ECE 445
Spring 2020
Senior Design

Three Piece Automatic Bike Lock

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1 Introduction

1.1 Objective

The hassle of fumbling with current bike lock designs takes time and efficiency out of people's day when utilizing a bike as a mode of transportation. For bike commuters the time it takes to take out a bike lock, secure the bike lock and ensure the bike is properly attached can add time to the daily commute. For example, many commuters in Chicago ride to the metra train station; it is often the case that people miss their train by a couple minutes or even seconds. The extra time added by fumbling with the currency bike lock designs can cause a missed train or bus.

Our goal is to reduce the time necessary to lock/unlock one's bicycle. We aim to solve this problem by using a fingerprint sensor to authenticate the owner of the bicycle and trigger a locking circuit which will automate the process of locking/unlocking the owner's bicycle.

1.2 Background

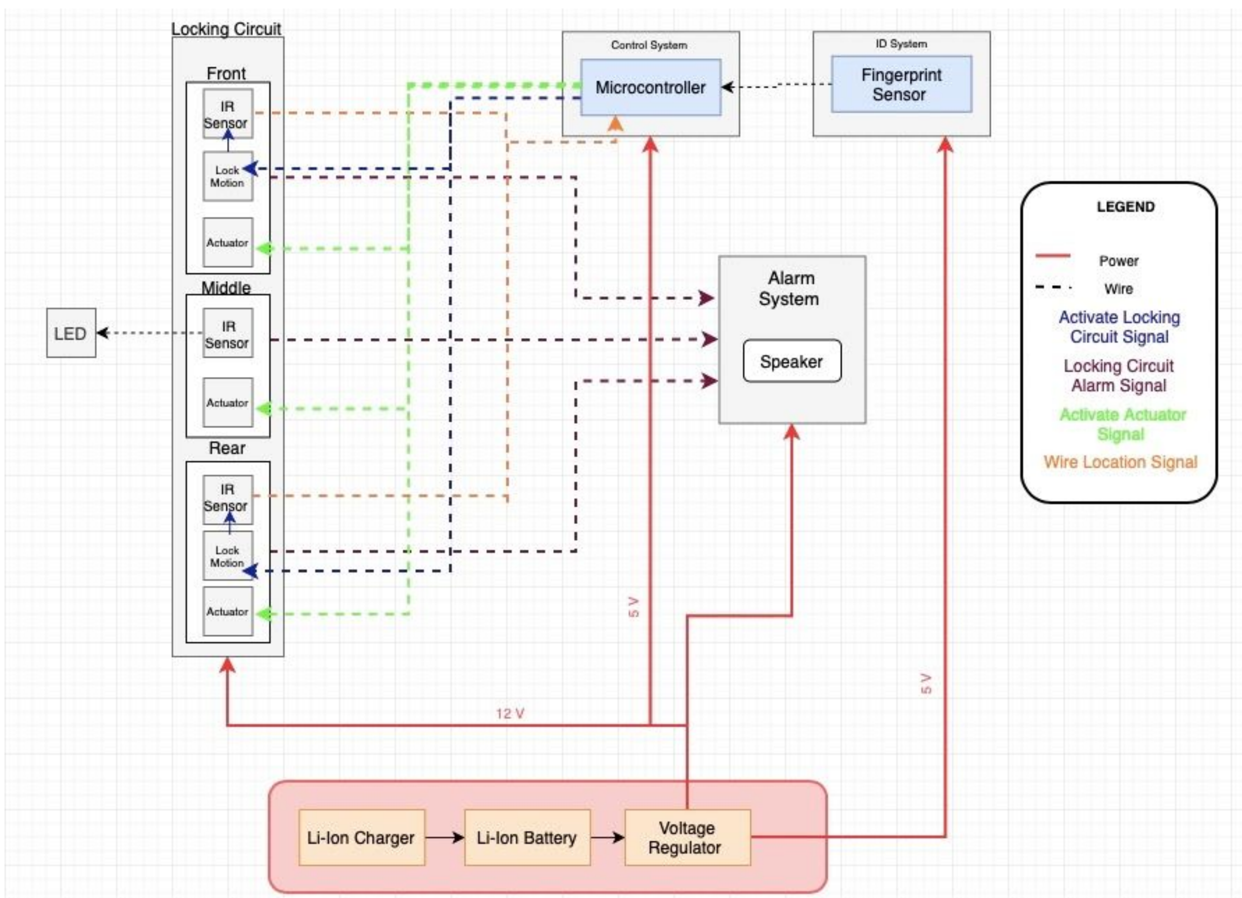
There have been automatic bike locks in the past such as products by Linkalock [5], but these products do not secure every part of the bike. Often these products only lock the back wheel of a bike or they lock the bike to a rack leaving the user to purchase additional locking devices to get better security. Our system will automatically lock the user's bike and will prevent theft of any major part of the bike.

1.3 High-Level Requirements

- Upon entering a fingerprint the locking system will activate the actuator in the middle lock, the two DC motors of the rear/front lock, and the actuators of the front and rear locks.
- If the system is locked, the correct fingerprint will unlock each locking system at once.
- A damaged locking system or an incorrect fingerprint will trigger the alarm system.

2 Design

The locking/unlocking process starts with the ID system. If an authorized user inputs their fingerprint then the microcontroller will control each of the locks in order to secure the bike. The front and rear locks utilize a DC motor with a gear attached to move a locking rod, a IR sensor to report if the wire is at an optimal position, and an actuator to fully secure the wire. The middle lock is more simple and uses a chain that the user uses to lock the bike to a rack. The IR sensor in this powers a LED that will glow green if the chain has been inserted at an appropriate location for the actuator to secure the chain. Each of these locks including the microcontroller can activate the alarm system. This occurs if any locks have been tampered with or if an unauthorized user inputs their fingerprint. If the alarm is active then the correct fingerprint will silence the alarm. The voltage regulator will provide the front and rear locking circuits with 5V while the middle locking circuit will be fed 12V.



