March 14, 2019
Craig Scratchley
School of Engineering Science
Simon Fraser University
Burnaby, BC V5A 1S6

Re: ENSC 405W Design Specification for UniLoq

Dear Dr. Scratchley:

The attached document provides a detailed design specification for the implementation of the U-Loq system. With this system, UniLoq aims to prevent the plague of bicycle theft through a cost-effective and intelligent bike lock.

The U-Loq will use a two-part system of a smart bike lock and a small GPS tracker to ensure that any stolen bicycle can be retrieved by their owner. Whenever the bike lock portion of the system is broken or cut the owner will receive a notification with the real-time GPS location of their bike, which will allow their bike to be recovered and remain in their possession.

The design specification document will detail the implementation and execution of all the components of the U-Loq's design. Firstly, the product will be introduced, and a high-level overview of its functionality will be given. This document will then go on to specify the electrical/ hardware design, the firmware design, the design of the android application and the mechanical design of the product. Through these sections, the requirements listed in the requirements document will be justified and their implementation detailed. Lastly, this document contains two appendices which outline an acceptance test plan for the design in this document and a User Interface (UI)/appearance design for the U-Loq.

The UniLoq team is comprised of the following six upper year engineering students with varied experience and specialties: Miguel Fernandez, Charles Chang, Jason Liu, Jameson Roy, Haotian Ye, and Zuo Xiong. Together this team will produce deliverables that meet all requirements and is consistent with the product this document details. UniLoq can be contacted directly for any questions or comments at cca214@sfu.ca.

Regards,

Jameson Roy

DESIGN SPECIFICATION FOR UNILOQ

Team 4

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Revision 1.0.0

Abstract

The U-Loq system is a unique approach that tackles one specific but very prevalent problem in many cities around the world - bike theft. The goal of our system is to provide greater security and recoverability compared to a single lock, which will increase bike theft arrest rates. In turn, this will hopefully deter future potential bicycle thieves and provide peace of mind to all bike riders everywhere.

The system contains both a robust smart U-lock as well as a reliable GPS Tracking and system monitoring device. These work together to recognize nearly all instances of bicycle theft and provide a way for the user to retrieve their stolen bike or contact appropriate authorities. The U-lock will contain smart technology, being able to recognize when it is opened or cut. Fundamentally, it will function just like any other U-lock, allowing for ease of use through an established standard. The GPS tracker will be mounted under the seat, and it is responsible for sending data over the cellular network to the user. This will provide the necessary GPS, Battery, and overall system status information to keep the user informed about his/her U-Lock, which will all be displayed intuitively on our custom U-Loq Android Application.

The U-Loq system is overall simple, but quite an ambitious project. Many details have gone into creating a product that satisfies the goals stated above, all while remaining accessible and cost-effective. The purpose of this document is to outline these details and design decisions that allow us to create a system that is secure, intuitive and robust. In order, the electrical/hardware, firmware design, android application and mechanical design of the product is examined, expounding on design choices and justifying them. Attached are also appendices in which the test plan and User Interface (UI)/appearance design of the U-Loq are outlined.

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Glossary

Term	Definition
Abus	A bike lock company.
Arduino	Arduino is an open-source hardware and software company, project and user community that designs and manufactures single-board microcontrollers and microcontroller kits for building digital devices and interactive objects that can sense and control both physically and digitally. [1]
BLE	Bluetooth Low Energy. A Bluetooth module that can operate in remarkable low energy mode.
GPIO	General Purpose Input Output. It is one of the most common input output interfaces on hardware for communications.
GPS	Global Positioning System. A system that can locate current position by three or more satellites signal.
GSM	Global System for Mobile communications. It is the protocols for second-generation (2G) digital cellular networks
Kryptonite	A bike lock company.
OnGuard	A bike lock company.
SparkFun	SparkFun Electronics is an electronics retailer.
UNV-SIM868	UNV-SIM868 is a GPS/GSM/BT built-in development board with a SIM868 processing chip.

1 Introduction

1.1 Background

The invention of the bicycle has changed the way people travel since the early nineteenth century. It is a relatively lightweight and fast means of travel. As biking is known as a healthy and environmentally-friendly activity, there is an increasing number of people traveling around the city by bike. In 2013/2014, an estimated 7.0 million people reported that they had cycled in the past 3 months, up from 6.5 million in 1994/1995. [2] However, cyclists are facing a severe issue: bike theft. Square One Insurance shows that the bike thefts are increasing, Figure 1 Reported bike thefts data . Most of the bikes that were stolen were secured with a bike lock, which indicates traditional bike locks cannot protect bicycle thoroughly.

Figure 1 Reported bike thefts data [3]

Focusing on the problem pointed out above, UniLoq has decided to fight against the bike theft by making a smart bike lock called U-Loq. This smart bike lock can detect if the lock is broken by someone. If so, the bike lock system will send the notification with GPS location to the user's mobile device to alert the user his/her bike might be stolen. The GPS module will continually report the current position to the user to help them retrieve their stolen bicycle or contact appropriate authorities to catch the bike thief.

1.2 Market Acceptance

According to the guide found in "*The 6 Best Bike Locks in 2019*", the bike lock market has the "big three: Abus, Kryptonite and OnGuard" [4]. These three are the most trusted names in bike locks which makes breaking into the market with a new product difficult. Out of these big three, it appears only Abus offers any smart bike lock solution with their U-Lock 440 Alarm and U-Lock 770A SmartX™ [5]. Both solutions just offer alarming and smartphone integration which does not have nearly as many security features as the U-Loq.

This leaves room for UniLoq to pursue one of two options for bringing the U-Loq to market. The first is to bring the U-Loq final product to an established bike lock vendor in order to leverage their resources and brand to mass produce and get an edge in the market. If interest is not found from an established brand, then UniLoq can then bring the U-Loq to market and compete in the much younger and less established smart lock (also known as e-lock) market. According to the Smart Bicycles Market by Components assembled by Infoholic Research, the "e-bike lock system is expected to grow at a CAGR [Compound Annual Growth Rate] of 8.0% during the forecast period to reach revenue of $123.1 million by 2023" [6]. This helps demonstrate a growing market that established bike lock brands will need to start competing in or a brand such as UniLoq may gain a new kind of trust.

1.3 Scope

This document outlines the system overview, product requirements, and product specifications. The product specifications are classified in different categories by stages. All the product specifications must be met to ensure the functionality of the final product. Also included is a test plan for assuring the final product meets the outlined standards.

1.4 Intended Audience

The intended audience of this document is UniLoq company members, technicians, and developers specifically, as the specifications are for the members who in charge of manufacturing, producing, modifying and testing the product. To guarantee that the outcome matches what is wanted, members who are responsible for developing it must know and follow the requirements and specifications.

1.5 Design Classification

All design requirements in this document will follow the classification format in Table 1 Classification encoding below. These design requirements will also contain references to the requirements from the requirements document that they either partially or fully satisfy with their specification.

Des <Section>. <Subsection>. <Design Number>-<Development Stage>

Encoding	**Development Stage**
C	Proof-of-Concept
P	Engineering Prototype
F	Final Product

Table 1 Classification encoding

2 System Overview

U-Loq is a sophisticated and comprehensive anti-bike-theft integrated system, which is designed for bike owners to provide the highest security level for their bike.

Without sacrificing either practicality or beauty, the U-Loq is approximately 20cm tall, 11cm wide and 14mm in depth (thickness), with 2 Kg weight. The system combines a traditional steel bike lock with a built-in control/feedback communication system, which will physically detect the status of bike lock by a series of sensors. The only action users need to take off are attaching the U-Loq to the bike and locking it. The U-Loq will automatically update the real-time information to the user's mobile device if it is cut. The self-alarm system is embedded into U-Loq will trigger in case of it being cut if the user so chooses.

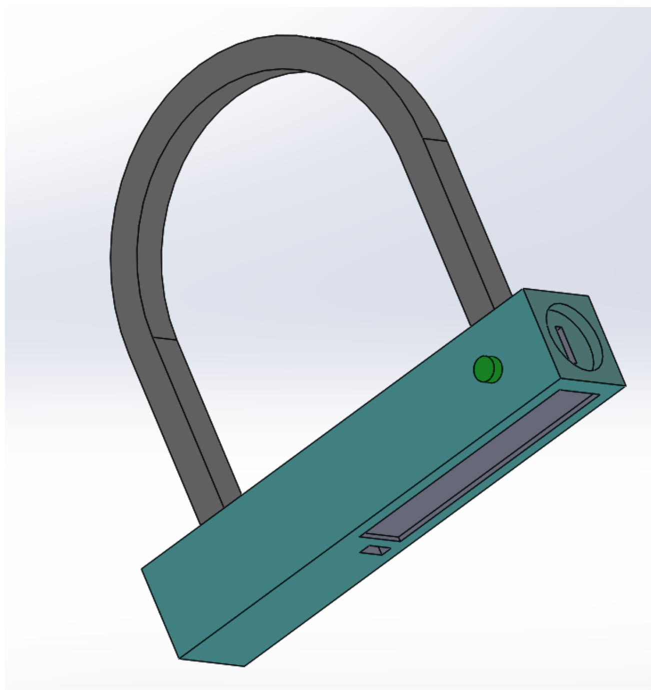

Figure 2 Concept design picture

Figure 3 System block diagram shows the concept design for U-Loq. This bike lock achieves a high-level of portability, reusability, practicality, and security in its purpose of bike protection. With this U-Loq system, the real-time status and location will be transmitted to the user's mobile device. The U-Loq will precisely provide a real-time map of bike location, battery status notification, and bike lock physical status notification to the user to ensure comprehensive control of the bike.

The U-Loq is a system comprised of two parts: the bike lock body, and a GPS tracker system. The bike lock body appearance is the same as that of a standard bike U-lock. However, it has a sensor built-in that can recognize if the lock is damaged or forced open in some way. Further, the lock body has a BLE (Bluetooth Low Energy) which is a remarkably low power Bluetooth unit that transfers the lock status to the communication system. The primary functionality of the bike lock body is to secure a bike and to monitor any attempted breakage. As for the communication system, it has more units built in such as a BLE, GSM, GPS module and a microcontroller. The system regularly monitors the bike lock body and verifies if the lock is in intact condition. If so, the communication system will remain in low power mode. I.E., the GPS module will sleep. However, if the bike lock body acknowledges the communication system, the system will wake up in a high-power mode, activate the GSM and GPS module to send the notification to the user and receive GPS data from the satellite. Therefore, it communicates with the lock body and the user. The GPS tracker system will be hidden in/on the bike to prevent damage.

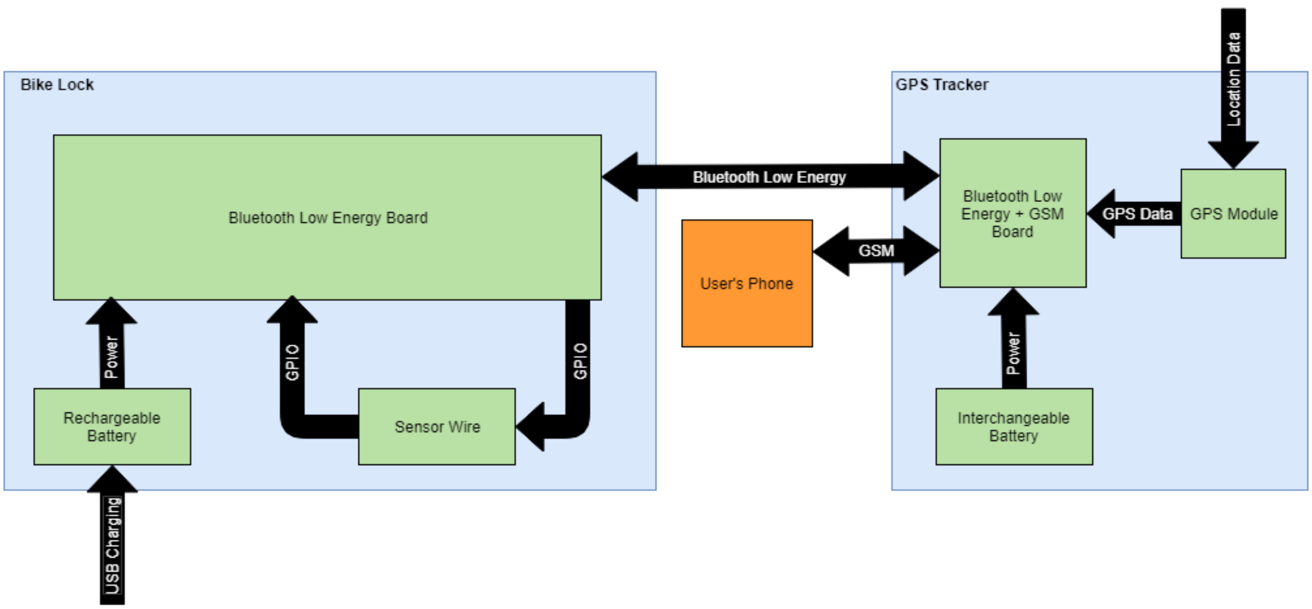

Figure 3 System block diagram

An Android app is designed for communication/information handling. U-Loq will represent the real-time notification effectively and directly. After data been collected by the terminal devices (bike lock and GPS tracker), all the information will be decoded and transmitted to this app through GSM.

