Self-Charging Automatic Bike Lock

Team 18

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Fall 2023 ECE 445: Senior Design Laboratory

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1. Objectives and Background

1.1 Problem

Stolen bikes are a big problem in Champaign. In 2014, it was reported that roughly 856 to 1070 bikes were stolen that year [1]. This meant around $150,000 in bikes were stolen [2]. These statistics necessitate security measures like bike locks and alarms. However, basic bike locks are mechanical, and once broken, the bike can be easily stolen. Also, most bike alarms require a remote to enable and disable it.

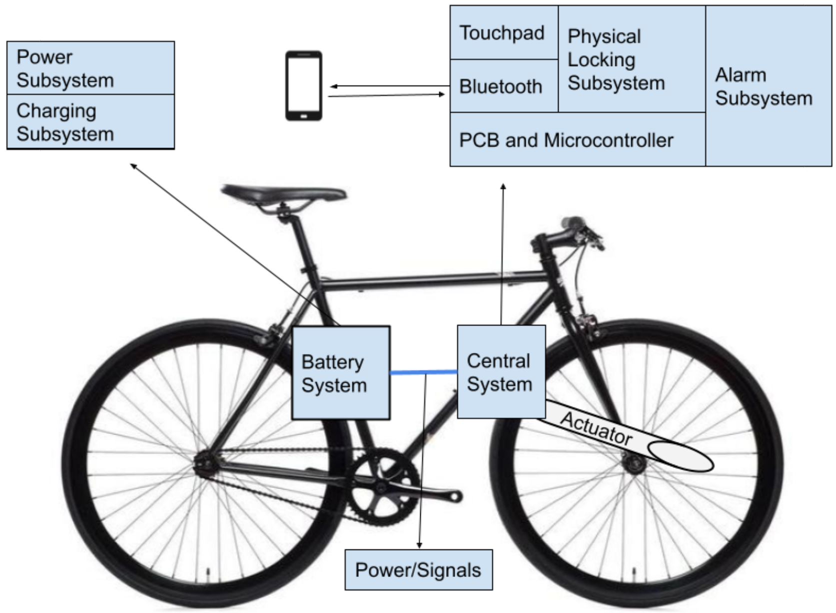
1.2 Solution

Our solution to this issue is an automatic bike lock with an alarm system. This device will be attached to a bike with a clamp and will contain a physical locking mechanism and an alarm device. The physical lock will consist of a linear actuator that inserts itself through the wheel spokes (therefore preventing the wheel to spin) and an array of touch sensors whose input will change the linear actuator's state, while the alarm device will have a small speaker and a flashing light. The device's microprocessor will also have bluetooth functionality. To lock and unlock the device, it has to be paired to the user's phone with bluetooth and then the user can press on the touch sensor array lock or unlock the device. If the user does not have the Bluetooth device (in the case where they forgot their phone or it ran out of charge) the user must input a correct sequence onto the touch sensor array. The device also contains a self charging subsystem, which will charge the device when the vibration sensor is triggered (bike is moving).

1.3 Benefits and Solutions

- Two levels to lock security with an alarm system means it is less likely a bike with this device gets stolen.
- No need for a remote for the alarm system.
- Modular design to ensure encompassing compatibility with various if not all bike designs.
- Rechargeable system allowing for usage without worrying about replacing/removing batteries.

