

Enkidu Bike Locker

ECE 445 Design Document
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Group 26
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2/21/19

1 Introduction

1.1 Objective

The bicycle was invented in motion due to a volcanic eruption two hundred years ago. It becomes a new way of individual transportation to represent the quality of lives, which means being healthier and environmentally friendly, in cities. As transportation technology developed better and better today in cities, the bicycle still takes an important role in urban areas [1]. From 1992 to 2006, bicycle sales increased from 15.3 million to 18.2 million per year in the United States. According to National Crime Victim Survey(NCVS), approximately 1.3 million bicycles stolen report to the police, perhaps the actual bicycles stolen four or more times greater than the number of stolen report, which means there is at least total of 6.5 million bicycles stolen at 2006 in the United States [2].

Our goal is to reduce the bicycle stolen rate. Instead of using traditional locks to lock the bicycle, we will use the Enkidu Bike Locker, which is an anti-theft device that when the usual lock is somehow broken violently, a second lock will be automatically locked and an alarm will be sent at the same time. Only the facial recognition or fingerprint of the owner can unlock it.

1.2 Background

Intelligent Fingerprint padlock, designed by Tinkux, can unlock the lock by fingerprints, which costs \$149.99 on Amazon[13]. Smart Bike Lock, designed by LINKA, can lock and unlock the lock when smartphone approaches, which costs \$194.99 on Amazon[14]. The costs for locks are not affordable for most bicycle users.

Our lock must be as affordable as possible to ensure bicycle to users experience the best reliable locks with the lowest price.

1.3 High-level Requirement

- Locks must be able to work at least one month without being charged and during the hazardous weather conditions.
- The unlocking system should have decent reliability under various circumstances.(i.e The facial or fingerprint recognition must have an one time accuracy of at least 90%).
- Locks must be as low-cost as possible, ideally under \$50.

2 Design

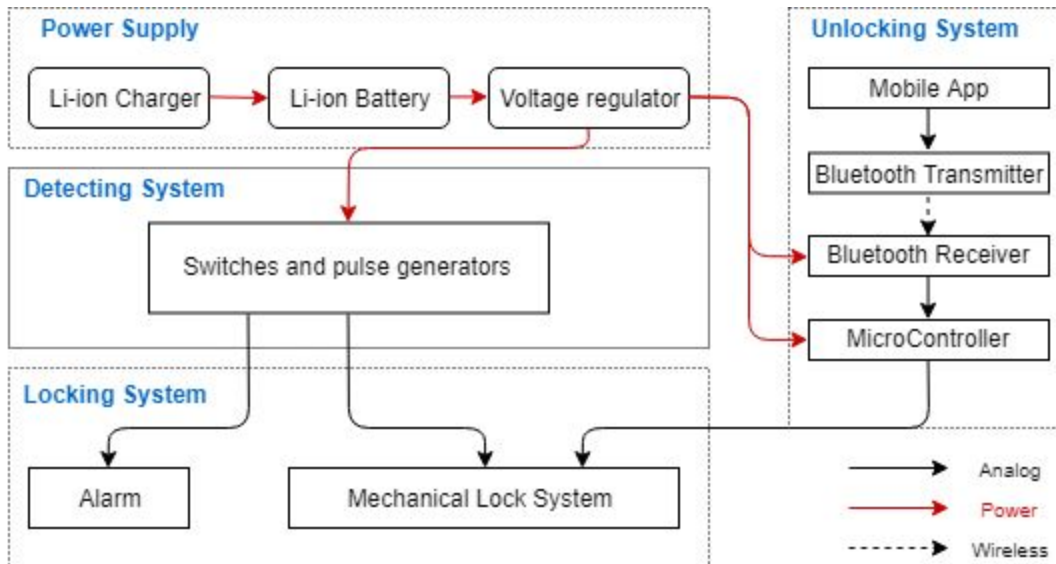


Figure 1. Block Diagram

Provided below is our physical design for the “lock sub-system” in the Locking system shown above in the Block Diagram.

