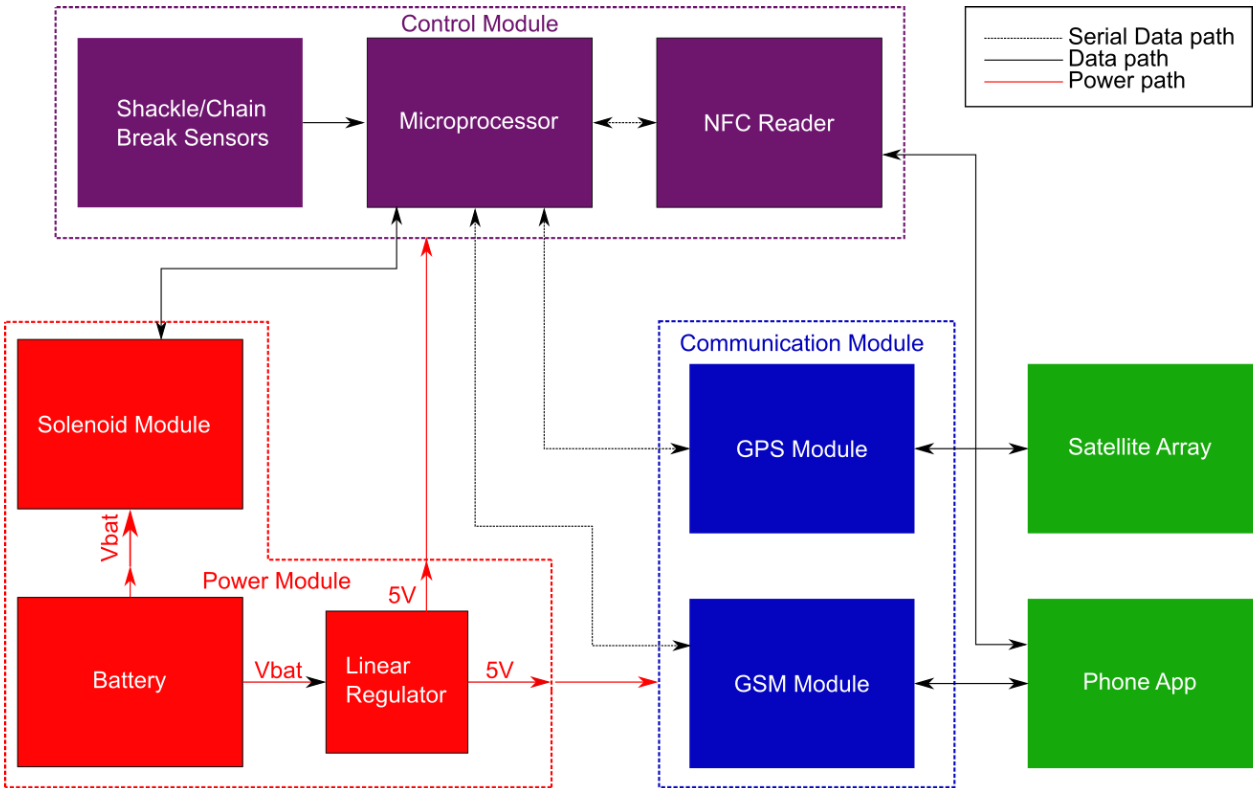

Fig 1. Block Diagram of proposed smart lock solution

The design overview can best be understood via the block diagram in figure 1. This figure is arranged such that all submodules receive the same voltage I.E. all components of the control module run off of the same 5V rail. Communication between the microprocessor and the individual components is performed as a serial data transfer. Communication to a phone and from the GPS satellite will use appropriate data transfer standards for those applications. Components in green are not a module in our design, but are important external components that our system interacts with.

2.1 Physical Design

The physical design of the lock consists of several components. Firstly, there is the lock body which provides the bulk of the mechanical stability for the whole system and houses the electronic components. The lock body concept can be seen in figure 2, with an etched indicator of where a user would place their phone to perform an NFC handshake as well as the slots for the shackles. Figure 3 depicts the rear side of the lock body with the mounting mechanism attached. The mount is designed to close around the main portion of a bike frame, to be secured and tightened by a pair of proprietary screws which are incompatible with standard driver heads. In addition these screws will be hidden with small rubber or plastic caps. These features seek to deter a thief from removing the lock itself which would prevent us from tracking the stolen bike. The shackles, as seen in figure 4, hold a chain in place. One shackle will be attached permanently to the lock body along with one end of the chain. This is to allow a seamless and secure connection of the short-detection wire. The other shackle will be held in place by our solenoid bar and can be removed. The wire connection on this side will be placed somewhere discrete, close to the hole for the shackle.