1.4 Visual Aid

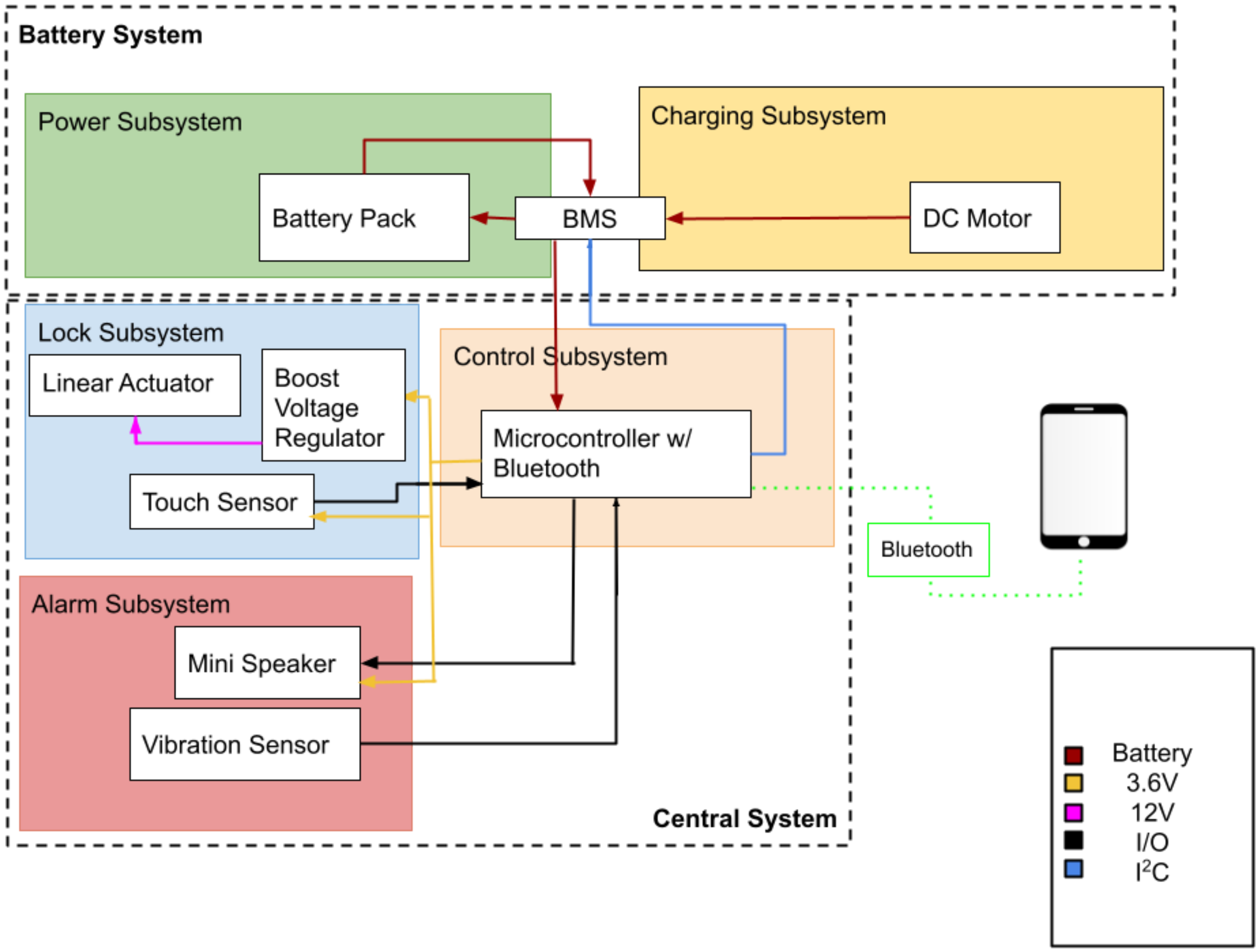


1.5 High-Level Requirements List

- The bluetooth range must be limited to a 12 inch radius from the device, resulting in the ability to change the state of the device by touching any one of the sensors on the touch sensor array.
- The self charging system must be able to generate 6 watt-hours and be able to power the device through multiple trips.
- If there is not an established bluetooth connection to the device, the device's state can be changed by inputting the correct pattern into the touch sensor array.
- When in the locked state, the linear actuator should extend to its full length of 4 inches and prevent the front wheel from spinning, thus preventing someone from stealing the bike.

2. Design

2.1 Block Diagram



2.2 Subsystem Overview:

2.2.1 Control Subsystem

The STM32WB55CC [11] includes a bluetooth system and will require a bluetooth connection from a mobile device to access the array of touch sensors. Then, a tap from the array of touch sensors is required to unlock the physical subsystem as well as disable the alarm subsystem. If there is no bluetooth connection then the locking subsystem can still be disabled by a correct sequence of taps on the array of touch sensors. The microcontroller will make sure the bike is in motion with the vibration sensor in order to enable the charging subsystem. The charging subsystem will disable when there is no vibration detected based on a certain threshold to allow variables like wind and minor bumping. Then a correct code from the array of touch sensors will enable the physical locking subsystem and enable the alarm subsystem. This subsystem controls the overall interactions among all subsystems.