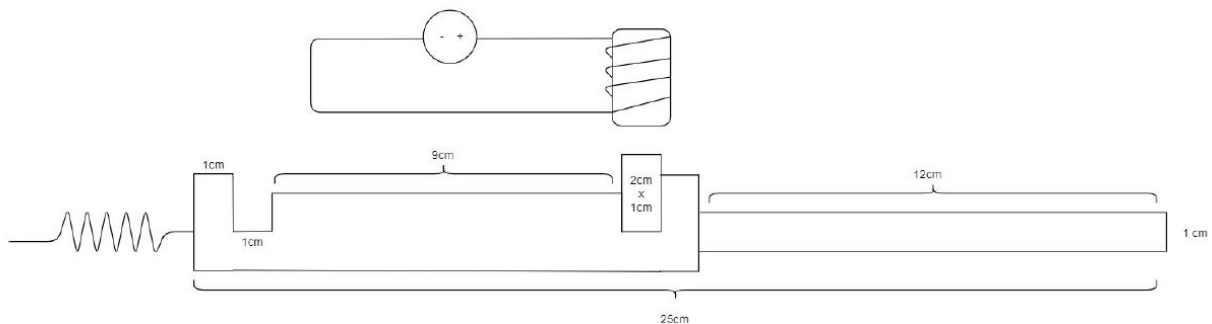


Figure 2.1. Physical Design -1

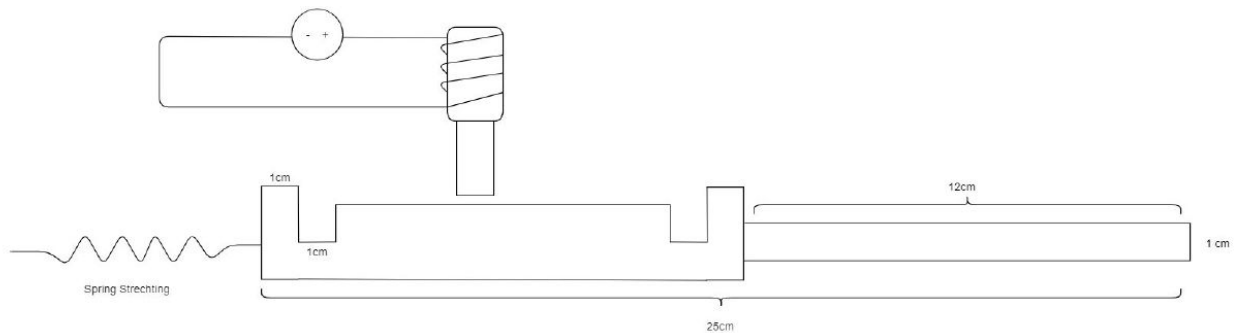


Figure 2.2. Physical Design -2

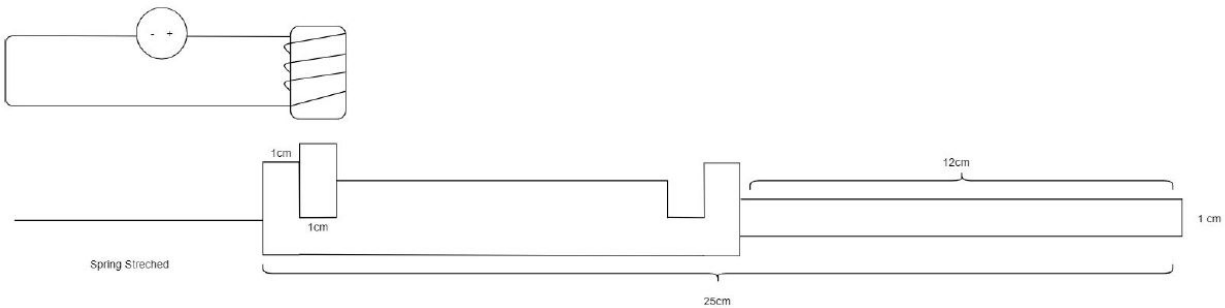


Figure 2.3. Physical Design -3

There will be shells and constraints surrounding the device in order to protect it and restrain the movements of the plugs (they will not be able to move along the directions into or out of the screen). Those are not drawn above for the neatness of the diagram. Also in the real world, the spring will not be completely straight after stretched by itself, but it is not drawn like that for the clear demonstration in the diagram.

When there is no current passing through the electromagnet, the system will stay as demonstrated in Figure 2.1 as the spring remains compressed. Once current passes through the electromagnet, the metal plug will be attracted so the lock will move to the right due to the compressing spring. Again when the current is gone, the metal plug will drop and fall into the second plug down below. The metal stick will be pushed out for around 10 cm after such a process indicated above.

To unlock the front tire lock, a steady current will be sent to the electromagnet from the unlocking system. There will be indication for the user to know when the lock is ready to be unlocked. The user will need to pull the plug back in and store the potential energy back onto the spring to unlock the system manually.

Note: Modification of the physical design after the discussion with Mr.Greg Bennett at ECE Machine shop.

Modification 1: We will use a solenoid instead of an electromagnet.

Modification 2: We will make plug 2 round so the rusts can fit the plug 360 degrees.

The reason we made the above changes was the feasibility and cost. We stated above about the constraints that is necessary to keep the device from moving randomly, especially for the original plug 1 since it will be loose once the voltage goes off. A solenoid solves this problem perfectly by having its own constraint to fix the motion of the metal plug. Also, by having our original plug 2 made round, we do not need constraints anymore since the plug can function with the solenoid from all angles.

The schematic of the modified plug 2 is shown below:

