Deployable Prototype Documentation
comBATS: Bicycle Anti-Theft System

Thor Bakken, Blake Ramos, Tasneel Singh, Ian Wollenslegel

Instructor: Dr. Belkhouche
Date: April 29, 2018

Contents

List of Tables

List of Figures

Executive Summary

ComBATS is our proposed solution to the rampant problem of bicycle theft and the recovery of stolen bicycles. ComBATS addresses the issue of bicycle thefts in America, and especially in areas of high risk of bicycle theft, like college campuses. This is a problem that we see affect many people, and we believe that comBATS can provide an excellent solution.

The design of comBATS is broken down into its two major components, the U-Lock and the Tracking Unit. The U-Lock contains an IMU, lock break detection circuit, arming and disarming mechanisms, and a speaker. The Tracking Unit has GPS tracking and the ability to send and receive text to and from the user. Both components have a rechargeable power component, and have communication capabilities through the use of radio frequency modules. The target cost of our final device is a reasonable $100. Development of our product has currently cost the group $273 collectively, however, this is an inflated price due to development materials being counted towards this number.

The risk associated with this project has been dissected at every level. The individual components of the system have been analyzed for risk, and so has the integrated design. High risk components include: the GPS tracking, the texting service, the RF communication, the power supply circuits, and the casing and its features. All the components have been prototyped individually before being integrated. This was done in part to distribute the workload and to reduce the risk of any one part failing horribly. There have been unforeseen circumstances, like the compact PCB for our designs, not showing up; however, we have had backup plans that have allowed us to continue working on our system.

The comBATS bicycle lock system is highly marketable. It combines many useful features from devices on the market like an alarm and GPS tracking, but combines them in a way unlike anything currently on the market. ComBATS has a good chance of making an impact on bicycle security products, and will be an asset in lost bicycle recovery efforts.

At the end of last semester, we had a working prototype of the comBATS system; by the end of the coming weeks, we hope to have a fully functional, market ready comBATS. Although we have had setbacks, we still believe that we can make a marketable product in the next two weeks. All of our electronic hardware components and software features have been added and tested throughout and are robust. At this time, we are mainly focusing on miniaturization of hardware components for comBATS as well as the outer casing and overall presentability of comBATS.

Deployable Prototype Documentation comBATS: Bicycle Anti-Theft System

Thor Bakken, Blake Ramos, Tasneel Singh, Ian Wollenslegel

***Abstract*—This document is the documentation for the comBATS project. comBATS is a bicycle anti-theft system that consists of two parts: the lock and tracking device. The problem of bicycle theft is a major problem that affects a large number of cyclists. Then our solution is outlined as well as how we arrived to our Deployable prototype over the past two semesters. This document outlines the process in the entire project, from start to finish.**

***Index Terms*—Bicycle Theft, Bicycle Lock, Alarm System, Tracking System, U-Lock, GPS, IMU, RF, 2.4 GHz, Sequence Detector**

I. Introduction

ComBATS is an accumulation of a year of research and prototyping. The first step was to determine a societal problem for us to solve; this involved research into the problem and what solutions have already been attempted. After researching, our group had to create a new product that addressed the issues of current bicycle security products on the market. Once we determines the product, we distributed the workload according to our groups strengths and weaknesses. Project milestones have been recored and the risk associated with each component and the design as a whole has been deeply analyzed. This document is a cumulation of the research, documentation, and status of our work with comBATS, the Bicycle Anti-Theft System.

II. Societal Problem

According to the FBI, in the past 22 years, over 4.5 Million bikes have been reported stolen in the United States. Many bicycles that are stolen go unreported due to the stigma that once your bicycle is stolen there is little the owner can do to get it back. The recommended bicycle locks, tips on how and where to lock your bicycle, and Internet of Things (IoT) solutions are a few ways to combat theft, but more can be done. Bicycle theft can be detrimental to the victims personally as well, especially if the bicycle is their only mode of transportation. Currently the only methods of securing bicycles are: mechanical and electrical locks and GPS tracking systems. These methods of bike theft prevention are not as effective as it could be. These devices are essential because the resources necessary to employ a guard to watch over the bicycles that are being stored is too costly. Hundreds of thousands of bicycles are stolen each year leaving many people without a mode of transportation. Our team is going to come up with a solution that will attempt to reduce the impact of bicycle theft.

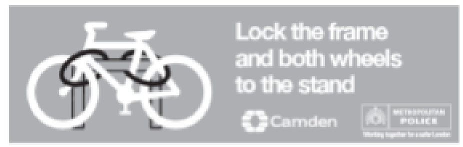


Fig. 1. Image of intervention sticker [1]

Bicycle theft is a major societal problem that has many issues associated with it. Those who ride bicycles are three times as likely to have their bicycle stolen over car owners having their car stolen [1]. This causes a problem with those who rely on a bicycle as their sole means of transportation. In the case that the bicycle is stolen from such a person, essential transportation may become difficult until a replacement may be acquired. In their first study, Sidebottom et al perform an intervention by placing a sticker on the bicycle racks reminding the cyclist to lock their bicycle and both wheels to the bicycle rack seen in Figure 1 [1].

Bicycle theft is a problem affecting people from all over the world and has a major economic impact to the victims and the worlds economy as a whole. Those who rely on a bicycle as their primary or only method of transportation are seriously disadvantaged if their bicycle is stolen. The fact that many college campuses are a place with a highly concentrated number of bicycles in a small area leads them to be a highly sought-after target for thieves.

Although many campuses such as California State University, Sacramento have implemented measures to curb bicycle theft while on campus, thefts still do occur. Some measures that have been taken are having enclosed and monitored designated areas that under surveillance by a guard. Solutions such as this are very resource intensive due to the labor costs required to employ an individual to watch over the bicycles while their owners are away. Thus, there is a need for an engineered device to help reduce the impact to the victim. Current engineered solutions to this problem include: mechanical and electrical locks and GPS tracking devices. Many of these devices can be easily thwarted by a thief due to low resistance to cutting or the device being removed in the case of a GPS tracker.

III. Design Idea

A. Constraints and Requirements

The design requirements and constraints for the bicycle security system must be established in order for the results of the project to be successful. Some of these constraints consist of economic, environmental, ethical, legal, safety, political and social issues. For this project, it is necessary that the material cost of the solution be no more $100. If the cost is any higher, the consumer would likely not want to spend the money on such an expensive item, especially if the value of the bicycle is low. If the cost of the solution was lower, the quality of the device would be sacrificed and would not be able to satisfy solving the problem statement. The solution must also not cause significant harm to the environment over its entire lifecycle. Therefore the materials used to manufacture the device must have minimal environmental impact. Therefore the design must use materials that can be recycled at the end of its lifecycle. In addition the device should use minimal power and utilize batteries that have long lifecycles and can be recycled at the end of their lifecycle. Lithium ion batteries have many advantages because they can have high storage capacity, high current discharge, and excellent cycle durability [2]. Due to their long life cycle due to excellent cycle durability [2] this results in fewer replacement batteries needed throughout the lifecycle of the device. Some legal requirements may be noise nuisance laws regarding the loudness of the alarm in the lock portion of the solution. If the alarm activates without a credible problem and it causes a nuisance, the owner may be liable. In addition the device must be lightweight and small however based on the components being used there will be no considerable weight being added which will be noticeable in normal bicycle operating. The main constraint which the project will face is that the size of the internal component must be small enough to fit inside the frame of the bike. If this constraint is not met then the device will be rendered useless. It also must have an appropriate battery life to prevent the use of the device from becoming a nuisance for the owner. There are many constraints for necessary for this project and if any of these are broken the product will not work in its intended environment and therefore will not fulfill the needs presented in the problem statement.

