ECE 445

Senior Design Laboratory

Fall 2022

Design Document

Distributed Bike Lock System

Team 3

Praneeth Mekapati, Rohan Sreerama, & Cameron Obrecht

TA: Hanyin Shao

9/29/2022

Table of Contents

1. Introduction

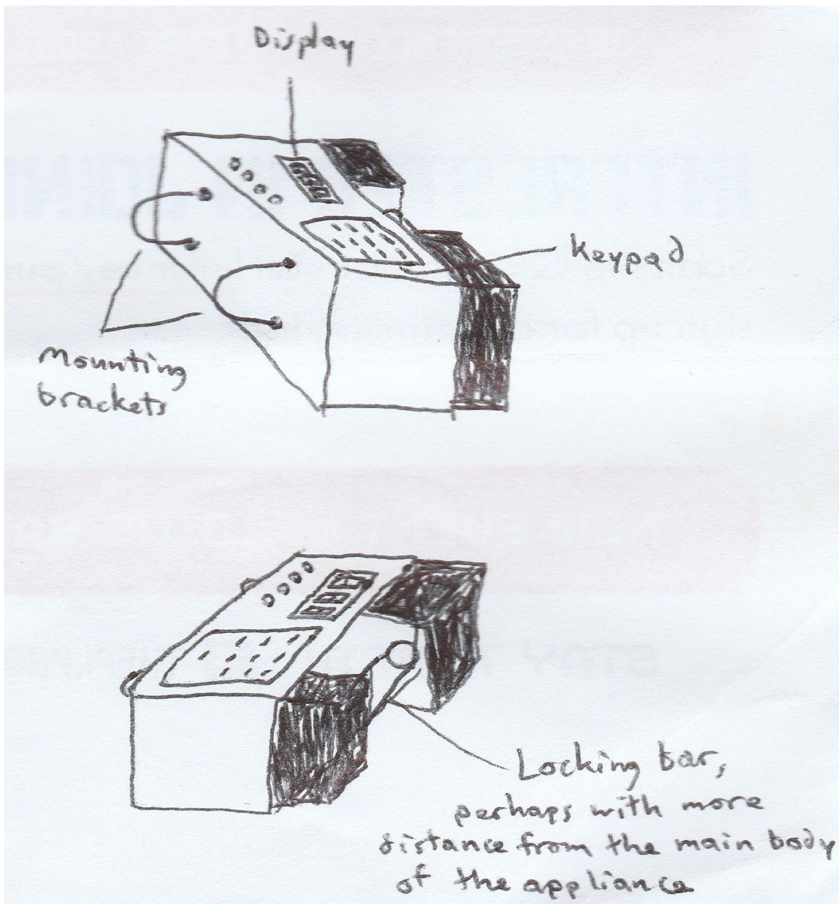
1.1 Problem

Bicycle theft has always been a big issue. One bicycle is stolen every 30 seconds, and almost two million bikes are stolen every year, corresponding to over $350,000,000.[1] Although many people use locks, thieves are able to cut these locks with tools such as bolt cutters, even the common U-shaped solid metal locks. This shows that bikes are able to be stolen even when the bikes are locked at bicycle racks. There are also times when people forget to bring their locks, or perhaps would rather not carry around the extra weight of a lock. This also can be a problem when they need a way to keep their bikes dependably safe at a public place.