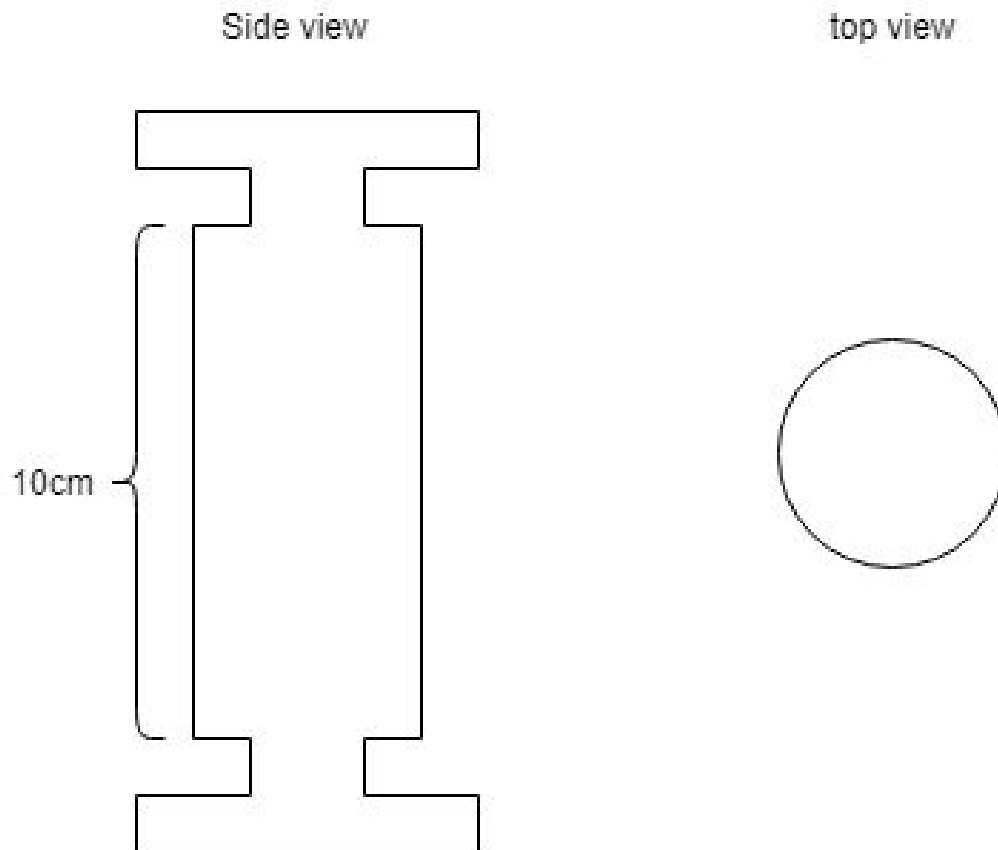


Figure 2.4. Physical Design -modified plug 2

The length is fixed since we need that distance of travel so the lock can go through the tire of the bicycle. The rest of the dimensions will be decided based on the dimension of the solenoid[15] which will be measured when it is delivered.

Provided below is the overall physical diagram of the design.