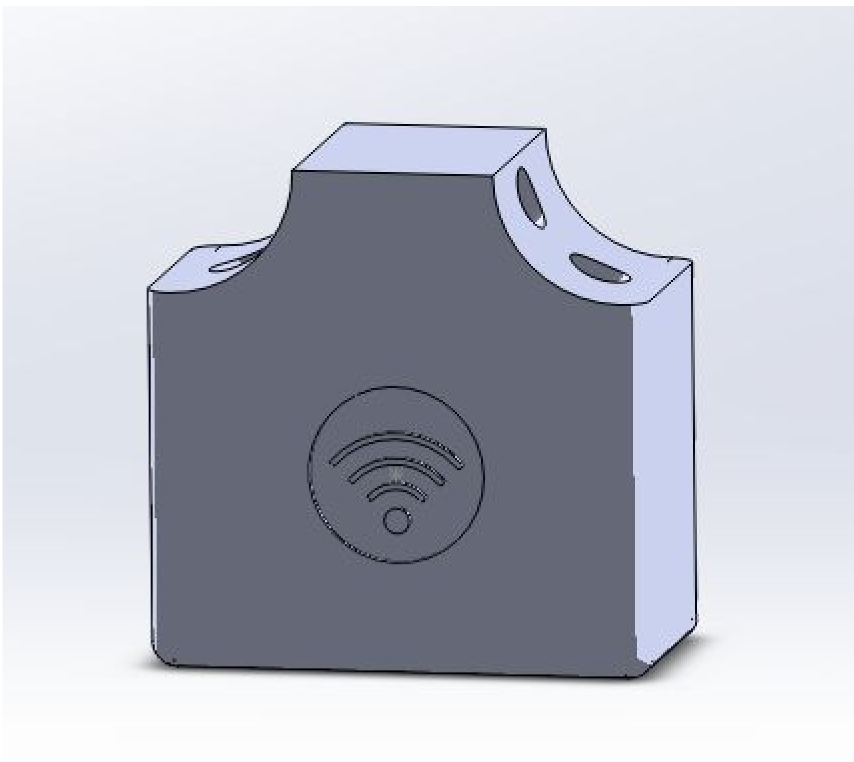

Fig 2. Front side of the lock body with shackle holes and NFC etching displayed

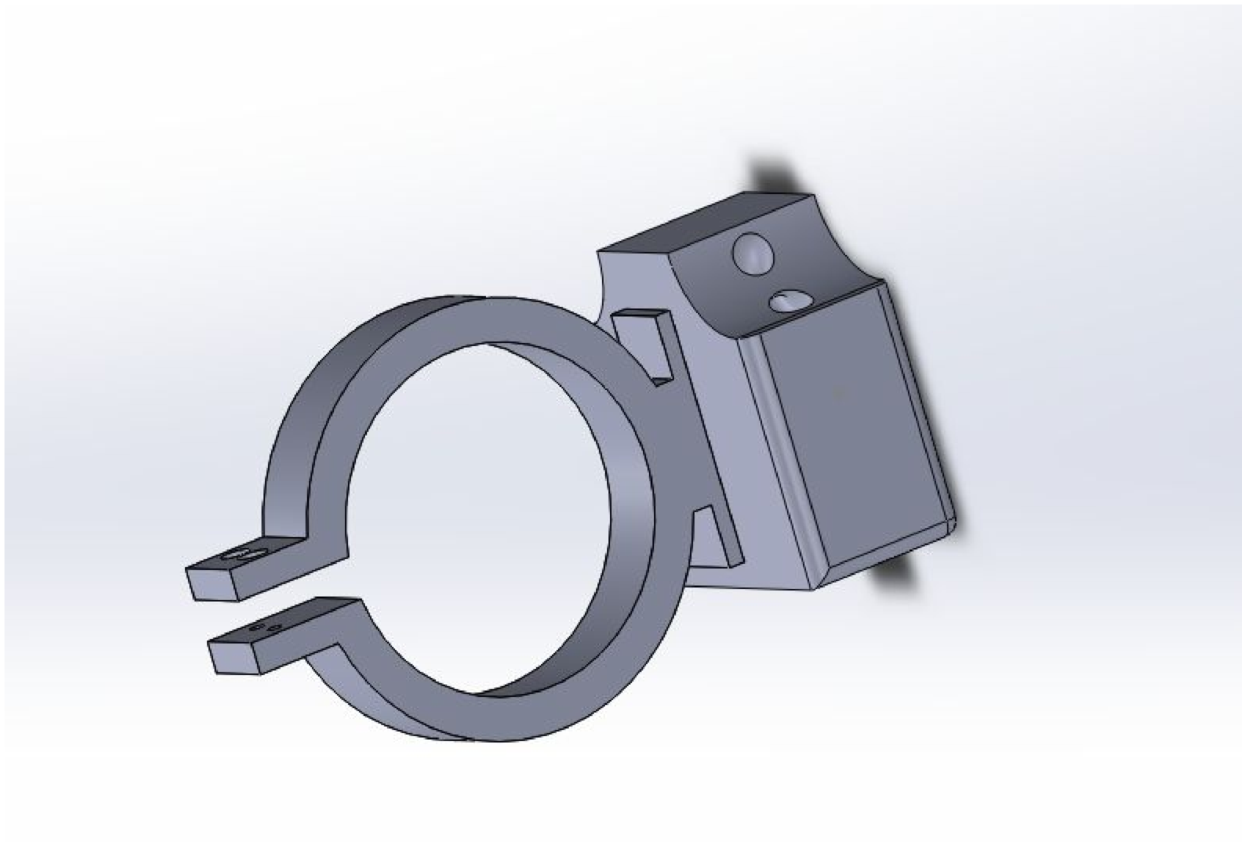

Fig 3. Rear side of lock body demonstrating frame mount mechanism

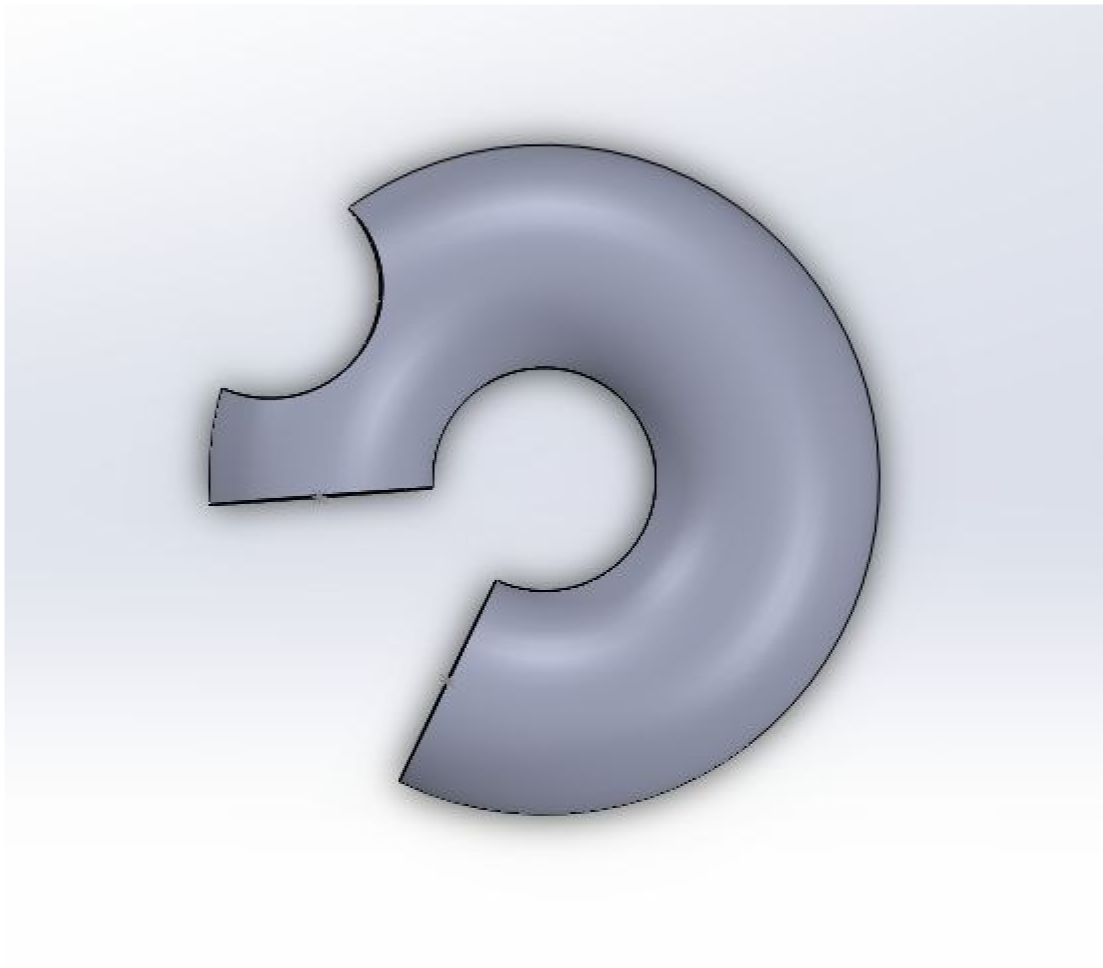

Fig 4. Concept for a removable shackle

2.2 Control Module

2.2.1 Microprocessor

A small microprocessor is needed to control the lock, as well as communicate the status of the device to the owner. A simple controller like an ATmega 328 can perform this function. [11] However, both the GPS and Wireless modules require a serial connection, so the microprocessor must be able to support connections to each. Software serial libraries will work since the data rate for each module is not very high.
Since the ATmega 328 is a very popular processor, schematics for connecting it into external circuits are widely available. In particular, the Arduino Pro Mini’s design will be suitable for our project, with unused I/O leads removed to save space. Fig. 2 Below shows this reference design.