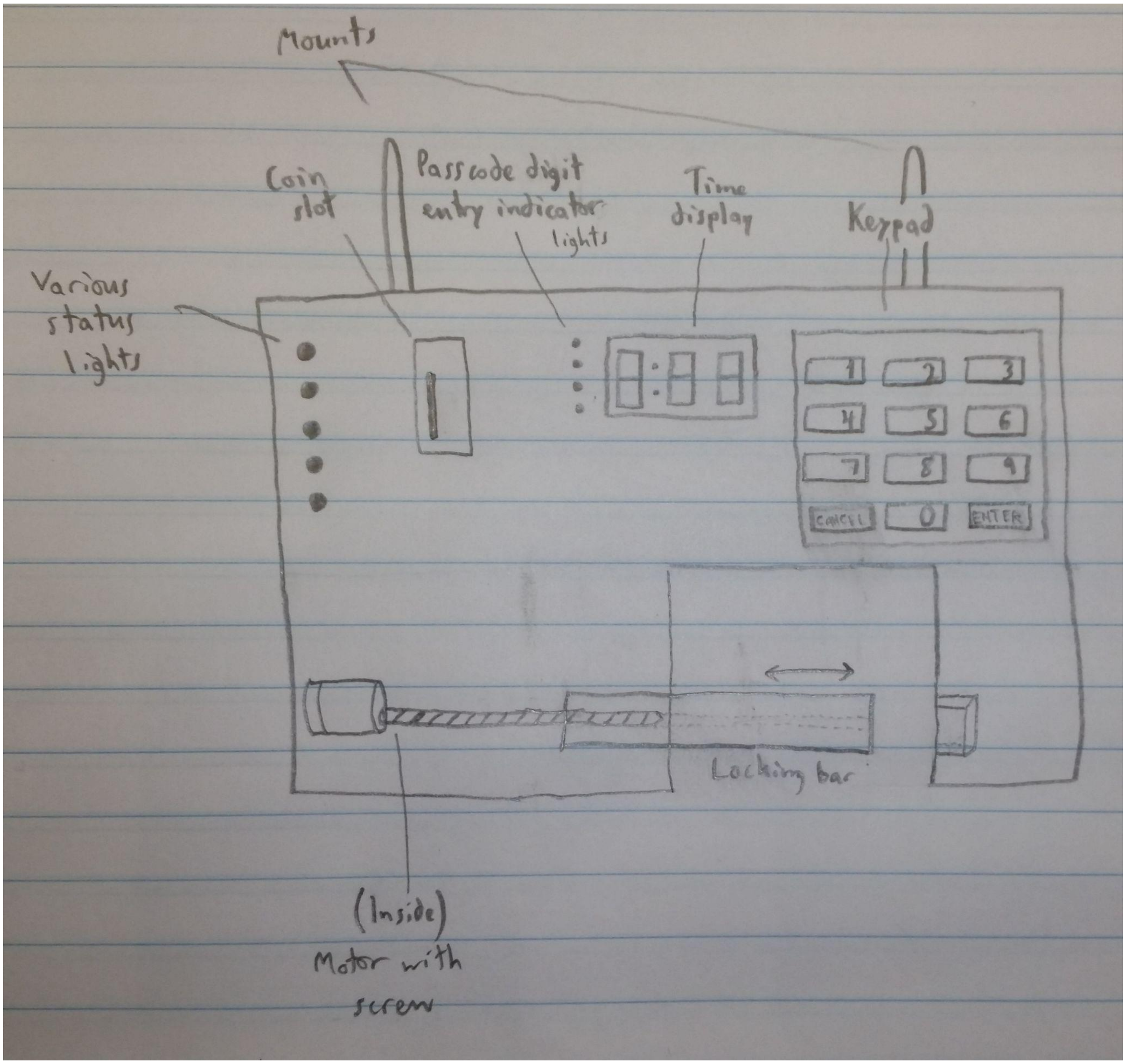
1.2 Solution

In order to solve the problem of bike theft, we are proposing a distributed bike lock system. This is a group of independent, public, automated, durable, passcode-driven, pay-to-park locks permanently attached to existing bike racks. They will be placed on the racks so that a user does not have to bring their own lock, and they can serve as a source of revenue for the owner of the racks, whether it is an institution or a private landlord. Each device will sound a high pitched alarm when there is a sign of physical theft activity, using force sensors. It will take user input of the number of hours to lock their bike, and will accept coins as payment according to the number of hours specified. The device will use a thick motor-controlled metal bar, significantly thicker than the common locks on the market today, which will clasp loosely around the bicycle frame after payment is made and make it impossible to take the bicycle.