The U-Loq is a reliable, small and powerful device that will prevent or track any thief attempting to steal the bike. Further, U-Loq will significantly decrease the crime rate regarding bike stolen/lost, with an affordable price to all public individuals, which is the project objective.

3 Hardware/Electrical Design

3.1 GPS Tracker

Identifier	*Design Requirement Description*
Des 3.1.1-C	GPS Tracker output signal will not exceed the current limit of microcontroller GPIO pins [**Satisfies Requirement 6.2.8**]
Des 3.1.2-C	The electrical components of the GPS Tracker will not pose fire or explosive risk under normal usage conditions [**Satisfies Requirement 9.1.3**]
Des 3.1.3-P	GPS Tracker will have a low power mode when the Bike Lock is not broken [**Satisfies Requirement 6.2.1**]
Des 3.1.4-P	GPS Tracker will have a high-power mode when the Bike Lock is broken [**Satisfies Requirement 6.2.2**]
Des 3.1.5-F	GPS Tracker's battery will last at least 24 hours in high power mode [**Satisfies Requirement 6.2.3**]
Des 3.1.6-P	GPS Tracker will have a replaceable battery [**Satisfies Requirement 6.2.4**]
Des 3.1.7-F	GPS Tracker's battery will last at least 5 months in low power mode [**Satisfies Requirement 6.2.6**]
Des 3.1.8-F	GPS Tracker lithium battery size will fit the enclosure so that it can be easily hidden in/on the bike [**Satisfies Requirement 6.2.7**]
Des 3.1.9-C	GPS output signal will not exceed the current limit of microcontroller GPIO pins [**Satisfies Requirement 6.2.8**]

Table 2 GPS tracker electrical design requirements

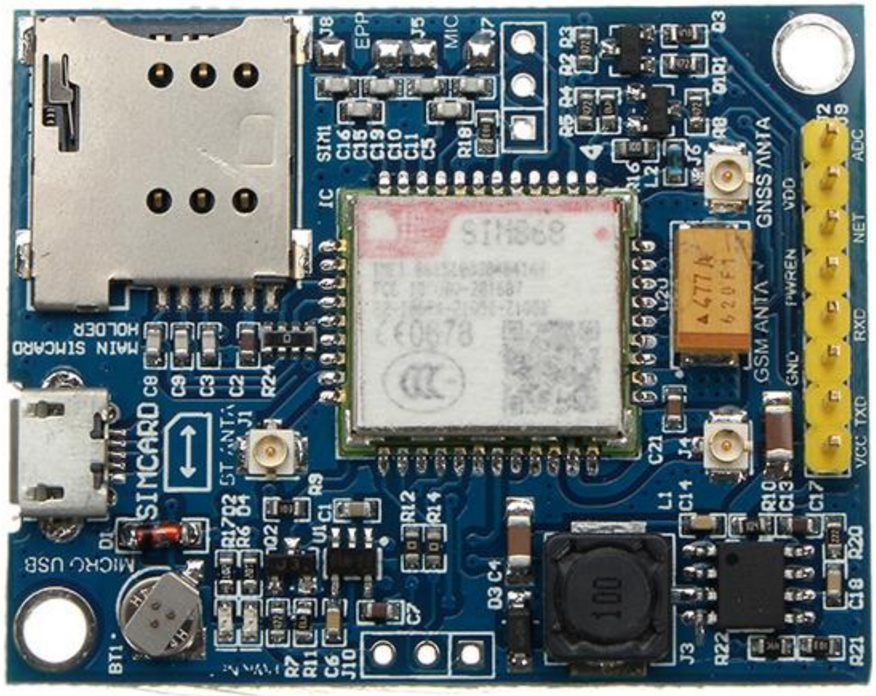

Figure 4 UNV-SIM868 board

When we are deciding on the selection of the developing board for GPS Tracker section, the board must have three main functionalities that are Bluetooth low energy, GPS module, and GSM module. Also, the size of the developing board must be considered since it should be mounted and hidden underneath the bike seat so that bike thief cannot find it easily. We found out that UNV-SIM868 developing board will be a perfect choice not only because it has all three functionalities: BLE, GPS, and GSM module but also has different operation modes based on what functionality you need to use. For example, when bike lock is not broken, UNV-SIM868 will be in low power mode (normal operation mode that GPS and GSM modules are both in sleep). When bike lock is broken, UNV-SIM868 will be in high power mode (GPS and GSM modules are ready for data transfer). The size of UNV-SIM868 is 17.6 * 15.7 * 2.3mm which is tiny enough to be hidden underneath the bike seat. Furthermore, UNV-SIM868 is designed with power saving technique so that the current consumption is as low as 0.65mA in sleep mode. Table 3 UNV-SIM868 specifications is a summary of the specification of the UNV-SIM868. We will be using the UNV-SIM868 during our design process from proof of concept to final product.

The Arduino Nano is chosen as the microcontroller to control the UNV-SIM868. The first reason is that the power consumption of UNV-SIM868 when GPS is tracking takes 21mA, and each input or output pin of Arduino Nano can provide or receive a maximum of 40mA so that GPS output signal will not exceed the current limit of microcontroller GPIO pins. The second reason is that the size of Arduino Nano is only 18 * 45 mm which is very tiny compared to other Arduino microcontrollers such as Arduino Uno and Mega. We need to make sure the overall size of GPS tracker is as small as possible in order to avoid the detection from bike thieves. The combination of UNV-SIM868 and Arduino Nano will be a perfect choice to meet this requirement.

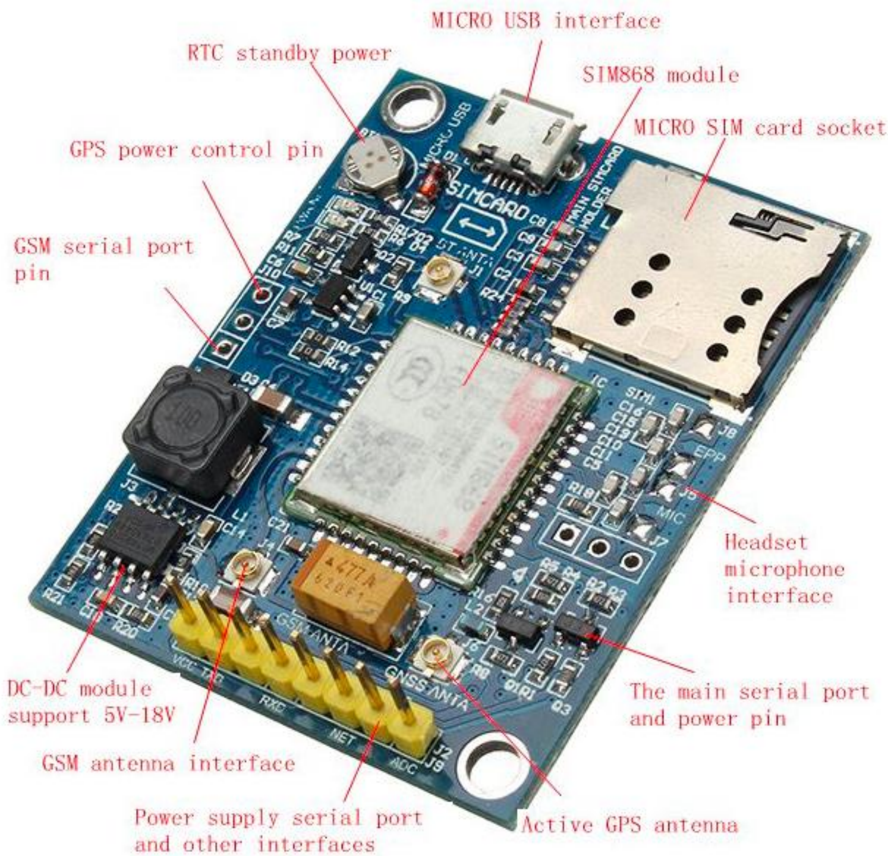

Figure 5 UNV-SIM868 detail diagram

Power Supply	3.4 - 4.4V
Power Saving	Typical power consumption in sleep mode is 0.65 mA
Flash Memory	32MB
RAM	32MB
GSM	850,900,1800 and 1900MHz
Transmitting Power	• Class 4 (2W) at GSM 850 and EGSM 900 • Class 1 (1W) at DCS 1800 and PCS 1900
GPRS Connectivity	• GPRS multi-slot class 12（default） • GPRS multi-slot class 1~12 (option)
Temperature Range	• Normal operation: -40°C ~ +85°C • Storage temperature -45°C ~ +90°C
Data GPRS	• GPRS data downlink transfer: max. 85.6 kbps • GPRS data uplink transfer: max. 85.6 kbps • Integrate the TCP/IP protocol • Support Packet Broadcast Control Channel (PBCCH)

	• PAP protocol for PPP connect
SIM Interface	Support SIM card: 1.8V, 3V
External Antenna	Antenna Pad
Serial port and USB port	**Serial port**: • Default one Full modem serial port • Can be used for AT commands or data stream • Support RTS/CTS hardware handshake and software ON/OFF flow control • Multiplex ability according to GSM 07.10 Multiplexer Protocol **USB port:** • Can be used for debugging and upgrading firmware
Physical Characteristics	• Size:17.6*15.7*2.3mm • Weight:1.5g

Table 3 UNV-SIM868 specifications [7]

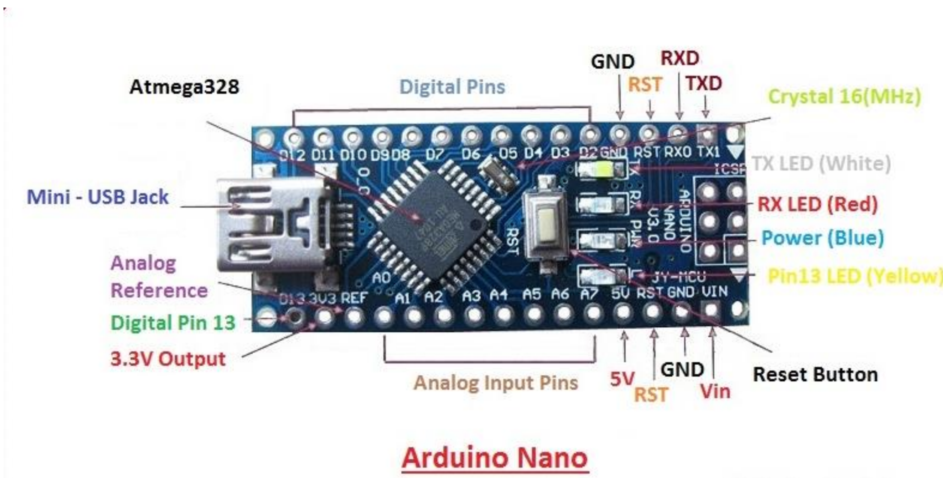

Figure 6 Arduino Nano board

Microcontroller	ATmega328
Operating Voltage	5V
Flash Memory	32 KB of which 2 KB used by bootloader
SRAM	2KB
Clock Speed	16MHz
Analog IN Pins	8
DC Current per I/O Pins	40 mA (I/O Pins)
Input Voltage	7-12 V
Digital I/O Pins	22 (6 of which are PWM)
PWM Output	6
Power Consumption	19 mA
PCB Size	18 x 45 mm
Weight	7 g

Table 4 Arduino Nano specifications [8]

3.1.1 GPS Tracker Battery

Figure 7 16430 Lithium-Ion Battery with 3.7V and 1200mAh [9]

The battery we will be using to test our proof of concept will be 16430 single-cell Lithium-Ion (Li-Ion) battery with 3.7V and 1200mAH as shown in Figure 7 16430 Lithium-Ion Battery with 3.7V and 1200mAh. The summary of the specification of the battery is in Table 5 GPS Tracker Battery Specification . The reason why we use this battery is that the operating voltage of UNV-SIM868 is between 3.4 to 4.4V and the power supply must be able to provide enough current up to 1.2A. Another reason is that Ni-Cd and Ni-MH's maximum voltage can rise over the absolute maximum voltage of UNV-SIM868 and damage it. Li-Ion battery will not cause this problem and can be connected to UNV-SIM868 directly. Moreover, the diameter and height of this battery are 1.6cm and 3.4cm. The size of the battery is also tiny which are very similar to UNV-SIM868. The final decision for our battery will be based on the result of the proof-of-concept prototype.