Physical Design

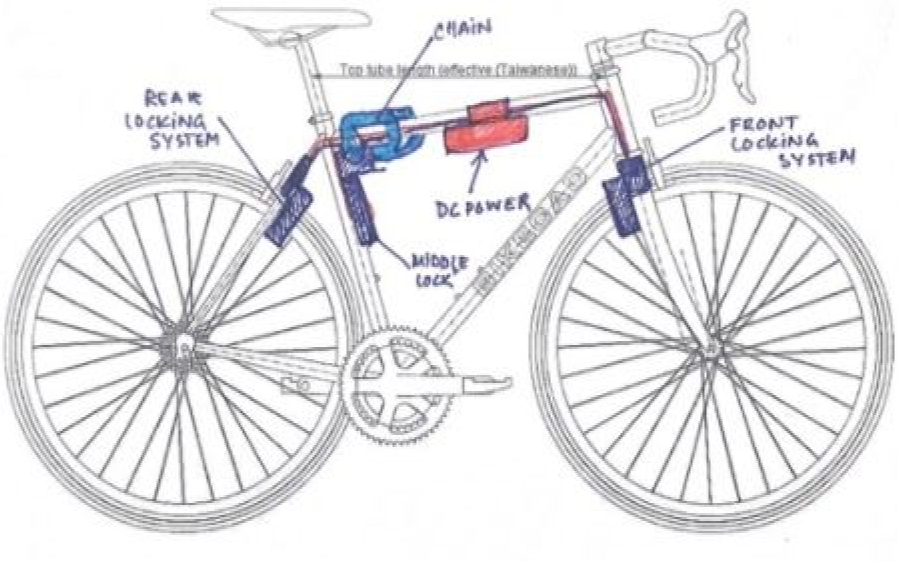


Fig 3.1 Overall Design

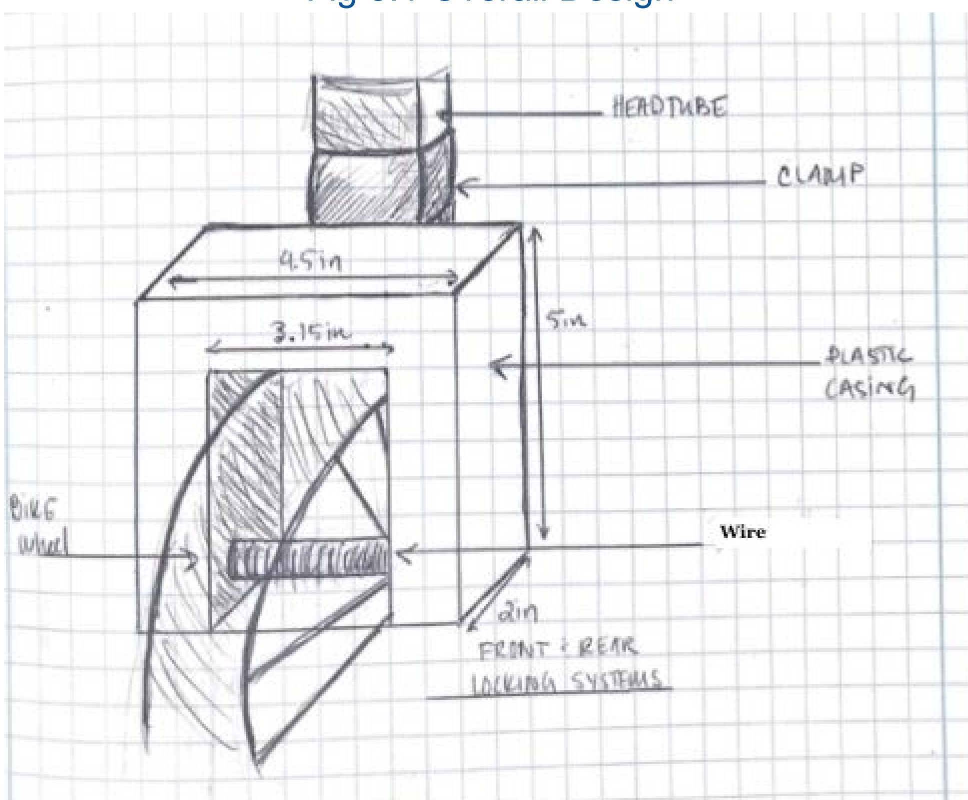


Fig 3.2 Front and Rear Locking System

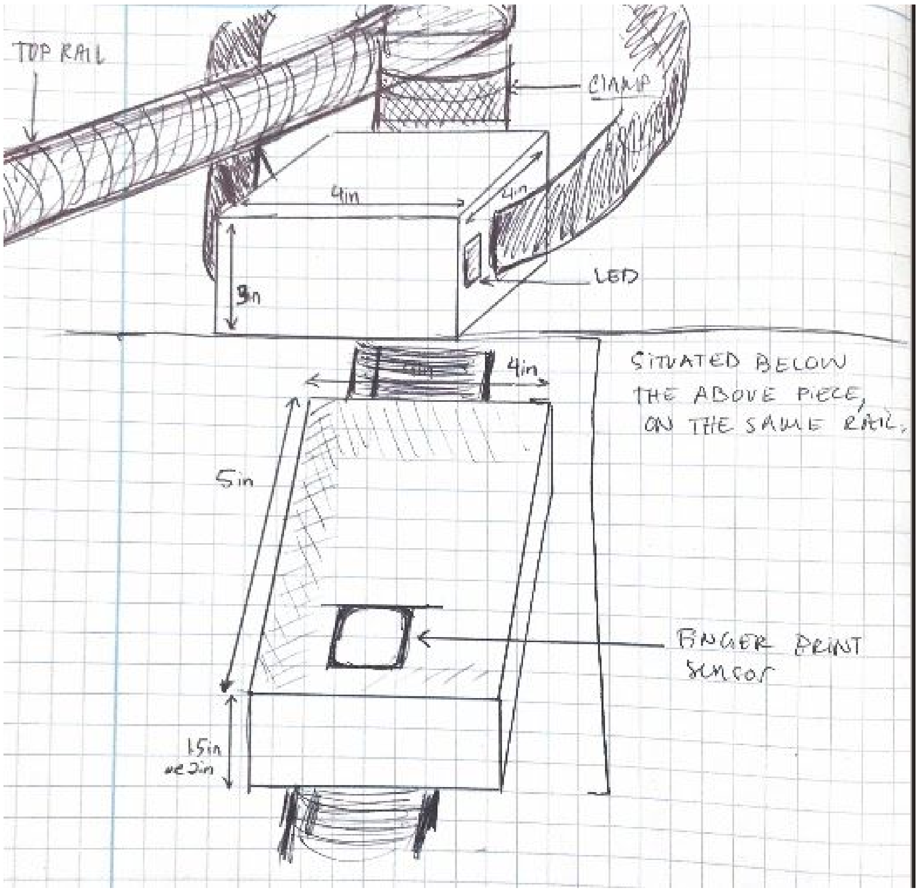


Fig 3.3 Middle Locking System

2.1 Identification System

The identification system outputs the appropriate signal determined by the user’s fingerprint to the microcontroller.

2.1.1 Fingerprint Sensor

We will utilize a TTL fingerprint scanner that has a thin optical sensor, the scanner will keep track of the owner’s fingerprint and will be powerful and dynamic enough that even in moist or dry conditions the scanner will be able to pick up on a fingerprint. The scanner will also be scratch resistant. We will need a voltage divider circuit in order to safely communicate with a 5v device. The serial UART exists at pins 1 and 2, while VCC is at 4, requiring 3.3 -6 v and gnd is at pin 3.