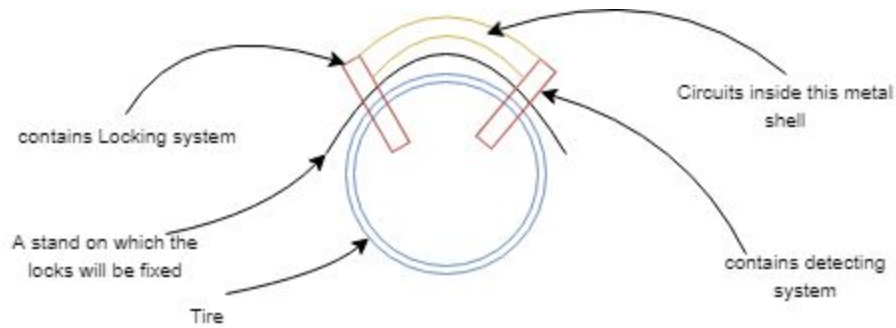


Figure 2.5. Overall Physical Diagram

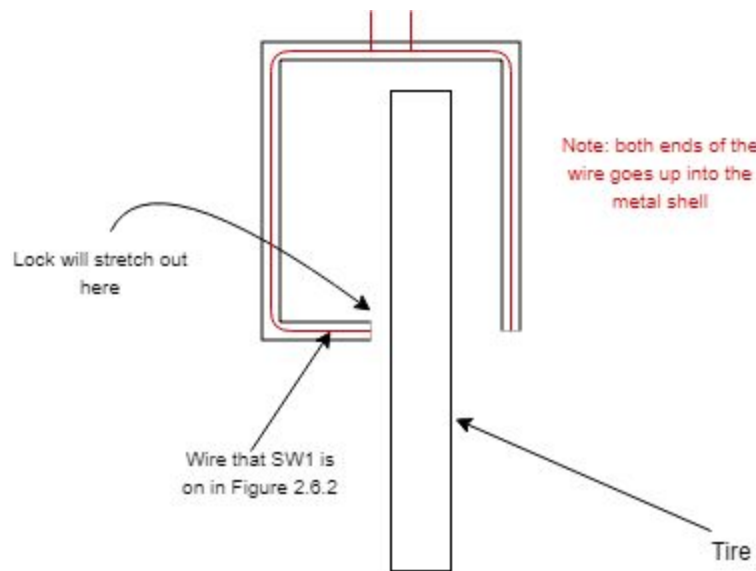


Figure 2.6. Detecting System Mechanical Diagram

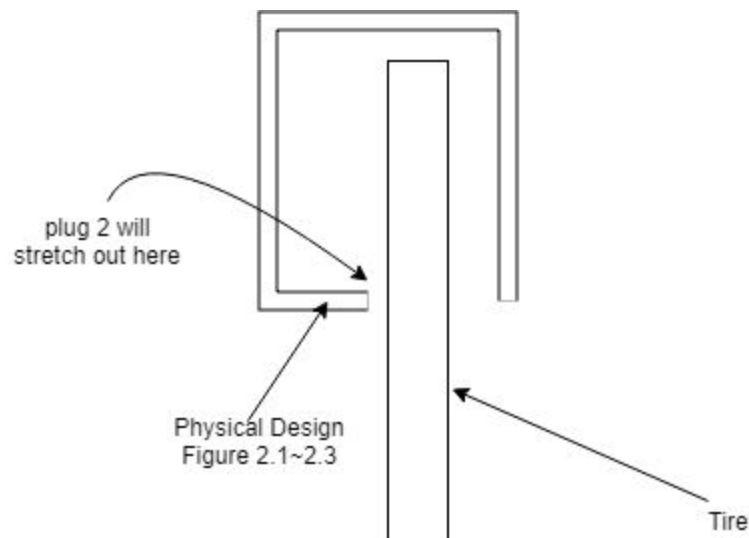


Figure 2.7. Locking System Mechanical Diagram

2.1 Power Supply

A power supply is required to make the whole system work when needed. Power is delivered from a Li battery which is rechargeable. The battery has 9V output and regulated to 5V for the rest of the circuit.

2.1.1 Li-ion charger

The node will charge the li-ion battery through a charger. The charger is powered by wall power outlet of 110V. The charger should fully charge the battery within 6 hours. A li-ion charger has a constant-current output of 90mA and constant-voltage of 9V.

Requirements	Verifications
<ol style="list-style-type: none">1. Transform 110V voltage from wall power supply to 9V.2. Charge the Li-ion battery with a continuous 90mA charge current, from the power source of 9V.3. Stay below 125°C when maximum current and voltage is applied.	<ol style="list-style-type: none">1.<ol style="list-style-type: none">a. Plug the charger to the wall power supply.b. Use a voltmeter to test the output voltage to be within the range of 8.9-9.1V.2.<ol style="list-style-type: none">a. Discharge a li-ion batteryb. Charge the battery using the chargerc. Connect the ammeter between the charger and the battery and ensure the current is $90\pm 5\%$mA3.<ol style="list-style-type: none">a. Throughout the charging cycle outlined in verification 2.b-c, observe the temperature. Use an IR thermometer to ensure that the charger does not reach temperatures greater than 125°C.

2.1.2 Li-ion battery

The charger will power the battery. The lithium-ion battery must be able to provide power when needed. We plan to use the battery of 800mAH to ensure that enough power could be provided when the whole system needs to work.

Requirements	Verifications
<ol style="list-style-type: none"> 1. The battery must be able to store enough power to lock the Locking lock a month after it is fully charged 2. Stores >780mAh of charge. 	<ol style="list-style-type: none"> 1. <ol style="list-style-type: none"> a. Put the battery into the whole system b. Connect an ammeter in series with the battery and test the current c. Calculate the remaining power by multiplying the current with the time of one month d. Ensure that the remaining power of the battery is >50mAh. 2. <ol style="list-style-type: none"> a. Discharge the full-charged li-ion battery at 300mA. b. Ensure that the discharging time is over 3.5 hours.

2.1.3 Voltage regulator

This low-dropout regulator supplies the required 5V to the node system from the 8.4V battery. We are using L7805 voltage regulator[8].

Requirements	Verifications
<ol style="list-style-type: none"> 1. The voltage regulator must provide 5V +/- 5% from a 8.4V source. 2. Must maintain thermal stability below 125°C. 	<ol style="list-style-type: none"> 1. <ol style="list-style-type: none"> a. Connect the output of the voltage regulator to VDD, and draw 90mA b. Measure the output voltage using an oscilloscope, ensuring that the output voltage stays within 5% of 3.3V 2. <ol style="list-style-type: none"> a. During verifications a and b, use an IR thermometer to ensure the IC stays below 125°C

2.2 Detecting System

Detecting system represents the lock for everyday usage if we implement this device on a bicycle.

It will set off the alarm when the lock is not properly unlocked. No alarm will be sent when it's properly unlocked.

2.2.1 Circuit Description

The circuit consists of mainly two manipulatable switches and a pulse generator.

Switch 1 represents the locking part of the lock. When switch 1 is opened, it means that the Detecting lock is unlocked properly. Under this circumstance, no false alarm should be sent to the whole device and it should still be able to function properly afterwards.

Switch 2 represents the rest parts of the lock besides the locking part. When we turn switch 2 open, it means that the Detecting lock is unlocked improperly (i.e broken violently by the thief). Under this circumstance, the system should output a current pulse signal to the Locking system and therefore lock the Locking lock.

Requirements	Verifications
<ol style="list-style-type: none">1. The circuit should output a current pulse signal when switch 2 is opened.2. Nothing should happen when switch 1 is open and the whole circuit should output nothing and function properly.	<ol style="list-style-type: none">1.<ol style="list-style-type: none">a. Simulate the circuit on LTSPICE to make sure that the simulation gives us the correct result.b. Measure the output of the circuit after it is implemented.2.<ol style="list-style-type: none">a. Short the circuit consists of switch 1 so it will not affect the circuit. Measure the output after implementation to make sure it gives the correct result.

