Sentinel: A Car Collison Detection System for Bicyclists

(Technical Research Project in Computer Engineering)

Robotic Police in the United States: A Divisive Innovation

(Sociotechnical Research Project)

An Undergraduate Thesis

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

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Department of Electrical and Computer Engineering

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Sociotechnical Synthesis

The main problem that my thesis aimed to address was How can the U.S. integrate robotic autonomous systems to improve everyday life in the public sphere?

In the technical portion of the thesis, the problem was narrowed down to: how can autonomous sensors be used to reduce bike collisions with cars? Bikes are used across the world for fitness, recreation, and sustainable transportation. However, this utility is hampered by the risk presented by motorists on the road. To address this problem, my capstone team invented a simple bike radar unit "Sentiel" that helps protect cyclists from rear-end collisions. Using radar and an intuitive display unit mounted on the handlebars, the unit alerts cyclists of approaching vehicles long before they pose a risk, allowing riders avoid potential hazards. This device is designed specifically for riders who use bicycles for their daily commutes as well as people with auditory impairments which prevent them from interpreting auditory queues. The system can generate enough energy from our solar panel on a worst-case day to accommodate nearly all commuting use cases. The technical project fulfilled all 7 project goals: distance sensing (can detect objects up to 40m away), relative speed sensing (can detect if a car is approaching too fast), intuitive notification (always alerts based on sensor data), backup power storage (2 hours of backup power storage), native power generation (solar-powered), and weatherproofing.

In the Sociotechnical portion of my thesis the use of robotics in the police force was analyzed through the actor-network theory. In recent years, there has been an increasing presence of robotics in the United States public sphere. Robotics has even found its way into the United States police force. The morality of autonomous lethal force is gray at best. Furthermore, police, politicians and civilians often do not want robotics in the public sphere to begin with.

Actor-Network Theory

Even though robots are inanimate objects, they have the capabilities to create and shift social networks. A main way that robotic use can be seen via the actor-network theory is how robotics allow the groups in power to stay in power. These power dynamics become even more dangerous as the autonomous systems become lethal.

Robotic policing raises ethical questions. There is no standard for coding autonomous robots in situations of moral uncertainty (Lin et al., 2020). If enabled to act in the physical world, police robots would need to be "trained" to deal with infinite case by case situations. Overall, autonomous systems capable of lethal force should be avoided at all cost.

In 2020, the New York City Police Department (NYPD) leased a $94,000-dollar robotic dog "Spot" from Boston Dynamics, a robotics company whose mission is "to imagine and create exceptional robots that enrich people's lives" ("Boston Dynamics", 2021). However, public opposition to Spot forced the NYPD to cancel their lease in 2021. Some people worry the increased surveillance could contribute to the predictive policing of marginalized communities. If not done right, robotic police presence on the streets could inherently make the public space a hostile and cold environment.

Introducing Spot into the NYPD was one of the first instances of police use of robotics in the public domain. It is easy to see why the project got shut down so quickly; a future where the public trusts robots roaming the streets is hard to imagine. People feared the power robotics gave to the police force. Whether or not the robots put to use in New York were ever used for malicious purposes, allowing robotics in public places sets a dangerous precedent.

Many police and security robots are used for non- lethal operations such as "scanning for pedophiles …. reciting warnings and more" (Lin et al., 2014). Even if police do not want lethal force, robotic surveillance should be dissuaded, due to the unsettling tensions it could create between the police and people.

While the use of robotics may have good intentions, their capabilities to create an intrusive and dangerous police force are too much of a risk. Robots as inanimate objects, as explained through the actor-network theory, play a key role in the policing system. The indeterminate and unpredictable actions of autonomous systems mean they should not be allowed to use lethal force. In the future, policy makers must make sure that autonomous systems are properly regulated. This means that engineers that create autonomous systems should never be allowed to design autonomous systems that cause harm. The use of robotics for surveillance also should be banned.

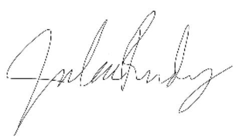
The End of Our FUN

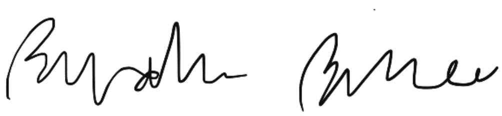
Rex Serpe, AJ Cuddeback, Brandon Brnich, Julia Graham, Julia Rudy

December 17th, 2021

Capstone Design ECE 4440 / ECE4991

Signatures





Technical Report

Statement of Work

Brandon Brnich

My primary role in this project was to design the firmware architecture of this system. This responsibility included extensive planning at the beginning of the semester in order to create an efficient workflow between myself and Julia Rudy. The planning for the system level design began by first assisting AJ in the selection of the radar sensor. My contribution to this selection derives from reading through the communication protocols of each prospective sensor in order to choose one that is not only powerful, but also provides intuitive and easily decoded information. Once the sensor was selected and the group knew the data that had to be processed, I was tasked with selecting the microcontroller that would be used in the design. Since our group is constrained with conserving as much power as possible due to relying heavily on solar charge, this selection process was quite methodical. After this selection was made, Julia Rudy and I were able to effectively split up the firmware tasks in order to complete the project.

