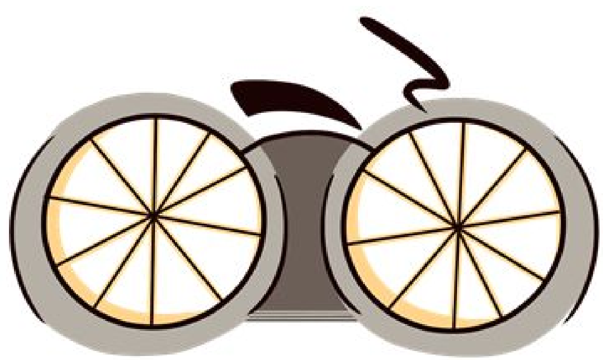
Product Proposal: Bike-Nocular



March 25, 2018
Mike Wazowski, Campus Security Supervisor
UC Santa Barbara
Santa Barbara, CA 93106

We are writing to inform you about our new product, the Bike-Nocular — a bicycle management and live traffic system. The Bike-Nocular is a bicycle attachment and an accompanying mobile device application that will allow owners to track their bike, reducing stolen or lost bikes and creating a crowdsourced bike traffic system for college campuses.

Biking is one of the most common methods of commuting for students amongst college campuses. However, many safety concerns — including collisions and bike thefts — remain unaddressed. Our product would alleviate these issues by promoting bike security and reducing traffic congestion on campus.

The Bike-Nocular hopes to be an affordable bicycle safety device for both university security and students. Enclosed is our proposal detailing the hardware and software components of the Bike-Nocular and how these features interact with each other.

Thank you for your time. Please let us know if you have any questions regarding our proposal.

Sincerely,

The Bike-Nocular Design Team

Executive Summary

Bike traffic and security — two major issues amongst college students — have been amplified by the growing student population on campuses. This leads to more tardiness, more accidents, and more dangerous situations for students biking on campus. We developed the Bike-Nocular to solve issues of bike path congestion and bike theft using WiFi and Bluetooth enabled trackers and GPS.

The issue of lost or stolen items is not new and, as such, there are many tracking devices on the market that can be used to mitigate the issue of bike security. However, since these trackers are marketed toward use by the general public, they are very limited in functionality and/or longevity. Current bike trackers can only locate bikes when parked, lost, or stolen; they cannot provide live traffic and are limited by a poor battery life. In addition, by marketing this product specifically toward college campuses, we can expand our feature set to implement crowdsourced bike traffic by utilizing existing campus resources, like WiFi, to run our product.

Bike-Nocular consists of a physical bicycle attachment accompanied with a mobile app that provides live bike traffic and safety features to users. The physical unit contains a Raspberry Pi Zero W Board, an Adafruit Ultimate Breakout GPS Breakout, an MPU 6050 accelerometer and gyroscope. Additionally the outer casing is equipped with an anti-tampering system to prevent thefts. The mobile application is connected to a large server that collects data from all users who have the Bike-Nocular attachment. The devices communicate with each other, providing the user with less congested bike routes.

To accurately analyze bike traffic, Bike-Nocular's mobile app collects data from all cyclists who have the Bike-Nocular attachment. Using the GPS, WiFi, and Bluetooth modules, the attachment will periodically ping its location to a server. Assuming that the majority of students will have the Bike-Nocular attachment, the app will have a sufficient database to accurately determine the density of traffic in bike paths.

The anti-tampering system consists of wire mesh sensors and UV ink. Wire mesh sensors measure the impact force on the system, allowing the device to determine when a person is trying to break the system. If the anti-tampering system is triggered, an alert is sent to the mobile app, and invisible UV ink is sprayed on the bike. Because the anti-tampering system is a one use system, the user can exchange their unit for a new one through campus security after the device is triggered.

Bike-Nocular uses lithium-ion batteries for their high energy density and long lifespan. To extend battery life, the accelerometer and gyroscope work together to determine whether the bike is active. If the bike is not in motion, the device will enter a power-saving mode. Bike-Nocular also features photovoltaic cells to charge the battery during the day, ensuring minimal maintenance. If the attachment needs emergency power, for example, to identify the owner of the bike, a USB Type-C port is included.

Various design options for the Bike-Nocular have been developed for different situations. One model, named Bike-Noculock, includes an integrated steel cable bike lock which will trigger the alarm system

when cut. Another model, designed for areas where solar would be an insufficient source of power, includes a pedal-powered generator to charge the batteries while biking.

The Bike-Nocular has been developed to keep environmental detriment to a minimum. Should the attachment be damaged, only the anti-tampering mesh would require replacement. The other components, such as the Raspberry Pi and the accelerometer, can be reused. Although ABS plastic, used in the attachment frame, produces pollutants when made, the plastic itself is easily recyclable. The batteries and photovoltaic cells also emit pollutants during production, but the long lifespan and the use of renewable energy outweighs the immediate impact on the environment over the long term.

Although Bike-Nocular is not designed to completely solve bike traffic or theft, Bike-Nocular aims to alleviate these issues through private and crowdsourced tracking. By funding the Bike-Nocular, commuters will be able to travel more efficiently and safely around college campuses.

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1. Introduction

In the past five years, the University of California, Santa Barbara (UCSB) saw an increase of 3130 students in fall enrollment, to a total of 25,057, with other UC campuses seeing similar increases [1]. As the student population expands, the number of bikes on many college campuses increases, and more bicycle related issues arise regarding traffic, student safety, and bicycle security. Bike-Nocular aims to alleviate these problems by utilizing crowdsourced data to monitor bike location and deter thefts.

1.1. Problem

Every day, over 20,000 bicyclists – students, faculty, and staff – commute on the University of California, Santa Barbara (UCSB) campus, leading to heavy bike traffic [2]. The inability to monitor traffic patterns on bike lanes prevents bicyclists from taking the optimal route to their destination. This congestion increases the risk of crashes, particularly before and after classes.