2.2 Control Unit

The control system is responsible for authenticating the owner of a bicycle, triggering the locking circuit that physically locks/unlocks the bicycle and triggering an alarm when an unauthenticated user repeatedly tries to unlock the bicycle.

2.2.1 Microcontroller

We will utilize an arduino uno as a microcontroller which will be responsible for handling the authentication and communication between the TTL fingerprint scanner. The arduino will also be responsible for triggering the locking circuit to activate when a user wishes to unlock / lock their bicycle. The arduino will trigger an alarm if a user fails authentication multiple times as well.

Requirements	**Verification**
1. The microcontroller should be able to transmit data via UART communication. 2. The microcontroller should be as low power as possible ideally. Since many of the sensors,actuators and fingerprint sensors will require much of the voltage requirement of 12v.	1. Test this by verifying that the fingerprint sensor is connected to the microcontroller at pin 1 and pin 2 on fingerprint sensor, which are UART_RX and UART_TX. If still unable to transmit data , ensure that there is voltage division from 5v to 3.3v which is the voltage required by the fingerprint sensor. 2. Test by utilizing an voltmeter and ammeter to calculate power consumption of all of the parts in use and check that the voltage requirement is less than 12v.

2.3 Locking Circuit

This system is responsible for locking the front wheel, rear wheel, and the bike to a rack. This system is controlled by the control system and this system can control the alarm system.

2.3.1 Front and Rear Lock

The front and rear locks are designed to prevent any theft of the front or rear wheels. These locks will operate once an authorized user has been correctly identified by the identification system. The locks are also used to control the alarm system if they are damaged. Both locks will utilize a metal rod, that has one loop on its end, which will move through the wheels, via a DC motor, and be secured by the actuator. The locking rod will have teeth on the top of it and they will fit with the gear that will be fitted on the DC motor. When the motor moves clockwise the rod will move through the wheel and lock the device. When the motor moves counterclockwise the rod will move the opposite direction.

2.3.1.1 Lock Motion

This block is responsible for the motion of the locking rod. Once the user uses their fingerprint this block will activate, leading to the activation of the DC motor which will move the locking rod through the wheel.

Requirements	**Verification**
1. DC motor should be able to rotate 360 degrees so that the locking rod can move to the other end of the housing. 2. When unlocking, the DC motor needs to rotate back 360 degrees so the locking rod has retracted back into the housing.	1. A. Using a voltmeter, test that if supply 5v to the 1A pin of the IC and 0v to the 2A pin that the motor will rotate in the clockwise direction uninterrupted. B. Verify via using the pwm feature on the IC that the motor is rotating 360 degrees. We will do this by slowing down the motor and manually checking its rotation amount. 2. A. Using a voltmeter verify that if there is 5v on the 2A pin and 0v on the 1A pin that the motor will rotate counterclockwise. B. Verify that when rotating back the locking rod is retracting.

2.3.1.2 IR Sensor

The infrared sensor will indicate when the lock motion block has moved the locking rod at an appropriate distance for the rod to be fully secured. The locking eos will have a part of white tape that is before it's loop, the IR sensor will be right next to the actuator so that when it sees the color white, it will indicate to the microcontroller to activate the actuator.

Requirements	**Verification**
1. The IR sensor must be able to indicate to the microcontroller when it sees the color white. 2. Needs to be put at an optimal position so that it can indicate when to activate the actuator.	1. Using the software of the microcontroller, point various white objects in front of the sensor so that we can get a range of values that correspond to the color white. 2. Place the IR sensor to the right of the actuator and verify that when the sensor detects the color white on the locking rod, the rod is at an appropriate location to be secured..

2.3.1.3 Actuator

This block is controlled by the microcontroller. As stated above, once the proximity sensor indicates that the locking rod has moved to an appropriate location, the microcontroller will power the actuator, which will then fully secure the locking rod by having the actuator move through the other loop of the wire..

Requirements	**Verification**
1. Must fully extend so that it goes through the loop of the locking rod. 2. Must be fully secured in its mounting so that the locking rod is rigid when locked. 3. When unlocking the actuator must retract so the locking rod can move to its unlocked position.	1. A. Using a voltmeter verify that when the 1A pin of the actuator circuit IC has 12v and the 2A pin has 0v, the actuator will extend. B. Activate the actuator and measure its maximum length and then place the actuator in the housing at a distance less than its max so that it will be able to go through the locking rod's loop. 2. Pull on the locking rod when the system is locked and confirm that it is very difficult to move. 3. Using a voltmeter verify that when the system unlocks the 2A pin of the actuator's IC is 12v and the 1A pin is 0v.

2.3.2 Middle Lock

The middle lock is different from the other two locks in the sense that the user is responsible for moving a chain around a rack and to the other side of the lock in order to secure the bike. The actuator of this system is controlled by the microcontroller whenever the user uses their fingerprint. This system also can control the alarm system, if tampered with.

2.3.2.1 IR Sensor

This sensor is used so that the user knows if they inserted the chain at an appropriate depth within the lock housing. We will use white tape on one end of the chain and the IR sensor will be used to indicate when it sees the color white. Once the sensor returns to the microcontroller that it has a value that corresponds to the color white, the LED should glow green and if the actuator gets activated, it will secure the locking rod.

Requirements	Verification
1. Sensor needs to return to the microcontroller when it sees the color white.	1. Using the software of the microcontroller, point various white objects in front of the sensor so that we can get a range of values that correspond to the color white.

2.3.2.2 Actuator

This device is controlled by the microcontroller. When the user enters their fingerprint the actuator will be activated regardless of the value of the proximity sensor. The actuator used is a power door lock actuator which is locked/unlocked from a door lock relay. Signals from the microcontroller are fed to a 451M Door Lock Relay, which signals the actuator to unlock or lock.

Requirements	Verification
1. The actuator of this device must secure the locking chain. 2. The device must be able to hold the chain when in locking or hold mode. 3. The actuator must retract when the user wants to unlock their bike.	1. A. Using a voltmeter verify that when 12v is applied to the + pin of the actuator the actuator extends. B. When extended verify by shaking the locked end of the chain up and down to see if the actuator has fully secured the chain. 2. Before mounting, apply 12v onto the actuator's positive pin to activate it. After this we will hang one end of the chain on the actuator, holding the other end, and verify that it can hold the chain's weight. 3. Check that if there is +12v applied to the (-) pin of the actuator from the battery, the actuator will retract. We will do this via a multimeter.