B. Possible Solutions

During the design phase of any project there are always many possible solutions to a problem. However, We found that many of these solutions were thrown out due to metrics such as performance, cost, ease of use, and reliability and maintenance. One proposed solution for our problem was a standalone GPS tracker which would fit inside the bike frame. This device would have a GPS tracker, sim card capabilities, and accelerometer or tilt sensor to detect bike movement [3][4]. This device also had the possibility for an alarm sound. We found however that this device would not be user friendly due to multiple problems with the overall design. Firstly we found that the possibility for false alarms stemming from the bike being bumped would be bad for the reliability. Also with this solution it would be necessary to text a activate and deactivate command to the bike every time you wanted to set the alarm. Also the possibility for forgetting to set your bicycle alarm would make it difficult to use. Another possible feature of this device which we decided against was a camera which would be run from the device and mounted somewhere in the front of the bike in order to get a picture of the bike thief in the event it is stolen. However, we found that this approach would cause the solution to be difficult to use due to the requirement of running the camera and also having to modify the bike. Another possible feature which we believed would be a great addition would be a self recharging lock which would consist of a small generator attached to the inside of the bicycle wheel hub. This would allow for the device to remain fully charged and allow for long periods of use without charging. However, this feature would require modifications to the users bike would would not make it easy for the user to install. It would also be impractical for us to be able to create a working model of this feature which would satisfy our design requirements. Another possible solution which we explored was a smart chain lock. This lock would work by having some kind of wire or other electrical device which would see the chain being intact as a closed circuit, while the chain or wire being cut would be a open circuit. This would allow for a system with a alarm siren and text alert which would not be prone to false alarms. This solution would be a great deterrent to theft, however we found that the possibility of the bike still being stolen and being unable to locate it without an accompanying gps tracker would severely hinder the performance of the solution. The other possible solution which we explored was creating a bicycle security system which was housed inside a pre assembled handlebar assembly. This would house our gps tracking device along with a camera. The main benefit to this solution would be that the handle bars could be modified as much as required in order to secure our gps device and in order to mount a camera. However we found that this could hurt the cost of our product since the user would need to have handlebars which would fit their specific type of bicycle. This would also require manufacturing of the solution to make use of multiple different types of handlebars.

C. Proposed Solution

The proposed solution to reduce the impact of bicycle thefts is a concealed GPS monitoring system that is accompanied by an ordinary looking bicycle lock that acts as a means to arm and disarm the GPS system. That is, the solution we propose will have two main parts: the bicycle lock, and the concealed GPS system. The bicycle lock will be based on existing U-Lock designs, however, with electronic enhancements, and the GPS system will be concealed within the frame of the bicycle. The U-lock portion will be a custom casing that will be equivalent to an IPX4 water rating. Meaning the casing will be able to perform in rainy conditions. The lock will also act as a deterrent to criminals looking to steal the bicycle; much like a car alarm, the lock will have an audible alarm feature that will go off if the lock has detected that it has been tampered with. It will also distract a thief from looking for further theft prevention; in the case that the alarm is not enough, the GPS system is to be concealed in the frame of the bicycle and will go unnoticed by a thief. The GPS can then be used to track the bicycle and aid in recovery of the bicycle. There are already bicycle locks on the market that apply each of these security measures independently of each other. Bicycle locks have existed with and without electronic enhancements and hidden GPS systems also exist. The problem with existing bicycle locks is that once they are broken or cut, they are useless. Existing GPS systems are bigger and can be taken off a bike easily if a thief is on the lookout for such devices [5]. The proposed solution is different than what is on the market because it comes in two unified parts and attempts to improve on the existing design of both. The proposed solution will have two parts that interact with each other through wireless RF signals. The main bicycle lock will be an enhanced version of a bicycle lock. It will use an existing mechanical bicycle lock design and will be enhanced to fit the proposed specifications. It will use motion sensors such as vibration sensors, tilt sensors, or an accelerometer to detect motion; if there is too much motion, an alarm will go off from a compact speaking inside the bicycle lock [4]. This is also when the bicycle lock unit will alert the GPS system that someone is attempting to steal the bicycle; this will prompt the GPS unit to start alerting the user through text messages. The GPS unit will be concealed in the bicycle frame. Unlike other GPS systems in existence, the proposed GPS unit that goes in the bicycle frame will be lodged into the frame and will be difficult to remove; the proposed design is some mechanism that expands into the bicycle frame so that it cannot be easily recovered. The GPS unit will also be connected to the user through a text service; this is both because the GPS will require it and because it is simple and should not require extensive knowledge of how an app or website works, which will be easier for the end-user. Both devices will be in a normally disarmed, standby, or power-saving state. When the bicycle lock is engaged, both devices will be notified to go into an armed state. In the disarmed state, the bicycle lock will be waiting to be armed and the GPS unit will be waiting for a signal that the bicycle lock was armed or that the user requested GPS information from the bicycle. Once the bicycle lock is engaged, the bicycle lock will be in the armed state and will send a wireless signal to the GPS unit to go into the armed state. Once in the armed state, the bicycle lock will monitor the motion and be able to set off its alarm and the GPS unit will send updates about the bicycles whereabouts to the user. The GPS unit will also be waiting for a signal from the bicycle lock to know if it has been compromised or not, and will alert the user if someone has attempted to steal the bicycle. There will be two buttons on the lock that will have to be pressed in the correct sequence to disarm the system which will be set by the user or press and hold either button to arm the system. In order for the devices to be small and fit within the required space, the inside of the bicycle and the lock housing, each component will need to have a PCB board created specifically for each purpose. The lock unit will need a PCB board that contains all the required components and circuits on that board. These include the microcontroller, the arm and disarm buttons, and the RF system to communicate with the tracking unit. A separate board for the tracking unit will be created that will contain the microcontroller, GPS, cellular system, and RF communication modules to communicate with the lock unit. To save power and battery life, the bicycle lock and GPS units disarmed state will be a low powered mode that does not do much except for waiting to be armed. The microcontrollers we use will also have watchdog capabilities to prevent hang-ups and other power issues. To provide power to the devices, both the lock and GPS unit will have some form of rechargeable battery. The GPS unit may need a separate battery because the GPS unit will not be easy to remove, once lodged into the bicycle frame. In order to ensure that our device works properly, we will test its functions and capabilities. These tests will include test of the devices battery life, how it functions when integrated into a bicycle, and functions of the device like arming and disarming, as well as the theft deterrent systems like the alarm and GPS. The device should work in real world situations. This means that it should functions with reasonable delay, no longer than a couple seconds, and should be able to last a full work day, approximately eight hours. It should also be reasonably water resistance to weather conditions like rain.

IV. Funding

TABLE I
COST BREAKDOWN OF ITEMS AND MODULES BOUGHT TO USE FOR THE PROJECT.

Item	**Cost ($)**	**Buyer**
3D Printing	20	Ian
A7 GSM/GPS	16	Ian
Arduino Mega2560	12	Ian
Arduino Mega2560	14	Thor
Arduino Nano	15	Tasneel
Arduino Uno	10	Blake
Bicycle Lock	25	Thor
IMU	8	Blake
PCB	103	Thor
Regulators	10	Thor
Misc Electronics	30	Thor
NRF24L01 2.4Ghz	10	Ian
Speaker	20	Blake
Total:	**273**	

Table I shows the cost breakdown of components bought for our project. Overall we found that our total costs for the project exceeded our initial prediction of $100 at $273. Normally this would be a problem, however, we expect the final product to come out cheaper. Some lab prototype costs will be unnecessary for the deployable prototype. Such as just the multiple Arduino boards came out to $51. Also, in a market production of our product, components would be much cheaper when bought in bulk, which would drive down the price of production significantly.

V. Project Milestones

There are several major milestones that have occurred throughout this semester in the progress toward creating our laboratory prototype. The first major milestone that occurred during this project was when all the individual components were working and tested. These individual components include: the Inertial Measurement Unit (IMU), Global Positioning System (GPS), cellular device, text service User interface (UI), power supplies, lock break detection circuit, arm/disarm button, speaker, and radio frequency communication (RF). This milestone was met because each individual component worked when debugging as a separate part and was not yet incorporated into the system. This milestone occurred on November 6th. Then the next major milestone was when the hardware components were integrated in order to facilitate software integration. This milestone was met because all of the hardware components were working and were connected together as a system and all of the test code developed during the work from the individual components functioned correctly. This milestone occurred on November 13th, 2017. The next major milestone was the completion of the software integration. This milestone was met because the software was able to operate the devices with the intended functionality. The software integration milestone occurred on November 20th, 2017. The next milestone was the completion of the ULock and Tracker PCB board designs which occurred on or around February 30th, 2018. Due to unforeseen circumstances however these were not received and therefore could not be used. Our next major milestone was the completion of the 3d printed ULock case to secure the lock components together. This occurred on April 13th, 2018

VI. Work Breakdown Structure

The work breakdown structure is a method of breaking down the work that is required to be done. This allows equal distribution of the work between the team members to happen and allows for the creation of a plan to distribute the work. We created a work breakdown structure during the fall semester for items that had to be accomplished for the entire project.