2.3 Locking System

Locking system is a back-up safety plan of the bicycle for security purpose. It will be automatically locked when the Detecting system is not unlocked through a proper and legal way(i.e. switch 2 is turned open rather than switch 1). The system will not be unlocked unless a

signal is received from the unlocking system which can only be passed by the owner of the bicycle.

2.3.1 Lock sub-system

The physical design of this sub-system is provided in the physical design section.

The system consists of mainly an electromagnet (with a current source), two plugs (material remains to be decided, the preferred choice is aluminum): plug 1 (a cuboid of 1cm*1cm*2cm), plug 2 (consists of two ruts to hold plug 1 and the stick used for physically locking the bicycle. Around 25 cm long), a spring (used to store the potential energy in order to lock the system when plug 1 is pulled out of the rut).

The preferred choice for the material of the plugs will be aluminum. From the perspective of feasibility, aluminum is lighter than copper or steel. Also it's corrosion resistant compared to other competitive choices.

Functions used to compute the needed magnitude of current [4]:

$$F = \frac{B^2 A}{2\mu_0} \quad (1)$$

$$B = \frac{NI\mu}{L} \quad (2)$$

Where A is the cross section area of plug 1 vertical to the direction of the magnetic flux. μ_0 is the magnetic constant ($\mu_0 = 4\pi \times 10^{-7} \text{ H}\cdot\text{m}^{-1}$). N is the number of turns of the coil around the electromagnet. μ is the permeability of the material (permeability of aluminum is around $4\pi \times 10^{-7}$ to $1.256665 \times 10^{-6} \text{ H}\cdot\text{m}^{-1}$ [5]). L is the distance between plug 1 and the electromagnet.

From our design, assuming that we are using aluminum as the material for plug 1, then the mass of plug 1 will be 7g at maximum (5.4g calculated). F is needed to be at least 0.07N to be able to pull on plug 1. $A = 2 \times 10^{-4} \text{ m}^2$. By calculating using the above data, we have $B = 0.03\text{T}$.

From our design, we can see that the maximum distance a plug can be lifted by the electromagnet is 1.5cm. The distance should be around 5 cm in total. Plug in the numbers, we finally get our desired IN value:

$$IN = 1180 A$$

This is a reasonably small number. It should not be hard for our system to provide such a current source for our electromagnet.

Functions that will be used to decide the choice of spring:

$$mg\mu = -kx \quad (3)$$

Where k stands for the spring constant, m the mass of plug 2 and μ the friction coefficient.

From our design, our spring will be needed to stretch out for around 10 cm = 0.1m. The mass of our entire plug 2 is around 45g (assuming aluminum as the material, 37g calculated).

Through our calculations, we get

$$-\frac{k}{\mu} = 4.5N/m$$

at minimum.

The friction coefficient between metal surfaces are usually below 1.[6]

As we can find on the online shops, the spring constants of most of the spring we can find on the online shops are above the value of -4.5N/m. It is a reasonable number for us to implement the system.

Note that for this part, aluminum does not have to be the material of plug 2. In fact, for the purpose of feasibility, we will use materials much lighter(rubber or plastic). The assumption of using aluminum is just to calculate the limit of the critical value.

Requirements	Verifications
1. The system will lock itself using the lock sub-system once it receives the signal sent from the control unit caused by the inappropriate unlock of the Detecting system. When locking itself, the current	1. <ol style="list-style-type: none"> Input a pulse signal with a relatively short time constant (around 1s) to the device and observe the result. The spring should stretch and the metal stick should be pushed out for around 10 cm as indicated by the physical

<p>will stay for around 1 sec so that the solenoid will lock into the rut and lock the system.</p> <p>2. When a signal is sent from the unlocking system described below, the current will stay for a longer period of time (around 5 sec) to allow the user to compress the spring and manually unlock the system.</p>	<p>design.</p> <p>2.</p> <p>a. Input a pulse signal with a relatively long time constant (around 5s) to the device and observe the result. The metal stick should be able to be manually moved and the spring should be able to be compressed.</p>
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2.3.2 Alarm

Alarm is activated when there is a violent break on the regular lock. The main purpose of the alarm is to threaten the thief. The alarm sound would last about 30 seconds before it stops.

Requirements	Verifications
The alarm should be loud enough that people can hear it 30 meters away.	<p>a. Activate the alarm</p> <p>b. Make sure that people from 20 meters away can clearly hear the alarm sound</p>

2.4 Unlocking System

Unlocking system provides the only way to unlock the Locking system lock. As the owner of bike uses either facial recognition or fingerprint to authorize the access of the bike on an iPhone application, the bluetooth of the phone will send a unlocking signal.

2.4.1 Mobile Application

Mobile application is used to recognize whether it's the owner of the bike or not. Facial recognition or fingerprint recognition is used for the authentication in the application. Once it is passed, signal would be sent to the bike using the built-in bluetooth on the phone.

Requirements	Verifications
One-time facial recognition in the application should have at least 90% accuracy.	<ol style="list-style-type: none"> Take several pictures of the owner in different environments (i.e. in sunny days, windy days and nights) Test the pictures and ensure the accuracy to be above 90%

2.4.2 Bluetooth Transmitter

In most cases, a phone has the bluetooth transmitter in it. The built in bluetooth transmitter has to meet some requirements so that it could pair with our system and work properly.