2.4 Alarm System

This system takes in input from the locking circuit. If any of the locks are tampered with then this system will sound. The microcontroller can also activate this system if an unauthorized user attempts to use the fingerprint sensor. This system will consist of a circuit which utilizes a speaker.

2.4.1 Speaker System

This system will take in input from the three locking circuits along with the identification system. If any of these systems has been compromised then the speaker will activate. If activated the speaker will stop if an authorized user uses their fingerprint.

Requirements	**Verification**
1. The speaker must activate if either lock is damaged or if an incorrect fingerprint is used. A damaged lock occurs whenever the tripwire of the circuit is cut. 2. The speaker must stop after 10 seconds if active.	1. A. We will verify that when 1v is connected to the alarm circuit that the alarm will sound. We will verify this via a voltmeter. B. We will cut the tamper wire in various combinations to verify that the input pin of the alarm driver circuit will have 1v. We will use a voltmeter for this. 2. We will verify that the input pin of the alarm circuit will have a value of 0 after 10 seconds.

2.5 LED System

This system is fairly basic and is only controlled by the proximity sensor of the middle lock. There will be a single LED that will glow red if the middle chain is not placed at the correct location for the actuator. If this is not the case then the LED will glow green. The standby color for the LED is red.

Requirements	**Verification**
1. Must glow red when the chain is not at an appropriate location for locking. 2. Must glow green when the chain is able to be locked.	1. When 5v is applied to this circuit the red LED will glow. Verify the voltage and current of the input with a multimeter. 2. When 5v is applied to this circuit the green LED will glow. Verify the voltage and current of the input with a multimeter.

2.6 Power System

This system provides power for the Identification system, the locking circuits, the alarm system, and the LED system. We will be using a 12v Li-ion battery for the system.

2.6.1 Li-ion charger

This block is used to charge the Lithium ion batteries that are used for the project. The user will be able to use this charger to charge the locks using a wall adapter.

Requirements	**Verification**
1. Be able to charge the 12v battery for the project.	1. Test the batteries capacity after a 4 hour charge with a multimeter.

2.6.2 Li-ion Battery

The batteries are used to power each component of the three piece lock. This will be a fairly simple DC battery that gets fed into a voltage regulator. We will be using a 12V 6000mAh Power Li-ion Rechargeable Battery Pack.

Requirements	**Verification**
1. The battery must be able to power each device used in the project.	1. Using a voltmeter verify that the battery's output is 12v. Using an ammeter verify that the battery is able to supply enough current to each device in the project

2.6.3 Voltage Regulator

The voltage regulator will be used to prevent any motor or actuator from getting too much voltage which would lead to a dead device. The front and rear locks will have the same regulator.

Requirements	**Verification**
1. The regulator must be able to step down the 12v supply so that no components get burned out during operation.	1. We will use a voltmeter to verify that the output of the regulator matches the operation voltage of each circuit.

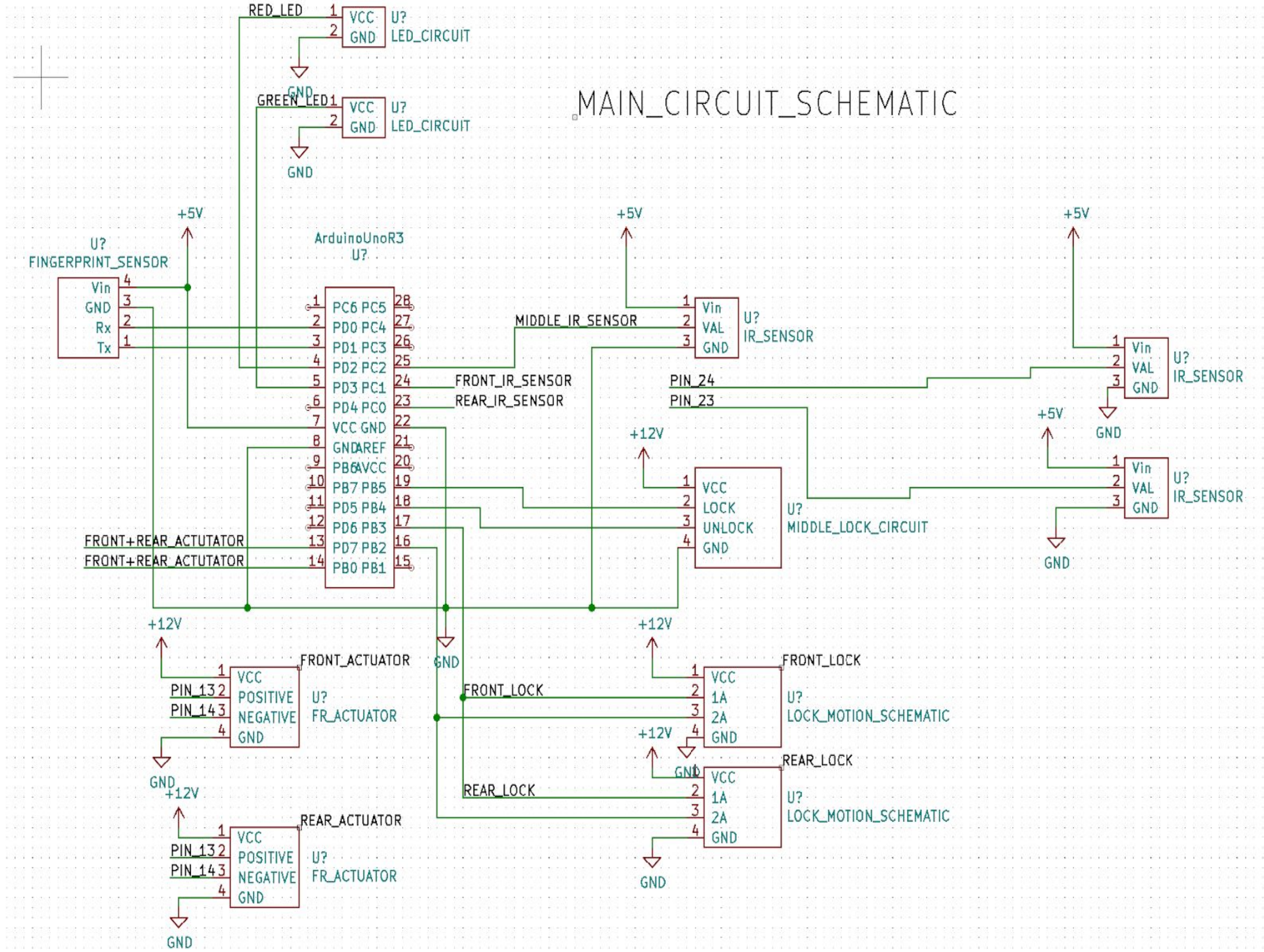
2.7 Risk Analysis

The front and rear locks are a significant risk to the successful completion of the project. These locks need to be fully automated and need to move the locking rod all the way through the wheel back into the housing for locking. These locks also need to be able to be run in reverse so that the bike can be unlocked. We will need to design a motor drive circuit that will rotate the motor long enough for the locking rod to fully move through the wheel, and this circuit must be able to reverse the direction of the motor for unlocking purposes. Another risk can be if a spoke of the wheel is in the way of the locking rod, if this is the case then the motor can burn out.