1.3 Visual Aids



Lock Appliance



Appliance Interface in Further Detail

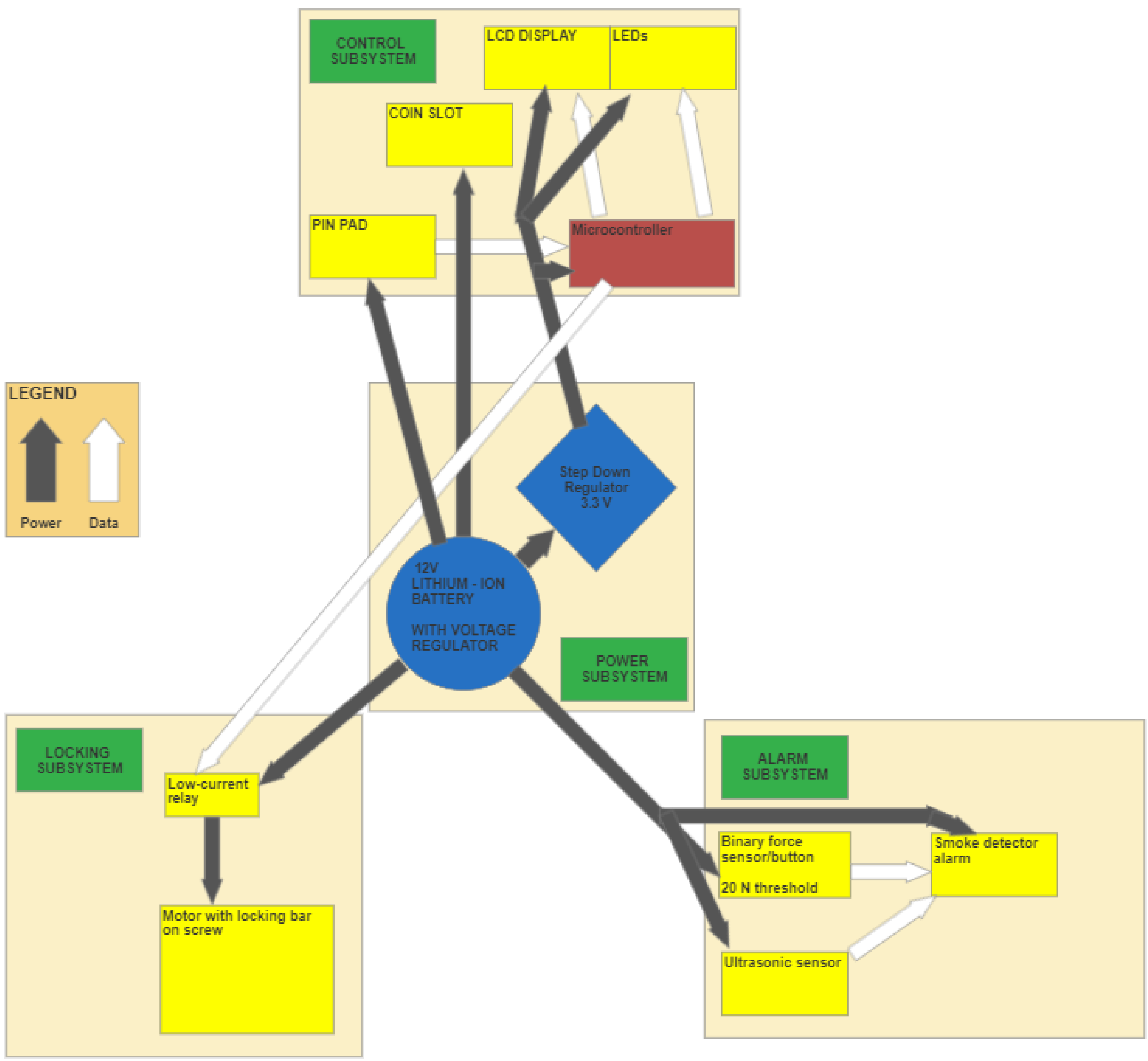
1.4 High Level Requirements

The finished appliance will have to:

- Be secure. The appliance will have to be difficult for a malicious actor to destroy, whether by preventing the attempt or by continuing to hold the bicycle securely even if severely damaged. It must sound the alarm if someone exerts a strong physical force on the locking bar, as if attempting to dislodge or break it.
- Accept payment honestly, without failing to accept a coin. It must internally update the cumulative amount paid upon receipt of each coin, and indicate preparedness to lock when the proper amount has been paid according to the desired parking duration. It must also keep the bicycle past the end of the parking period and charge the correct additional amount if the user fails to redeem their bicycle by the end of their specified period.
- Register input and display output correctly. Have a proper way of memory storage for the user when they want to unlock their bike especially