Requirements	Verifications
<ol style="list-style-type: none"> The bluetooth transmitter should be able to find the correct receiver. The bluetooth transmitter should send a strong enough signal that could be received in 10 meters. 	<ol style="list-style-type: none"> <ol style="list-style-type: none"> Search for bluetooth receiver on the phone and make sure it can connect successfully. <ol style="list-style-type: none"> Walk away from the receiver at least 10 meters. Test if the bluetooth still works by sending a test signal.

2.4.3 Bluetooth Receiver

Bluetooth receiver on the bike should receive the signal sent by the sender on the phone. The bluetooth receiver output the serial signal through the TX-O pin to the microcontroller[9].

Requirements	Verifications
Latency should below 30ms	<ol style="list-style-type: none"> Measure the time between the signal is sent by the transmitter and the receiver receives the signal Ensure that the time should be less than 30ms

2.4.4 Microcontroller

Microcontroller translates the signal from the bluetooth to the pulse that can be directly used to unlock the Locking lock. We will use Arduino to program the controller. Once the authorization is passed on the owner's phone, a specific string of numbers would be sent to the microcontroller. The controller will not send the signal to front tire until it receives the correct code. The output of the microcontroller is a digital signal, for the reason that we need a pulse to unlock the front tire lock.

Requirements	Verifications
Can receive and transmit the signal from bluetooth to a pulse signal for the Locking system.	a. Connect microcontroller to a bluetooth receiver b. Send the correct code bluetooth receiver c. Ensure that output signal is a pulse

2.6 Schematics

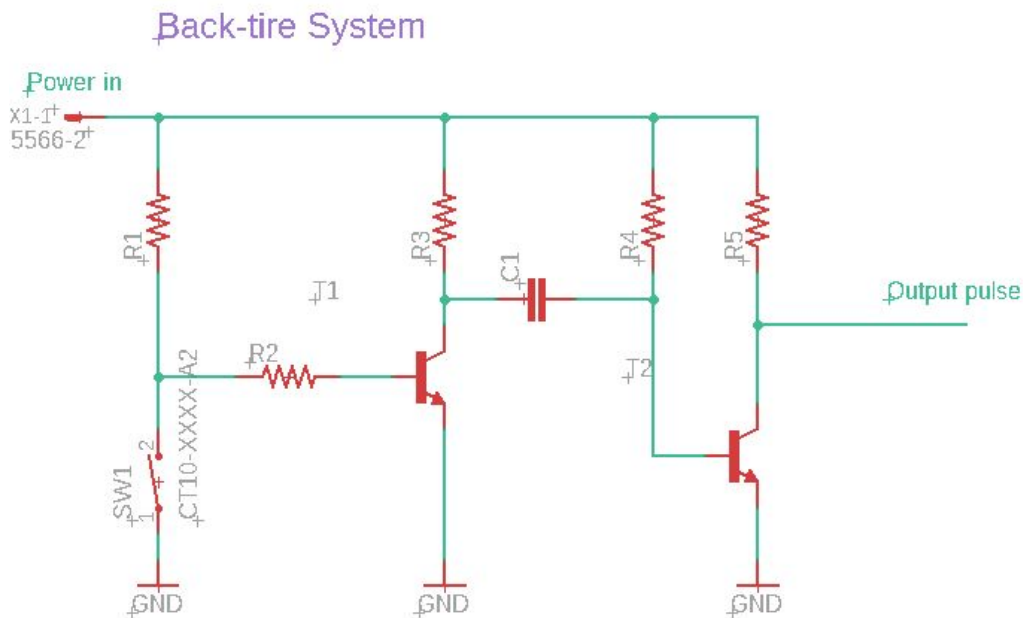


Figure 2.6.1 Detecting system schematic

Input of the Detecting system will be a step function, and the output will be a voltage pulse signal. The time constant for the pulse will be defined by

$$\tau = R4 * C1 \quad (4)$$

The value of the components will be chosen to meet the requirements specified in the R&V table.