2.8 Schematics

2.8.1 Main Circuit Schematic

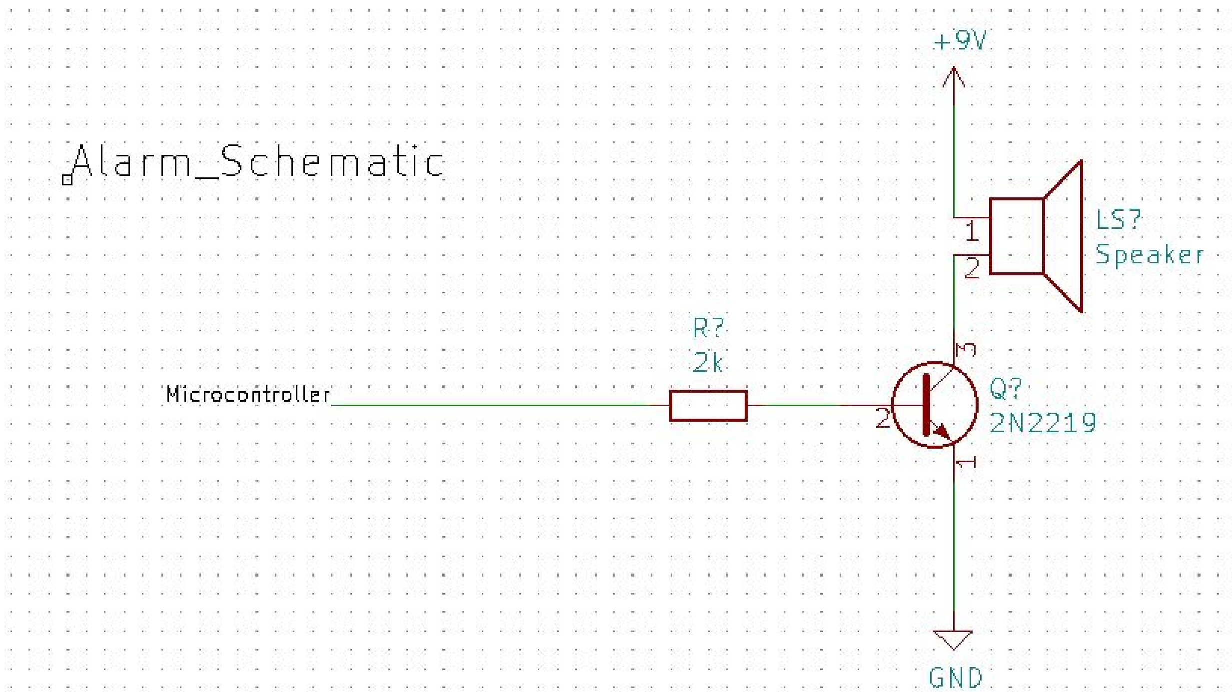
This is the schematic for the entire project. For our design the alarm circuit, fingerprint sensor, led circuits, and the middle lock circuit will all be on the main pcb that contains the IC for the microcontroller. The rear/front circuits will be on their own pcbs which will connect to the IC from a distance. The majority of the devices in this project will be powered from the digital output pins of the arduino IC. The only source of analog input is from the IR sensors which are used to detect a white object. Otherwise each circuit takes in input from the digital pin of the IC. This circuit will allow for the IC to take in feedback from various devices, fingerprint sensor and IR sensors, and use the feedback to control the locking mechanisms and the alarm circuit.



MAIN_CIRCUIT_SCHEMATIC
RED_LED
GREEN_LED1
LED_CIRCUIT
LED_CIRCUIT
ArduinoUnoR3
FINGERPRINT_SENSOR
Vin
GND
Rx
Tx
+5V
+12V
PC6 PC5
PD0 PC4
PD1 PC3
PD2 PC2
PD3 PC1
PD4 PC0
VCC GND
GND AREF
PB6 AVCC
PB7 PB5
PD5 PB4
PD6 PB3
PD7 PB2
PB0 PB1
MIDDLE_IR_SENSOR
FRONT_IR_SENSOR
REAR_IR_SENSOR
IR_SENSOR
VAL
PIN_24
PIN_23
MIDDLE_LOCK_CIRCUIT
LOCK
UNLOCK
FRONT+REAR_ACTUTATOR
FRONT_ACTUATOR
REAR_ACTUATOR
FR_ACTUATOR
POSITIVE
NEGATIVE
PIN_13
PIN_14
FRONT_LOCK
REAR_LOCK
LOCK_MOTION_SCHEMATIC
1A
2A
U?