2.2.2 Power Subsystem

Our power subsystem will consist of a rechargeable Lithium ion Battery (3.7V 6600mAh) [3] in parallel that allows us to power the PCB and microcontroller. To ensure that we meet the demands of all of our subsystems while also ensuring even power distribution we also plan on including a Battery Charger IC (BQ25756) [4] to ensure no power spikes or drops affect the overall apparatus. Depending on the readings of the vibration sensor, the power system will either be in a state of charging through the charging subsystem, or in a state of discharging. If a certain amount of vibration is detected (i.e. you are riding the bike around) we want to shut off the discharge of the battery pack and allow it to recharge. If the amount of vibration is lower than a certain threshold (i.e. the bike is stationary) we want to begin discharging the battery pack and therefore power the entire system.

2.2.3 Charging Subsystem

We will attach a friction generator (G.I. Bicycle Steel Dynamo) [10] to the side of a wheel on our bicycle. As the wheel spins, the friction generator will spin along with it, therefore creating the energy that we will use to charge our rechargeable battery pack. We must pass the generated power to the battery management system (TI Battery Charger IC) to regulate the voltage before charging the battery pack directly. The charging subsystem will only be active when there is bluetooth connection, meaning the user is near or riding the bike, and the vibration sensor detects enough movement.

2.2.4 Locking Subsystem

The second security level of our locking system. In case the bluetooth signal is recognized, the user must press the touch sensors to unlock and lock to ensure no mistakes of unwanted automatic locking and unlocking.

In the situation of the bluetooth device being unavailable, then the device will require a correct touch sequence on the array of TTP223B Capacitive Touch Sensors [6]. If the correct sequence is met, then the physical locking subsystem will disengage or engage according to the previous state of the physical locking subsystem. We need this second level as more of a user safety device than an anti-theft mechanism. This will address the edge cases in which the bluetooth device is within detectable range but the owner does not wish for the physical lock to change states or when the user is riding the bike and loses their remote and it falls out of range.

This subsystem also contains the primary physical component of our system. Consisting of a linear actuator (Mini Linear Actuator B07ZJ46947) [5] that extends through the wheel spokes when the lock is activated, the linear actuator prevents the movement of the wheel the locking apparatus is clamped to. We plan for this subsystem to be attachable to either the front or rear wheel through the use of a clamping mechanism that connects to the different cylinders that make up a bicycle. To ensure that the linear actuator gets the power it needs to operate, we include a boost voltage regulator that will mediate power requirements from the microcontroller to the linear actuator.

2.2.5 Alarm Subsystem

The inbuilt alarm subsystem to the overall system enclosure. This subsystem consists of a speaker (COM-07950) [8] that should act to draw attention to the fact that someone is attempting to steal a bike. This subsystem should be activated if the overall system is being tampered with. This includes repeated mistakes in the touch combination in the case a bluetooth device is not nearby and the vibration sensor detecting large movements like attempting to forcefully close the linear actuator.

2.3 Subsystem Requirements

2.3.1 **Control Subsystem:**

- STM32WB55CC Microcontroller [11]:
    - In order for the microcontroller to be fully functioning we need to deliver it with a range of 1.7 - 3.6 Volts(V), and output the same amount of voltage as its input in order to fully power all of our components.
    - There is a maximum of 1MB Flash Memory for burning.

2.3.2 Power Subsystem:

- Adafruit Lithium Ion Battery (3.7V, 6600mah)[3];
    - This battery pack must supply the microcontroller, which runs at 3.6V and a maximum of 12mA
    - This battery pack charges at a constant 1.5A or less
    - This battery pack can discharge at 3.7V, 6600mAh.
- TI Battery Charger IC [4];
    - This IC accepts a wide input voltage operating range: 4.2 to 70V.
    - With a wide battery voltage operating range: max 70V
    - With input regulation of 400mA to 20 Amps(A) Charge current.
    - Since the battery pack has a maximum of how much amps it can charge by a battery management system, the Battery Charger IC must regulate to 1.5A or less.