A. Alarm System

The person responsible for implementing the smart bike lock alarm system is Blake Ramos. The system will consist of a speaker, possibly an amplifier, and software to create the alarm sound.

a. 1.1.1 Speaker The speaker that is going to be used is called, PUI Audio X-5735-LW350-S-2-R. It has a 125db sound pressure level, 12VDC voltage rating, 1.53 inches in height, and 2.22 inches in length [6]. The compact speaker can be seen in Figure 2 and cost $ 8.62[6].

The compact speaker comes with mounting brackets, which will make it easy to mount the speaker to our final design come May 2018. The speaker itself should be easy to configure to sound like an alarm, but the speaker should only turn on when motion detection system tells it to. This compact speaker will not only help keep our smart lock compact in size, but is also powerful enough to deter a thief from stealing the bicycle.

Fig. 2. PUI Audio X-5737-LW350-S-2-R Speaker [6]

b. 1.1.2 Software The software needed for the alarm system to work will created using Arduinos IDE [7] and code to make the speaker function like an alarm. The alarm will be similar to a car alarm and will be 100db. The reason for a loud alarm is to hopefully deter a thief from stealing the bike and alerting people in the area to what is happening.

B. Motion Detection

The person responsible for implementing the motion detection system is Blake Ramos.

c. 1.2.1 IMU Sensor The motion detection system will include an IMU Breakout and the software needed to take advantage of the features that the IMU Breakout can provide[10]. The specific IMU sensor that will be used is the SparkFun MPU-6050 [4]. This IMU sensor combines two chips, that provides the user a 3-axis gyroscope and a 3-axis accelerometer. The IMU sensor in Figure 4 is very compact in size, has great gyro performance, and provides a very stable 9 degrees of freedom[9].

b. 1.2.2 Software The software needed to take advantage of this chip will be coded in Arduinos IDE [10]. The point of this software will be to tell if someone is trying to steal and or move the bicycle when it is not supposed to move. In order for this code to properly detect if the bicycle is

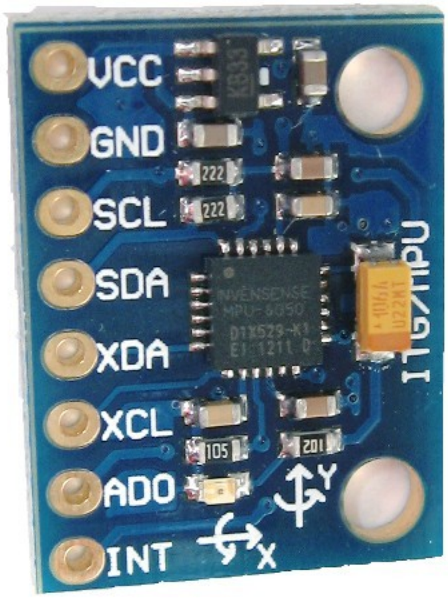


Fig. 3. InventSense MPU-6050 [9]

being stolen or not, many tests will need to be done. Some of these tests will include the amount of acceleration and orientation of the IMU sensor itself[10]. The combination of acceleration and orientation will enable the motion detection system to work properly. The total time required to create and test the software needed to use the IMU sensor will be around five days[10]. The total cost of the motion detection system is $ 14.95. This price does not take into consideration the continuous research for higher quality and cheaper components. If and when a component is found that is cheaper and provides the same result that part will be purchased and used[10].

C. Lock Circuit

The break detection circuit is an important part of the design inside the U-lock. This circuit detects if the lock has been broken. The constraints of this circuit are that it must fit inside the enclosure for the U-lock and that it must work reliably. If the lock has been broken, the lock will then activate the audible alarm through the speaker. In addition the lock will send a signal to the tracking unit to send a text message to the owner that their lock has been broken and will include the location in the form of GPS coordinates [7]. This circuit will consist of a resistor and the lock in series connected to a digital input pin on the microcontroller and a pull down resistor connected to pull the input pin down if the lock is broken. The approximate time to design this circuit is one hour. Thor Bakken is responsible for this work package[10].

Fig. 4. U lock to be used to implement break detection circuit [10]

D. Arm/Disarm

The U-Lock will need some means of arming and disarming itself. In its armed state, the U-Lock will be taking in input from the Motion Detection and Lock Circuit to ensure that the bicycle lock is not being tampered with[10]. A button will act as the method to disarm the lock so that it is not wasting power and so that the alarm can be disengaged if it has been triggered. Tasneel Singh will be responsible for the button and software behind the arming and disarming mechanism[10].

E. Communications

The U-Lock portion of the overall design will be able to communicate with the GPS module through some sort of Radio Frequency Transmitter. The RF transmitter's main objective is to act as one-half of the link that allows both portions of the device to communicate with each other; the other half is the RF Receiver that is in the Tracker portion[10]. This RF transmitter will be able to notify the GPS module about the current status of the lock and alert the module if the lock has has been tampered with[10]. This can be accomplished by using a 2.4 GHz transceiver where one acts as a transmitter and the other as a receiver; because they are transmitters, they should be able to both send and receiving messages and will allow the design to be enhanced later on. These modules can be bought in bulk for $ 11.98 a piece[10]. Tasneel Singh will be responsible for designing a system by which these modules will be able to communicate to each other. Communication between the two main components of the design is critical to the overall design concept so this work package must be completed before the other components are brought together[10].

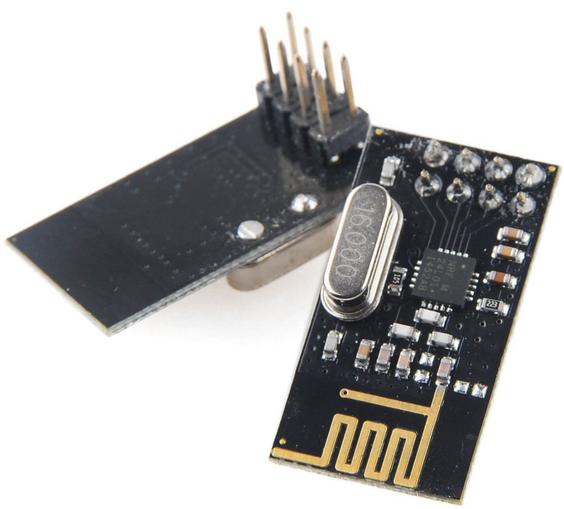


Fig. 5. A 2.4 GHz RF Transceiver [10]

F. Waterproofing

The person responsible for making sure the smart lock and Tracker are waterproofed properly is Blake Ramos. As of right now waterproofing is something that will be done after the laboratory prototype is complete, but there are a few ways to properly waterproof each device[10]. One possible method is to coat each chip and or electronic component of our smart lock with Semblants nanotechnology[10]. This method exposes the components to certain gases which coat the electronic components making them waterproof. This method will work, but will be very expensive. The other method that will work is to make sure the housing is completely sealed off so that nothing inside can get wet. This method will be way cheaper because of 3D printing[10]. 3D printing a housing unit that is big enough to fit everything and it waterproof will be the most cost-effective way to ensure that our smart lock still works in harsh weather[10].

G. Power Supply

Thor Bakken is responsible for this work package[10]. The power supply for the U-lock part of the design also has its own constraints that must be met in order for the solution to meet the needs of the problem statement[10]. This power supply must be small enough so that it does not make any potential thief suspect there is a power supply and possibly damage it. The battery in this device must also last long enough for one day of use minimum[10]. This power supply must meet the power and voltage requirements of the components in this device. These components include the RF communications components, the break detection circuit, the microcontroller, and the IMU. This power supply must also have hardware for charging the battery and an indicator that will notify the user the battery is low. This indication will be provided by text message[10].

This power supply will consist of a lithium ion battery, voltage regulation hardware for each voltage requirement, as well as charge controlling hardware that will allow the battery to be recharged effectively. The time required to complete the design of this power supply is approximately four hours[10].

H. Communications (Tracker)

The main feature of this project will be the GPS tracking feature[10]. The communications part of this project which includes the Texting services and the Cellular device will allow for full two way communications between the Tracker of the project and the user As well as two way communication between the Tracker and Lock of the system using Radio Frequency transmitters[10]. By allowing full two way communication the Tracker will be able to send notifications such as GPS locations updates, battery status reports, and other functions which can be expanded upon based on the client's need. This will also allow for the User to request these updates at a moment's notice which will allow constant GPS location updates in case of theft, location of temporarily misplaced bike, and general system status[10].