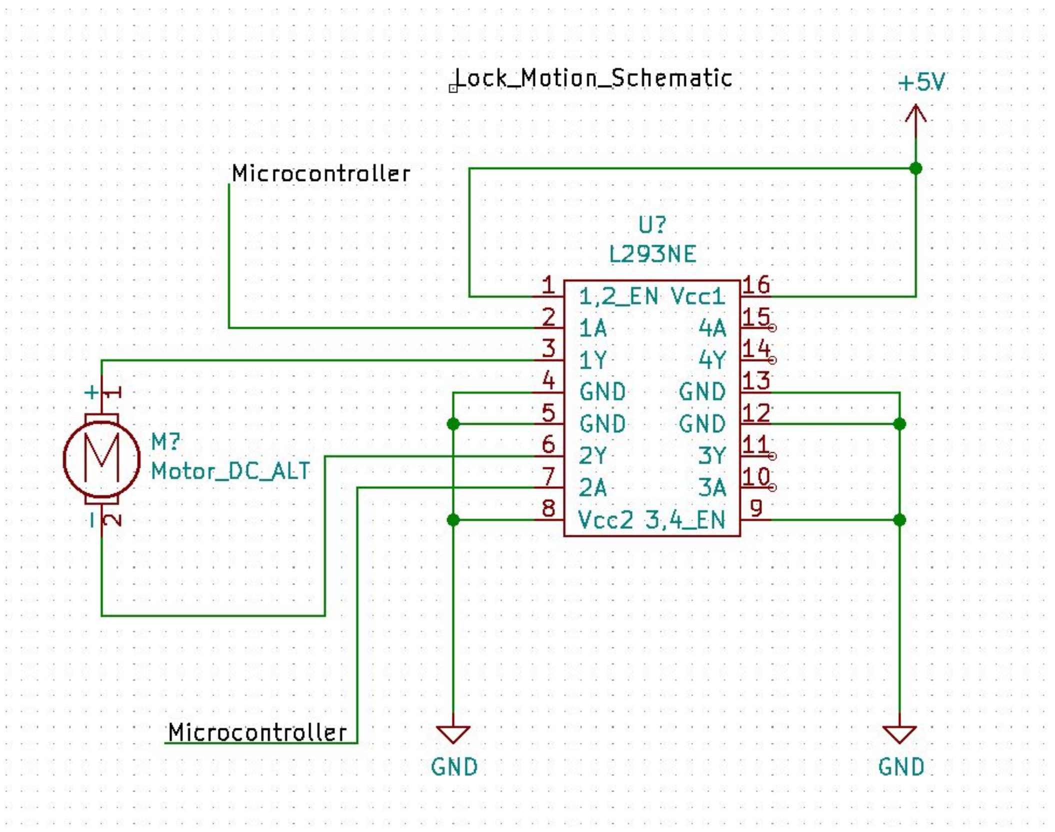
2.8.2 Alarm Circuit

This circuit utilizes a basic speaker along with a BJT which will amplify the sound of the speaker. The resistor is in place so that we can control the level of amplification that will occur on the speaker's output from the BJT. The speaker will use 9v which we will supply via a 9v battery which the user will be able to change when the battery runs out. The input to this circuit is the microcontroller which will output 1v when the speaker needs to be activated, otherwise the microcontroller will output 0v. If the speaker is active for 1 minute, then the microcontroller will output 0v to stop the system from continuously running.



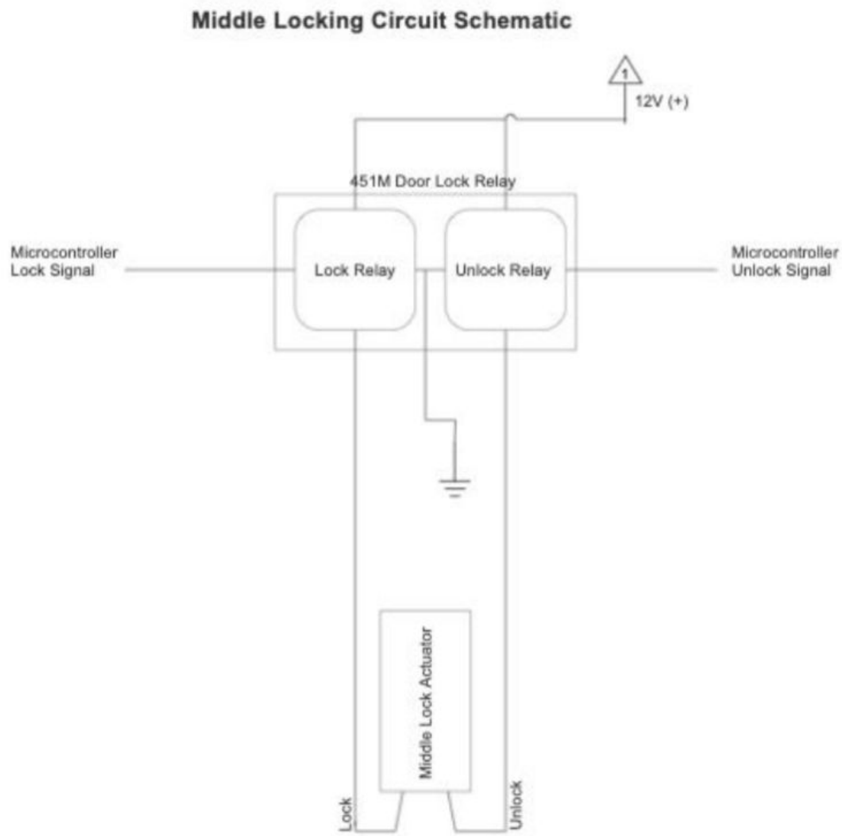
2.8.3 Lock Motion Schematic

This circuit utilizes a L293NE IC which is a half H bridge circuit. This circuit takes in 5v from the power supply and it's only other input is the microcontroller. When the microcontroller indicates that the circuit needs to be locked, it will output 1v on the 1A pin and 0v in the 2A pin. When this occurs the motor will rotate clockwise. When the microcontroller wants to stop the motor it will output 0v to the 1A pin. For unlocking the microcontroller will output 1v and 0v on the 2A and 1A pins which will cause the motor to rotate counterclockwise, retracting the locking rod.



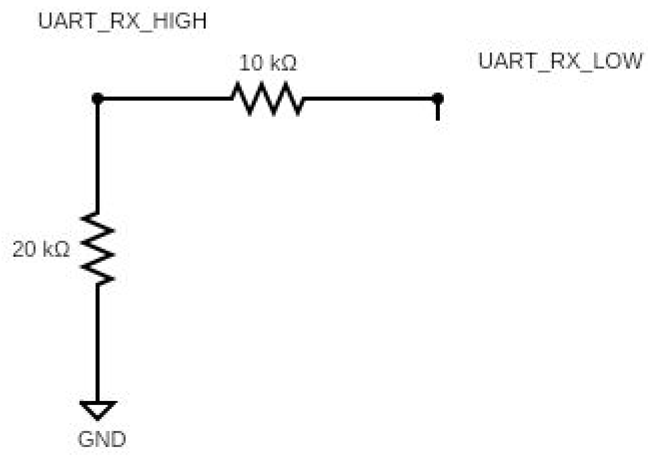
2.8.4 Middle Locking Circuit

The middle locking circuit consists of a door lock actuator, and a 451M Door Lock Relay. The 451M Relay module contains a lock relay and an unlock relay. When executing the lock or unlock action, the microcontroller sends a signal to the correct relay. Once a relay receives it's microcontroller signal, it can then activate the actuator to either its lock or unlock position. Both the relay and the actuator require 12 Volts.