Rated Capacity	1200mAh
Nominal Voltage	3.7V
Max Charge Current	1200mA
Normal Charge Current	500mA
Dimension (diameter * height)	16mm * 34mm

Table 5 GPS Tracker Battery Specification [9]

3.2 Bike Lock

Identifier	*Design Requirement Description*
Des 3.2.1-C	Bike lock battery charging time from 0% to 100% will not exceed 3 hours [**Satisfies Requirement 6.1.9**]
Des 3.2.2-C	Battery of bike lock will have the same voltage as the microcontroller input voltage [**Satisfies Requirement 6.1.10**]
Des 3.2.3-P	Bike lock will use built-in lithium-ion battery [**Satisfies Requirement 6.1.1**]
Des 3.2.4-P	Bike lock will charge via USB battery charging [**Satisfies Requirement 6.1.2**]
Des 3.2.5-P	Bike Lock will have a low power mode when it is unlocked [**Satisfies Requirement 6.1.5**]
Des 3.2.6-P	Bike Lock will have a high-power mode when it is locked [**Satisfies Requirement 6.1.6**]
Des 3.2.7-P	Bike lock battery will be able to last at least 24 hours while locked [**Satisfies Requirement 6.1.8**]
Des 3.2.8-F	Bike lock will notify the Software when the battery is low [**Satisfies Requirement 6.1.3**]
Des 3.2.9-F	The connector of lithium battery will allow for easy user replacement [**Satisfies Requirement 6.1.7**]
Des 3.2.10-C	The electrical components of the Bike Lock will not pose fire or explosive risk under normal usage conditions [**Satisfies Requirement 9.1.3**]

Table 6 Bike lock electrical design requirements

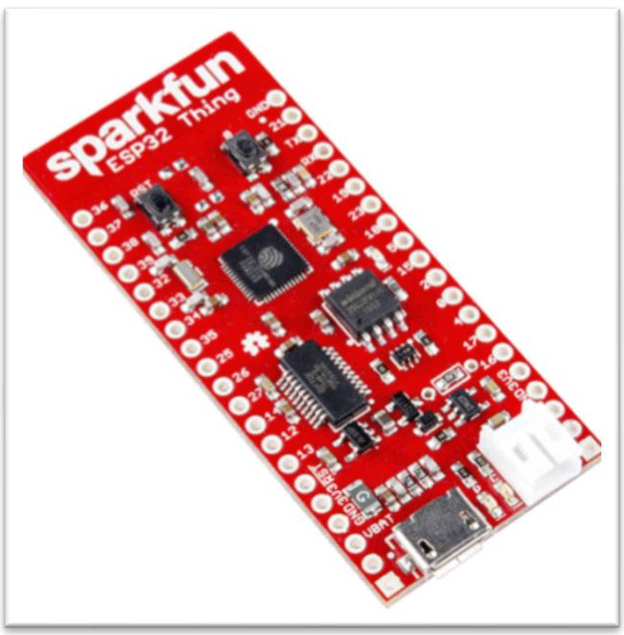

Figure 8 SparkFun ESP32 Thing [10]

When we are deciding on which development board to use for our bike lock, the consideration on the size and the functionality of the module are our top priority. We need a board to be as small as possible, provide Bluetooth Low Energy (BLE) and battery charger functionality. Moreover, if the board is programmable with Arduino IDE that will be a bonus. The SparkFun ESP32 Thing (Figure 8 SparkFun ESP32 Thing) has both Wi-Fi, Bluetooth Low Energy (BLE), battery charging capability, and programmable with Arduino IDE. The size of the board is about 3cm by 6 cm, which is small enough to fit into a bike lock. Table 7 SparkFun ESP32 Thing Specification is a summary of the specification of the SparkFun ESP32. We will be using the SparkFun ESP32 during our design process from proof-of-concept to final product.

The board will be used to detect open circuit (open lock) and uses Bluetooth to transmit the message to the GPS module to inform the open lock. We will be using the GPIO ports to detect open circuit. The final decision on what port number we will be using depended on the port location that will suit our machinal constraints. Figure 9 SparkFun ESP32 Thing Schematic is the schematic diagram of SparkFun ESP32 Thing and Figure 10 SparkFun ESP32 Thing Port Diagram is the overview of the functionality of each pin.

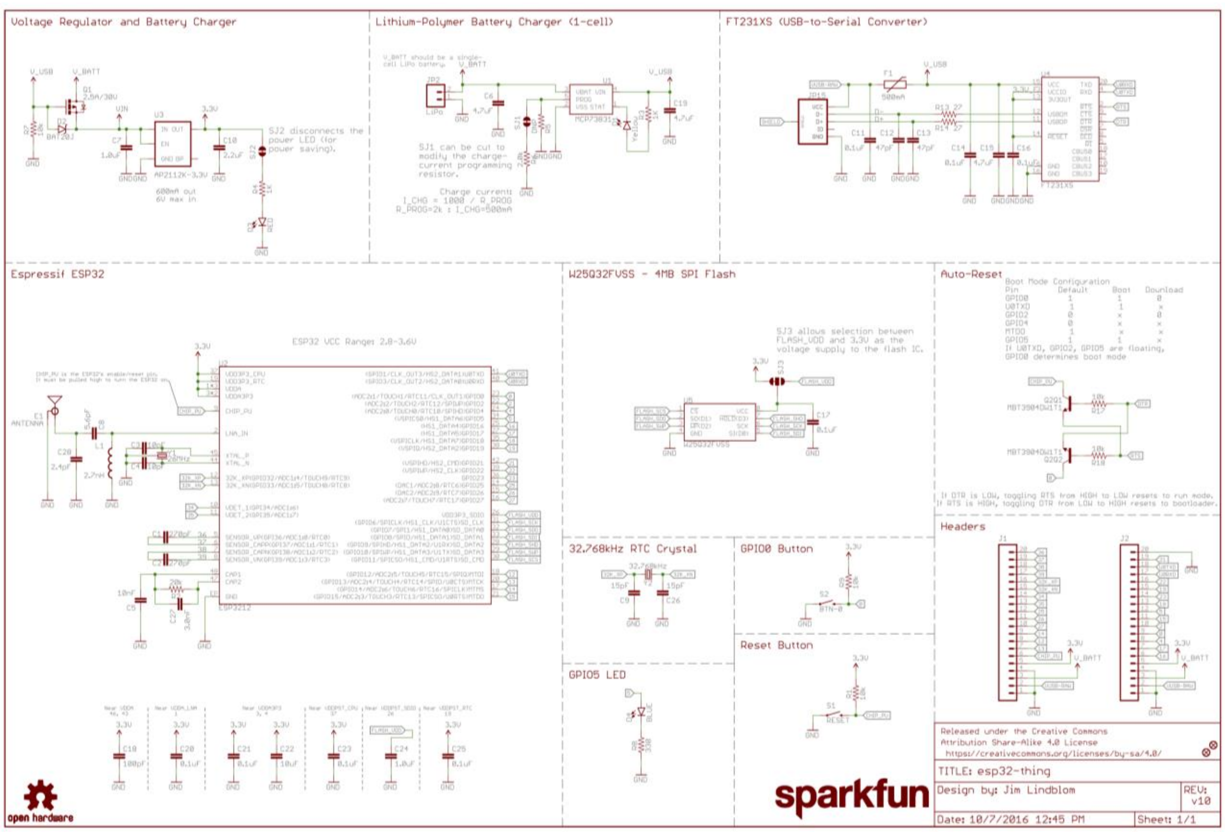

Figure 9 SparkFun ESP32 Thing Schematic [10]

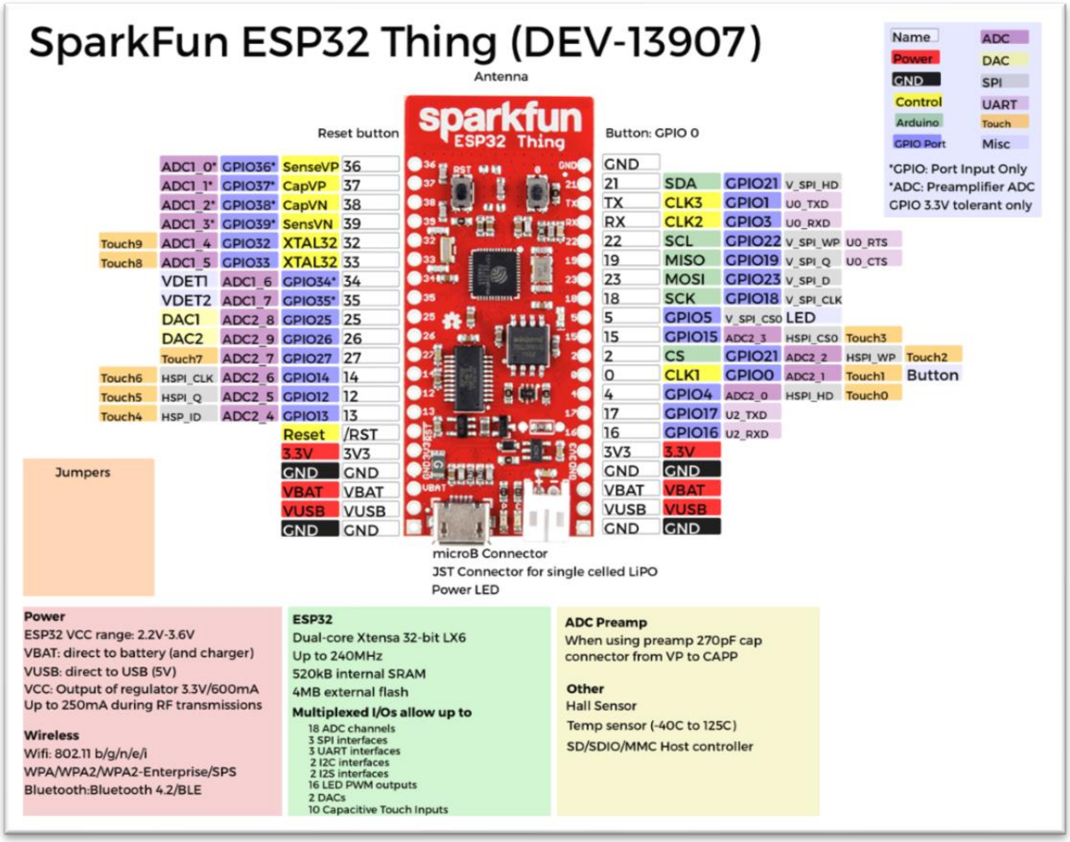

Figure 10 SparkFun ESP32 Thing Port Diagram [10]

Microcontroller	ESP32
Microprocessor	Dual-core Tensilica LX6
Operating range	2.2 to 3.6V
VCC	Output regulator 3.3V/600mA
Sleep Current	2.5 µA
Flash memory	4MB
Internal SRAM	520kB
Clock frequency	Up to 240MHz
Number of GPIO	28
PWM outputs	16
analog-to-digital converter (ADC) channels	18
SPI interfaces	3
UART interfaces	3
I2C interfaces	2
digital-to-analog converters (DAC)	2
I2S interfaces	2
Dimension (W x L)	25.4 mm x 58.9mm

Table 7 SparkFun ESP32 Thing Specification [10]

3.2.1 Bike Lock Battery

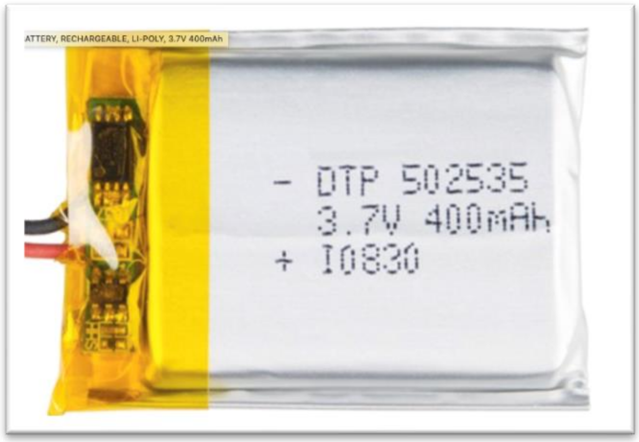

Figure 11 LiPo Battery [11]

The battery we will be using to test our proof-of-concept will be the single-cell lithium-polymer (LiPo) battery (Figure 11 LiPo Battery) with 3.7V and 400MAH. The summary of the specification of the battery is in Table 8 Battery Specification. We choose this battery for our proof-of-concept to demonstrate the charging capability of the SparkFun ESP32 Thing. Moreover, the dimension of the battery about the same size as the SparkFun ESP32 Thing, which we can show that all the electronics will fit into a small enclosure. The final decision for our battery will be based on the results of the proof-of-concept prototype. The prototype results will give us better information on the performance of the current battery and rather there is a need to make any changes.