The texting service of of the project will be the main interface between the user and the Tracker of the security device and will be the responsibility of Ian Wollenslegel[10]. The user will be able to send and receive messages through a simple SMS (short message service) which allows for communications through a combination of the standard letters, numbers, and symbols. On the Tracker to user side of the text service there will be periodic and also event driven messages to inform the user of significant events. These events include battery status, movement detections, and GPS location updates[10]. These events will be fine tuned to achieve our performance and simplicity constraints however will follow a common series of events and responses. In the event that the Motion Detection system is triggered an alert will be relayed to the Tracker and in turn a SMS message will be sent to the user alerting them to Bike Motion Detected. This will be a first step in alerting the user that someone is tampering with their bike. In the event that the U-Lock of the bike is cut and the break detection feature is triggered a message will be sent to the user alerting that Bike Lock Cut[10]. At this point The Tracker would enter a recovery state where GPS location data could be sent periodically every X minutes. The time between GPS updates X can also be customized by the user. This will give an accurate depiction of where the bike is heading in order for recovery of the bike[10]. The user can also manually set the bike to a recovery state in the event that the bike lock either fails to alert the user, or if it is potentially carried off. This could be set by the user sending Set Recovery State which would default to send location updates every X minutes. Alternatively the time between updates and a recovery state could be set at the same time using Set Recovery State X[10]. An extra feature of this text service would be being able to locate your bike if you have forgotten where your bike was stored. This could be done using a simple locate command which will respond with a single location update. It is also important to note that the GPS coordinates on most mobile devices when received can be simply clicked in order bring up a map which will show the received location. The last main feature of the texting service will be a periodic update of the battery status[10]. This is an important feature to guarantee that the battery is of sufficient charge to not die when needed. This depending on the battery life should be sent approximately every 10 to 20 percent depletion in power. This will give the user an accurate view of how fast their battery is depleting in order to find the time to recharge it[10]. The battery status along with other system information could be tested using a system state command which would give relevant data such as current battery charge, armed or disarmed state, and other relevant data. The final command would be a rarely used but important system diagnostics command which would check every individual function of both the Lock and Tracker of the system for correct operation. This would check functions such as RF communications between Lock and Tracker, Battery updates for both devices, and the Locks motion detection and security alarm states. The cost of this feature will rely upon the Cellular Device hardware[10].

The text service feature will rely on the Cellular device and sim card hardware in order reliably send and receive data. The hardware we will use for this project will be the A7 GPRS+GPS chip[10]. This chip includes both GPS capabilities and access to the Cellular device network when connected to a sim card. For the Cellular Device feature we will have our device connected to a Sim card for this feature[10]. The cost of the sim card is $ 3 while the cost of the monthly service plan will depend upon how much text service the user will need. This will depend upon the period status updates and also the amount the user communicates with the device. Based on these variables the cost to the user would be expected to be between $ 4 to $ 5 on a monthly basis based on Figure 7. The A7 chip will be ideal since it has a working voltage between 3.3v-4.2v which will allow for a standard Lithium Ion battery operating at 3.7 volts to power the chip[10]. The A7 chip also has a low standby power consumption of 5mA which will help with our power constraints[10].

The Tracker portion of the overall design will be able to communicate with the U-Lock through

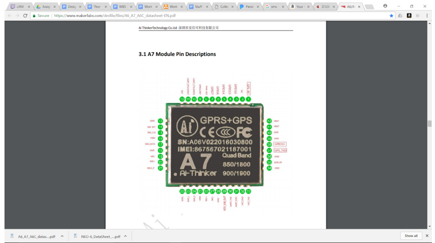


Fig. 6. A7 GPRS+GPS Chip [10]

a Radio Frequency Receiver[10]. The RF receiver's main objective is to act as one-half of the link that allows both portions of the device to communicate with each other; the other half is the RF Transmitter that is in the U-Lock[10]. The RF receiver will get notified by the transmitter when the bicycle lock has been tempered with which will subsequently allow the GPS module to take action and notify the user. Like the transceiver, we can use a 2.4 GHz transceiver to take the place of the receiver. This again allows us to expand the design if we wish to do so later on and keeps the cost low[10]. Tasneel Singh will also be responsible for making sure that the receiver can receive messages from the transmitter. This will need to be finished in conjunction with the RF transmitter to ensure that both modules work properly and that the two main parts of the design have some method of communicating with each other[10].

I. Tracking

The GPS tracking part of this project will be the critical feature which will require an activation event and also a way to communicate its location data with the user. This work package will be the responsibility of Ian Wollenslegel. For this feature we will use the A7 GPRS+GPS Board[10]. This board costs $ 17 and will be used for the testing phase of the project. The GPS tracking device will be in standby mode until an activation event such as an alarmed state or the User requests the GPS location data. In order to make use of this GPS data it must use the text messaging feature in order to relay the necessary data to the User. This is where the A7 chip will be of great help to the project[10]. It allows for both GPS and sim card capabilities in one package which will help with the size constraints of the project. The GPS location data will be sent in the form of latitude and longitudinal coordinates which can be easily used on a mobile devices maps function[10].

VII. Risk Assessment

There is a level of risk associated with different aspects of this project. In each aspect of this project there are risks with that work package. The risk for each work package from the work breakdown structure in the previous section is analyzed. Then the risk is analyzed based on each work package and the potential problems that may occur. The probability of occurrence is estimated as well as the level of impact to the project. One or more mitigation strategies are proposed in the event that the proposed problem occurs. The probability of failure and impact of failure is ranked on a scale from one to five, with one being low probability or impact, and five being high probability or impact. A risk matrix with ranking the impact out of five vs the risk out of five is shown in Figure 7 [11].

A. Shared Components

1) RF Transceivers: A major component to our overall design is the ability for the two main units, the U-Lock and the Tracking Unit, to be able to communicate with each other wirelessly. Because this feature is essential to our design, it is an item on the critical path; the likelihood of failure is a two out of five and the impact of failure is four out of five [11]. Sending and receiving information will be accomplished with two NRF24L01 2.4 GHz radio frequency modules which can send packets of information to each other using the 2.4 GHz band of frequency. Risks involved in using these modules include loss of information over the air, power issues, interference and pollution on the 2.4 GHz frequency, and interference from materials, such as a bicycles metal frame [11].

Loss of information can come in two forms, loss of connection between the two modules or dropped packets dues to noise and interference. Loss of connection should not occur in our system because the two RF units will have to communicate with each other over a small distance of only a meter or two at most. Noise and power issues can be resolved by placing a decoupling capacitor across the power and ground signals of the modules [12]. The NRF24L01 have very strict power requirements; the modules can only handle a maximum of 3.6 V [13]. This