Furthermore, I programmed a lot of the fundamental system code that was used in our project. Specifically, I wrote the drivers for the clock to be used at 8 MHz, timers for interrupt driven code, as well as configuring our system to read the JavaScript Object Notation (JSON) packets be sent from the radar sensor using the Universal Asynchronous Receiver-Transmitter (UART) protocol [1]. Once I verified that the byte data was properly being read into the microcontroller, I was tasked with placing the data into a buffer in the necessary format for Julia Rudy to properly parse the information for the display. Lastly, I wrote code to synchronize the data being read from the sensor and the data being processed by the JSON parser. This needed to be done in order to not waste processing time reading in data that wouldn't be used, as well as assuring we are reading in data that is relevant to the surroundings of the current situation, rather than reading information that no longer pertains to the user's surroundings.

AJ Cuddeback

My primary role in this project was system-level design and product integration. System-level design included solving problems which didn't fall into any specific technical domain and interfacing with target users to engineer user experience. Product integration included communicating with each team member to determine how their parts interfaced with each other and troubleshooting interface issues as they arose.

Examples of system-level design include selecting our sensor and conducting end-user validation of our notification system. As the sensor provided the core functionality for this project, sensor selection required interfacing with Rex, Brandon, and Julia R. to determine sensor communication and power constraints and researching safety metrics to determine performance constraints. Once the sensor was selected, I became the primary point of contact for sensor-related troubleshooting which included communicating with sensor manufacturers to obtain additional sensor datasheets and working with individual team members to debug sensor integration. To validate our notification system, I collaborated with Professor Reid Bailey from Systems Engineering to select and approach for test-driven development of our notification system. I collaborated with Julia R. to develop an example notification to distribute to target users for testing. After collaborating with cycling clubs at UVA to survey target users, I worked with Brandon and Julia R. to implement a notification system based on the survey results. I organized and conducted field testing of sensor performance to determine both the extent of information available to drive the notification system and points where the firmware needed to correct for sensor error.

Julia Graham

My primary responsibility was mounting and waterproofing of the various parts of the project. This involved compiling information about potential mounting methods, purchasing screws and mounting materials, and taking inventory of various physical dimensions. The first step of the mounting process began by taking a detailed look at the constraints: the board print sizes, battery size, available tools, and timeline. I created the first revision of the front LED display 3D print using Solidworks. I also designed all five revisions of the back mount box which houses the MSP, Power Board, sensor, and battery pack. As someone who had never utilized Solidworks, a CAD based software, a significant portion of time was spent learning the intricacies of the program, including its vast capabilities, especially related to drill holes. I identified a bike rack that was mountable on standard bike sizes and could accommodate the weight of the solar panel. I also worked alongside Julia Rudy to select various materials, including the front mount kit and screws. I scheduled a time to work with a friend in the Architecture school to get the plexiglass piece cut into the correct sizes by a laser-cutter in the Architecture shop and created DWG files describing the necessary cuts. I assembled the bike rack and aided in the physical assembly of the wiring. Lastly, I assisted in the testing of waterproofing.

Julia Rudy

I was primarily responsible for the code that controlled the intuitive LED display. I decoded the JSON data provided by the Radar Sensor via UART. I also wrote the LED driver code that initialized the hardware PWM that controlled the LEDs. I worked on dynamically changing the LEDs blinking frequency using the hardware PWM based on dynamic range data given by the sensor. As my secondary responsibility, I help with the product mounting. I was responsible for the front 3D printed box that housed the LEDs mounted on the handlebars. This included getting all accessories that allowed the front box to be waterproofed and stably mounted (jacketed wires, handlebar mount, waterproof wire connectors). I also provided help by doing field testing with the sensor, testing range capabilities.

Rex Serpe

I was primarily responsible for developing the power PCB. I developed circuit schematics for a solar MPPT battery charger, a high efficiency switching converter to create a 5V power rail, and a linear regulator circuit to produce a 3.3V rail. This involved spending extensive time reading datasheets and becoming familiar with the various integrated circuits required to implement such a design. I also designed the physical layout of the board such that it could effectively interface with the radar sensor, MSP430 header board, battery, and solar panel through various connectors and interfaces. I converted these circuits into a manufacturable circuit board layout and carried out ordering and assembly. I then tested this board, carrying out a hardware testing process that culminated in a second revision of the circuit board. My secondary responsibility was to assist in the development of the LED display board, as well as wiring and integration of the complete system.

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Abstract

Bikes are used across the world for fitness, recreation, and sustainable transportation. However, this fantastic utility is hampered by the risk presented by motorists on the road. Bike crashes can be catastrophic for cyclists: 843 people were killed in bicycle-car accidents in 2019 alone [2]. To address this problem, we have invented a simple bike radar unit that helps protect cyclists from rear-end collisions. Using radar and an intuitive display unit mounted on the handlebars, the unit alerts cyclists of approaching vehicles long before they pose a risk, allowing riders avoid potential hazards. This device is designed specifically for riders who use bicycles for their daily commutes as well as people with auditory impairments which prevent them from interpreting auditory queues. The system can generate enough energy from our solar panel on a worst-case day to accommodate nearly all commuting use cases.