Another growing issue among university campuses is bike theft. According to a report by the UCSB Police Department in 2014, there are over 200 reported bike thefts each year on campus, equating to almost $60,000 in property loss [3]. UCSB's Community Service Organization (CSO) has attempted to mitigate the problem through bike registrations. However, bike theft continues to be the most commonly reported crime at UCSB.

1.2. Product

Bike-Nocular is a bicycle attachment and companion mobile application that targets the issues listed above - bicycle traffic and theft.

The primary functions of the Bike-Nocular device are

- Tracking bike location(s) using GPS, Bluetooth, and WiFi
- Monitoring live bike path traffic using crowdsourced data
- Deterring thefts with the Bike-Nocular's anti-tampering system

1.3. Current Market Offerings

There are limited alternative solutions to bike thefts on college campuses. Students at UCSB can register their bikes with CSO to establish ownership. This method reportedly increases the chances of recovering a lost or stolen registered bike to 33% [3]. However, this recovery rate could be improved.

Current bike tracking products exist primarily for consumers to locate their bikes when parked, lost, or stolen. Many of these products contain GPS modules and motion sensors to detect movement or location. However, the batteries in these products typically do not last longer than a few weeks. For example, the Sherlock bike tracker lasts two weeks, and generally must be charged with a cable, though some variations utilize photovoltaic cells [4].

Conversely, general use trackers may have long lasting batteries, but are still limited. The Tile reportedly lasts one year, but has a limited range due to the sole use of Bluetooth technology, which has a maximum range of 100 meters [5].

Bike-Nocular aims to combine the long range tracking and safety features of current market bike trackers, with the battery life of other tracking products and the traffic data integrated in applications such as Google Maps.

2. Product Design

The Bike-Nocular is a bicycle safety and traffic alert system that uses a bicycle attachment device that interacts with a mobile application. Bike-Nocular devices communicate with one another to crowdsource traffic data; the more Bike-Noculars present in a given area, the worse the congestion. This data is then sent to the app where it alerts users of traffic conditions. By working with campus security, bikes can be monitored so that they can be returned to owners if lost. The Bike-Nocular is composed of three main parts: the physical device, campus integration, and the companion mobile application.

2.1. Bike-Nocular Device

The physical Bike-Nocular Device is an attachment designed to provide additional safety features for the user. The device is a thin, rectangular box — with approximate dimensions 120x60x60 mm — that clamps onto any part of the bicycle frame. The inside of the device contains four major components: WiFi and Bluetooth communication chips, GPS and accelerometer sensors, anti-tampering mechanisms, and an internal battery. As the user travels with their bike, the internal components work together to collect and communicate the necessary tracking data to the mobile companion application.

Due to the complex nature of the battery system, the battery component of the Bike-Nocular is split into its own dedicated section.

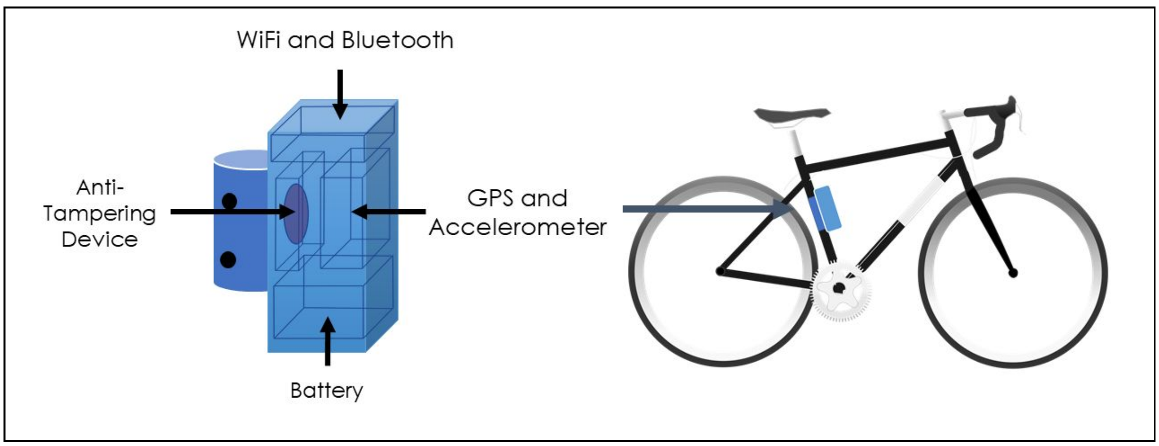


Figure 2-1 Preliminary design of Bike-Nocular product.

2.1.1. Bike Frame Attachment

The Bike-Nocular is attached via bike clamp that is tightened with proprietary screws strengthened with thread locker. These features are used to limit the number of individuals who can efficiently remove the bicycle attachment, allowing the device to work effectively as a bike tracker and a theft deterrent.

2.1.2. Bike-Nocular Enclosure

The ideal material for the Bike-Nocular enclosure would be lightweight, impact resistant, low cost, and easy to manufacture. Being lightweight would allow the Bike-Nocular to be less noticeable when biking. As for impact resistance, this property would ensure that the Bike-Nocular unit remains intact in the event of a collision. The low cost and manufacturability criteria makes it possible to pass the cost savings to the consumer, making people more likely to buy our product. Based on these conditions, we have decided plastics would be a viable solution.

After a comparison of types of plastics (ABS, PVC, HDPE, etc.) it was determined that ABS plastic was the most suitable material to create the main enclosure based on its high impact resistance and versatility in manufacturing. Although it has a greater cost, the end product is clean, rigid, and strong. While PVC was a close contender, its corrosive property when molded would hinder the manufacturing process and an overall less pleasant appearance.

2.1.3. Main Processing Unit - WiFi and Bluetooth

The Bike-Nocular attachment operates using the Raspberry Pi Zero W. This board was selected due to its small size, features, and affordability.