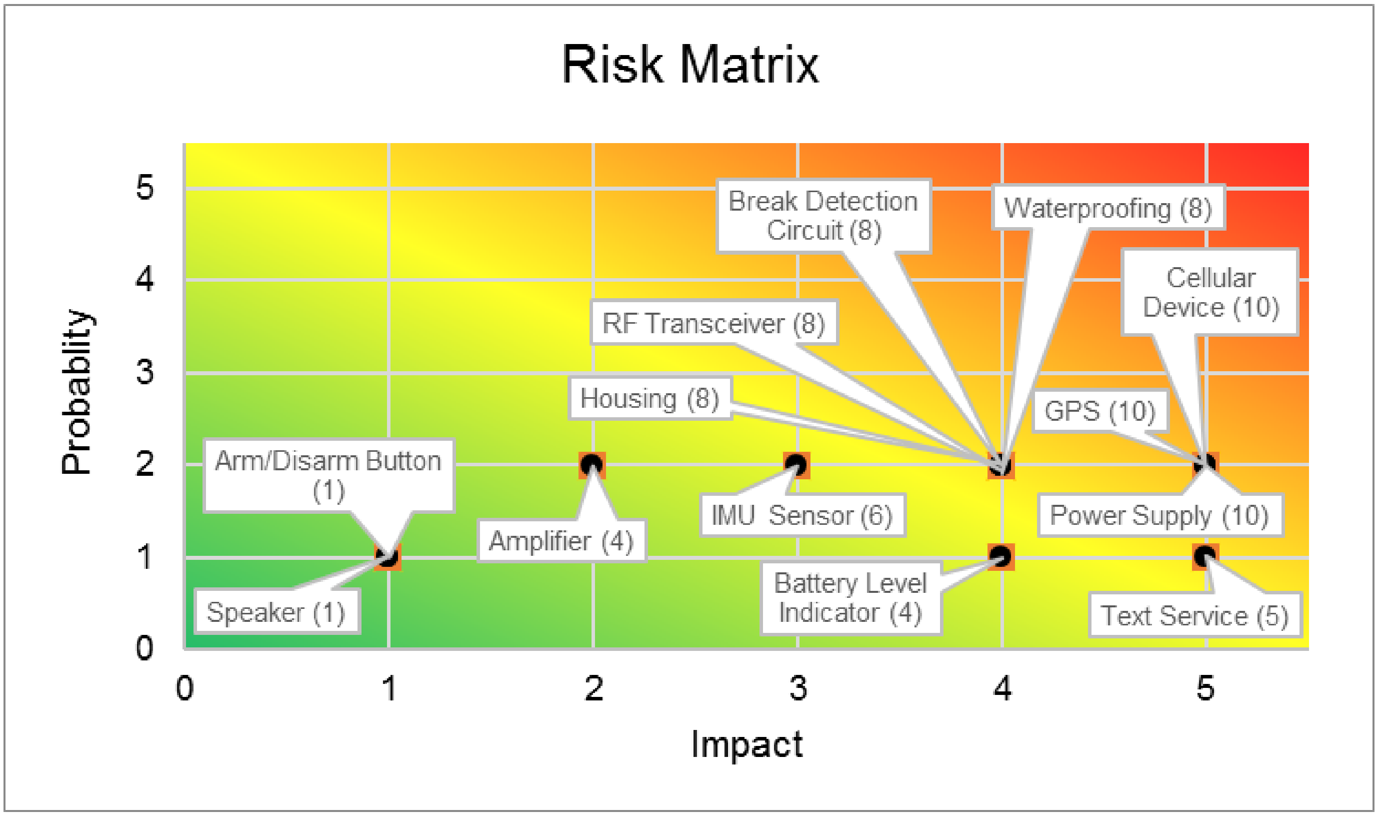


Fig. 7. Risk Matrix showing the Impact of component failure vs. the Probability of occurrence on a scale of 1 (low) to 5 (high). [11]

shouldnt cause problems as long as we use the 3.3 V output on the Arduino device we use. Other issues that may come up are with interference and signal pollution which can came from other signals using the 2.4 GHz band frequency. This should also not be a huge issue since we can tell the modules to avoid channels like one through fourteen which are used for Wi-Fi [14]. The final type of interference we may encounter will come from the metal frame of a bicycle. To combat this type of interference, we could adjust the positioning of the modules on the bicycle or adjust the settings for the module to use more power. Overall, interference from the body of a bicycle is the one risk that we may have to accept as part of our design.

2) Power Supply and Battery: The purpose of the power supplies and batteries are to provide power to the lock unit and tracking unit. The power supply has a low probability of failure of approximately two out of five. The impact to the project if these components do fail is estimated to be four out of five [11].

3) Battery Life Monitor: The battery life monitors are important because they indicate to the user how much battery life is left in each device. The approximate probability of failure is one out of five and the impact if this does occur is estimated to be four out of five [11].

B. U-Lock Components

1) Lock Break Circuit: The purpose of the lock break detection circuit is to detect if the lock is opened or cut while the device is armed. The risks associated with the lock break circuit are poor contacts with the U portion of the U-lock the probability of this occurring is estimated to be one out of five and the impact if this occurs is high at four out of five [11].

2) IMU: The IMU sensors main function is to serve as an onboard monitoring system that can detect if the smart bicycle lock is trying to be forcibly removed. Both the risk and probability of this sensor failing is a one out of five [11]. The IMU will only fail is it is wired incorrectly or fed too much current.

3) Speaker: The speaker has a low probability of failing or breaking. Both the probability and risk of this happening is a one out of five [11]. The speaker will only stop working if it is fed more power than it can handle. Luckily for us the power coming from the Arduino Uno isnt enough to damage the speaker.

4) Arm/Disarm Buttons: The Arm and Disarm button and software will have relatively little risk involved. They are simply buttons that will be used to arm and disarm the device. The risk involved is a one out of five and the impact to the overall design will be a one out of five [11]. The only real risk with this mechanism would be some failure that wouldnt allow it to work properly, ie. the U-Lock would not be able to arm and disarm itself. Because we use simple push buttons, we dont see much risk involved with this mechanism. If the buttons do not work properly, the texting service to arm and disarm the bicycle lock is still available.

C. Tracking Unit Components

1) GPS: The GPS portion of this project is a critical component used for locating the bicycle when needed. As such in the event of failure this would result in complete failure of the system. The main point of failure in the GPS unit is interference which causes a signal loss. This can occur in certain large buildings and also areas such as tunnels or elevators. These factors are uncontrollable and therefore must be accepted. However, we can mitigate the impact some by saving the last known coordinates. While far less accurate this will still give a general area in which the bike is located. Overall the impact of failure is a five out of five while the probability is two out of five [11].

2) Text Interface: The text interface portion of this project incorporates both the user interface and the text messaging function. The text interface is the main way for two way communication between the user and the device therefore it is a critical part. The text interface relies upon receiving and sending a standard text message from any cell phone. Should the device be unable to send or receive messages due to signal loss. Then complete failure of the device can occur. It is also possible that the user is unable to send properly formatted commands to the device. While the chance of signal loss must be accepted, we can ensure that if invalid commands are received that the device responds and assists the user. Overall the probability of failure is a one out of five while the impact is a five out of five [11].

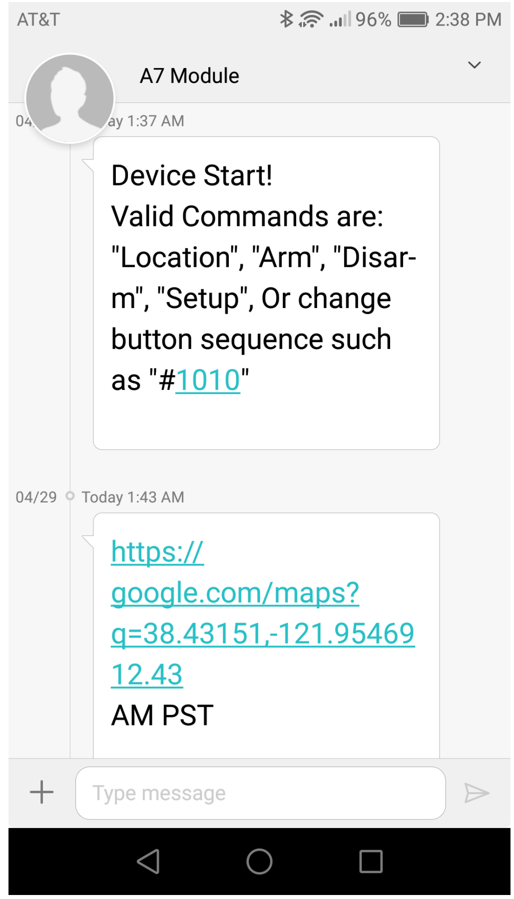


Fig. 8. Location Tracking.

VIII. Design Overview

ComBATS is like nothing else on the current market for bicycle locks and bicycle security. The system is split into two major components: a traditional U-Lock, and a hidden Tracking Unit. The U-Lock is a modified version of a U-Lock; these modification give the U-Lock the capability to detect when it's being tampered with and sound off an alarm to ward off potential bicycle thieves. The Tracking Unit is meant to be a small, concealed device that hides inside the frame of the bicycle and has the capability to send its GPS coordinates if you send a text message to the device. These products are similar to what is available on the market; what makes comBATS different, is that the two components, the U-Lock and Tracking Unit, have the ability to communicate with each other. This means that the Tracking Unit can tell the user if the U-Lock has been tampered with, and the U-Lock can be armed and disarmed when the user communicates with the Tracking Unit. This two part design also means that if the U-Lock is compromised, the Tracking Unit is

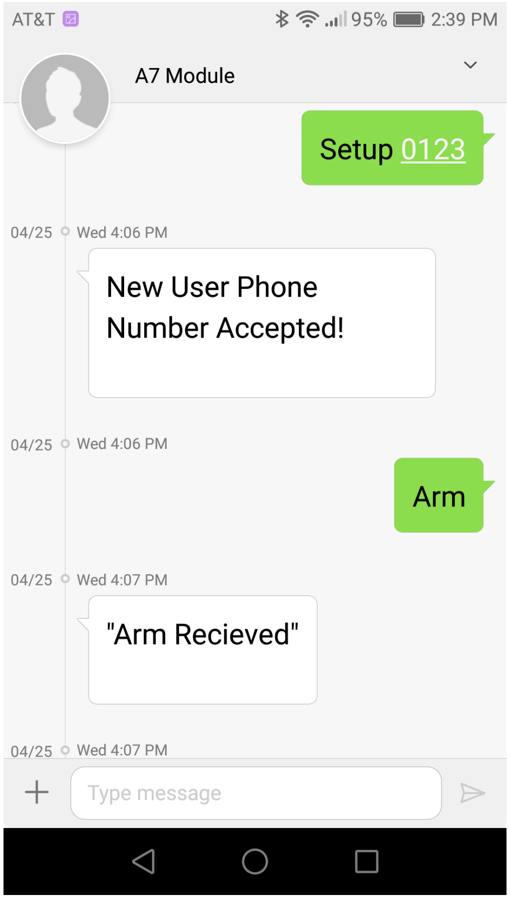


Fig. 9. Text Interface.

still operational, and can still notify the user of the bicycle's location.