Rated Capacity	400mAh
Nominal Voltage	3.70 V
Max Charge Current	1C (400mA)
Normal Charge Current	0.2C (80mA)
Dimension (W x L x H)	26.5mm x 36.9mm x 5mm

Table 8 Battery Specification [11]

4 Firmware Design

The firmware design section explains in detail how the firmware will be implemented on both the Bike Lock and GPS Tracker portion of the U-Loq. Both firmware designs must be capable of communicating with each other through Bluetooth but due to other requirements of each device, their design will vary greatly. This section, along with previous Hardware/Electrical section give a complete picture of the design of both GPS Tracker and the Bike Lock.

4.1 GPS Tracker

Identifier	*Design Requirement Description*
Des 4.1.1-P	GPS tracker firmware will activate and response to Bluetooth and cellular network messages from bike lock or user devices [**Satisfies Requirements 3.2.2**]
Des 4.1.2-P	GPS tracker firmware will change between low and high power modes [**Satisfies Requirements 5.1.5, 6.1.6**]
Des 4.1.3-C	GPS Tracker firmware will send notification of Bike Lock breaking to the user via GSM [**Satisfies Requirements 3.2.1, 3.3.1**]

Table 9 GPS tracker firmware design requirements

The GPS tracker is implemented base on a UNV-SIM868 GPS/GSM/BT board and an Arduino Nano controller. The GPS tracking system can be divided into three parts. Firstly, the baseboard UNV-SIM868 provides all sorts of useful functionalities required in this project like GPS and GSM tracking, SMS sending and receiving, cellular network communication, Bluetooth communication, and audio output. Secondly, it is the Arduino Nano controller. It is responsible for controlling the behavior of UNV-SIM868 and handling the data from UNV-SIM868 and the lock system. Due to the UNV-SIM868 not having microcontroller built-in, there needs to be a controller for it to function. Arduino Nano is known as small, low power consumption and easy to implement, it is suitable to use in the system.

The data flow is shown as the Figure 12 GPS tracking system data flow diagram below. All the data will be first received by the UNV-SIM868 and will be transmitted to Arduino. User command will be executed on Arduino or pass to UNV-SIM868 for execution. Lock interrupt will be handled by Arduino and it will activate the high-power mode on UNV-SIM868 to enable GPS/GSM module, receive GPS location then sent to the user. This implementation allows the user or the lock to request the GPS tracker to enable high power mode and to get GPS location information.

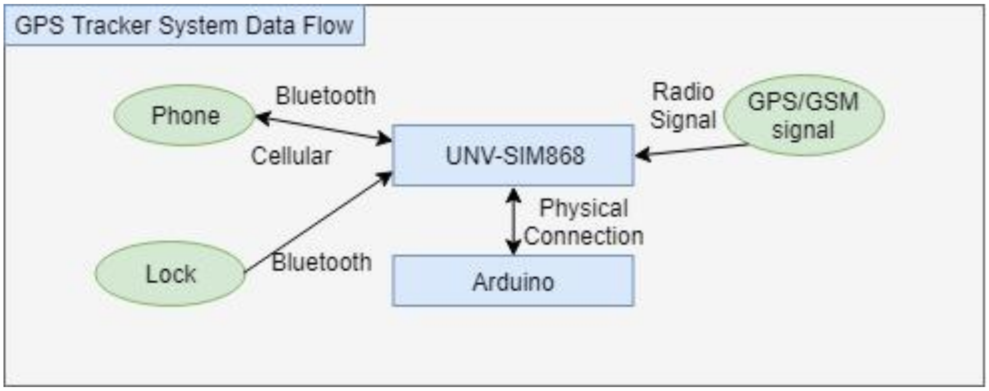

Figure 12 GPS tracking system data flow diagram

The state diagram Figure 13 GPS tracker state diagram indicated that in this system there will be three states.

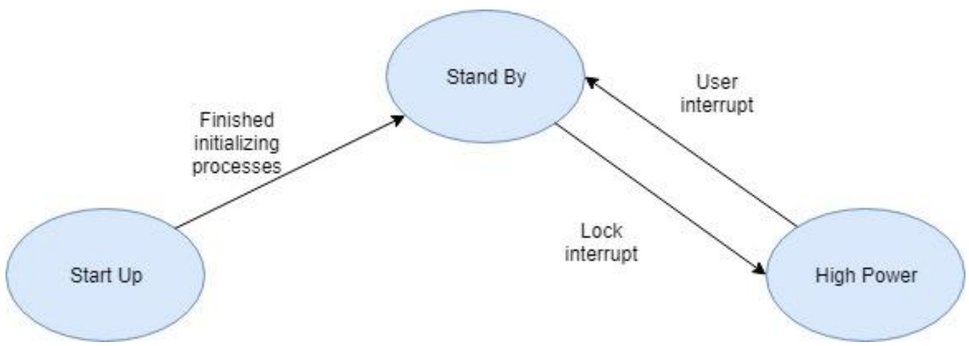

Figure 13 GPS tracker state diagram

State	**Description**
Start-up	Once the system is booted, it will enter the start-up state. In the start-up state, the system is working on initializing the modules. It will take approximately 2-5 seconds.
Stand By	Once the system is finished initializing, it will go to the stand by mode which will monitor all the data flow and interrupts. In stand by state, the GPS will be disabled for extending the battery life. However, the cellular and Bluetooth will still be enabled for receiving the signal from bike lock and user devices. The cellular remains enabled so the GPS Tracker can update the user with its status periodically so the App can notify a user if a thief disables the tracker.
High Power	Once there is lock interrupt, the system will enter high power mode and wake up the GPS module to continuously receive GPS data from satellite and send it to the user. Once the user sends interrupt signal to the system, it will go back to stand by mode.

Table 10 States of the GPS tracker

4.2 Bike Lock

Identifier	*Design Requirement Description*
Des 4.2.1-C	Bike Lock firmware will recognize when the lock has been cut [**Satisfies Requirement 3.1.1**]
Des 4.2.2-C	Bike Lock firmware will recognize when the bike lock is locked and unlocked [**Satisfies Requirement 3.1.3**]
Des 4.2.3-C	Bike Lock firmware will use Bluetooth to alert the GPS Tracker when it is broken [**Satisfies Requirement 3.3.1**]
Des 4.2.4-P	Bike Lock firmware will activate the alarm when the bike lock has been cut [**Satisfies Requirements 3.1.6 ,4.1.6**]
Des 4.2.5-P	Bike Lock firmware will receive and respond to Bluetooth messages from GPS Tracker [**Satisfies Requirements 5.1.9, 5.1.11, 5.1.13**]
Des 4.2.6-P	Bike Lock firmware will change between low and high power modes [**Satisfies Requirements 5.1.5, 6.1.6**]
Des 4.2.7-F	Bike Lock firmware will enable/disable alarm depending on user configuration [**Satisfies Requirements 3.1.7**]

Table 11 Bike lock firmware design specifications

The board used for the Bike Lock component of the U-Loq is a SparkFun ESP32 Thing as detailed in the Hardware/Electrical design above. This board comes with a couple of recommended ways to program it which are the Espressif IoT Development Framework (ESP-IDF) or the Arduino esp32 core (both written in C). The Arduino esp32 core is an abstraction on top of the ESP-IDF which simplifies the design and allows the use of Arduino libraries. The cost of this abstraction is a loss of some of the more in-depth development features but there is a method to bypass this and access the ESP-IDF directly. Due to this ability and the easier nature of Arduino design, the Arduino esp32 core is used for the Bike Lock firmware instead of ESP-IDF directly. [12]

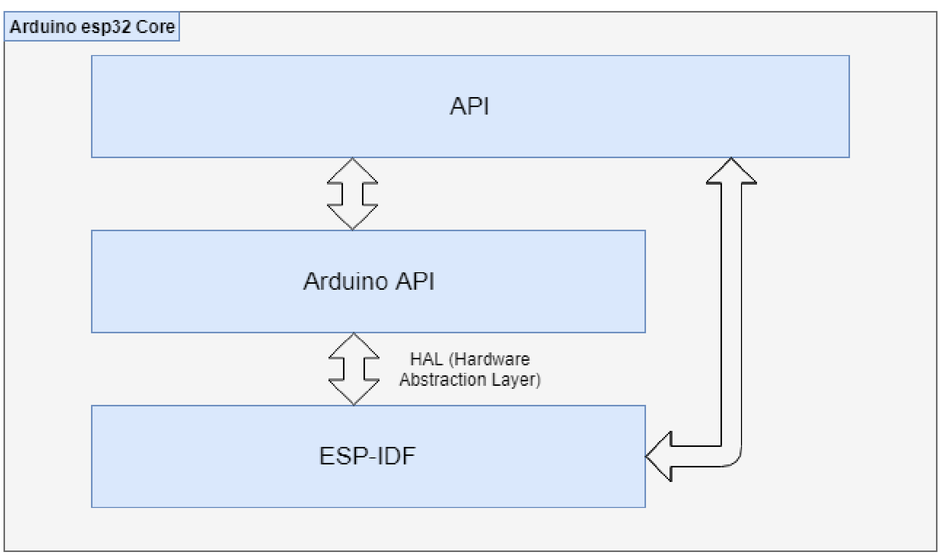

Figure 14 Arduino esp32 Core API

The Hardware Abstraction Layer (HAL) is the main programming interface between the Arduino API and the ESP-IDF. Since the ESP-IDF is the default development firmware for the ESP32 boards most of the functionality of the Arduino esp32 core comes from this firmware. ESP-IDF is consists of several different API's (Application Programming Interface) and packages that allow for a high degree of customizability depending on the application. [13]

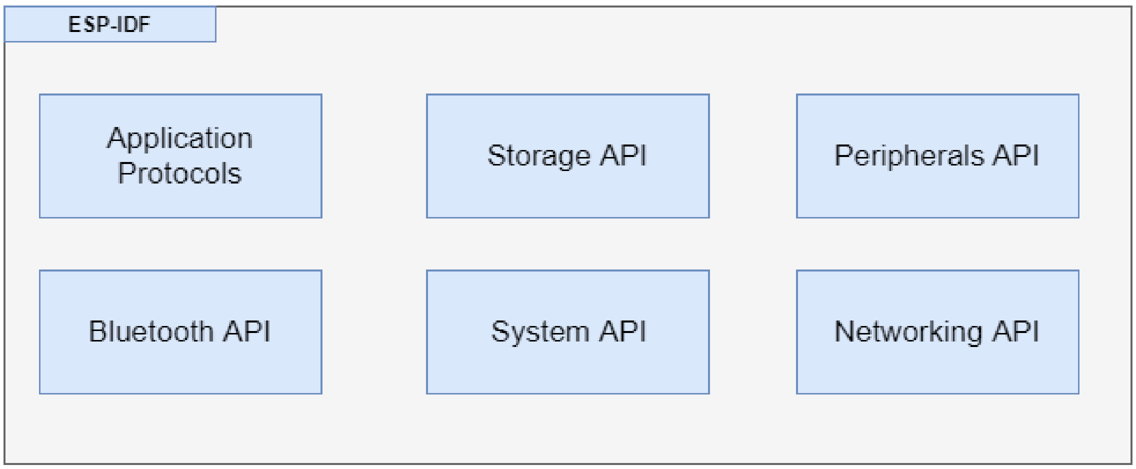

Figure 15 ESP-IDF API collection

The different APIs are all extensively documented which allows for easier problem troubleshooting and better implementations. Any additional development capabilities not supported in the Arduino esp32 are available through these APIs. This also makes understanding any lower level features of the board easier and clearer.

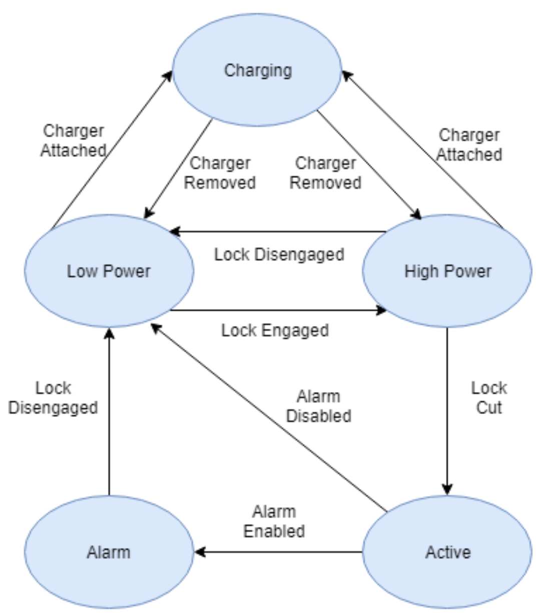

Figure 16 Bike Lock Firmware State Diagram

The Bike Lock's firmware execution follows the state diagram in Figure 16 Bike Lock Firmware State Diagram. A state model is chosen due to the multiple power modes and the necessity to only have some of the device's functions available at any given time. The following Table 12 States of bike lock system will give a description of all the states and their functions:

State	Description
Low Power	This state is essentially the sleep state for the Bike Lock. The device remains in this state when not locked and will not be accessible to the GPS Tracker via Bluetooth.
High Power	This state is for when the Bike Lock is locked. Here the device can detect if the loop has been cut and is in communication with the GPS Tracker via Bluetooth. This state will also send a still alive message to the GPS Tracker every three seconds which will allow the GPS Tracker to activate even if the Bike Lock circuit is destroyed. This is the devices main operation state and as such the power consumption is kept minimal to increase battery life.
Active	The Bike Lock enters this state when it has been cut. The goal of this state is to alert the GPS Tracker of the lock being cut quickly and with guaranteed message delivery. This state is kept separate from Alarm to ensure that the device's battery doesn't die before the GPS tracker is alerted.
Alarm	The Bike Lock enters this state after it has completed the task of the Active state if the user has the alarm enabled. In this state, the built-in alarm will be activated and continue until either the lock is disengaged or the battery dies.
Charging	This state if for when the battery is charging. The Bluetooth will be active in this state but due to it being unlikely that the GPS Tracker is in range the battery status will be indicated by an LED.