The Raspberry Pi Zero W is a small device, about the size of a credit card, that includes: [6]

- 1GHz CPU and 512MB RAM for low-level computing
- Bluetooth Low-Energy (BLE) and WiFi modules for connectivity to the Bike-Nocular companion app and server
- Pins to connect to other devices, like the GPS and Accelerometer units detailed below.
- Micro-USB port for easy charging of the device and all other components

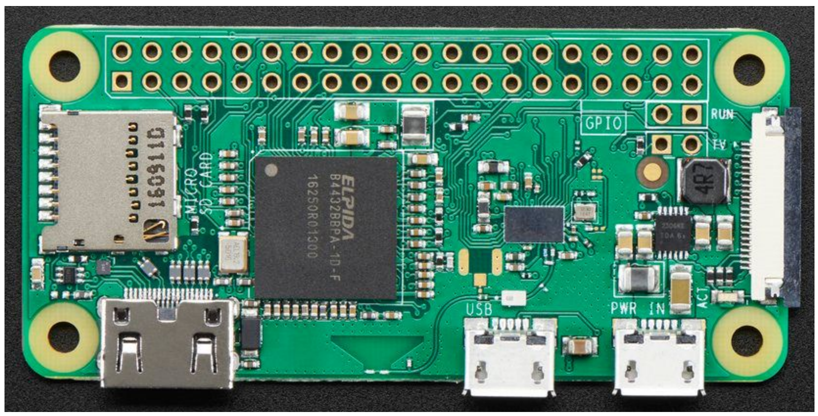


Figure 2-2 Raspberry Pi Zero W board with dimensions 66.0 mm x 30.5 mm x 5.0 mm [7].

The Raspberry Pi is also power-efficient, consuming only 120 mA when idling and up to 230 mA when performing CPU-intensive tasks [8]. The power consumption for the Bike-Nocular will be lower since the Bike-Nocular is set to power save mode by default and operates only when it detects movement or is pinged. Further testing will be done with a Raspberry Pi unit to determine power consumption.

2.1.4. GPS

Figure 2-3. Adafruit Ultimate GPS Breakout with dimensions 25.5 mm x 35 mm x 6.5 mm [9].

The GPS component of the Bike-Nocular is an Adafruit Ultimate GPS Breakout which utilizes an MT3339 GPS chipset. The GPS module is able to update location at a rate of 10 Hz, while only using 20 mA when in use [9]. This will help preserve battery life for our product

In addition, the GPS unit used has a position accuracy of ±3 meters, which makes this ideal for finding a bike's approximate location, even in large parking lots.

2.1.5. Accelerometer and Gyroscope

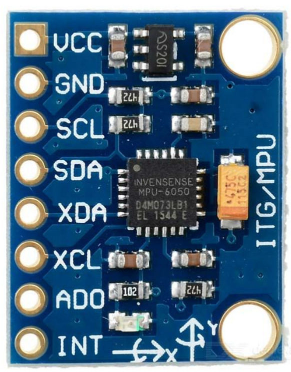


Figure 2-4 MPU 6050 with dimensions 25.5mm x 15.2mm x 2.48mm [10].

The MPU 6050 accelerometer and gyroscope determines whether the bike is in motion or not. Using this data, the Bike-Nocular can be energy efficient by only tracking when being ridden or pinged by the mobile app. The MPU 6050 uses 3.8 mA when in use.

2.1.6. Anti-Tampering Device

The anti-tampering device is composed of wire mesh sensors and UV ink to deter bike thefts and identify stolen bikes. Manufacturing for anti-tampering devices divide its functionality based on three protocols: detection, response, and evidence [11].

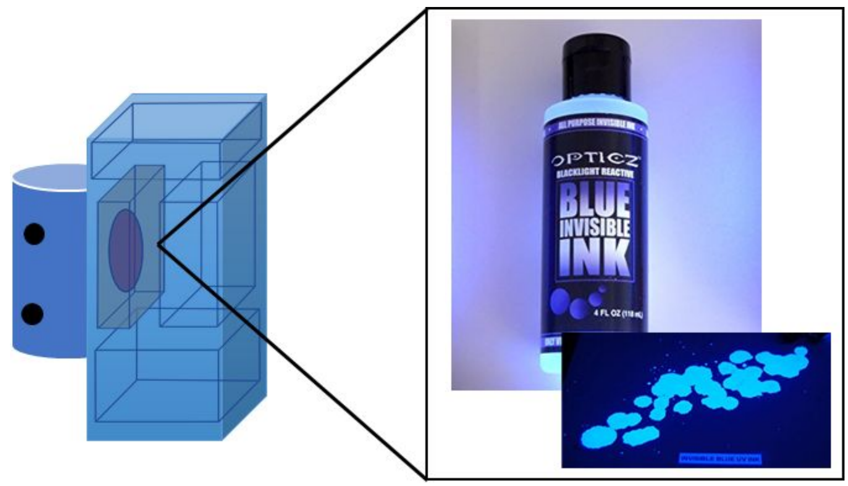


Figure 2-5 Ultraviolet invisible ink containment in anti-tampering device.

2.1.6.1. Detection -- Wire Mesh

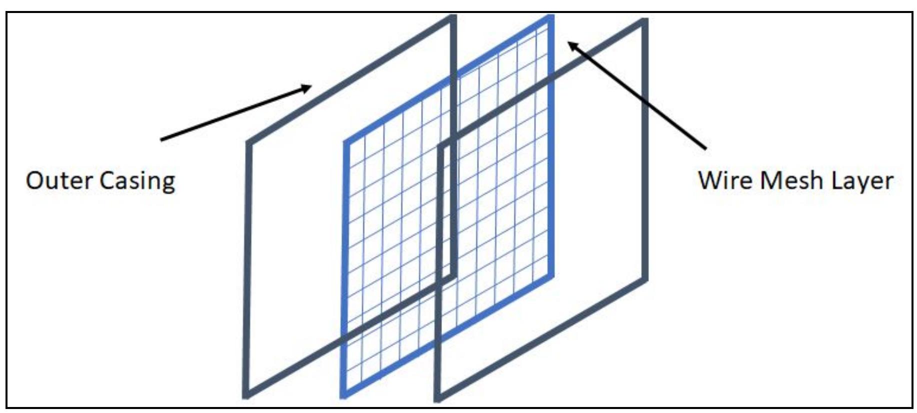


Figure 2-6 Wire mesh sensors inside Bike-Nocular outer casing.