A major aim of comBATS is to provides a means of bicycle recovery if a bicycle is stolen. Because of this, some tracking mechanism needs to be hidden on a bicycle well enough for a potential thief to not notice it; this is why our Tracking Unit is a small, hidden device. GPS tracking is not preventative. It allows a user to know the location of their bicycle, but does not prevent a thief from taking their bicycle. It would also be useful for there to be a primary form of theft prevention. The U-Lock serves as a primary form of theft prevention as well as a theft deterrent. The alarm is like a car alarm, but for a bicycle; it makes a loud sound that alerts the public of misconduct and makes a bicycle less appealing to a criminal. The two devices will communicate with each other to create a full system that the user can rely on to both prevent theft, and help recover stolen property if the prevention fails.

IX. Deployable Prototype Status

Our deployable prototype has satisfied all of our design idea requirements. The two component system works as planned as has been throughly tested. Our device test plan was completed and held as predicted. Once each individual component was tested and worked. The components that depend on one another were put to the test to see if the system could function as once cohesive unit.

The quantifiable test results can be found in our Device test plan document and our design idea requirements were laid out earlier in this document. The system's core functionalities such as arm, disarm, and gps tracking work. The user can text comBATS to arm, disarm, and check the location of the bicycle. On the U-lock side if the lock detects that a thief is trying to physically remove the lock, the 100db alarm will go off. Also, if a thief cuts the U-lock, this will also trigger the alarm to go off. If the alarm goes off the user will be automatically notified via SMS with the location and state of their bicycle.

Since our expertise is more of the system itself, we had to figure out how to design and 3D print a casing. The casing for both the U-lock and tracking unit took multiple iterations, but we finally designed a formed fitting case that is both functional and strong.

X. Marketability Forecast

In order to get our project to a manufacturable condition there are a few key things which must be finished and refined such that our device will flourish in the open market. Firstly we must change over our design to take advantage of indsutrial manufacturing. This will allow us to decrease costs by using bulk components and scaling down the project. This decrease in project size by moving to PCB boards will also make our product more desireable in the market since it will not be as bulky and unrefined as our current prototype. Another major step would be to have our own custom locks created which will be able to securely hold the electronics and also be completely waterproof. This will also allow us to make the ULock hardware itself more robust and harder to cut.

To make our product desireable to the end user we must ensure that any bugs in the software and hardware are fixed to ensure a properly working devce. This will be done through thourough testing before being released into the market. This testing will allow values such as the accelerometer values to be properly calibrated. This will also allow for any real world problems not yet encountered with the device to be fixed. One potentially major issue that must be fixed is the long term useage of our device. We must ensure that proper safeguards are inplace such that the device will not enter an unrecoverable state rendering it useless. In the event of a malfunction we must make sure there is a way to recover the device without interverention from the user. Another potential problem to marketability of our device is battery life. Currently we have tested our battery life of at least 6 hours. We need to ensure that our devices batteries last as long as possible. To do this we need to have low power modes fully implemented to extend battery life.

XI. Conclusions

The fall semester had its challenges, but our team managed to complete the documentation and laboratory prototype on time. Once the societal problem, design idea contract, and work breakdown structure were complete our team was able to devote all of our time and energy to completing our comBATS system.

After the fall showcase, our team received some feedback about our laboratory prototype and took it into consideration when the Spring semester approached. During the Spring semester, our main goals were to shrink our components down, make our system reliable, and design our own casing. Throughout the semester we ran into some problems with the PCB boards not being delivered on time and this forced our team to rapidly create an emergency backup plan and execute it. Even though we were not able to fully conceal the tracking unit inside of the bicycle, with more time we should have been able to do so.

Overall, our team believes our system is better than any smart bicycle lock on the market because comBATS provides the user with theft prevention, detection, and recovery. Giving the user peace of mind that their bicycle is safe and if it is stolen he or she has the GPS coordinates for recovery.

References

[1] A. Sidebottom, A. Thorpe, and S. D. Johnson, Using Targeted Publicity to Reduce Opportunities for Bicycle Theft, European Journal of Criminology, vol. 6, no. 3, pp. 267286, 2009.

[2] A. Yoshino, The Birth of the Lithium-Ion Battery, Angewandte Chemie International Edition, pp. 5798-5800, Feb. 2012.

[3] C.Noppadol, ”Real-time tracking management system using GPS, GPRS and Google earth - IEEE Conference Publication”, Ieeexplore.ieee.org, 2008. [Online]. Available: http://ieeexplore.ieee.org/document/4600454/.

[4] Ladyada, Tilt Sensor, Adafruit. [online]. Available at:https://cdn-learn.adafruit.com/downloads/pdf/tilt-sensor.pdf

[5] Sherlock. (2017). Sherlock — The ultimate anti-theft device for your bike. [online] Available at: https://www.sherlock.bike/en/

[6] X-5735-LW350-S-2-R PUI Audio — Mouser, Mouser Electronics. [Online]. Available: http://www.mouser.com/Search/ProductDetail.aspx?R=X-5735-LW350-S-2-Rvirtualkey66500000virtualkey665-X5735LW350S2R. [Accessed: 01-Oct-2017].

[7] Arduino - Software. [Online]. Available: https://www.arduino.cc/en/Main/Software. [Accessed: 01-Oct-2017].

[8] A. Industries, Stereo 20W Class D Audio Amplifier - MAX9744, adafruit industries blog RSS. [Online]. Available: https://www.adafruit.com/product/1752. [Accessed: 01-Oct-2017].

[9] Arduino Playground, ”MPU-6050”, Arduino Playground. [ONline]. Available: https://playground.arduino.cc/Main/MPU-6050. [Accessed:04-Apr-2018].

[10] B. Ramos, T. Bakken, T. Singh, and I. Wollenslegel, ”Assignment 3: Work Breakdown Structure” unpublished.

[11] T. Bakken, B. Ramos, T. Singh, and I. Wollenslegel, Assignment 5: Risk Assessment Report. unpublished.

[12] JIMB0, Capacitors, SparkFun. [Online].

[13] nRF24L01, Nordic Semiconductor. [Online].

[14] I. Poole, Wi-Fi / WLAN Channels, Frequencies, Bands & Bandwidths, Radio-Electronics.com. [Online].

[15] T. Bakken, B. Ramos, T. Singh, and I. Wollenslegel, ”Assignment 7: Lab Prototype Documentation.” unpublished.

Appendix A
User Manual

A. Charging

In order to charge the devices, you must connect them with a micro-usb charging cable for a minimum of two hours to reach a fully charged state.

B. New User Setup

In order to allow the device to communicate to your phone, you need to let the device know what your phone number is. In order to do this you need to text the device via it's phone number ”Setup0123”. Then the device will reply ”New User Phone Number Accepted!”.

C. Button Sequence Update

You can update the button sequence on the device in order to disarm it without using a cell phone by sending it a sequence of ones and zeros. In order to disarm the device, you press the buttons on the device in the sequence you send.

In order to update the sequence, send the Lock a text message Starting with #, then your sequence up to 16 digits long. For example you would text the lock, ” #1011” to change the sequence to 1011.

D. Locking the Device

when you arrive at a location where you wish to lock your device, you simply lock the U-Lock around a secure place, then close the lock and scramble the combination. You can then lock the device either by pressing and holding either button on the lock for at least one second, then releasing. You can also arm the system by sending it a text message saying ”Arm”. When you are ready to leave, you can unlock the device either by entering your sequence on the buttons or sending it a text message, ”Disarm”. Then you can unlock the device by entering the combination on the lock, removing the U, and placing it in a secure spot and then you can ride away.

E. Locating Your Device

If you recieve a text message from the lock notifying you that your device has been stolen either, via the motion detection or the lock was broken, then you will receive location updates periodically until you disarm the device, either by sending a text message to ”Disarm” or you physically disarm the device by entering your sequence.