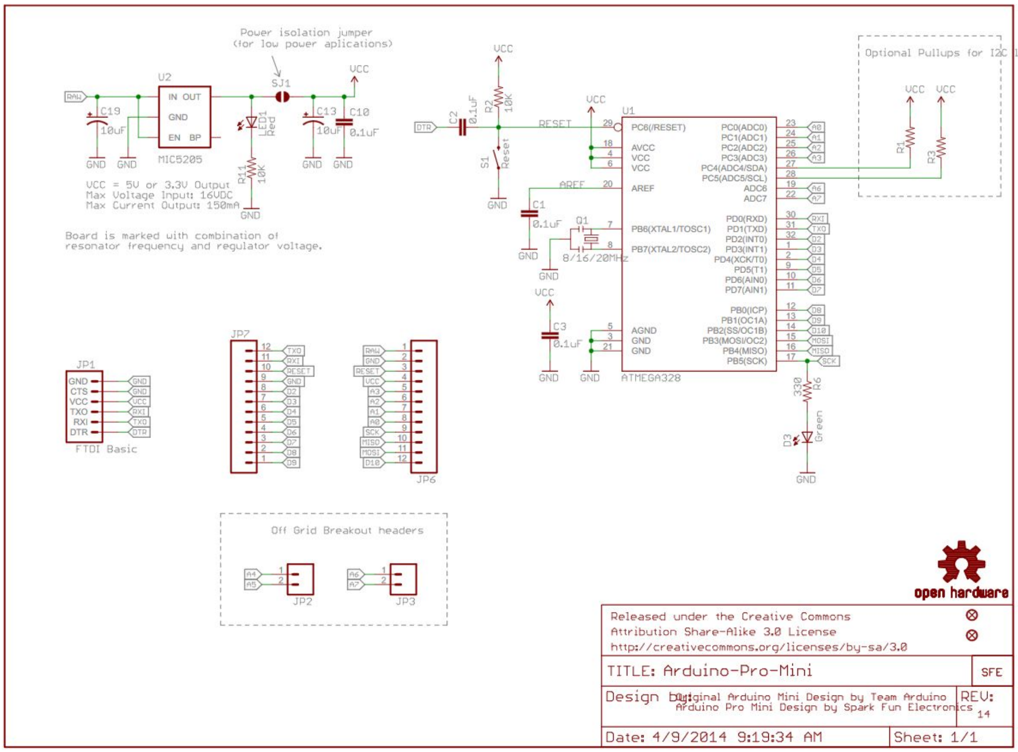

Fig. 5 A reference design for the ATmega 328 to use in our design

Requirement	Verification
The microprocessor should draw no more than 10mA while in standby.	1. Connect an ammeter between a 3.3v bench power source and the power lead for the microprocessor module (including required circuitry) and a debug console to the device 2. Allow the device to powerate normally for at least 60 seconds after turning on power to allow for bootup 3. Wait for low-power state to be reached (a message will be sent from debug console) 4. Measure current draw at power line in 5. Repeat 3-4 for at least 5 low-power cycles, averaging current across all test points

2.2.2 NFC Reader

The lock must be able to acknowledge when the user wants to open it, so an NFC reader will be built so that the user can hold their phone while using the application to be able to unlock the lock. NFC is better than other communication methods because it does not require sending data over an internet connection, potentially providing more attack vectors.

Requirement	Verification
The lock must be able to unlock while a phone running the app is less than 2cm from NFC reader.	1. Load a phone with the app, and activate the lock with the app 2. Verify that the lock opens when the phone is placed near it 3. Repeat 2 at least 5 times to esure that unlocking is repeatable

2.2.3 Lock Status Sensors

We could place something like an IR emitter/sensor pair pointing at the shackle so that if the shackle were to be broken, the signal from the sensor would change and the break would be detected. For detecting the chain, we would conceal a small 25 AWG wire running around the length of the chain and run current through it sourced by the microcontrollers internal pull-up resistors. If the chain were to be cut so would the wire and we would detect an open circuit. This pullup resistor is 50KΩ, and with the 5v supply, should apply 10μA of current across this wire. The low voltage and current should keep the chain safe to cut and handle even when the circuit is live