Tamper detection refers to the process of monitoring various sensors or inputs in the system for any abnormalities that could identify a potential tampering event. Inside the outer casing of the Bike-Nocular will be a thin layer of conductive wire mesh sensors. The sensors can be manufactured to withstand up to 300^{o}C and 10 MPa of pressure [12]. In a tampering event where a person applies a large amount of force to the Bike-Nocular, the wire mesh will alert the device. Due to the nature of our product, further testing is needed to determine the impact resistance of the internal components of our product to calibrate a range for the wire mesh to output an appropriate signal for when a tampering event occurs. This way, we can adjust the force threshold so that the wire mesh can avoid false detections from external events such as bike crashes, only triggering when the event is from a malicious attack. There is also a period of time where the user can manually disable a false alarm through the mobile app before the device is triggered.

2.1.6.2. Response -- Emergency Ping

Tamper response is the action the system undergoes upon detection of a tampering event. Anti-tampering devices can have either a destructive or non-destructive response. A destructive response is a single occurrence that is irreversible once activated. The mechanism for destructive systems are relatively simple, however the device will be permanently deactivated and not recoverable. Non-destructive responses are more complex in design and are more prone to false alarms, but they will not compromise the entire system, making it recoverable [13].

For our purposes we will be using the destructive response model for the anti-tampering mechanism. In the event that the wire mesh triggers the tamper detection, a signal will be transmitted from it to the wifi or bluetooth module, sending out an emergency ping to the server. This ping will identify the location and time of the tampering event, and the info can be found from the user's app.

2.1.6.3. Evidence -- UV Invisible Ink

Tamper evidence refers to the method the system uses to indicate that a tampering event has occurred. Typically the indicator should be irreversible so that the evidence is accessible through further investigation.

Inside the Bike-Nocular device (located next to the bike clamp) will be a small tube that contains Opticz Invisible Ink that breaks upon detection of a tampering event. The ink is difficult to remove once it spreads onto the bike, and is only visible under ultraviolet light [14].

2.2. Power Consumption

Bike-Nocular requires an energy source to sufficiently supply power to the electronic components detailed above over long periods of time. The Bike-Nocular features a self-charging system to minimize maintenance requirements, and a manual charging port as a backup power source in emergency situations.

2.2.1. Battery

The Bike-Nocular attachment is powered using four lithium ion (Li-ion) rechargeable batteries. This allows for a product requiring minimal effort to maintain and while still functioning to its full capacity. The advantage of using Li-ion batteries over other types of batteries is that they have a high energy density, meaning they can hold a high amount of energy within a smaller volume compared to other batteries such as nickel cadmium or lead acid batteries [16]. Additionally, lithium ion batteries are only affected minutely by the memory effect, meaning the total battery life is almost unaffected by partial charges and discharges [17].

The battery to be used in the Bike-Nocular is the Panasonic rechargeable lithium ion cylindrical battery (part number: NCR18650BF). This battery has been chosen due to the long battery life, small size, and versatility in operating temperature ranges. Each battery provides a capacity of 2965mAh at a voltage of 3.6V at a mass and cylindrical volume of 46.5g and 17cm^3 respectively, meaning these batteries can power the entire Bike-Nocular attachment while still leaving enough space for the remaining components. Using the values given in section 2.1, four batteries alone will be able to power the Bike-Nocular for up to 2 days of active use. This value can increase significantly when considering idle time, up to a maximum of 4 days of use.

The battery operates at a temperature range of -20°C to 60°C (-4°F to 140°F) allowing the Bike-Nocular to be used at most university campuses year round. The battery can also undergo many cycles (charges and discharges) before any significant loss in capacity; the datasheet reports only about a 20% loss of capacity after 500 cycles from 2950mAh to roughly 2350mAh at 25°C (77°F). As a result, the product can be used over extended periods of time without extensive upkeep [18].

2.2.2. Charging

2.2.2.1. Photovoltaic Cells

The Bike-Nocular features four flexible photovoltaic (solar) cells so the product can function without consumers worrying about manual charging. These photovoltaic cells are connected to the Bike-Nocular using wires, but can be attached to anywhere on the bicycle to maximize solar energy conversion. As stated in section 2.1.2, the product enters a power-saving mode when not in motion, so photovoltaic cells can be expected to sufficiently supply enough power to the Bike-Nocular throughout its usage life.

The particular photovoltaic cell to be used in the Bike-Nocular device is the Panasonic N330 Photovoltaic Module HIT. The output of this cell is reported as 330W making it more effective than most other cells on the market. Furthermore, the cell is 22% efficient compared to other solar cells, which have efficiencies typically between 15% and 20% [19]. As our product will not be in the sun all the time, a high value for efficiency is important to ensure as much energy generation as possible. The cell has been tested to withstand hailstones of diameter 25mm (1”) at speeds of 23 m/s [20] meaning the cells can be expected to operate in typical college campus weather. This also means that the cells will likely be able to withstand impacts from bicycle accidents and collisions, except in extreme scenarios.

2.2.2.2. Manual

In addition to self-charging, the Bike-Nocular has a USB Type-C/Thunderbolt 3 charging port (a male micro-USB to female USB Type-C converter is attached to the Raspberry Pi). This allows consumers to provide energy to the device should the photovoltaic cells prove insufficient. It also allows campus security organisations to turn devices on in emergency situations if necessary, for example, to identify the owner of a bike whose device has run out of battery.