2.3.3 Charging Subsystem:

- GI Bicycle Steel Dynamo Friction Generator [10]:
    - The maximum voltage the generator can deliver to the battery is 12V.
- TI Battery Charger IC [4];
    - This IC accepts a wide input voltage operating range: 4.2 to 70V.
    - With a wide battery voltage operating range: max 70V
    - With input regulation of 400mA to 20 Amps(A) Charge current.
    - In order to properly power the microcontroller chip, we need to deliver it with 3.6V given it has a range of 1.7 to 3.6V.

2.3.4 Locking Subsystem:

- Mini Electric Linear Actuator [5]:

    - For full functionality we must deliver 12V and a range of 0.1 to 0.2A to the linear actuator.
    - We must be able to measure a stroke of 2 inches from the linear actuator if fully functional.
- TI Boost Voltage Regulator [12]:
    - We use this in order to boost our voltage delivered from our microcontroller (1.7 to 3.6V) to the necessary voltage needed for our linear actuator (12V), we know this is fully working if we are able to deliver 12V and a range of 01 to 0.2A to the linear actuator.
    - Input Voltage Range: 3V to 40V
    - Output Voltage: Adjustable (up to 40V)
    - Output Current: Up to 3A
- HiLetgo Capacitive Touch Sensor [6]:
    - In order for the touch sensors to work we need to provide them with a range of 2 to 5.5VDC.
    - Fully functioning touch resistors will be able to signal to the microcontroller when touches are registered and in which sequence they happen on the sensor array.

2.3.5 Alarm Subsystem:

- Piezo Vibration Sensor [7]:
    - In order to ensure successful operation of the vibration sensor, the operating temperature must be maintained at a range of 0 to 85C.
    - We must code in the ability to distinguish between minimal and therefore inconsequential vibration and the vibration that would occur from attempted thefts or tampering.
- COM-07950 Mini Speaker [8]:
    - In order for the mini speaker to be operational we need to deliver it a range of 3.0 to 5.0V.
    - We must also only deliver a mean current of 35mA max.

2.4 Risk Analysis

The grouping of subsystems that poses the greatest amount of risk in our overall subsystem is the power and charging subsystem as it handles the full delivery of electrical power in our bike lock. Within the charging subsystem we have a rechargeable Lithium Polymer 3.7V 6600mah battery and our generator, a GI Bicycle Steel Dynamo Friction Generator [11]. Through our research we know that the friction generator can deliver 12 Volts (V) and 0.5 Amps (A) and the Lithium Polymer battery should only be fed 1.5A when recharging. In order to manage this risk, in which we attempt to deliver too much power to the battery from the generator we will feed the friction generator through the TI Battery Charger IC [12], allowing for proper regulation for power delivered to the battery within a tolerance of ±0.5% for charge voltage regulation, ±3% for charge current regulation, and ±3% for input current regulation.

Another grouping of subsystems that pose a risk is the control subsystem and all components within the alarm and physical locking subsystem that are dependent on the microcontroller. The STM32WB55CC [11] has a low-power mode that consumes only 205 - 250 µA, which decreases the power consumption by the system on standby. We know that the microcontroller can take 1.7 to 3.6V as its input, and will output the same amount of voltage. The devices directly powered by the microcontroller include the linear actuator through the boost voltage regulator, the touch sensor array, and the mini speaker. We know that the mini speaker requires 3.0 to 5.0V and a maximum average of 35mA to fully function. We handle the risk of providing too much power to the mini speaker by not having the maximum output of the microcontroller to exceed the safe range. The capacitive touch sensors are safe to operate within a range of 2 to 5.5VDC. Just as the mini speaker, we mitigate the risk of providing too much power to the touch sensors by limiting the amount of voltage available to the sensor to be within the optimal range. The risk for our linear actuator comes from under powering rather than overpowering. For the linear actuator to work, we need to provide it with 12V and a range of 0.1 to 0.2A. Given that our microcontroller can only provide within a range of 1.7 to 3.6V we need to find a way to boost the voltage, we use the boost voltage regulator to accomplish this. The boost voltage regulator can take an input voltage range of 3V to and output an adjustable voltage of up to 40V and also deliver an output current of up to 3A. This allows us to pass through the boost voltage regulator, adjust to our necessary voltage and current, and then successfully power the linear actuator. Thus mitigating the risk of under powering the linear actuator and having the key component responsible for the physical lock not be functioning.