F. Locating Your Device

You are able to locate your bike at any time by sending a text message saying ”Location”. It will respond with a link to the google maps map showing where the bike is located.

APPENDIX B
HARDWARE

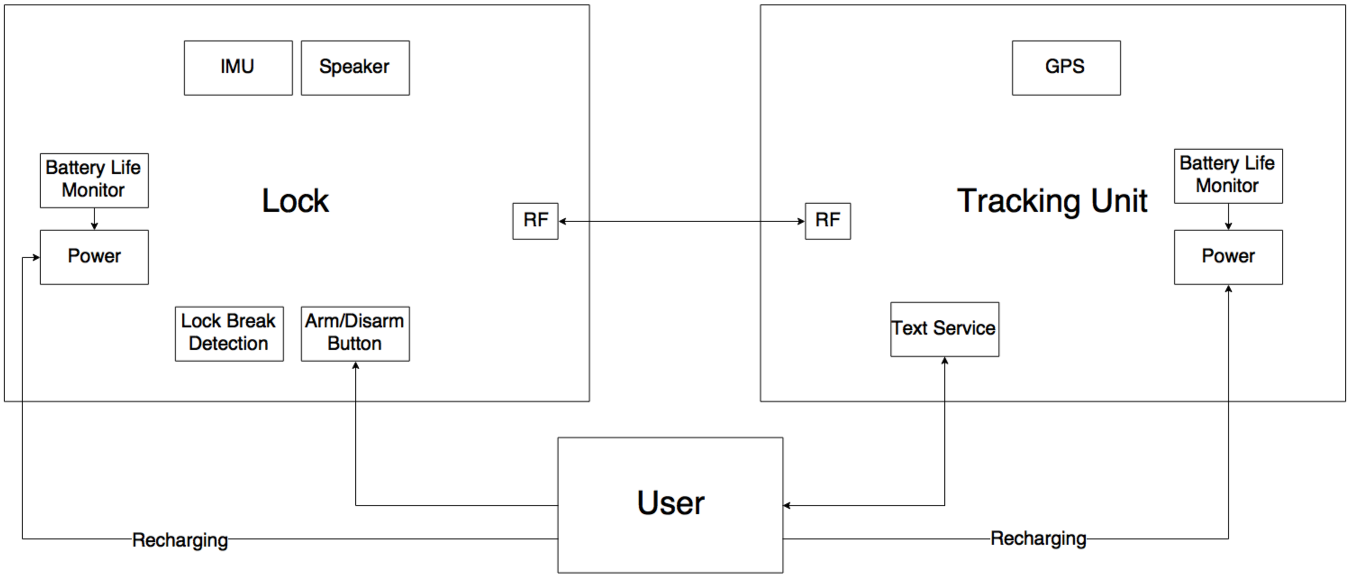


Fig. 10. Block Diagram of comBATS

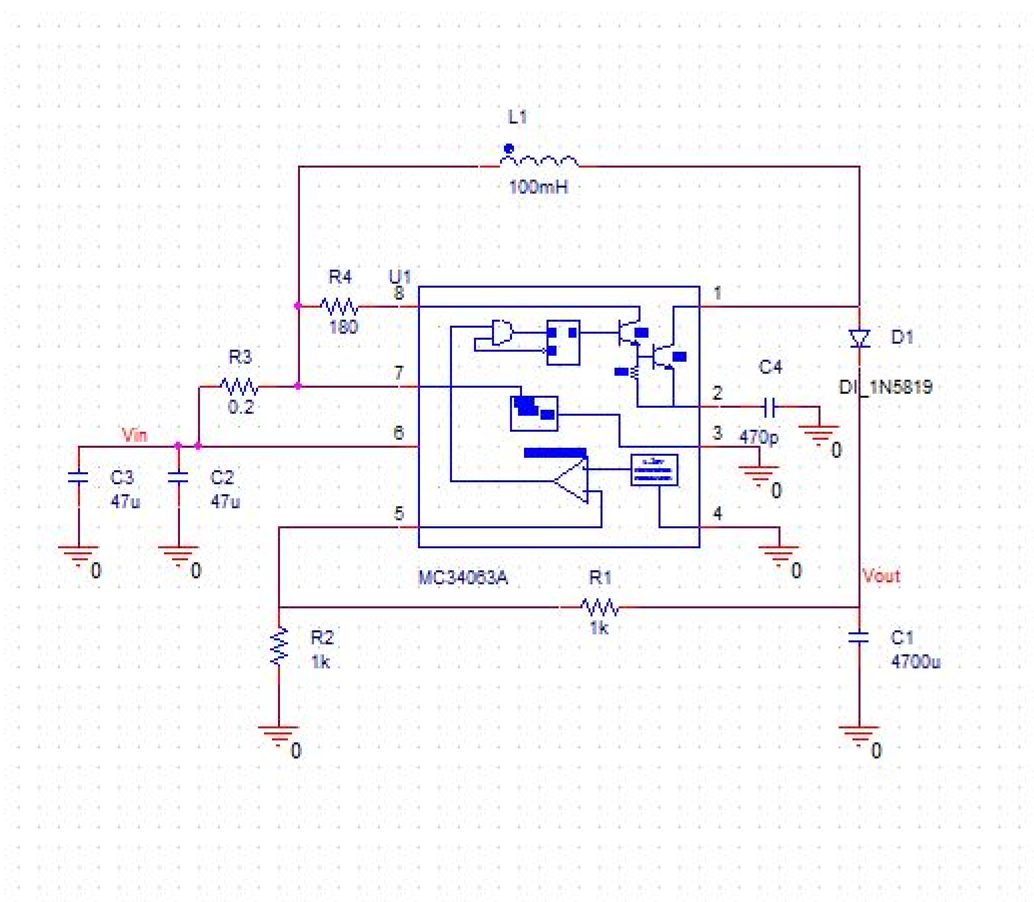


Fig. 11. Power Supply Schematic [15]

Appendix C
Software

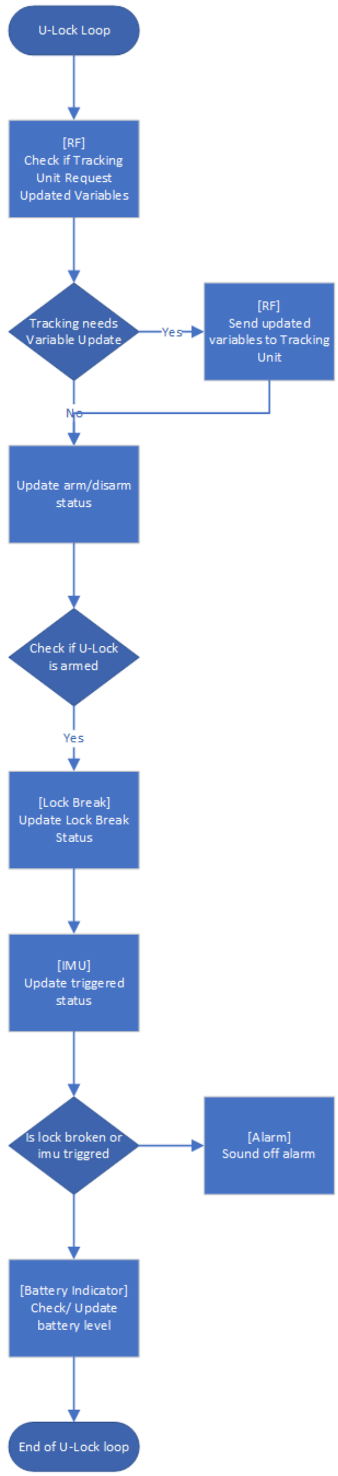
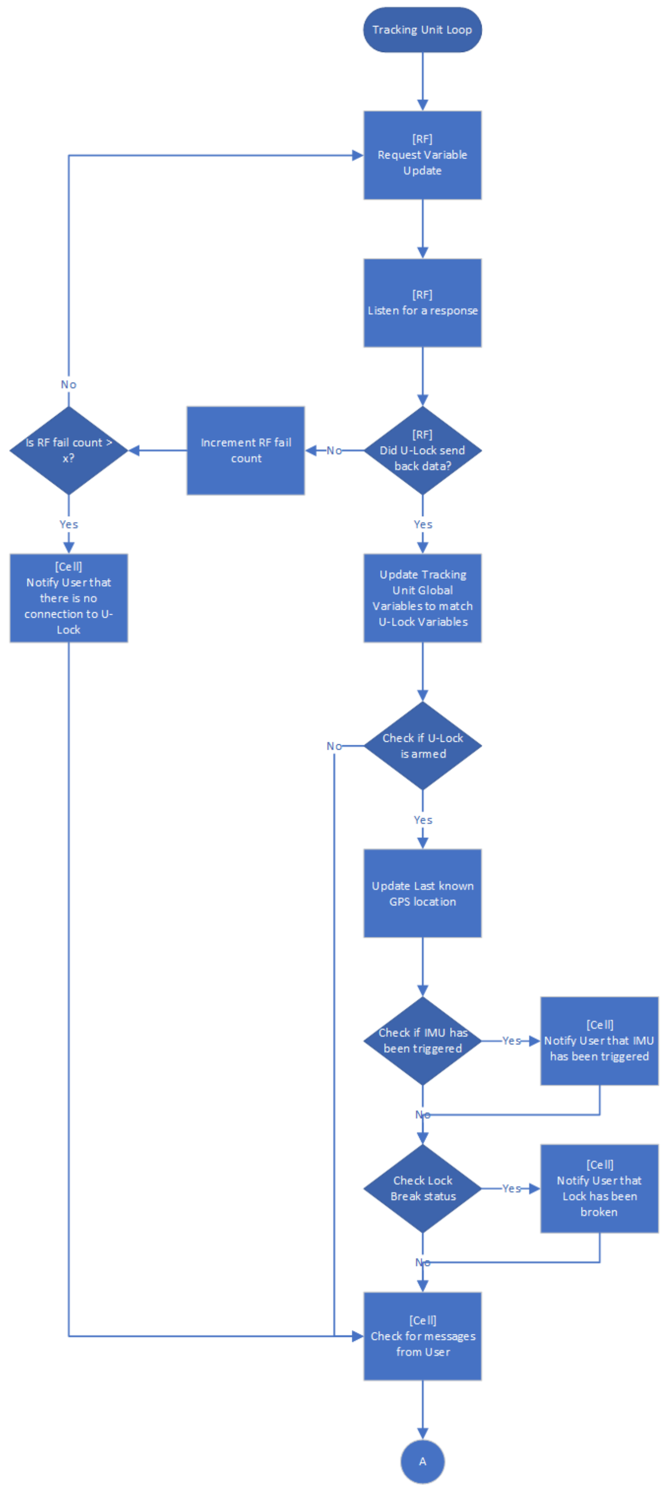