2. Design

2.1 Block Diagram



2.2 Subsystem Overview

2.2.1 General Device Action Scenario: The user walks up to the bike rack with their bicycle. If the appliance is not in use, a green LED will be on, and a seven-segment LED display will show 0:00, indicating that it is ready for use. If it is in use, and there is a bike locked there, a red LED will be on. The first thing a user does after approaching an available and unused rack is to use the up-arrow and down-arrow buttons to increase or decrease the desired parking duration by half hour increments. The seven-segment display changes to 0:30, then 1:00, et cetera, with each press of the up arrow. When the desired duration is shown, the user presses an “enter” button, and a light comes on next to text saying “Enter new passcode.” The rack fixture will include a numerical keypad, and the user can enter a 4-digit PIN, and then press “enter.” Another status light comes on saying “Confirm passcode.” The user enters the same PIN, and presses “enter.” The status light turns off, and another comes on, saying “Insert coins.” The price of 50 cents per half hour of bicycle parking will be stated on a decal or other inscription on the outside of the device. The user inserts coins into a coin slot, and when at least the proper amount has been inserted, another light will come on, saying “Press enter to lock.” The user positions the bike properly and presses “enter,” and the locking bar slowly slides out of its hole and across a segment of the bicycle frame, stopping a short distance into a hole on the opposite side of the recess in the device. The microcontroller resets the seven-segment display to 0:00. The user can walk away knowing that the bicycle is secure.

If the user wishes to cancel and unlock the bike early (which is recommended to do at least a few minutes in advance of the end of the parking period to avoid further charges), the user can walk up and enter their unique passcode, without a refund. The user has ten attempts to get the passcode correct, after which the appliance will keep the bike locked for the next 24 hours (free of additional charge), as a theft deterrent. If the number of tries were any less, then there is a greater risk of a prankster coming by and deliberately entering incorrect passcodes to keep all the bicycles locked there, which would deter people from using the appliances in the future. If the number of tries were greater than 10, there would be a greater chance of correct guesses by potential thieves. If the user does enter their passcode correctly, the appliance will unlock, and await the next user. If the user has not entered their passcode to unlock their bicycle after their duration has expired, the appliance will keep the bike locked, and require additional payment of $1 per half hour over the initially specified duration.

2.2.2 Alarm Subsystem: Sounds the alarm when there is a thief attempting to steal the bike, with a high pitched continuous beep. It is operated directly by a battery, in an analog circuit with no need for intelligent alarm activation as long as a force signals the sensors. The sensors will act as a switch to send power to the alarm, which will sound a beeping noise with a high enough frequency to be unpleasant to the ears and audible from a distance. This includes the force/motion sensor to detect any movement of the thief along with the ultrasonic sensor to detect the movement from a particular distance. The ultrasonic sensor will need to be run by the microcontroller (connection not shown in the block diagram), since by nature it needs a computing device to interpret the data it collects. If both the sensors are able to detect unusual or suspicious activity with strong force or object or hand movement close to the alarm system, then this would trigger the alarm.

2.2.3 Lock Subsystem: Rotates a long screw to shift the bar left or right based on the signal from the microcontroller. This makes sure the bike is firmly locked in a way that no thief can try to force the lock to open with any tools or break it. The screw will be rotated by a relay-controlled geared motor with a gear reduction on the order of 500 times, which has a built-in controller that will send and receive data to and from the microcontroller. If the particular motor we ultimately use does not have a relay or similar device built into its controller, we will also include a low-current relay device in the Lock Subsystem to forward the low-current signal from the microcontroller to the motor. The Alarm Subsystem is also near the lock and this is the best way to ensure no tool or force comes near the lock to steal the bicycle. This is operated with the use of the control subsystem. The lock is activated when the control system successfully receives and processes the input signals from the keypad and the coin slot. Overall, the lock subsystem is reliant on the control subsystem.