Table 12 States of bike lock system

5 Android Application Design

Identifier	Design Requirement Description
Des 5.1.1-P	Android Application will include a real time map view showing the location of the U-Loq tracker module **[Satisfies Requirement 5.1.1-P]**
Des 5.1.2-P	Android Application will receive system status, GPS, and battery level data from the tracker module **[Satisfies Requirement 5.1.2-P]**
Des 5.1.3-P	Android application will be available to all android devices supporting internet connection **[Satisfies Requirement 5.1.5-P]**
Des 5.1.4-F	Android application will use standard Android notifications to notify when battery level of either tracker module or bike lock is below 15% [**Satisfies Requirements 5.1.6-F, 5.1.7-F]**
Des 5.1.5-C	Android application will use standard Android notifications to notify user of bike lock failure **[Satisfies Requirement 5.1.8-C]**
Des 5.1.6-P	Android application will have a dedicated view showing current battery life and power mode of system **[Satisfies Requirements 5.1.9-F, 5.1.10-F, 5.1.11-P,5.1.12-P]**
Des 5.1.7-P	Android application will have a dedicated button to toggle alarm sound on/off **[Satisfies Requirement 5.1.13-P]**

Table 13 Android application design specifications

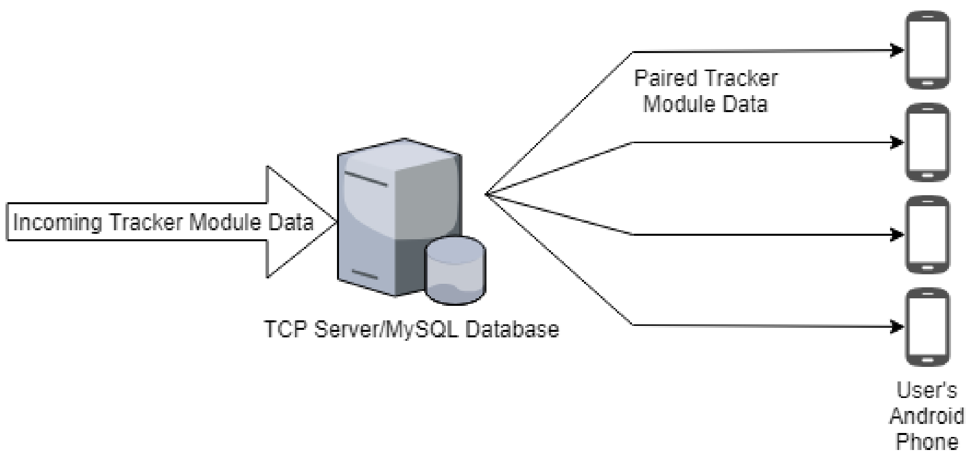

Figure 17 Application data flow diagram

The backend of our system is responsible for handling the incoming data received in real time from tracker modules. This consists of a server that will subscribe to said data via a TCP connection, which will then be placed in a database managed through MySQL. In the proof of concept stage of development, the TCP server and the accompanying location database will be located using an in-house solution - a Python-based system running on an engineer workstation. This solution, however, is not scalable, therefore during the final phase, the backend will be migrated to an Amazon Web Services Relational Database Service. Using an established system such as this will allow for the great scalability and reliability necessary for pushing forward a product for the masses.

The accompanying Android Application will be very lightweight, boasting only three simple core features. This is to increase usability and accessibility as much as possible for potential users. The three core features of the app correspond to the sets of data mentioned previously: overall system status, real-time GPS data, and battery level. Upon initial start-up of the application, the user will be able to see the status of their U-Loq immediately. As shown in Figure 18 Example software interface below, this view will sport as a status indicator in the middle of the screen, as well as the map icon, GPS toggle, alarm toggle, and battery icon along the bottom.

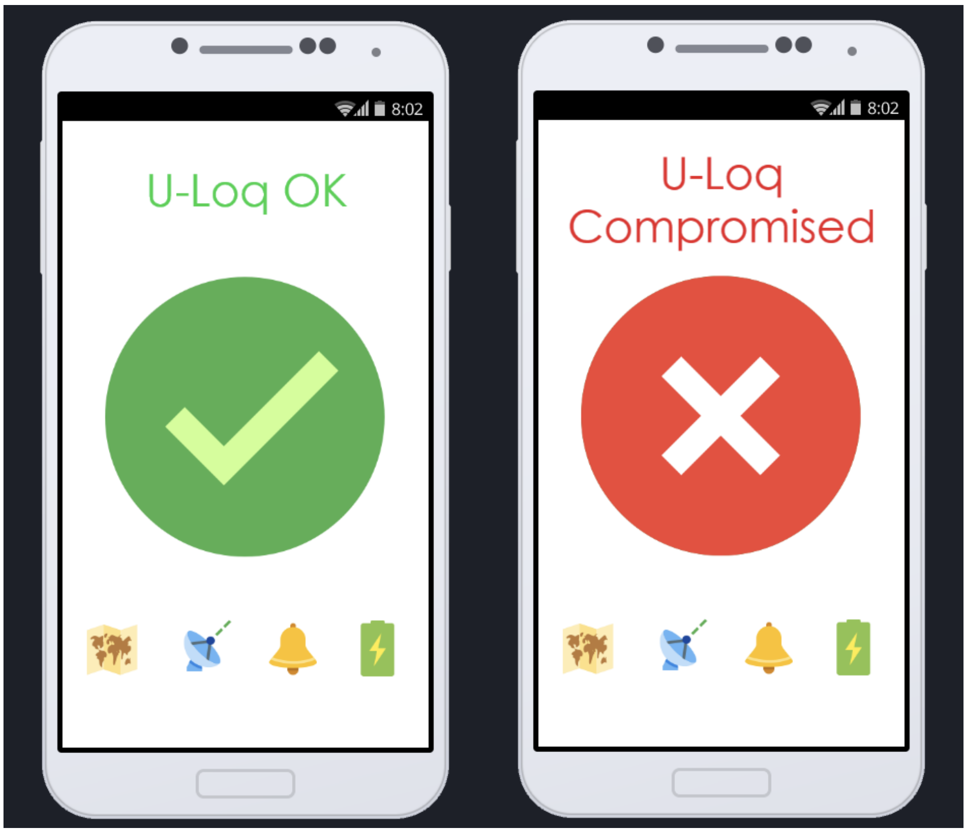

Figure 18 Example software interface

The middle system status indicator can be either a green or red circle. A green symbol indicates that the lock is working as intended. All modules are functional, and the lock has not been unlocked, forced open, or damaged in any way. The red on the other hand will be the general indicator that any one of those things has occurred. If this is the case, the firmware will send a signal which then triggers a notification on the user's phone, and GPS data will begin streaming in real-time to the application. The user may then tap the map icon to open the map view, which will be centered on the location of the U-Loq tracker module. Using Google Maps standard API, updating the location is possible every second.

It is worth noting the high power (GPS Enabled) mode is available regardless of lock failure. The user may simply tap the GPS toggle icon located on the start-up view at any time. However, using GPS-Enabled mode in this way is not recommended due to the U-Loq system's increased power requirements. The app will issue a warning to the user about the drawbacks of high-power mode and will prompt the user to either continue or cancel. This toggle exists as a fallback if the bike is stolen without the lock failure trigger occurring.

Tapping on the alarm toggle in the home view will do just that- toggle the alarm on the bike lock between mute and audible. To the right of this is the battery icon, which will open the battery level view when tapped. Displayed here is the current battery level of both the U-Loq tracker module and the bike lock itself. We can also see the system's power mode here (normal or high).

Overall, we believe the design choices outlined above allow for the accomplishment of the software requirements set out in the Requirements Specification document, doing so in a way that allows for a seamless and intuitive user experience.

6 Mechanical Design

Identifier	Design Requirement Description
Des 6.1.1-C	Bike Lock will have a simple locking function operable by a key [**Satisfies Requirement 3.1.2**]
Des 6.1.2-C	Bike Lock and GPS Tracker will have separate casings [**Satisfies Requirement 3.3.5**]
Des 6.1.3-P	Bike Lock will not be heavier than 4kg [**Satisfies Requirement 3.1.4**]
Des 6.1.4-P	U-Loq system will be hard to be disabled by force, I.E. the GPS Tracker is disguised [**Satisfies Requirement 3.3.3**]
Des 6.1.6-P	Bike Lock will have a USB charging port [**Satisfies Requirement 6.1.2**]
Des 6.1.7-F	GPS Tracker case will be water resistant [**Satisfies Requirement 7.1.5**]
Des 6.1.8-F	Bike Lock body will be water resistant [**Satisfies Requirement 7.1.6**]

Table 14 Mechanical design specifications

As our project objective, the U-Loq is assigned to achieve the highest standard of security. Take both security and systematic completeness into consideration, we decide to implement our U-Loq into two parts, U-lock and GPS tracker. These two parts are both embedded with integrated circuit block, power/operational indicator and USB port in the purpose of battery charging and firmware update/log extraction, and consistently transmitting data to user mobile device.

In this section, the mechanical design concept and graph are presented. The design approach of both parts is reviewed, and the concept diagrams are simulated and build in the SolidWorks platform. The final product may vary from this as future modification may apply.

In order to achieve a high level of system simplicity, completeness and security, two parts will be introduced.

6.1 Bike Lock

Our first part is a U-shape lock with integrated circuit block embedded. The lock chain, also refers to U part, will physically attaches to an object that is firmly fixed/installed with ground, such as pillar, metal fence or bike station, together with either crossbar of the bike or bike wheel. This will make sure the bike cannot be rolled away from its intended position by theft.

Our first part is a U-shape lock with integrated circuit block embedded. The lock chain also refers to U part, will physically attach to an object that is firmly fixed/installed with the ground, such as pillar, metal fence or bike station, together with either crossbar of the bike or bike wheel. This will make sure the bike cannot be rolled away from its intended position by theft.

Detailed bike lock diagram and the functional block are presented:

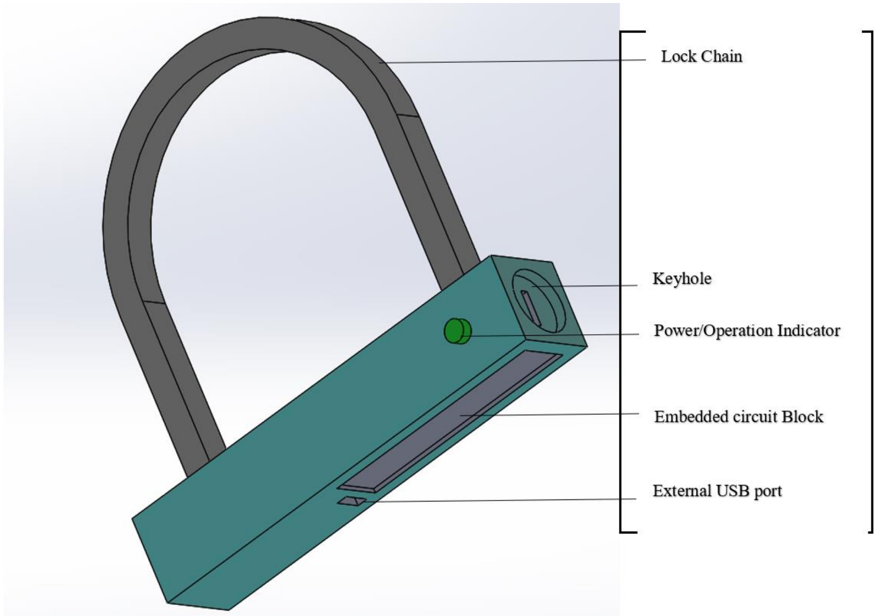

Figure 19 U-lock functional block and overview

This U-lock is equipped with an internal circuit block, combined with traditional lock, together with the USB charging port, and a power/operational indicator.