Fig. 12. Software flowchart of U-Lock component of comBATS


Tracking Unit Loop
[RF]
Request Variable Update
[RF]
Listen for a response
[RF]
Did U-Lock send back data?
No
Increment RF fail count
Is RF fail count > x?
No
Yes
[Cell]
Notify User that there is no connection to U-Lock
Yes
Update Tracking Unit Global Variables to match U-Lock Variables
Check if U-Lock is armed
No
Yes
Update Last known GPS location
Check if IMU has been triggered
Yes
[Cell]
Notify User that IMU has been triggered
No
Check Lock Break status
Yes
[Cell]
Notify User that Lock has been broken
No
[Cell]
Check for messages from User
A

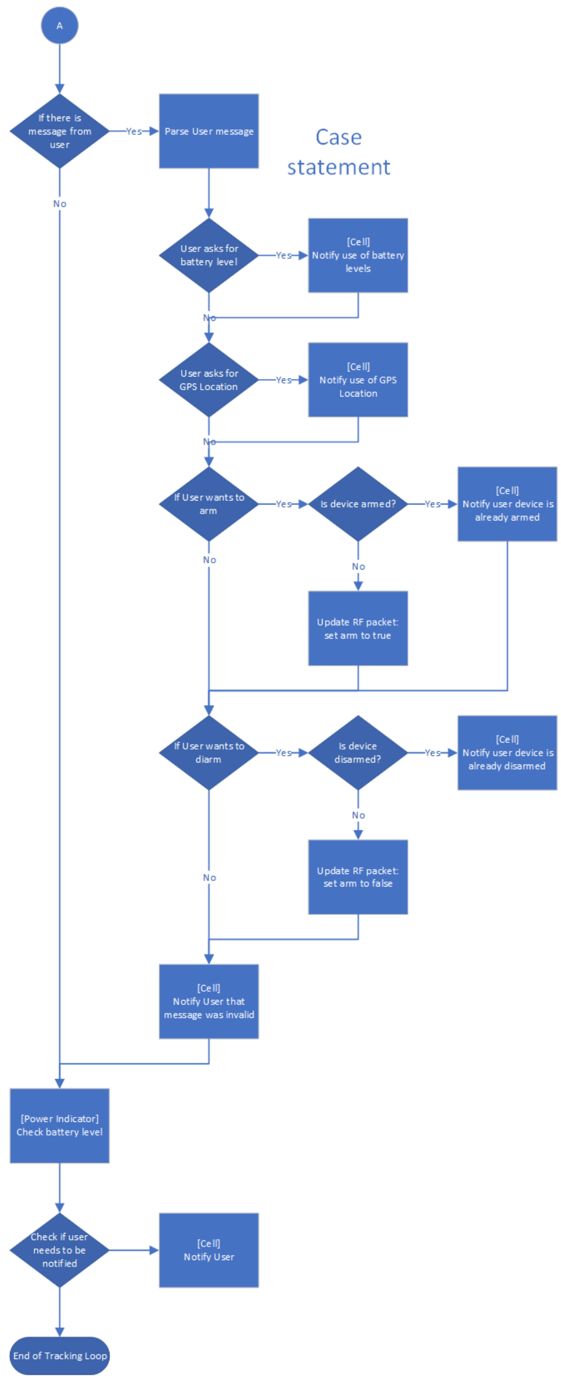


Fig. 13. Software flowchart of Tracking Unit of comBATS

Appendix D
Mechanical

Fig. 14. 3d Printed ULock Case

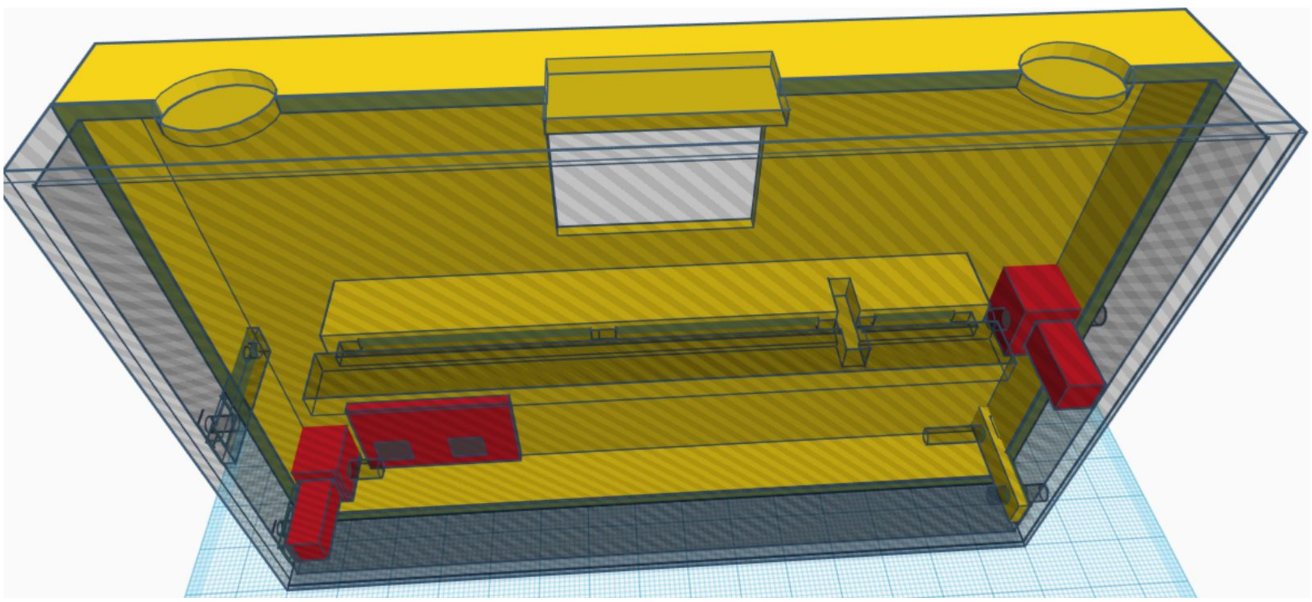


Fig. 15. ULock Case 3d model