The USB Type-C/Thunderbolt 3 input has been chosen as it is a newly popular charging port, meaning many consumers likely do not need to purchase a new cable solely for this device. This also provides the functions of quick data and energy transfer. The fact that this charging port is currently being used in mobile phones such as the Google Pixel and laptops such as the Apple Macbook is evidence of the ports rising popularity [21]. The charging cable is also reversible for the convenience of the consumer, unlike with typical USB ports or micro-USB ports [22].

2.3. Campus Security Management

The Bike-Nocular online management system can be integrated with local campus organizations to streamline the process of bike registration, recovery, and repair.

2.3.1. RFID

Radio frequency identification (RFID) is a system that uses radio waves to send and receive data through an online database. A unique RFID tag is located in each Bike-Nocular unit that can be scanned by a campus representative to identify bikes and establish ownership. [15] Should a bike be impounded by campus police, the original owner can easily be contacted.

2.3.2. Deactivate Device

In the event that a campus security representative or the owner may need to remove the Bike-Nocular unit (example: if the device needs to be repaired, or if a student is graduating), the device can be remotely deactivated via the Bike-Nocular application to prevent the anti-tampering device from triggering an alert.

2.3.3. Bike-Nocular Exchange Program

The anti-tampering system used on the Bike-Nocular attachment is single-use and must be replaced when the anti-tampering system is altered and the alert is triggered. However, many of the other parts, like the computer board, GPS, and accelerometer, can be reused. Because of this, students can trade in their old unit for a new one if the old one has been damaged, after proving ownership of their bikes through a short vetting process. (See section 3.1 below)

2.4. Bike-Nocular Companion Application

The Bike-Nocular Companion Application is a free website and mobile application that allows bike owners to remotely monitor and manage their bikes, and to view current bike traffic conditions.

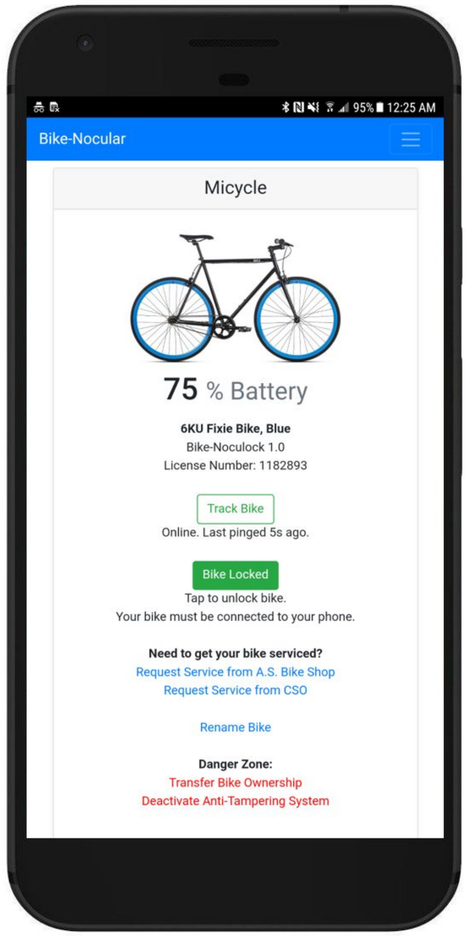


Figure 2-7 Prototype of Bike-Nocular mobile application showing example bicycle information and links.

2.4.1. Bike Tracking

One of the primary features of the Bike-Nocular companion application is the ability to locate your bike(s).

The Bike-Nocular utilizes the GPS module described in section 2.1.3 to grab the bike's location. The Bike-Nocular device will then use Bluetooth, when available, to report the location to the Bike-Nocular server. If a connection cannot be established via Bluetooth, the Bike-Nocular will utilize WiFi if a connection to a campus WiFi network can be made. The bike's location will be stored online for access by the owner whenever they need to access it.

If, at any time, the Bike-Nocular system is tampered with or is running low on power, the Bike-Nocular device will ping the server to notify the bike owner that their bike needs attention.

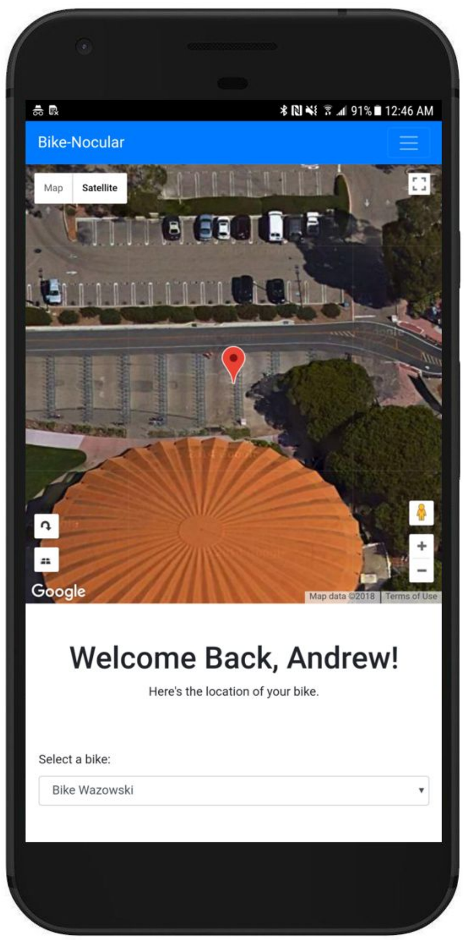


Figure 2-8 Prototype of bike tracking feature on mobile application showing the location of a bike.

2.4.2. Live Bike Traffic

Another primary feature of the Bike-Nocular companion application is the ability to view live bike traffic.

The Bike-Nocular uses crowdsourced data and location tracking of all active Bike-Nocular devices to generate a live traffic map. This is accomplished by dividing up bike paths into small areas and then constantly analyzing the density of bikers in each area. If a certain area is found to have a large amount of bikers, the map will reflect it with a red line, similar to many car navigation systems.

The application can also analyze the relative speeds of bikers to determine congestion, especially during rush hours and near roundabouts. If bikers in a certain area are biking at a lower-than-average speed, the map can warn users about it and potentially notify users of alternative routes.