Requirement	Verification
Microcontroller can tell when there is no current running through the wire with 100% accuracy	1. Connect device to a PC debug console 2. Connect the lock, and verify that the state is closed 3. Break the connection, and verify that the state is open 4. Repeat 2-3 for 30 disconnects in a row to measure accuracy of true positives and ensuring there are no false positives

2.3 Communication Module

2.3.1 GPS Module

A GPS module will be used to track the location of the lock and the bike attached to it, so that the owner can find their bike in the event that it is stolen or lost. This module will communicate with the microprocessor via a digital serial interface to send data over cellular to the owner's smartphone.

Requirement	Verification
The GPS module should be accurate to within 10 feet	1. Obtain the GPS coordinates of some location using a known-accurate GPS device (eg. smartphone) 2. With the device as close as possible to that location take a reading from the gps module and output to external debug console on a PC 3. Verify that the difference between the two coordinates is less than 12 feet to account for inaccuracies in the smartphone.[12] 4. Repeat 1-3 in at least 3 different location more than 20 feet apart
The GPS module should update its position at least once a minute	1. Put the device in a known location for at least 5 minutes to ensure that it is unmoved 2. Connect a debug console with a PC 3. Check that the correct position is displayed in debug console 4. Move the device to another location at least 20 feet away 5. Check that the updated position is reflected within a minute in the debug console

2.3.2 GSM Module

The lock will send location and security information to the users phone via a network connection across the internet. The device should be able to communicate in as many places as possible, so a GSM radio will achieve this while using infrastructure already built in place.

Requirement	Verification
The lock should be able to send status information (location, whether the lock is secure) at least once a minute while in cellular coverage.	1. Connect the signal and ground pin together using a switch in the ON position 2. Ensure that the phone reads “SECURE”, that it believes that the lock is intact 3. Turn the switch to the OFF position 4. Verify that the phone receives the “BROKEN” status within 1 minute

2.4 Power Module

2.4.1 Battery

For this device, we will be using two 1200mAh Lithium Polymer batteries with a nominal voltage of 3.7V [15]. We must use two batteries because each one has an operating voltage range from 3-3.7V. By combining the batteries, we can instead operate as if we had a single 1200mAh battery that ranges from 6-7.4V. In this case our “capacity” is not strictly 2.4mAh especially because it requires some losses to occur in various voltage regulators, however we will still be able to run the battery pack longer than if we had a single battery. In general, every component except for the solenoid will in turn off of either 3.3V or 5V as ability decrees with a preference for running at 5V. Linear regulators are very small and easy to use voltage regulators which can step down an input voltage and create a fixed output, but dissipate the current*(Vin-Vo) as heat loss so they are less efficient the more you need to step down the voltage. A switching power supply would be more efficient, but would introduce larger costs and significant EMI not to mention various design problems and could even require dedicated controls. The solenoid can take any voltage in our range and it will be the most efficient to simply operate it directly off of the battery voltage.

Requirement	Verification
-The battery should be able to power the system under regular use for up to 48 hours	-The system will be field tested for battery life multiple times after assembly to ensure a consistent user experience

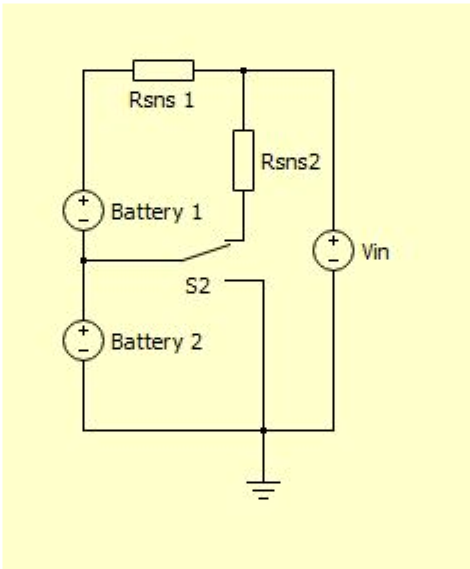

Fig 6. Simplified schematic of charging circuit

2.4.2 Battery Charging & Safety Setup

Battery charging and safety for these devices is a very simple process. They each have a small board attached to the output that protects against overcharge, overdischarge, and overcurrent. These basic protections will act as an assurance of safety during operation in tandem with a small temperature detection circuit consisting of a thermistor and some sort of switch which turns off the whole system during an overheat. During charging, each cell will be fed a constant voltage of 4.2V in turns and monitored by the controller, turning off charging for each individual battery once it has achieved a voltage of 3.7V. Since we do not have access to the cell itself and instead interface with its protection pcb, we can place a sense resistor as in figure 6 and measure the voltage across it. When the voltage across that resistor is 0, it means the protection pcb has blocked us from charging the cell any further and it is full.