2.2.4 Control Subsystem: Responsible for starting and stopping the motor, taking user input and payment, and giving user output. The microcontroller is the heart of this subsystem, as it interprets and governs everything. The microcontroller will run a program that tells it when to turn on which status LEDs and segments of the seven-segment display, and what each key on the keypad means, using variables and perhaps a small amount of RAM to keep track of internal numerical and Boolean values. It will be programmed to take 50¢ for each desired half hour of parking, and to stay locked and require a deposit of $1 for each half hour past the initially specified parking period before unlocking the bike.

2.2.5 Power Subsystem: This will provide power to all elements of the device using two different voltages. The lithium-ion battery will be a series arrangement of three cells to achieve approximately 12 volts, for running the motor, keypad, and other higher-powered components. The battery will be similar in size to what is found in hobbyist remote-controlled cars, with a capacity on the order of 5 amp-hours or more, to last months on one charge. It will be removable for charging by a custodian or other person responsible for maintaining the bicycle locking appliances, with a generic lithium-ion charger of which a variety are available commercially. It may need a 12-volt regulator, but we do not anticipate that the components using 12 volts will be particularly sensitive to fluctuations in voltage, as simple DC motors generally are not. It will however need a 3.3-volt step-down regulator, which will be responsible for powering the microcontroller, and the LEDs if the signal current from the microcontroller is not enough to power them.

2.3 Subsystem Requirements and Verification

Requirements	Verification
Lock Subsystem: 1. The motor will move the bar to either lock or unlock based on the signal from the microcontroller. 2. This will be based on the requirements being satisfied successfully in the control subsystem. 3. This will help with the microcontroller sending a signal to the alarm subsystem if any suspicious activity is detected such as penetration of the lock or strong force being applied to break the lock.	- 1. The motor based lock will have power from the lithium battery of 12 V and is connected to the microcontroller 2. The microcontroller will provide a signal to the motor to unlock based on successful verification of the user based on the passcode. 3. If successful the motor will rotate the bar to unlock the bike. Otherwise the bike will stay locked. 4. The bike will start to be locked when the user goes through the process inputting the number of hours greater than 0, inputting a 4 digit number code, and inputting the correct amount of money specified for the number of hours with the coin slot. 5. Afterwards the motor will get a signal to rotate the bar to lock the bike.
Alarm Subsystem: 1. Sound the beeping noise when the force from the binary force sensor goes above the given threshold.	1. In order to verify the sounding of the alarm, we have put a force threshold at 20 N. 2. This would be a good threshold because we understand that the bike is locked with a motor that

2. In this process we also have to make sure that the force is from a stranger and not an environmental action like wind.	has a tight locking bar and a thief would have to try really hard to break the motor. 3. The whole circuit will be enclosed in a physically hard shell and it would be hard to penetrate that shell or to try and unlock it. 4. If it goes above the threshold the current will travel to the alarm which will then sound the beeping noise for suspicious activity
Control Subsystem: Requires a microcontroller to take user input from the keypad and coin slot, and send output to the status LEDs, numerical display, and motor controller (embedded in the motor). The microcontroller is embedded on a PCB, and it interprets the data from the coin slot and adds the values of the coins to determine when the proper amount due has been paid. It then sends a signal to the motor controller when the right amount of money has been paid, according to the number of parking hours specified by the user. The microcontroller board is connected to a voltage-regulated power source via a plug. The microcontroller is responsible for starting and stopping the lock motor based on the number of revolutions traveled, which is sent as data by the motor controller. The keypad sends a signal to the microcontroller after the 4 digit PIN is typed. Then the	The keypad will have the same from the step down regulator. The LCD and the LEDs will be powered and programmed by the microcontroller. The coin slot will have power provided by the lithium battery consisting of 12 V and later connected to the microcontroller. The microcontroller will first display the message on the LCD to let the user type the number of hours they would want to lock their bike for with the use of the key pad. If the number of hours is greater than 0, the microcontroller then sends a signal to the LCD and the LCD will prompt the user to type in their 4 digit pin for verification. After the user enters it, the controller makes sure the user typed a 4 digit pin and it will later display the message in the LCD to prompt the user to insert coins for the inputted number of hours. If it successfully reads the inputted amount of money and correctly matches with the money required for the specified