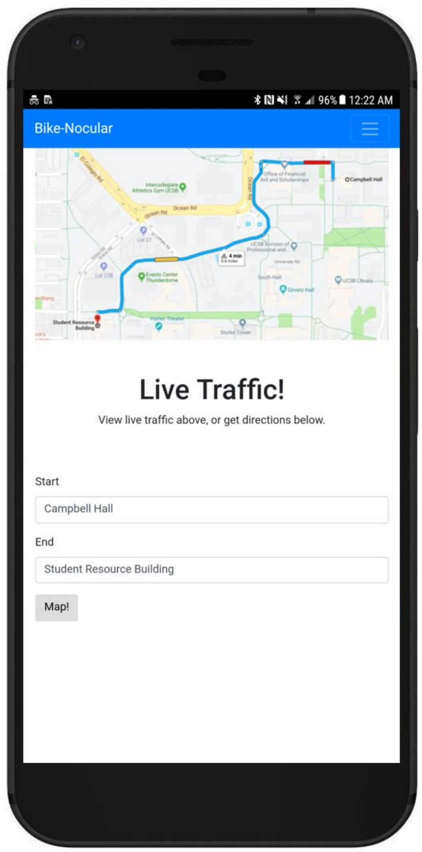


Figure 2-9 Prototype of live traffic feature within mobile application showing heavily congested routes in red, moderately congested routes in yellow, and slightly congested routes in blue along the path between two specified locations.

2.4.3. Bike Ownership

The mobile app allows you to prove ownership of the bike and facilitates the safe transfer of bikes from person to person.

To verify the student's identity, the Bike-Nocular application will utilize campus Single Sign-On (SSO) servers to safely authenticate students. This allows students to use their university credentials to access Bike-Nocular, instead of having to create a separate account, and thus not having to worry about identity fraud.

Transfer of bike ownership is simple, and does not require modification of the Bike-Nocular attachment. The original owner can log in to their application and enter the student information of the new owner, and be alerted once more that complete ownership will be transferred and cannot be reverted. The new owner will then be asked to confirm the transfer of ownership. When the process is complete, the online Bike-Nocular management system will reflect the new changes immediately.

3. Design Options

3.1. Bike-Noculock

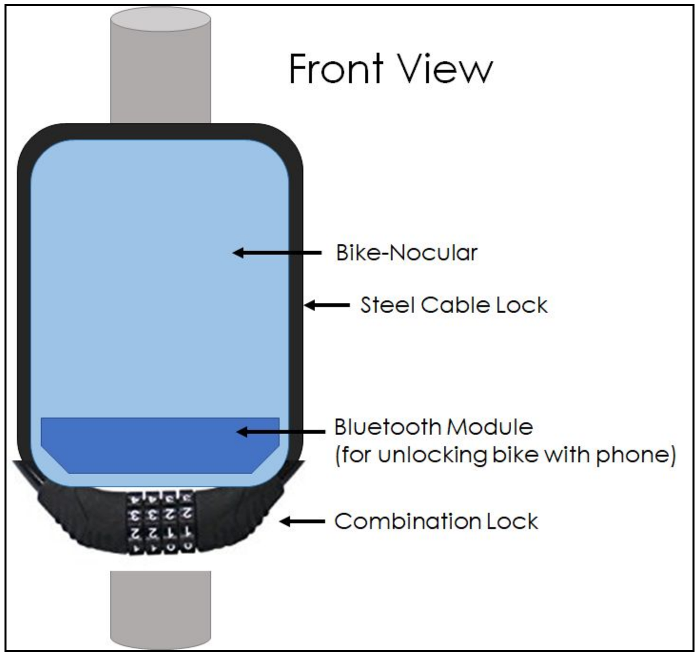


Figure 3-1 Bike-Noculock model showing steel cable bicycle lock wrapping around the device.

For additional security, we will have a different configuration with an integrated cable lock system called the Bike-Noculock. This model will have a cable lock connected from one side of the Bike-Nocular to the other for securing the bike to a bike rack. This lock can be unlocked with two different methods. The first method is by connecting to the bike via Bluetooth, and then using either a fingerprint scanner, Face ID, or a PIN code, to verify your identity and securely unlock the bike. The second method is by using a physical combination lock located on the bottom of the system. To alert the owner of possible theft, a current induced wire is run through the cable and triggered when cut, much like how the anti-tampering system functions with the wire mesh from section 1.1.5.

3.2. Generator Attachment

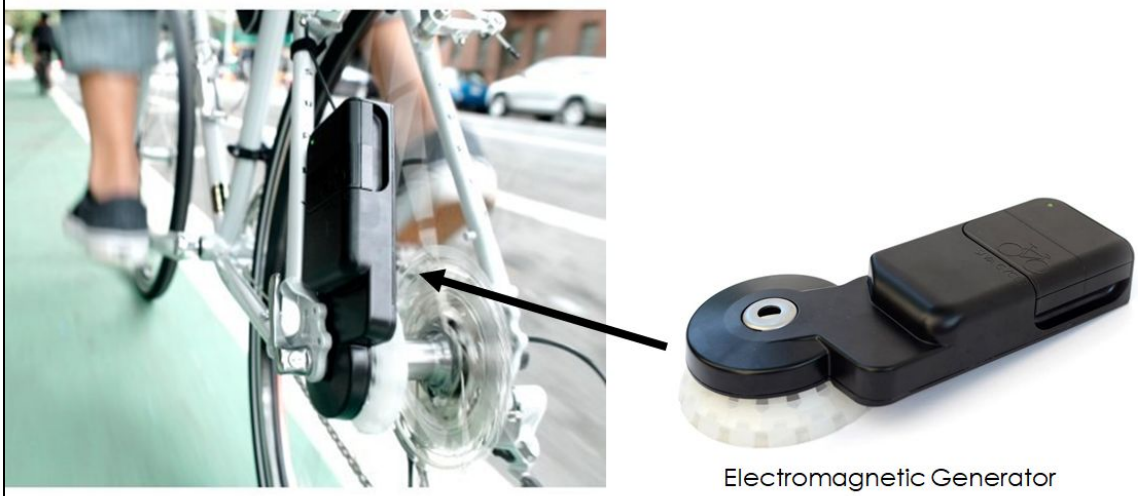


Figure 3-2 Bicycle generator attachment and how it fits onto the wheel of a bike [23].