Requirement	Verification
-Battery pack should be able to operate for its full duration with each cell remaining between 3-3.7V	-Battery voltage will be checked before and after various usage tests to ensure consistency in usage and charging

2.4.2 Shackle Solenoid

Our battery ranges from 6-7.4V depending on the amount of charge the battery has. Thus a 6V solenoid shackle was chosen so it can be opened even on the lowest charge. A solenoid lock only needs to be powered to pull in the pin that is holding the shackle. The chosen solenoid takes only 350mA of current while keeping the pin pulled in and operating at 6V. Assuming the lock is opened at most twice an hour with the lock staying open for 5 seconds, the power consumption of the solenoid is negligible.

Requirement	Verification
When the battery is connected to the solenoid, verify that the lock can open from the 5.5-7.4 range of voltages.	Hook up the battery to the solenoid during various levels of charge making sure the lock can still open.
Verify that the solenoid draws around 350mA of current during operation	When checking the first requirement, attach a multimeter to read current into the solenoid.

2.5 Mobile Application

The user of the lock can interact with the software system to learn what the status of the lock is and where the device is located. It would allow the user to unlock the lock using NFC and see its location using the GPS coordinates generated by the device. The mobile application should also be able to provide the user with battery charge information so the user can know when the lock needs charging.

Requirement	Verification
The user should be able to see location of the device with no more than 1 minute of latency	1. Put the device in a known location for at least 5 minutes to ensure that it is unmoved 2. Verify that this location seen by the app 3. Move the device to another location at least 20 feet away 4. Check that the updated position is reflected within a minute by the app
The lock should only open for the owner with the app installed on their smartphone.	1. Install app on 2 devices, configuring 1 to be the owner of the lock 2. Verify that the owner can unlock the lock, but the other device cannot
The user should receive a notification within 1 minute if the lock has been cut.	1. Connect the signal and ground pin together using a switch in the ON position 2. Ensure that the phone reads “SECURE”, that it believes that the lock is intact

	3. Turn the switch to the OFF position 4. Verify that the phone receives the “BROKEN” status within 1 minute

2.6 Tolerance Analysis

With the lock being strongly mounted and designed to continually operate after being stolen, hopefully for long enough to find the bike again, battery life is one of the most important features of the product. From the requirements of our microprocessor, we will select a processor that is able to idle at lower than 10mA. Assuming that no user tries to access the lock for 48 hours while the system draws 10mA, we would require a battery sized according to 48*10mA = 480mAh. This alone is fairly trivial. In general, solenoid actuation is energy intensive and would require as much as 1.28A running in a 3V system [4]. Assuming each actuation is 3 seconds, and 12 actuations in a busy day, we need to allocate 3s*12*1280mA*1h/3600s = 12.8mAh for that action which would be also trivial. The power required to perform an NFC handshake could be approximated by looking at the current use of an NFC transceiver IC which would only be a few mA for a duration of seconds and would be less than a single mAh in general per day of use. The GPS module is more power hungry than other modules, as it will need to be in its active mode more frequently than other components due to the acquisition time on nearby satellites. For a 1Hz sampling rate, a typical module will consume an average of 12mA of current [6]. Over the course of 48 hours, this would add 12*48 = 576 mAh of energy usage. Combined, the total system will consume approximately 480 + 12.8 + 576 = 1069 mAh of energy over a 48 hour period. Batteries in this range are very affordable and common, and can come in various form factors, voltages, and chemistries as the application requires. In this case, a lithium polymer battery suited for our application would cost only $10 and be relatively small [7].