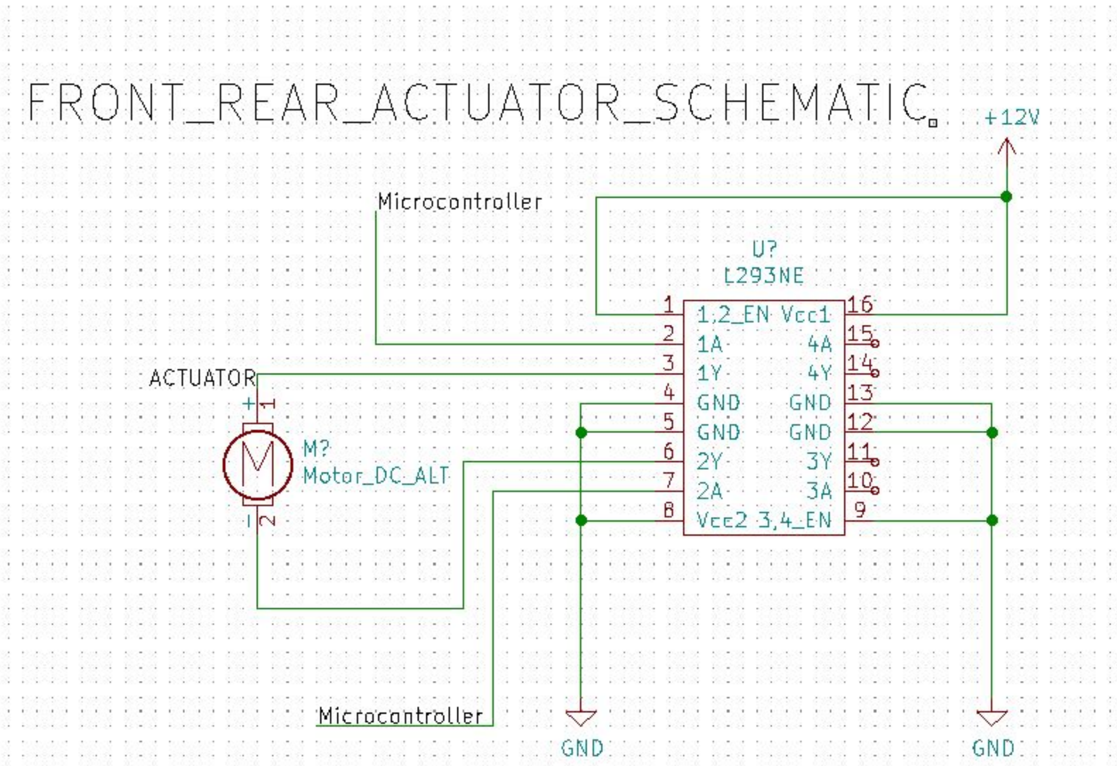
2.8.5 Fingerprint Sensor Circuit

The fingerprint sensor will require voltage division in order to smoothly connect to the arduino from the UART ports RX and TX on the fingerprint sensor. These correspond at ports 2 and 3 on the ATMEGA328p chip. The voltage division is necessary because fingerprint sensor requires 3.3 v and to meet these requirements we must do voltage division with 10k ohm and 20k ohm resistor.



2.8.6 Front/Rear Actuator Circuit

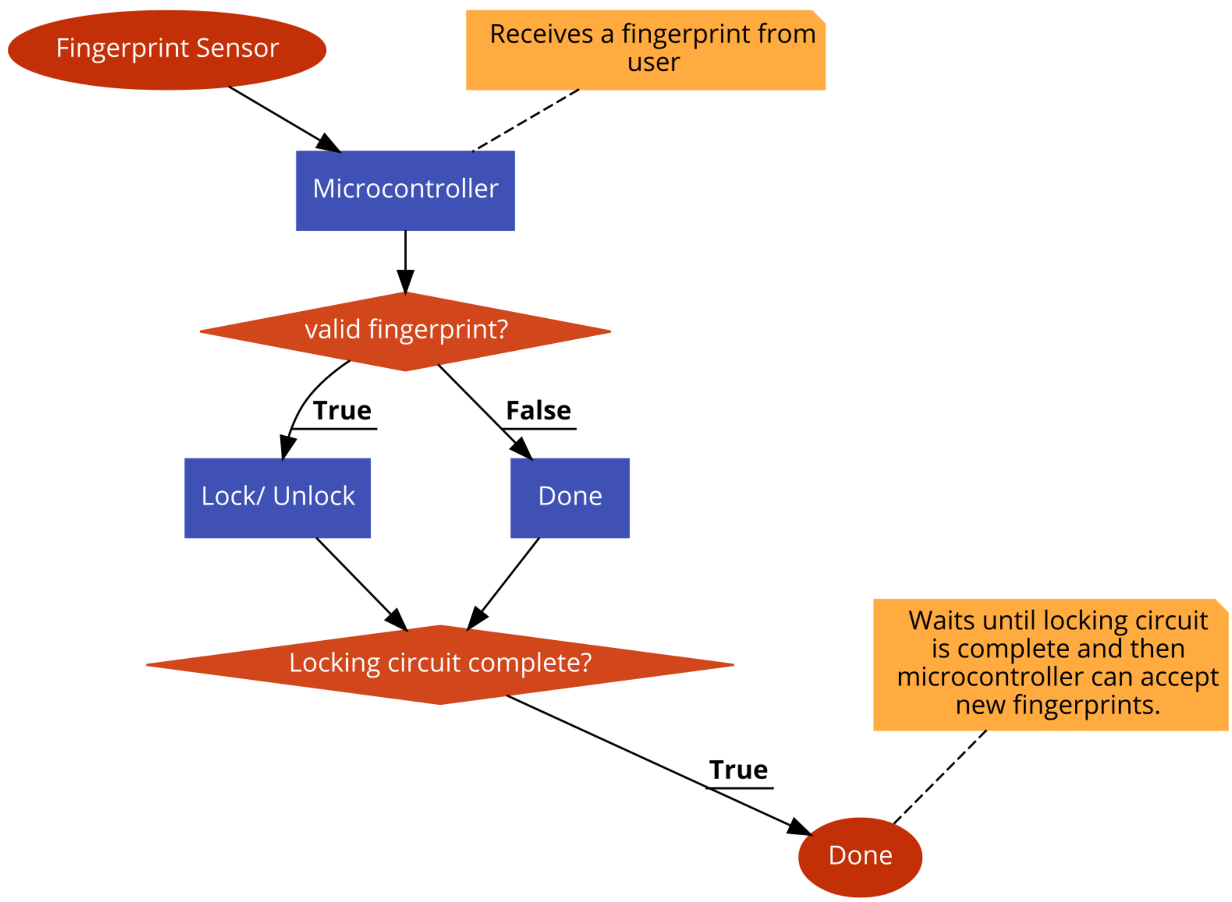
Since an actuator utilizes a DC motor, the same circuit will be used for this device. Thus this circuit operates in the same way as the lock motion circuit. The only difference is that after 5 seconds of the locking/unlocking process, the microcontroller will stop outputting to this circuit so that the actuator can stop retracting or extending.