Another subsystem that poses potential risk is the physical locking mechanism. The two inch linear actuator must be enabled and disabled at the appropriate times. Specifically, the status of the actuator should only change when either the bluetooth device is nearby and there is an input to the touchpad or the correct pattern is inputted into the touchpad. The primary risk involved with the linear actuator is the potential for it to be tampered with. Currently, the two inch linear actuator we plan on using has a load capacity of 20 N (Newtons) or 4.5 lbs (pounds). A force larger than that could potentially render the linear actuator unable to do its function as a locking mechanism.

3. Ethics

We the engineers of Team 18 swear to uphold the highest ethical and professional conduct during the entirety of the project in accordance with section 7.8 of the IEEE Code of Ethics [10]. We will hold paramount the safety, health, and welfare of the public during our testing phases of our project while also being transparent with any theoretical testing that may endanger the public or the environment. We will avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties if they do exist. We will be fully willing to seek and accept honest criticism based on realistic claims on available data of our technical work, and to acknowledge and correct those errors. After fixing those mistakes we will properly credit the contributions of others. We will maintain and improve our technical competence through training and learning and undertake technological tasks only if we are already qualified for such tasks.

We will treat all personas fairly and with respect, to not engage in harassment of discrimination based on characteristics such as race, religion, gender, disability, national origin, sexual orientation, gender identity, or gender expression. We will avoid injuring others, their property, reputation, or employment by false or malicious actions such as rumors, verbal, and physical abuse.

4. Safety

The safety concerns of our project is broken down into three subcategories: mechanical, electrical safety, and lab safety. Concerning mechanical safety, we foresee the majority of the risk on the mechanical end of our project happening during the testing phase of the project. In the case we have a faulty locking mechanism that happens to activate when the user (rider of the bicycle) is in motion, this would most definitely cause the user to crash the bicycle, possibly injuring themselves and nearby pedestrians. We plan to prevent this specific issue through our two-pronged locking and unlocking procedure which ensures that a user cannot be currently riding the bicycle when changing the state of the locking mechanism from unlocked to locked or vice-versa. Another safety risk connected to the mechanical design of the system comes from improper installation and fit of the clamping mechanism on the bike frame. If the system is not fully secured to the bike frame, users could have the system fall off during use, causing a safety risk to themselves and pedestrians around them. In order to circumvent the risk to pedestrians due to both primary mechanical concerns we plan to initially test our system in an isolated area with our team members only in order to minimize the risk to outsiders, and then only after passing multiple trials we will begin testing the product in more populated areas.

In terms of electrical safety the primary risk comes from our battery implementation and the dangers associated with it. In the case that our battery implementation is unsecure on our testing prototype (not fully soldered together, loose wires, or poor fit) then we run the risk of electrical damage to both our prototype and the user. In the case of our group, with a user being one of us, we run the risk of shocking ourselves. If an issue such as that were to occur for a theoretical consumer, they would also run the risk of being shocked or suffering from other electricity related injuries. We plan to circumvent these issues by fully ensuring that our initial prototype has no electrical issues in its wiring of components and general safety. We plan to ensure this by having our assembly work checked by all three group members as well as an outside opinion, who provides a fresh perspective on the total assembly of our prototype.

In a theoretical launch to market, our product will not require lab material access for customers to use, thus the laboratory risk factor for this project falls directly upon our group. Some laboratory risks we force range from soldering mishaps (fume inhalation and burns) to improper treatment of wiring and power supplies during breadboard testing (sparks and electrocution). In order to circumvent these issues our group will take utmost care to follow all lab procedures as taught to use during the University of Illinois Urbana-Champaign Lab Safety Course. We will also not work in the laboratory without qualified supervision and will follow any instructions regarding safety given to us by our supervisors.

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