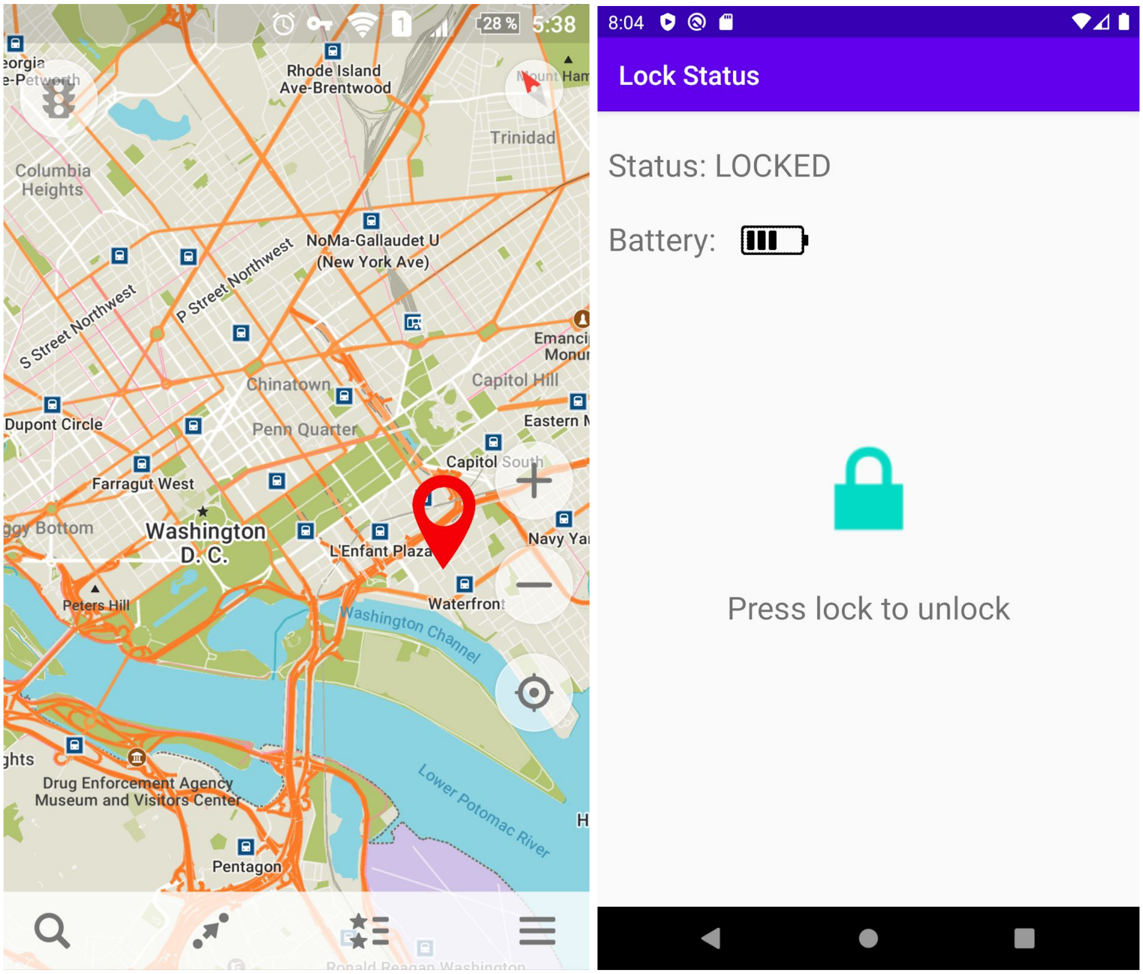

Fig. 7 A mockup of the location tracking screen (left) and lock status screen (right) for the app

2.7 Visual Aid

Fig. 7 shows an example of what a user would see when tracking their device. The red pin points to where the device is located overlayed on a map, so if the user is looking for their bike they can easily locate it in the real world.

Additionally, there will be a screen on the app to allow the user to easily see what the status of their lock is and quickly unlock it. The most important statuses will appear near the top so that the user can quickly determine if action needs to be taken to prevent their bike from being stolen.

3 Project Differences

3.1 Overview of Old Project

The Enkidu Bike Locker is the past project from which we are basing our current design. The Endiku used a front wheel locking mechanism that would lock the back wheel and send out an audible alarm plus a notification when the bike was unlocked improperly. The unlock mechanism for this lock is a mobile app that uses a fingerprint scanner or facial recognition to transmit a signal over bluetooth to allow proper unlocking. The lock is rechargeable and should by their metrics last a whole month. For the Smart Bike Lock, we still use a simple chain lock that is electronically unlocked with an app. The Smart Lock app does not use any extra security measures besides the innate phone protections. To compensate, our lock provides GPS tracking which allows for the retrieval of the bike. Arguably our lock is easier to remove forcefully but trades that with the ability to retrieve the bike without affecting the cost significantly.

3.2 Analysis

The Smart Bike Lock focuses on retrieval for securing the owner's bike. The Enkidu Bike Lock still suffers from the same issue of conventional bike locks where they can be cut with heavy duty tools like many of the standard bike locks plus with their lock, the bike could be simply carried away and worked on at a secure location. With the GPS tracking the owner is not only able to retrieve the bike after reporting it to the police, but also able to get the thief charged with a crime. This discourages further bike thefts since either the thief would be watched closer by the police due to their police record. Overall this would keep bikes from being stolen by thieves and would reduce the number of bike thefts in the future. The method for communicating with a cell phone over bluetooth is fundamentally insecure and also consumes more power than our approach of using NFC communication to unlock the bike. Sending unlock information over a ranged wireless connection introduces the possibility of spoofing, which would make it easier to steal bikes if the signal were reverse engineered.The phone app is also overengineered, most phones already have fingerprint scanners or facial recognition to unlock the phones, so making the app perform those actions as well is redundant. Even if the phone does not have those functions, the phones are usually secured by the owner and a password which we believe is sufficient security on the app side.