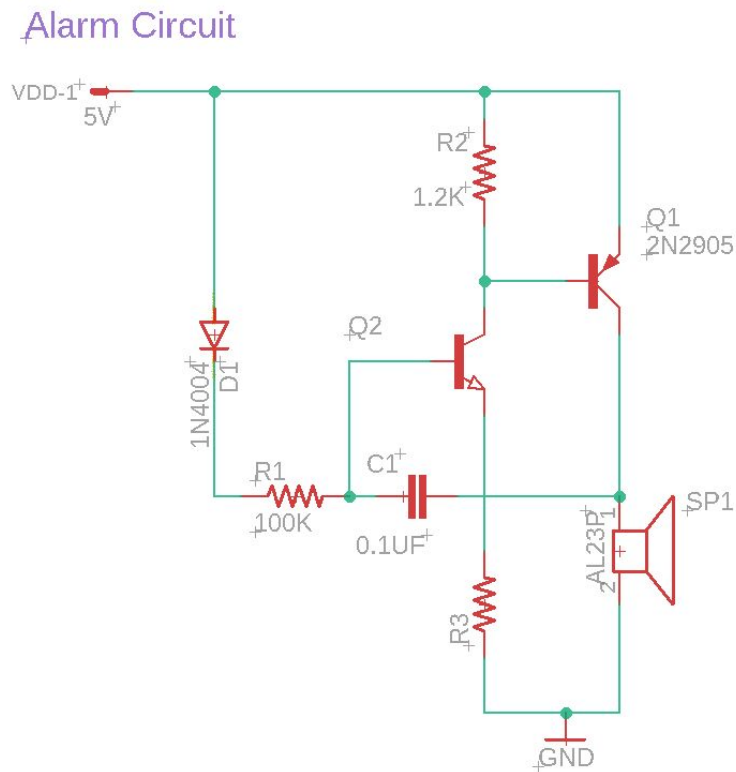


Figure 2.6.2 Alarm circuit schematic

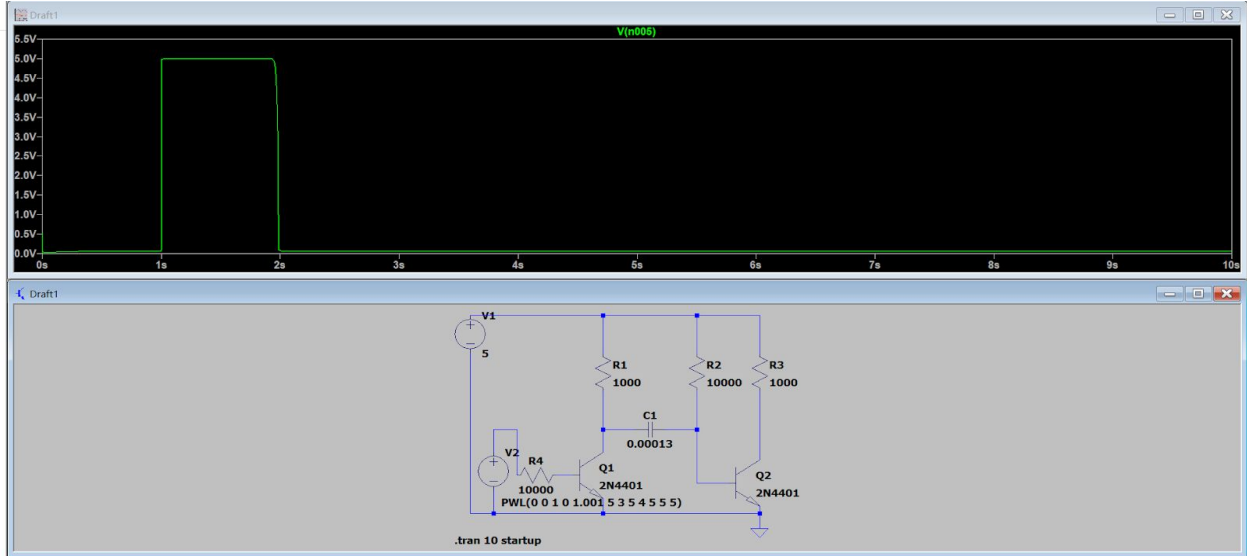


Figure 2.6.3 Detecting system schematic simulation with $c=0.00013$

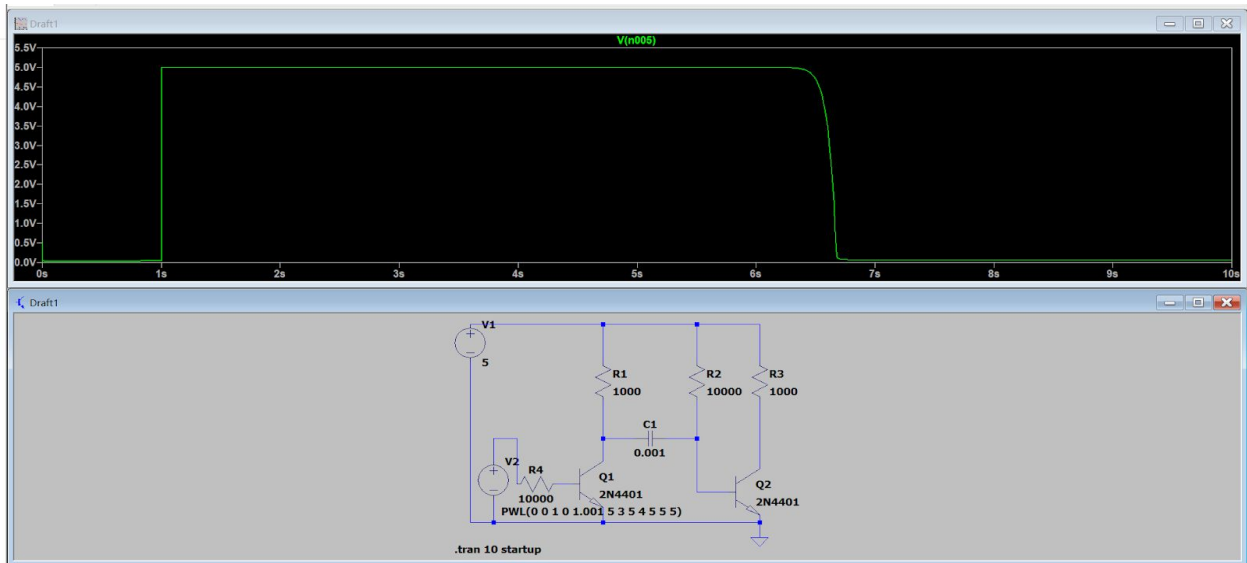


Figure 2.6.4 Detecting system schematic simulation with $c=0.001$

2.7 Tolerance Analysis

Although we choose aluminum, one of the most corrosion-resistant metal as the material to construct the lock of our Locking system, it is still unavoidable that the corrosion happens. After the discussion with our TA regarding this problem, we decide to do a tolerance analysis for the

critical requirement that all the aluminum parts of the system become oxide. The chemical reaction is described by the equation below:



The mass converting ratio between Al_2O_3 and Al is

$$R = \frac{56 \times 2}{56 \times 2 + 16 \times 3} = 70.0\%$$

The mass of plug 1 becomes

$$M_1 = 7g \div 70\% = 10.0g$$

The IN value needed to pull up plug 1 becomes

$$IN = \frac{(\frac{2\mu_0 F}{A})^{\frac{1}{2}} L}{\mu} = 1620A$$

This requirement can still be satisfied by all the electromagnets sold in the online shops. Such as the ones demonstrated at [15].

3 Cost and Schedule

3.1 Cost

Our fixed development labor costs are estimated to be \$30/hour, 10 hours/week and 16 weeks for three people.

$$3 * \$30/hour * 10hours/week * 16weeks * 2.5 = \$36000$$

Part	Cost(Prototype)	Cost(bulk)
800mAh Li-ion battery including charger (Amazon)[10]	\$24.99	\$10.95
Voltage regulator (SparkFun)[8]	\$0.95	\$0.4
Microcontroller(SprakFun RedBoard)[11]	\$19.95	\$9.95
Bluetooth(SparkFun)[12]	\$27.95	\$10.95
Alarm(SparkFun)[16]	\$1.95	\$0.95
Electromagnet	\$24.15	\$14.15
PCBs(PCBWay)	\$3.1	\$0.1
Assorted resistors, capacitors, ICs, crystals, sockets(Digikey)	\$10.0	\$1.0
Total	\$94.00	\$44.00

Table 3.1 Cost Analysis

We are going to build 1 sample lock, the grand total cost for the lock is about \$36120.00.

3.2 Schedule

Wee k	All group members	Shijie He	Jiahao Chen	Zhengyu Ji
2/18/ 2019	Design schematics and PCB and Write design document	Design schematics and PCB and Write design document	Design schematics and PCB and Write design document	Design schematics and PCB and Write design document
2/25/ 2019	Finalize schematics design	Program the unlocking system	Run final simulations	Contact the machine shop and draw CAD
3/4/2 019	Finalize PCB design and get the PCB board	Buy the microcontroller	Buy the bluetooth equipments	Buy the electromagnet and spring