As solar power is both inefficient and inconsistent around the world, the Bike-Nocular's photovoltaic cells may not provide sufficient energy in cities which receive little sunshine. According to the UK Department for Environment, Food, and Rural Affairs, the maximum ultraviolet index (UVI) at Reading, UK, was below 2 between the months of October 2016 and March 2017 (compared to an average of 6 over a 5 day period in Los Angeles, March 2018) [24] [25]. As UV sunlight can be seen as an indicator of how much sunlight is received by an area, it is evident that solar cells would not be suitable for cities such as Reading.

The Bike-Nocular can come with a pedal-powered generator which can act as an alternative energy supply if the photovoltaic cells prove insufficient. The pedal-powered charger will be an electromagnetic generator which converts some of the kinetic energy from the motion of the back wheel into electrical energy to be used by the Bike-Nocular. The generator will be attached to the back wheel of the bike in order to generate maximum energy because most bicycles use rear-wheel drive.

Although the generator will be made to be as versatile as possible, many bike frames are built differently, so the generator attachment may not fit specific bike models. The attachment will also create additional resistance on the wheel, so the user will need to pedal slightly harder in order to overcome this. As a result, the generator will only be used if the Bike-Nocular requires more energy [26].

4. Environmental Impact

4.1. Anti-Tampering System

The anti-tampering device used on the Bike-Nocular utilizes wire mesh to detect when the device is being tampered with. If the device is tampered, the wire mesh will break, causing the device to trigger the safety features outlined above in section 1.1.5. As a result, this anti-tampering system is single-use, and must be replaced when it is triggered. However, we can mitigate this issue by recycling some of the material for future use.

There will be minimal environmental impact in regards to the invisible ink fluid that comes from the anti-tampering device. The ink is primarily water-based and nontoxic. Since a Bike-Nocular only releases about 2-3 mL of invisible ink, it will not cause harm to people, plants, and animals that could potentially get in contact. The main concern is that the ink is designed to be permanent, meaning that it will require other chemicals to remove it.

However, only the anti-tampering system requires repair — the internal components can be reused. To help reduce costs, we will offer a trade-in program for used devices. If a user needs a replacement Bike-Nocular, they can bring their old one to their local campus police department and receive a new unit in return, for a discounted price. The old unit will be shipped back to the manufacturing plant, and the reusable components (the main board, GPS, accelerometer, and battery) will be extracted and placed into refurbished products.

4.2. Internal Component Manufacturing

While many electrical components can be listed as “eco-friendly” and “green”, the manufacturing and shipping process used can be hazardous to the environment. Bike-Nocular hopes to alleviate this by sourcing our components from responsible and, if possible, local manufacturers, in addition to utilizing more environmentally-friendly shipping practices.

The Raspberry Pi Zero W board used in the Bike-Nocular is manufactured in the United Kingdom. The Raspberry Pi utilizes Sony’s manufacturing plant in South Wales, and as a result, follows the same quality control and compliance standards set forth by their company. Sony’s Green Management program ensures that parts are ethically sourced and comply with the highest ecological standards [27].

The Adafruit GPS Breakout board is made by Adafruit Industries. While the GPS module itself is manufactured by GlobalTop Technology Inc. in Taiwan [28], the breakout board is manufactured and the final product is assembled by Adafruit in their Manhattan facility [29].

The MPU 6050 chip used in the accelerometer and gyroscope unit is made by InvenSense, Inc. When attempting to research their manufacturing processes, however, we were unable to find any publicly available information regarding their manufacturing plants or material sources [9].

In addition the process of shipping used devices will require the use of additional waste in the form of CO_2 gas emissions. To alleviate the carbon footprint of CO_2 due to shipping, we will use standard delivery options rather than rushed delivery, and order/ship components in bulk whenever possible [30]. This way, we can ship used Bike-Noculars in bulk, making transportation more efficient.

4.3. Battery and Energy Sources

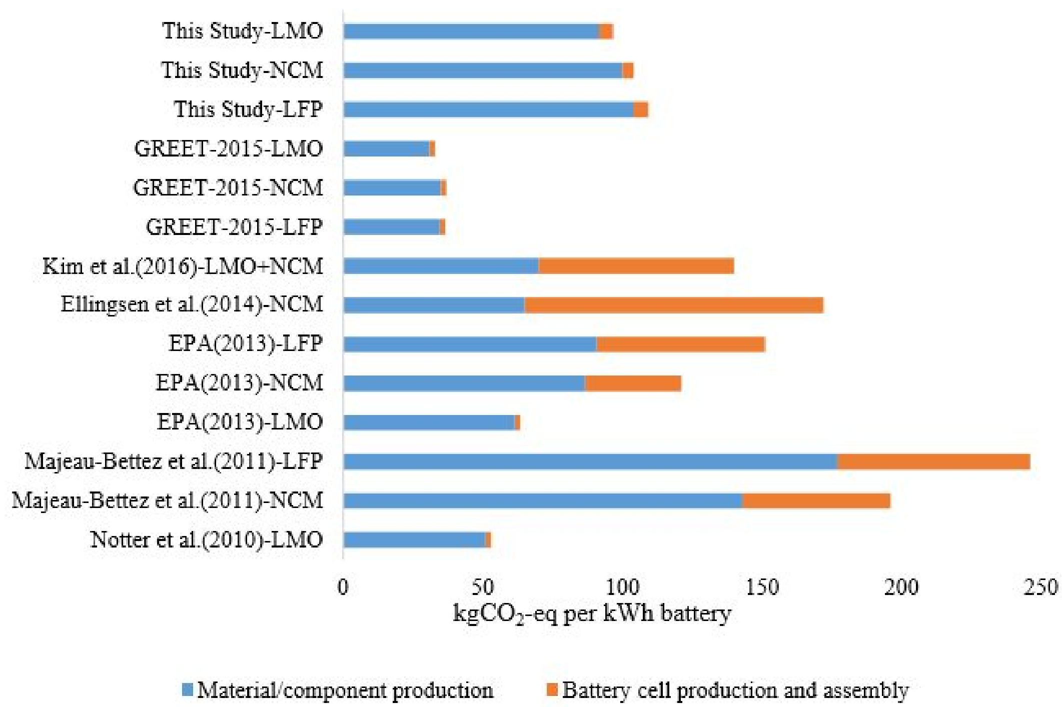
The lithium-ion battery in the Bike-Nocular uses lithium cobalt oxide ($LiCoO_2$) at its cathode. This compound requires special conditions to produce; in order to produce $LiCoO_2$ for lithium ion batteries, a reaction with water under supercritical conditions. In order to achieve this, the water must be at a temperature of 673K and a pressure of 30 MPa. According to Adashirib, $LiCoO_2$ could not be formed at lower temperatures [31]. As a result, it can be seen that the amount of energy needed to produce this material for the production of the batteries is high (for comparison, the Haber process is performed at about 673K and 20MPa). However, if energy used in this process of producing $LiCoO_2$ is "clean", renewable energy, the process itself will have a much smaller impact on the environment.