4 Cost and Schedule

4.1 Schedule

The schedule in Fig. 3 is an adjustable schedule that sets aside about a month of extra time such that it can be allocated where needed if any steps take longer than originally assigned. The schedule is also made as if we were starting this from the beginning of the semester.

TASK NAME	START DATE	END DATE	START ON DAY*	DURATION* (WORK DAYS)	TEAM MEMBER
Design Document					
Cost Analysis	2/18	2/26	0	9	Nate
Visual Aid	2/18	2/26	0	9	James
Power Requirements	2/18	2/26	0	9	James
Network Mapping	2/18	2/26	0	9	Nate
Mechanical Design					
Rudementary Design	2/18	2/26	0	9	J&J
Revision and Final CAD	2/26	3/15	8	19	James
Machining	3/15	3/29	26	15	Justin
Integration	3/29	4/6	40	9	All
Power System					
Power Requirements	2/18	2/26	0	9	James
PCB Design	2/26	3/3	8	7	J&J
Soldering	3/3	3/6	14	4	Justin
Unit Test	3/6	3/29	17	24	All
Integration	3/29	4/6	40	9	All
Microcontroller & Wifi-Module					
Coding of State Machine	2/26	3/8	8	12	Nate
Calibration of NFC Module	2/26	3/8	8	12	Nate
Unit Test	3/8	3/29	19	22	All
Integration	3/29	4/6	40	9	All

4.2 Cost Analysis

4.2.1 Labor

Additional labor outside the members of the group should not be necessary, apart from that factored into the cost of parts. Estimate 60 hours of work per person, at $40 an hour, for 3 people. Total labor comes to be:
60 * 3 * 40 = $7,200

4.2.2 Non-Standard Parts

Description	Manufacturer/Part No.	Quantity	Cost	Total

Mini Solenoid Shackle	UPC: 714890581463	1	$4.43	$4.43
ATmega 328p	ATMEGA328PB-AU	1	$1.34	$1.34
16Mhz oscillator	XC1776CT-ND	1	$0.38	$0.38
GSM module	HL6528RD_1103477	1	$19.22	$19.22
GPS module	TESEO-LIV3F	1	$14.22	$14.22
NFC reader	2221-U031-ND	1	$9.95	$9.95
Lithium-Ion Battery	258	2	$9.95	$19.90
Linear Voltage Regulators	NCP7905CTG	1	$.25	$.25
Total				$69.69

5 Ethics and Safety

5.1 Ethics

In the case of ethics, designing a smart lock for a bike is congruent with both the IEEE code of ethics and the ACM code of ethics. Most requirements of these codes are not strictly applicable to this project. Beyond non-applicable codes, the concept of a smart lock for a bike serves to integrate technology into society in a manner which provides individuals with greater security and comfort which is a concept represented in both codes. This concept is reflected most accurately by code 1.1 of the ACM code of ethics [9] and code 5 of the IEEE code of ethics [8]. In the design of such a commercial product with competitors, it is also imperative that we respect patent and copyright law. In designing our product, we will research competing products which will allow us to understand various industry standard design features whilst allowing us to differentiate our design from others both for the purpose of innovation and to respect the intellectual property of competing designs.

5.2 Safety

To stay safe, the current through the wire has to be sufficiently small as not to heat up and damage itself but also keep anyone from shocking and hurting themselves. The wire is just there to notify of a cut chain, not to hurt anyone. The heat issue also applies to the battery so we need to make sure we can sink that heat and keep it from burning up. Heat concerns for the internals can be handled by a thermistor and external thermals would be calculated based on wire specifications. This lock design does not have any inherently dangerous components that would reasonably be expected to cause damage to any person or property in the vicinity. In the case of a malicious attempt to break the lock, some amount of shrapnel could be produced or a battery failure could be caused, however the responsibility for the possible damages in this scenario are assumed to lie with the person destroying the lock i.e. due to gross misuse. As for regulations, we would primarily expect to need to comply with FCC standards and standards for rechargeable batteries. In the case of batteries, most responsibility seems to fall with the battery manufacturer and the end user. This includes strict regulations on the transport, manufacturing, and testing of such batteries [13]. It is difficult to find any material pertaining to regulations that the designer of a given product is burdened with. Because we are performing Radio Frequency (RF) communications, our device needs to be authorized by the FCC for use [14].

6 Citations

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