microcontroller waits for the input signal from the coin slot. The input will be successfully processed when the user pushes the correct amount of money into the slot. The microcontroller after having the correct amount of money from the user with a 4 digit pin will send a signal to the motor. The microcontroller will require a 3.3 V input from a power source which will be the step down regulator.	number of hours, the microcontroller will send the signal to the locking subsystem to start the process. If the user crosses the inputted time limit, the microcontroller will require the user to pay extra money to unlock their bike. In order for the user to unlock the bike, the microcontroller will utilize the LCD to prompt them to type their four digit pin. If correct, the microcontroller will send a signal to the lock to unlock it.

2.4 Tolerance Analysis

The possible risks of the system that can interfere with the completion are with the signals from the microcontroller to the motor-driven locking bar. This can be a problem with the time the motor takes to get the signal from the microcontroller, and also the time it takes for the motor to lock the bike (about 5 to 10 seconds). Another problem is with how well the motor locks the bike and the way it is unlocked. This is because the motor needs to stay firm in one place for the bike to be locked. We also need to make sure we have the clipped terminals (secured wiring) especially for the coin slot. The coin slot will not process the money properly and it can drop the coins in random places which can also increase the chances of money theft. The signal relays are important in that they have to be programmed properly with the Programmable Interrupt Controller. This includes taking signals from both the keypad and the coin slot and then outputting them to the LEDs and the LCD screen. Both the successful keypad 4-digit input, and the right amount of coins in the coin slot to start locking the bike with the motor, need to be taken into consideration.

3. Cost and Schedule

3.1 Costs

Microcontroller - $20
Battery regulator - $15
Batteries - $10
Smoke detector alarm - $8
Pin pad - $10
Locking system
Ultrasonic sensor - $6
LCD display - $12
Buttons - $5
Force motion sensor - $17
Coin Slot - $20
12 V Battery - $18
Regulator - $15

3.2 Schedule

Week of Oct 3:

Discuss architecture and finalize necessary parts particularly the microcontroller and the sensors

Week of Oct 10:

Order parts and test functionality and check if we need more/different parts.

Week of Oct 17:

Start working on the control subsystem by first creating the basic outline and circuit

Week of Oct 24th:

Integrate the components and test out the control subsystem to make sure the signals are properly transmitted. Leds should display properly when pressing the interrupts like enter and the LCD should give the right text for the user. The coin slot should be able to read the coins properly and record them into the microcontroller system and the system should be able to save the user 4 digit passcode.

Week of Oct 31:
Start working on the alarm subsystem and create a circuit

Week of Nov 7th:

Integrate the components for this subsystem and test it out to make sure the results are accurate in terms of the responses of the sensors. The system should sound when there is heavy pressure utilized in breaking the system with powerful tools or human force. It should also be able to detect wind speed and ignore that when testing the subsystem.

Week of Nov 14th:

Start working on the lock subsystem and integrate the lock provided by the ECEB into the circuit. Test to make sure that the lock receives the signal from the microcontroller when initiated to lock or unlock and see if the lock successfully locks the bike.

Week of Nov 21st:
Integrate the subsystems and create a final design. Test the design at nearby bike racks with multiple bikes and record results to prepare for the demo.

4. Ethics and Safety

The appliance of our design is not a particularly hazardous device. It uses 12 volts, which, across the natural electrical resistance of the human body (at least 2300 ohms according to the National Library of Medicine), does not allow a dangerous amount of current to flow (about 5 milliamps), seeing as the smallest current that can cause uncontrollable muscle movement is 10 milliamps according to OSHA.[3] Our appliance only contains one moving part that is visible from the outside. With the ACM Code of Ethics and Professional Conduct in mind, discrimination, fairness, respect, and privacy are in no way called into question by our design, simply because of the nature of the device. Anyone can use it, information is not shared, and the procedure for using it is made clear by the status lights and the writing next to them on the exterior of the device.