The desired size is shown as:

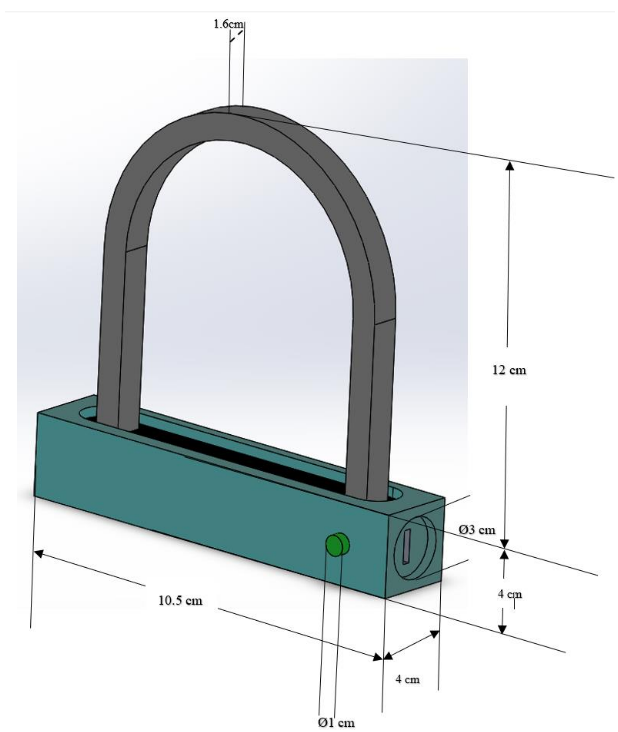

Figure 20 U-lock sizing and overview

Figure 21 U-lock top view

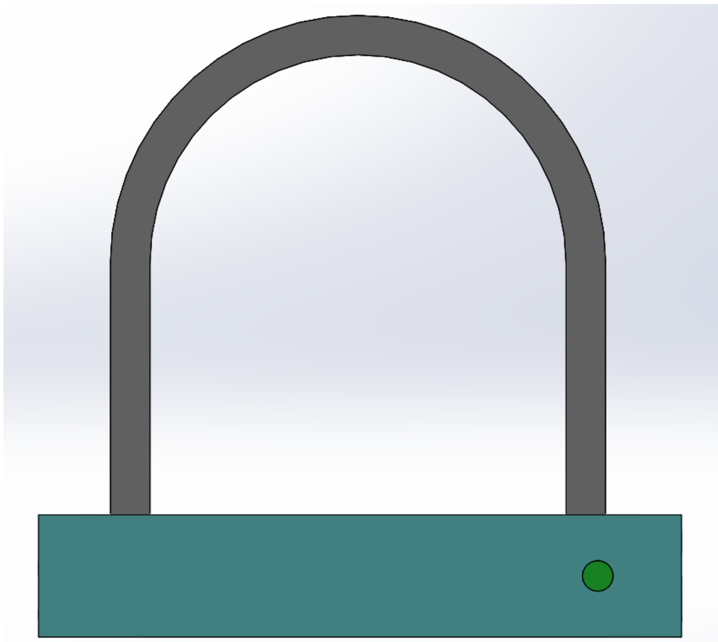

Figure 22 U-lock front view

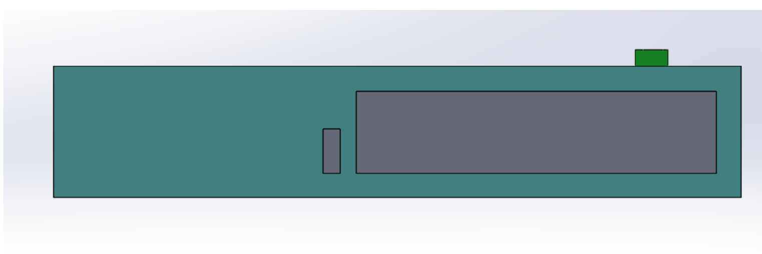

Figure 23 U-lock bottom view

As we want to reduce the cost as much as we can, as well as keep the lock portable and light, a relatively small U lock is designed. The circuit block will be in the right corner of the lock.

6.2 GPS Tracker

Our second part is a GPS tracking block that intended to be installed/fixed in the bottom of the bike seat. Insecurity purpose, we covered the tracker with a light reflector to avoid direct visualization from the public. To prevent potential physical damage, the tracker will be hidden so that bike theft cannot identify the circuit location.

Detailed GPS tracker diagram and the functional block are presented:

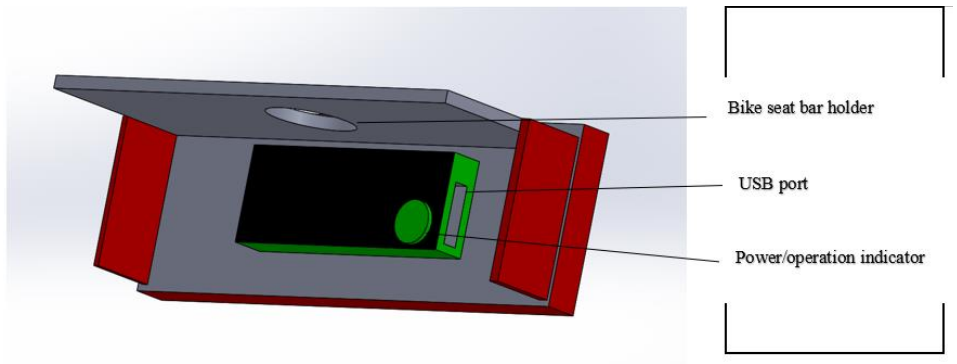

Figure 24 GPS tracker functional block

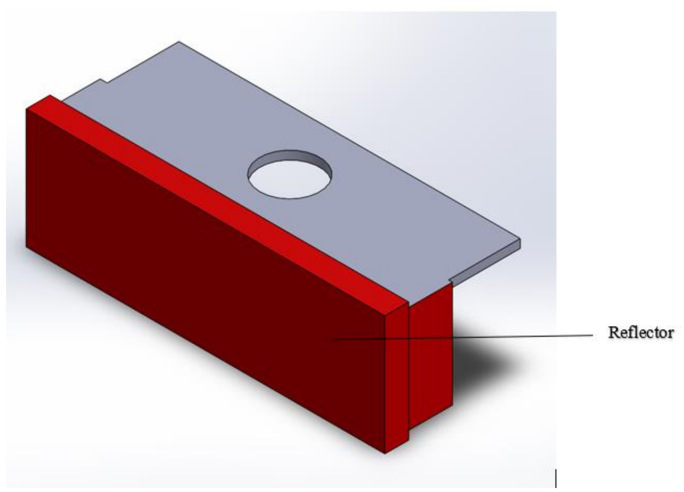

Figure 25 GPS tracker with reflector overview

The desired installation is shown:

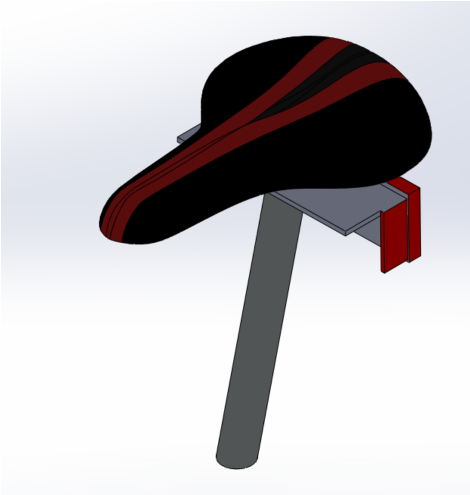

Figure 26 GPS tracker installation 1

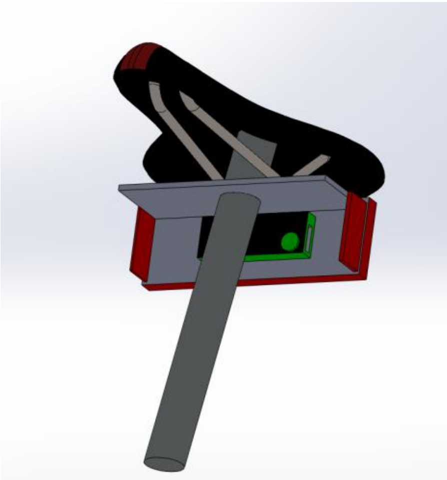

Figure 27 GPS tracker installation 2

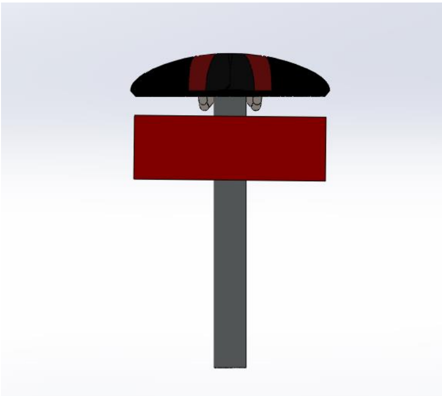

Figure 28 GPS tracker installation 3

This GPS tracker will responsible for data transmitting, GPS and GSM tracking, SMS sending and receiving, cellular network communication, Bluetooth communication, and audio output.

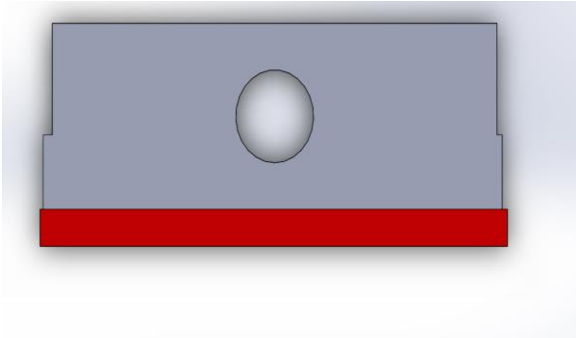

Figure 29 GPS tracker top view

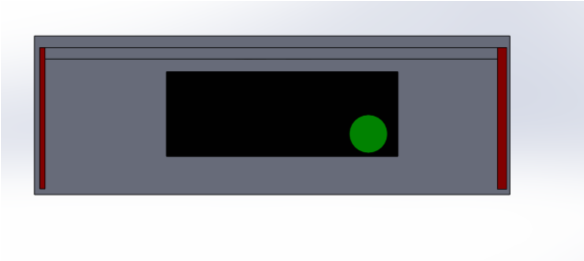

Figure 30 GPS tracker front view

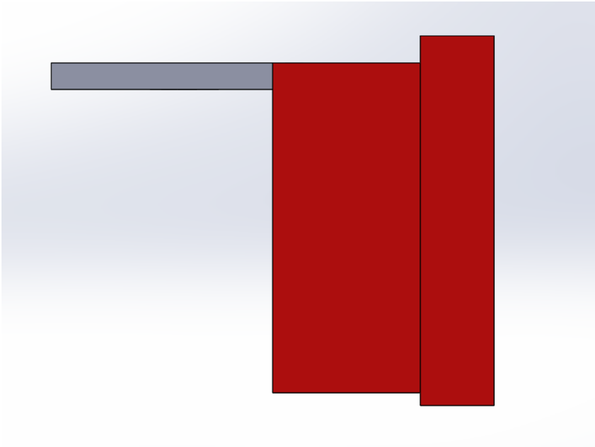

Figure 31 GPS tracker side view

The requirements for mechanical design should be fully fulfillment for our project objective and design concept, while the appearance (color, sizing) may subject to future modification and adjustment.

All simulations and solid modeling concept designs are based on the SolidWorks.

7 Conclusion

The U-Loq is designed as a tool to help all bike riders, many of whom have suffered from bike theft, fear bike thieves, and are dejected by the lack of effective means to retrieve their bikes. Further, U-Loq and its GPS tracking functionality can considerably decrease the incidence rate of bike theft in Vancouver and other cities in the world.

The U-Loq design is consist of four subsystems:

1. The Hardware/Electrical Design:

   a. GPS tracker: Has three functionalities that are Bluetooth Low Energy, GPS, and GSM module. Operates in low power mode when U-Loq is not broken and in high power mode when U-Loq is broken. We will use the combination of UNV-SIM868 and Arduino Nano for the design of GPS tracker.

   b. Bike Lock: Has the functionality of Bluetooth Low Energy. We will use ESP32 Thing to detect open circuit and use Bluetooth to transmit the message to the GPS tracker to inform that U-Loq is broken.

2. Firmware Design:

   a. GPS tracker: UNV-SIM868 provides functionalities like GPS and GSM tracking, cellular network communication, Bluetooth communication and audio output. Arduino Nano is responsible for controlling the behaviour of UNV-SIM868 and handling data from UNV-SIM868 and lock system.

   b. Bike Lock: Arduino esp32 core is used for the bike lock firmware. The bike lock's firmware execution follows the state diagram in Figure16. A state model is chosen due to the multiple power modes and the necessity to only have some of the device's functions available at any given time.