FRONT_REAR_ACTUATOR_SCHEMATIC
+12V
Microcontroller
U?
L293NE
1,2_EN
Vcc1
1A
4A
1Y
4Y
GND
GND
GND
GND
2Y
3Y
2A
3A
Vcc2
3,4_EN
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
ACTUATOR
+
M?
Motor_DC_ALT
-
Microcontroller
GND
GND

Software

The software required for our design will deal mainly with communication between the fingerprint sensor, microcontroller and the locking circuits. Our use case involves the need to unlock/lock the rear/front and middle locks when an user is successfully authenticated from fingerprint.The data will move from fingerprint sensor to microcontroller and wait for successful authentication and then will activate the locking/unlocking circuit.

Authentication Algorithm:



2.9 Tolerance Analysis

Our important tolerance that we want to maintain is that our rear/front locks have appropriate clearance to allow solenoid / actuator to engage and disengage lock without causing blockage or obstruction from the bicycle frame or the wheel. The target clearance we need the front/ rear locks to be is (¼ in- ⅛ in)/ 2 = 1/16 in on either side of the metal rod.

Assuming that we have an 0.5 x 0.5 x 5.5 in aluminum body and we know then that the volume of the block is 1.375 cubic inches. With unit conversion the block of the volume is 22.53 cubic centimeters. And we know that 1 cubic centimeter of aluminum is 0.1 oz. Therefore, the block's mass is 2.253 oz which is 0.06387 kg. Using the formula for Force due to friction.

$$F_f = \mu N$$

We know that an ideal aluminum-aluminum coefficient of static friction is 0.3, assuming lubricated and greasy. Then we know that the frictional force is 9.81 m/s^2* 0.06387kg * 0.3 = 0.188 N. Thus the block needs to push at least 0.2 N for the metal bar to move.

Another important tolerance to consider is if the middle actuator can withstand the weight of the locking chain. Assuming the weight of the chain is 3lb, which is 1.361kg. The length of the middle actuator is .0508m and the angle on the actuator from the chain in hold mode is 90 degrees. Using the formula for torque below:

$$\tau = rF\sin\theta$$

The torque applied to the actuator is (.0508)(1.361*9.81)(sin(90)) = .678 Nm. Thus the actuator must be able to withstand 1Nm of torque.

Another tolerance to consider is on how much force the middle actuator can take from someone pulling on the locked chain. This situation would occur if a thief tries to steal the bike when it is locked to a rack. We want this actuator to take 5Nm of torque. Using the formula above and solving for F, the force that the actuator needs to withstand is 98.42N or 9.98kg of force. Therefore, The chain cannot be pulled at an force >= 98.42 or can be converted to acceleration which is at 9.86 m/s^2. Anything above this force will cause malfunctioning of the actuator.

4 Cost and Schedule

4.1 Cost

Part	Cost
Finger Print Sensor	$35.99
Arduino Microcontroller	$22.95
InstallGear Universal Car Power Door Lock	$9.57
Battery	$19
Chain	$10
Front and Rear Locking Circuits	$12
IR Sensor	$4.98
LED	$0
Speaker *	$3
Clamps	$5
PCB	Provided
451M Door Lock Relay	$9.90
Arduino Uno r3 chip	$6.85
Total:	$139.24
Costs yet to be estimated	
Aluminum Casing (Machine Shop)	
Machine Shop Labor	

Name	Hourly Rate	Hours/Week	Total Over 7.5 Weeks	Total x 2.5
Julia Luzinski	$40.00	10	$3,000.00	$7,500.00
Rajiv	$40.00	10	$3,000.00	$7,500.00
Amrit	$40.00	10	$3,000.00	$7,500.00
			Total	$22,500.00

4.2 Schedule

Week	Rajiv	Amrit	Julia
2/24	Design and research about hookup and microcontroller code.	Design the Alarm circuit, front/rear lock circuit, and LED circuit.	Design the middle lock circuit, battery circuit. Order parts for both circuits.
3/2	Hookup fingerprint scanner and microcontroller and test	Design PCB for alarm circuit, front/rear lock circuit, and LED circuit.	Design PCB for middle lock circuit, and battery circuit. Bring design and dimensions to the machine shop.
3/9	Verify that fingerprints can be sent to microcontroller, work on pcb design.	Submit PCB design for creation	Start designing structural prototype.
3/16	Write fingerprint scanner code and code for alarm and locking circuit.	Spring Break	Spring Break
3/23	Test and verify that microcontroller and fingerprint scanner function appropriately with alarm and locking circuit.	Test the current PCBs, make any necessary modifications for first round orders	Test the current PCBs and structural design, make any necessary modifications for first round orders
3/30	Verify final PCB design	Verify final PCB design	Verify final PCB design
4/6	Verify final PCB design	Submit final PCB design	Submit final PCB design
4/13	Assemble all circuits with team	Begin connecting the 5 circuits and start testing	Begin connecting the 5 circuits and start testing

4/20	Testing/debugging if needed	More testing	Testing/debugging if needed
4/27	Final report	Begin final report	Final report
5/4	Final presentation	Prepare final presentation	Final presentation

5 Safety and Ethics

There are several potential safety issues for our project.

Damage done to the electrical and/or mechanical components can cause our design to break or short, causing a safety hazard.The outer casing of our design must be waterproof as well as able to withstand harsh weather conditions. The electrical circuitry must be protected appropriately to prevent the product from breaking or shorting. The outer casing must be durable enough to withstand weighted stress if the bike falls while it's parked or if a minor impact occurs. Additionally, our design must be structurally secure so that all parts maintain their integrity when the bike is in motion.

The dangers of lithium batteries pose another safety hazard for our design. If the battery is punctured, overcharged, overheated, or short circuited it can set fire or explode. To manage this hazard we will use preventative measures such as consistently monitoring the battery's condition before and after use.

There is also a risk in the locking system activating when the user is riding their bike. If this occurs then the user can be injured, as the front/rear locks can stop the motion of the front and rear wheels, or the locking system can be completely damaged. For this reason we will place the fingerprint sensor on the underside of the central lock so that a user cannot easily lock their bike when in motion.

We believe that our design is in compliance with the IEEE Code of Ethics [1] and the ACM Code of Ethics and Professional Conduct [2]. To prevent any harm done to the user and the environment, as stated in ACM, code 1.2, and similarly in IEEE Code of Ethics, code 1, we will make our design process and the final product as safe as we can. Additionally, as stated in the ACM Code of Ethics code 2.9, “Design and implement systems that are robustly and usably secure”, our fingerprint sensor will be intuitive and easy to use. This will make sure that our bike lock achieves its intended purpose, making the biker’s life easier.

6 References

[1] “IEEE Code of Ethics,” *IEEE*, Jun-2019. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 03-Feb-2020].

[2] “The Code affirms an obligation of computing professionals to use their skills for the benefit of society.,” *Code of Ethics*, 22-Jun-2018. [Online]. Available: https://www.acm.org/code-of-ethics. [Accessed: 03-Feb-2020].

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