The only issues that might arise during use of the device are honesty and physical safety. The device must accept coins without error or failure, especially since there is no coin return mechanism as there is on many vending machines. If there is a lapse in the functionality or communicative ability of the coin slot, however brief, it could have the effect of stealing from the user, with a coin or several coins not counted. In the design, we will have to ensure that all connections to the coin slot are secure, shock-resistant, and not prone to corrosion. Clips for connection plugs, or directly soldered wires, will ensure that connections will not come apart without deliberate human intention, and small amounts of conductive grease on electrical contacts will keep them free of rust (if clips are used). If there is any other problem, however, the device will need to have on the exterior the contact information of the managing or owning party, so that the dissatisfied user can have maintenance staff sent out from the (presumably nearby) building. This will be laser-engraved or somehow printed or inscribed on the exterior by the dealer when ordered by a client, and provision of appropriate contact information (such as a phone number) by the client will be a condition for the sale of the unit or units, if the dealer has an incentive to enact a policy like that. The owner of the bicycle racks and lock appliances must be familiar or employ a custodian familiar with the device, to remedy any potential problems when necessary.

As far as physical safety, there are two risks. The first is that the device will be both loose and bulky, and so can slide down the two-foot-tall bicycle rack tube and potentially land on the user's foot if the user accidentally lets go of the device while using it. It will need to be held up by hand during user interaction, although depending on the shape of the rack, the installer of the appliance may be able to mount it tightly, if possible without compromising its ability to be used with any bicycle. Rubber stops may also be necessary to prevent significant shock due to dropping, or from careless release after the user takes their bicycle and leaves at the end of the parking period. A decal can be attached to the outside of the device saying "dropping may cause personal injury" or something to that effect.

The second physical risk, and likely the more dangerous one, is accidental insertion of the user's finger into the locking bar receptacle, opposite the place where the bar comes out. The motor with its gearing has a great amount of torque, so any object that gets in the way of the locking bar when in motion will probably not stop the motor, even if it means that the object successfully obstructs the moving bar and the motor breaks out of its mounts inside the appliance. Some sensor could be employed to stop the motor if something got in the way of the locking bar, but we decided that it would be simpler to apply a decal to the exterior saying "keep fingers away" or something similar, and flash an LED continuously until the bar finishes its movement. A binary force sensor (or some button that requires a large force to press) could be placed behind the motor, so that anything that gets in the way of the bar will cause the force generated by the motor to be transferred into the button, which will tell the microcontroller to stop the motor and avoid damage to anything or anyone. The device is not exactly poor-judgment-proof, but there arises the need for safety decals, and the durable construction of the device may help to differentiate it favorably from any possible alternatives that the user may find. Generic "Warning" and "Danger" stickers are available commercially. The motor is not nearly powerful enough to need to meet National Electrical Manufacturers Association standards, as their minimum is 200 horsepower.

During development of the appliance, the only hazards are overloading circuitry by incorrect wiring, battery volatility, and injury from the strong motor. We will use a 12-volt arrangement of lithium-ion rechargeable batteries, which have energy density, cycle life, and ubiquity in their favor, but which deliver a spontaneous show of fireworks if impaled, deformed, overcharged, or heated too much. To avoid these hazards, care must be taken in wiring, and nothing overlooked, and the battery will have to be handled and stored with its potential volatility in mind, including the way in which it is charged. Battery management circuitry will have to be present, if it is not already built into the battery when we get it. Understanding the hazards is perhaps the most crucial element of this, and it is important not to underestimate the general dangers that will become apparent as we work on it.

5. Sources

"The Ultimate Guide to Bicycle Theft Statistics & Insurance." Simple Bike Insurance, Biker, 2 Oct. 2021, https://simplebikeinsurance.com/guide-bicycle-theft-insurance/.

Fish, Raymond, and Leslie Geddes. "Conduction of Electrical Current to and through the Human Body: A Review." Eplasty, Open Science Company, LLC, 12 Oct. 2009, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2763825/#:~:text=The%20%E2%80%9Ctotal%20body%20resistance%E2%80%9D%20of,the%20skin%2C%20and%20other%20factors.

Basic Electricity Safety - Occupational Safety and Health Administration. Occupational Safety and Health Administration, https://www.osha.gov/sites/default/files/2019-04/Basic_Electricity_Materials.pdf.