3. Android Application Design:

   The three core features of the app correspond to U-Loq overall system status, real-time GPS data and the battery level. The example software interface is shown in figure 18 which is made up of a status indicator in the middle of the screen, map icon, GPS toggle, and battery icon.

4. Mechanical Design:

   a. GPS tracker: GPS tracker will be installed at the bottom of the bike seat and covered by a reflector to avoid direct visualization from the public.

   b. Bike Lock: The U-Loq is equipped with an internal circuit block, traditional lock, USB charging port, and a power indicator.

This design specification will serve as a reference document for UniLoq as the team starts developing the prototype for the U-Loq in the coming months. The design specification will also serve as a guideline but may change throughout the development cycle for the prototype device.

8 List of References

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9 Appendix A: Test Plan

The tables below are the list of test plan that we will be using to test our design along the way through final product to ensure we are on track. The test plan is split into software, electrical, mechanical, functional, and user sections.

Software		
Test Case	***Pass/Fail***	***Comments***
1. Up to date GPS data is displayed in some manner when a bike lock is broken		
2. Notification alert system is functional		
3. Notification alert system is functional when is bike lock is broken		
4. Bike Lock power control system is functional		
5. GPS Tracker power control system is functional		

Table 15 Software test plan

Electrical		
Test Case	***Pass/Fail***	***Comments***
General Circuit		
1. Circuit are operational at temperature range -30 to 50 degree Celsius.		
2. The electrical components pose no risk of fire or explosion under any use conditions		
3.GPS module is in low power mode when the bike lock is not cut, vice versa.		
Battery		
1. Input Voltage from the lithium-ion Battery		
2. Has same voltage between battery and microcontroller input		

3. Charging time of the bike battery is appropriate for its power output		

Table 16 Electrical test plan

Mechanical		
Test Case	***Pass/Fail***	***Comments***
1. Lock mechanism is functional		
2. Keys does not stick in the lock		
3. Bike lock and GPS module casing is water/dust resistant		

Table 17 Mechanical test plan

Functional		
Test Case	***Pass/Fail***	***Comments***
General		
1. Bike lock recognizes the disconnection of the lock		
2. Bike lock recognizes the connection of the lock		
3. The lock cannot be open without a key		
GPS System		
1. GPS system is enabled when the lock is opened		
2. GPS connects to cellular communication when the lock is opened		
3. GSM module able to send data via the cellular network		
4. GSM module able to receive data via the cellular network		

Table 18 Functional test plan

User		
Test Case	***Pass/Fail***	***Comments***
1. User can operate the lock and the mobile App with no supervision		

2. User receive notification on mobile APP when the lock is opened		
3. User can lock and unlock the lock easily		
4. User can charge the bike lock and the GPS module		

Table 19 User test plan

10 Appendix B: UI and Appearance Design

10.1 Introduction

This purpose of the following appendix is to express in detail the User Interface (UI) design of the U-Loq and its associated components. The design consists of a user analysis, a technical analysis, an analysis of relevant engineering standards and analytic/empirical usability testing sections. The technical analysis will consider the "Seven Elements of UI Interaction" consist of discoverability, feedback, conceptual models, affordances, signifiers, mappings, constraints [1].

The U-Loq is a combination of several hardware and software components and as such will have different philosophies for each component. The GPS Tracker has minimal user interaction and therefore its design focuses primarily on keeping a sleek form factor to be as inconspicuous as possible. The Bike Lock however is most often interacted with by the user and as such the main goal of its design is to make it function as much like a standard bike lock as possible. The Android App follows a minimalist design concept where simple and easy user interactions are valued over more features.

UniLoq has a strong and consistent vision for the U-Loq's design. The goal is to make a smart bike lock that anyone can use and pick up quickly. This appendix analyzes both the users and their interactions with the U-Loq in order to achieve that goal.

10.2 User Analysis

UniLoq's main goal for the U-Loq is a simple system that requires minimal instruction to use. A big factor when analyzing users for the technology is always age because it says a lot about the technologies and UI that people are likely used to. The main users of the U-Loq are of course bicycle owners and according to the 2016 *Walking + Cycling in Vancouver Report Card*, "Cycling is most common for the 18-24 and 45-64 groups and less common for those over 65" [2]. This indicates a somewhat divided age group in their technological experience which presents some challenges in design.

The way to get around these challenges is to assume some common knowledge and experience between age groups. The first and safest being that they have some familiarity with bike locks and how to lock their bikes securely. The second assumption is of course that the user has a smartphone and is familiar with standard UI elements. The user also has to know how to charge a device and replace a battery.

The difference in user experience between the U-Loq and other bike locks will be kept to a minimum as much as possible. The main differences will come in the initial installation of the GPS Tracker, battery monitoring of the devices and of course the use of the application if their bike is stolen. All of this offers design challenges that this appendix addresses in detail.

10.3 Technical Analysis

This section will analyze U-Loq's user interface using the "Seven Elements of UI Interaction" which includes the following design factors: discoverability, feedback, conceptual models, affordances, signifiers, mappings, and constraints [1].

10.3.1 Discoverability

Discoverability means how easily a user can find all user interface elements when they see the product for the first time and understand how they can use those switches, buttons, ports and other elements. UniLoq's user interface is designed with minimalism in the concept where simple user interactions are valued way more over than features. UniLoq will strive to provide an easy and clean user interface with only the essentials such as lock hole, USB port, power indicator of the battery. These buttons are placed on the bike lock based on common bike lock design so that the user can use U-Loq intuitively.

Figure 32 U-lock overview shows the outside case of U-Loq. There has a lock hole on the side of U-Loq which made very similar to a standard bike lock. The USB port and integrated embedded circuit block are on the bottom of U-Loq. The user can charge the lithium polymer battery inside the circuit block through this USB port. There also has a power indicator of battery in front of U-Loq so that the user can easily notice that when they need to charge the battery.

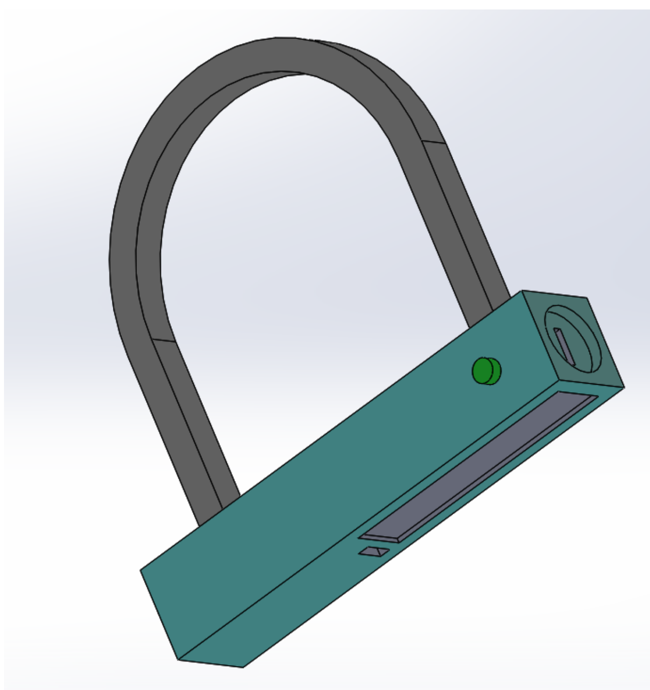

Figure 32 U-lock overview

10.3.2 Feedback

The primary source of feedback will be provided to users by our app design on the smartphone. The first feedback is a warning notification when U-Loq is getting cut, and bike theft happens. The second feedback is a real-time location of the bike which is transferred from GPS tracker. Users can try to catch the bike thief with the help of this feedback. The last one is a power indicator on U-Loq shows the user when they need to charge the battery inside the U-Loq.

10.3.3 Conceptual Models

The design of a product should provide all the information needed for users so that they can understand how to use the product's functionalities and features intuitively and then build a conceptual model.

With the help of electronic devices uses experience such as smartphones, users can build a conceptual model of our product easier. Moreover, the similarity between U-Loq and normal bike lock can also help users build the conceptual model. Users don't need to care about the power mode of our product at all.

10.3.4 Affordances

Affordances are a product's properties that show the possible actions users can take with it. UniLoq affords the user information on the smartphone app based on the cutting situation of U-Loq and the real-time position of the stolen bike. Moreover, Don Norman also mentioned about perceived affordance which implies that an object's affordance also depends on users' goal and past experiences [3]. Since our user interface is designed with minimalism in concept, the user's perceived affordance will be almost the same as the actual affordance.

10.3.5 Signifiers

Signifiers are meant to hint at the products affordances and help the user understand how to use the products main UI elements. A main signifier on the Bike Lock is the power indicator that notifies the user of battery state and if the Bike Lock needs to be charged.

Signifiers on the App include several pop-up messages and notifications. One message will be presented when the user manually activates the GPS Tracker that indicates the battery will drain much faster in this mode and another message will indicate when the GPS Tracker's batteries need replacing. The App also uses common UI elements to Android applications to ensure the user knows what they mean. These signifiers ensure the user knows when they need to take action and what the consequences of these actions will be.

10.3.6 Mapping

The mapping indicates the position of control elements relative to the object they control. The locking mechanism on the Bike Lock is located on the side right next to where the U shape disconnects from the top of the bike which indicates the relationship. Another design element on the Bike Lock is putting the power indicator in a clearly visible position to the charging port, so the user knows immediately that the charging process is activated.

On the Android App, the manual activation of the GPS Tracker is kept right next to the map indicating the function of activating it. The principal design element is making the map the front and center UI element when opening the Android App to show the main functionality of U-Loq system. These mappings make the simple UI easy to navigate and easy to understand the consequences of the actions a user may take.

10.3.7 Constraints

Constraints or Restrictions are used to stop the user from interacting with UI elements in an undesirable way. A chief constraint Lock is that the Bike Lock can't enter a mode where it thinks it has been cut unless the bar is secure, and the lock is engaged which is essential in preventing false positive of the lock being cut. The GPS Tracker has the constraint of only being installed in one orientation and under the seat to ensure that it has the best signal reception and transmission possible.

The UI elements in the Android App are limited purposefully to ensure that the user cannot change the primary elements of the U-Loq. These limitations in the main user interface are the best tool for UniLoq to impose constraints. These restrictions ensure that the system always works as expected and stops users from creating a situation where the U-Loq's integrity is compromised.

10.4 Engineering Standards

The following tables are the list of engineering standards that will be kept. Since the U-Loq system will require electronics, mechanical, and wireless communication system, it is imperative to follow engineering standards to ensure the safety and the reliability of this product. Moreover, one of the core philosophies of the team is to make a product that has the least negative impact on the environment as possible and thus environmental standards have also been included to ensure these goals are met.

10.4.1 Electrical

Standard	*Description*
IEC TR 62513:2008	Safety of machinery - Guidelines for the use of communication systems in safety-related applications [4]
IEC 62061:2005	Safety of machinery - Functional safety of safety-related electrical, electronic and programmable electronic control systems [5]
IEC 61192-1:2003	Workmanship requirements for soldered electronic assemblies - Part 1: General [6]

Table 20 Electrical engineering standards

10.4.2 Mechanical

Standard	*Description*
ISO/TTA 5:2007	Code of practice for creep/fatigue testing of cracked components [7]

Table 21 Mechanical engineering standards

10.4.3 Wireless Communication Standards

Standard	*Description*
IEEE 802.15.1	Standard for wireless Bluetooth communication [8]
IEEE 802.21	Standard for GSM communication [9]

Table 22 Wireless communication engineering standards

10.4.4 Environmental Standards

Standard	*Description*
ISO 13475-1:1999	Acoustics -- Stationary audible warning devices used outdoors -- Part 1: Field measurements for determination of sound emission quantities [10]
ISO 15270:2008	Plastics -- Guidelines for the recovery and recycling of plastics waste [11]

Table 23 Environment engineering standards

10.5 Analytical Usability Testing

Our design philosophy behind this product is to provide security and smooth user experience to our consumers. With this in mind, we minimize the user interface and product set-up both on the mobile app and the bike lock to ensure smooth and relaxed user experience. The user should be able to use our product with minimal instructions. The mobile App will be a clean interface and only display information that is most important to the user, such as the status of the bike lock. The bike lock will be a minimalistic design, with keyhole and USB charging port.

Table 24 Analytical Usability Testing Criteria below is a list of criteria for analytical usability testing. Tester has the choice of giving the test of grade from 1, does not meet the standards, to 5, meet the criteria.