Lithium-ion batteries also require raw materials to produce. According to Figure _ below, lithium ion battery production, including raw material extraction, produces between 32.9 kg and 246 kg of carbon dioxide per kWh of battery life, depending on the study. The report also states that carbon dioxide emissions vary based on location, and that production in China often raises the environmental impact compared to production in North America. Panasonic only has one factory in North America (in Mexico), but has multiple factories in China, so use of this battery will likely raise environmental impact of the Bike-Nocular [32].

Similarly, according to IEEE Spectrum and National Geographic, photovoltaic cells require environmentally harmful substances such as hydrofluoric acid to produce, detrimentally affecting the environment [33] [34]. However, as the photovoltaic cell and battery will likely be able to power the Bike-Nocular using renewable energy for years, meaning the Bike-Nocular will have little to no impact on the environment during use, these components remain the optimal choice for the Bike-Nocular in terms of functionality and environmental impact over the long run.

Table 1. Carbon dioxide production in kg per kWh of battery life according to multiple studies [35].

Reference	Battery Type	Battery Mass (kg)	Battery Capacity (kWh)	GHG Emission ($kgCO_2$-eq/kWh Battery)		
				Material/Part Production	Battery Cell Production and Assembly	Total
Notter et al. (2010) [3]	LMO	300	34.2	51	2	53
Majeau-Bettez et al. (2011) [5]	NMC	-	-	143	53	196
Majeau-Bettez et al. (2011) [5]	LFP	-	-	177	69	246
EPA (2013) [9]	LMO	-	-	61.5	1.9	63.4
EPA (2013) [9]	NMC	-	-	86.7	34.3	121
EPA (2013) [9]	LFP	-	-	90.8	60.2	151
Ellingsen et al. (2014) [6]	NMC	253	26.6	65	107	172
Kim et al. (2016) [10]	LMO + NMC	303	24	70	70	140
GREET-2015	LFP	230	28	34.6	1.9	36.5
GREET-2015	NMC	170	28	35	1.9	36.9
GREET-2015	LMO	210	28	31	1.9	32.9
This Study	LFP	230	28	103.8	5.5	109.3
This Study	NMC	170	28	99.9	4.1	104
This Study	LMO	210	28	91.5	5.1	96.6



4.4. Outer Enclosure

The outer enclosure is made of Acrylonitrile butadiene styrene (ABS), a plastic that is durable, stable, and rigid, requiring less resources in comparison to other materials [36]. The material itself has a health MSDS (Material safety data sheet) rating of 1 out of 4, meaning that the material may cause irritation in the manufacturing phase [37]. However, ABS plastics do release pollutants in the manufacturing process, and these figures widely vary depending on the factory. The table below shows the consumption and pollution per metric ton of ABS at a plastics factory in Ningbo, China.

Table 2. Resource consumption and pollutant release per metric ton of ABS plastic [38].

Items	Water (m^3 ton^{-1})	Electricity (kWh ton^{-1})	Steam (t ton^{-1})	Heavy oil (kg ton^{-1})
Consumption	5.99	823.80	0.44	27.65

Pollutant	Discharge mount
Wastewater (m^3 ton^{-1})	4.288
Discharge of main pollutants in wastewater (kg ton^{-1})	
COD	0.357
NH_3-N	0.0583
Waste gas (m^3 ton^{-1})	7368
Emission of main pollutants in the gas (kg ton^{-1})	
SO_2	0.347
Dust	0.202
Solid waste (kg ton^{-1})	27.26

The only significant consumption for ABS is electricity to power the manufacturing process. The breakdown of how the electricity is produced largely varies by location, but typical ways to produce energy is through both non-renewable(coal, oil, natural gas) and renewable sources (solar, wind, hydroelectric). As for reuse, while ABS can be easily recycled [39], not all recycling facilities have the capacity to recycle ABS.

5. Conclusion

Many college students use their bikes everyday to commute to and from campuses or to travel between classes. As such, bikes play an integral role in college students' lives. The Bike-Nocular ensures the security of bikes through tracking features, and protects users by alleviating bike path congestion through monitoring traffic at a low cost to users. The use of recyclable plastic, photovoltaic cells, and repairable internal components ensures minimal negative environmental impact over the long run. By providing the necessary funding, the Bike-Nocular will allow bikers on college campuses to travel efficiently and significantly increase the bikes' life-spans.

Thank you for your consideration and we hope you decide to support our work to continuously improve bike safety on college campuses.

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