3/11/ 2019	Solder PCB board with all parts implemented	Soldering	Soldering	Soldering
3/18/ 2019	Program the microcontroller	Test the utility of microcontroller and unlocking system	Circuitry modulo testing and debugging	Test the utility of electromagnet and spring
3/25/ 2019	Design the prototype case	Modulo test and debug	Modulo test and debug	Contact the machine shop and finalize CAD
4/1/2 019	Connect all the parts with PCB and power	Final test and debug	Final test and debug	Test the utility of the lock sub-system
4/8/2	Product stability and	Test the	Test the	Connect the lock

019	weather condition testing	waterproof quality of the device	stability of the device	sub-system to PCB
4/15/2019	Prepare demonstration	Prepare demonstration	Prepare demonstration	Prepare demonstration
4/22/2019	Prepare final presentation	Prepare final presentation	Prepare final presentation	Prepare final presentation
4/29/2019	Write final report	Write final report	Write final report	Write final report

4 Safety and Ethics

There are several potential safety issues with our projects.

Li-ion batteries will be extremely unstable if it is overcharged, charge with extremely high voltage or even exposed to the extreme temperature or conditions. We should consistently stay an eye on the condition of the Li-ion batteries to prevent it explodes. Make sure the Li-ion charge supply the 4.16-4.23 V and >300mA charge current and the temperature stays below 125°C.

We also need to design an outer case to prevent extreme weather. Due to the unknown outdoor weather conditions such as raining, snowing or fogging, the device might break or short, so we have to design the lock to be waterproof.

During designing Enkidu Bike Locker, we have to run huge amounts of facial recognition or fingerprint tests when we training the unlocking system. These data may be an invasion of other's privacy, so we need to be careful about ethical issues when picking those samples.

Also, when a company publicizes their product, the level of credential is the problem. These results are not honest and realistic during product publicity, which violates the #8 of the IEEE Code of Ethics, "to be honest and realistic in stating claims or estimates based on available data" [3]. We plan to encrypt every face data we used to prevent the data divulge. We will open our data sources to the public as the proof of our honesty.

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