Test Case	***Grade (1-5)***	***Comments***
1. The mobile app is easy to navigate		
2. User can easily identify the location of their bike in the mobile app		
3. User easily notify when the lock is broken		
4. The battery status is easily understood by the user		
5. The bike lock can be easily turn on/off through the mobile app		
6. The instruction on the mobile app is easy to understand		
7. The bike can be easily lock and unlock with keys		
8. There are no sharp corners on the bike lock that poses harm to the user		
9. Charging can be performed with ease		

Table 24 Analytical Usability Testing Criteria

10.6 Empirical Usability Testing

Empirical Usability testing is incredibly important in reaching our design goals of having an intuitive and accessible final product. However, we recognize one of the shortcomings of our product is have to break it in order to test functionality. As such, our core functionality will be tested during the proof of concept stage of development. This is before the material choice is finalized and implemented, and so device breakage can be simulated much more easily. This testing will mostly be done by fellow engineers.

Most of the user testing will be done towards the end, with the near-final design. Our target audience is the general public, which calls for a diverse group of people. We will be testing our product over several iterations with different subsets of the general population, which will include avid bike riders, friends, and older family members. These tests will consist of a standard set of tasks in the theoretical standard use case and will use a combination of thinking out loud and logging user actions to determine usability. Mistakes and slips will be recorded to provide a quantitative study of the results.

Through both phases of empirical usability testing (PoC and Final Design), our hope is to discover two things. First, our PoC testing goal is to find what changes are necessary to make our design more intuitive. This is important to discover early to reduce design cost. Second, without final design testing, we look to see if we have reached our design goals completely. This allows for early planning on what to do in the next revision of the design in the event of continuation past the scope of this course.

10.7 Graphical Representation

The figures below are our graphical user interface concept representation.

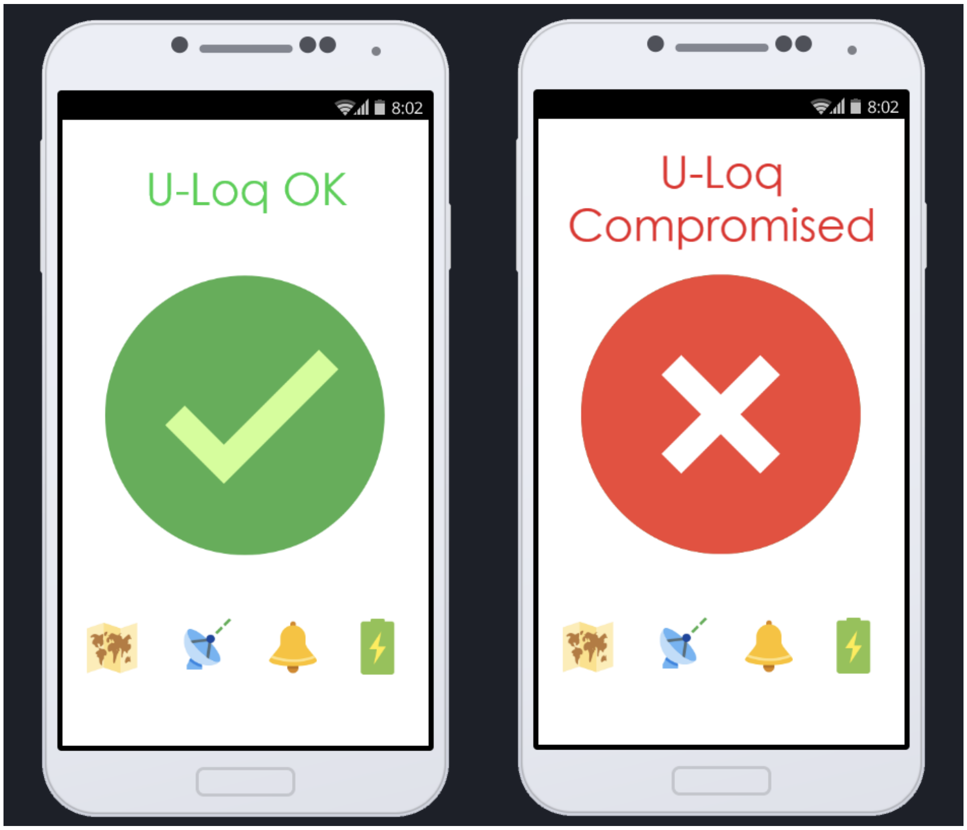

Figure 33 Example software interface

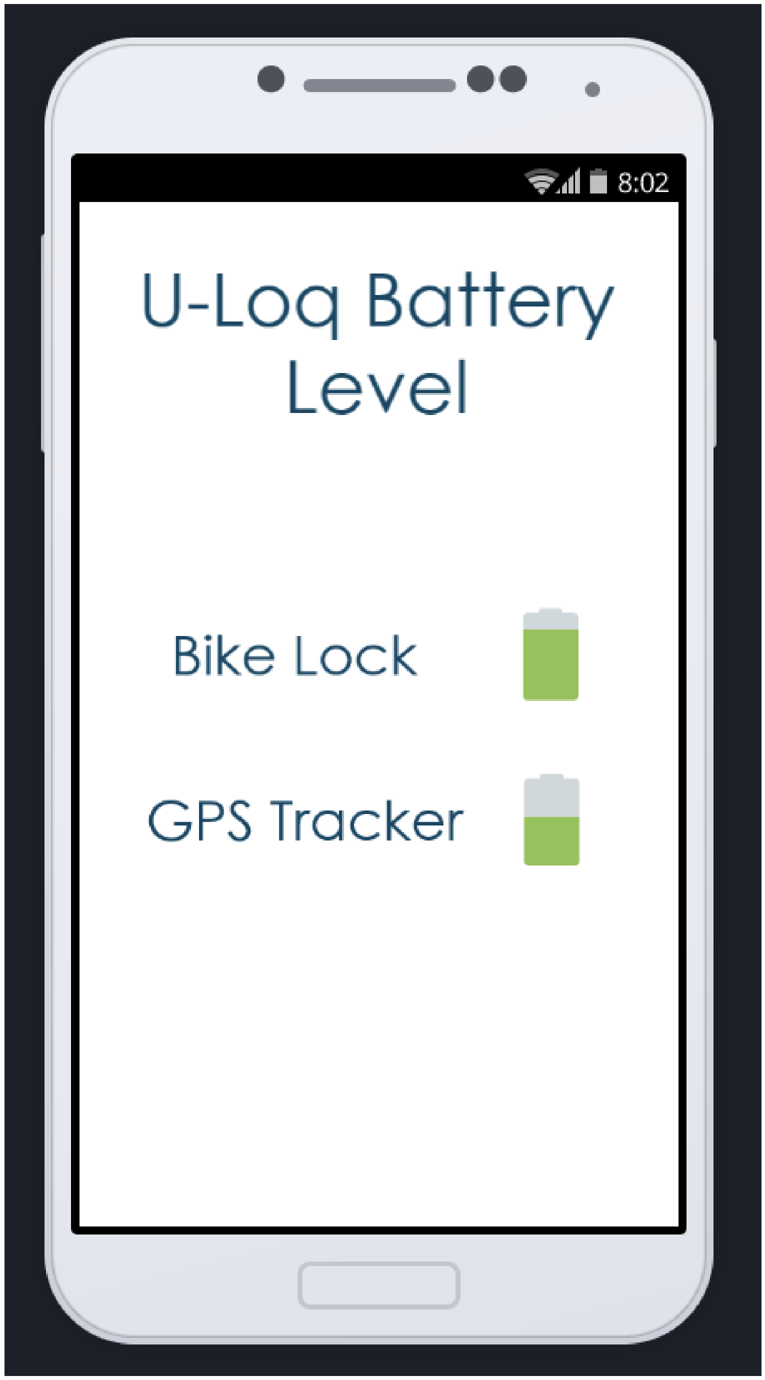

Figure 34 Example UI that indicates the battery level of the GPS tracker and bike lock

As the figure shown, the app can show the current bike location and update it periodically.

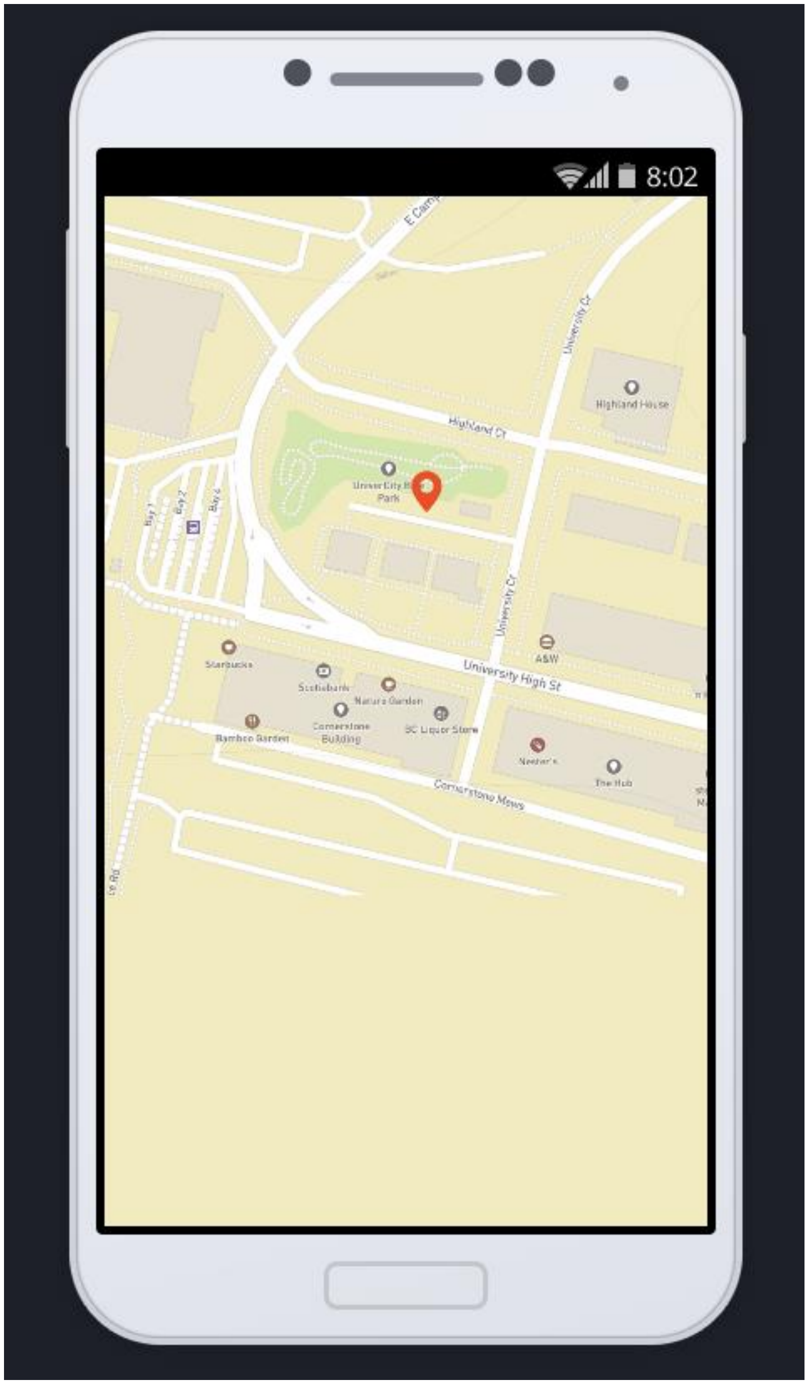

Figure 35 Example UI for locating the lost bike

10.7 Conclusion

The UI and appearance design, as with all consumer products, is one of the most critical components to the user. This appendix details in full how UniLoq is addressing this design to emphasize simplicity and familiarity for all users.

By first performing a user analysis the rest of the appendix is given direction from which to draw. Having a targeted audience such as cyclists allows UniLoq to analyze the users in greater detail as well as make safer assumptions about what prior knowledge users have. This knowledge is then considered and applied to the rest of the document to achieve a better UI and appearance design.

The technical analysis then breaks down the UI into discoverability, feedback, conceptual models, affordances, signifiers, mappings, constraints and analyzes how UniLoq addresses these. Through this analysis, the U-Loq is designed with a simple and user intuitive-mindset that values making the user experience as smooth and familiar as possible.

The engineering standards have created a list of coding standards that must be met for the U-Loq to be successful. These are important to ensure safety, sustainability, and usability with the U-Loq.

Usability testing is necessary for verifying and tracking exactly how the U-Loq performs as far as UI design. The analytical usability testing plan above details precisely the design philosophy UniLoq has and the key areas where user experience is most important with the U-Loq. Empirical usability testing allows UniLoq to make sure that the users are being addressed directly and biases are removed from judgment on usability. While a developer can easily avoid slips and mistakes subconsciously this plan ensures that they are not ignored.

Through this appendix and the above sections, UniLoq has ensured nothing important to UI and appearance design was missed. The U-Loq is a device that values simplicity and familiarity above all else and the design outlined in this appendix ensures that this is what is delivered.

10.8 References

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