Background

Statement of Objectives

Biking improves physical health, increases time outdoors, and is a cheaper and more environmentally friendly alternative to cars. However, biking also presents risks: riding in severe weather, hard terrain, and the potential for a crash. In a survey of over 1000 bicyclists, health benefits ranked as the top motivation for riding a bicycle, whereas the crash risk ranked the greatest discouragement [3]. Our product would aim to address this concern and increase bike safety so that riders can cycle with a greater sense of security. The objective tree in *Figure 1* divides the project's goal into 7 specific deliverables. These specific deliverables appear in the leaf nodes of the tree and are highlighted in green.

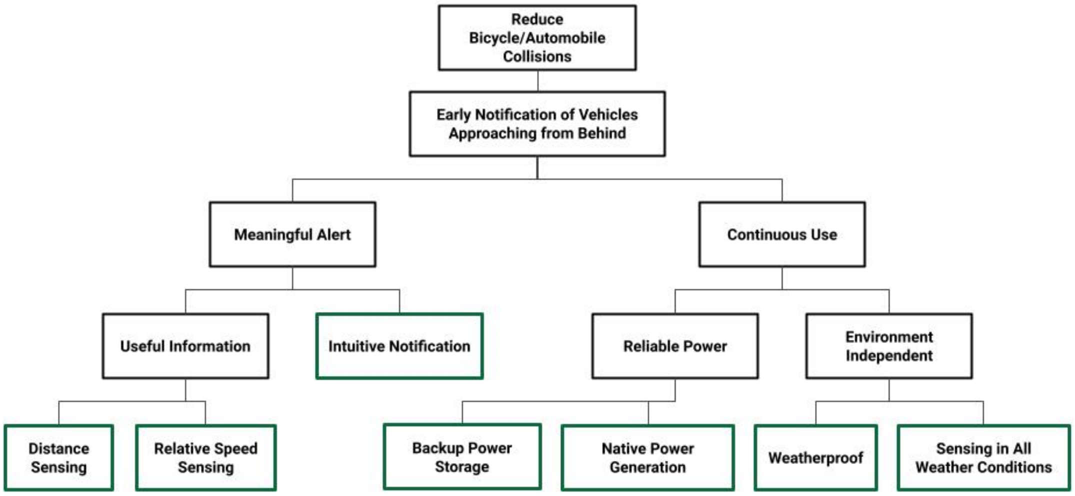


Figure 1. Objective Tree Showing Project Deliverables Outlined in Green

An intuitive display will alert the user of the distance and relative speed at which vehicles approach from behind. The device will accurately sense distance in various weather conditions.

A solar panel will charge a backup battery that can be recharged independently of the solar charger.

According to the US Census Bureau, “the average bicycle commute time is 19.3 minutes, and most bicycle commutes” are “between 10 and 14 minutes” [4]. Thus, our system must harness enough solar power to accommodate at least two 20-minute commutes per day. With this in mind, we will design our system to charge enough for three 20-minute commutes per day to account for non-ideal weather and charging conditions.

System Description

The block diagram in *Figure 2* describes the overall system configuration with its major power and logic connections.

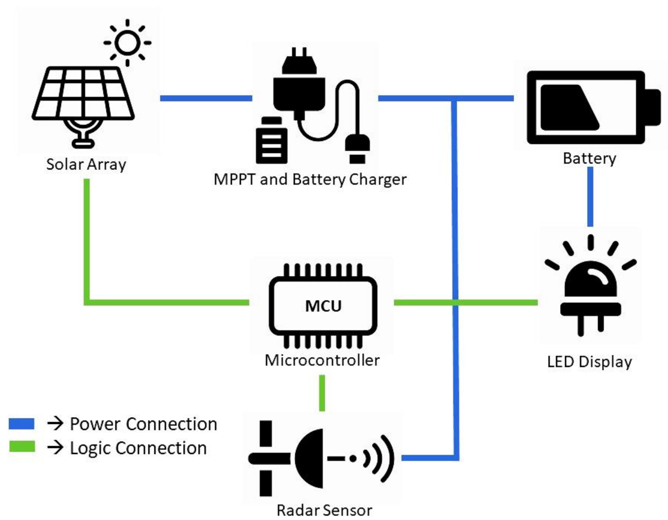


Figure 2. System Block Diagram

To detect and measure approaching objects, an OmniPreSense OPS243-C-FC-RP (OPS) radar sensor is mounted on the back of the bike. An MSP430F5529 [5] microcontroller reads the output signals from the radar. Sensor data is communicated via UART interface and includes motion detection, speed, and direction (inbound/outbound) [6].

As a car approaches a cyclist from behind, a series of LEDs mounted on the handlebars of the bike alerts the rider. An LED was chosen for the display system over an LCD/sound display for two reasons. First, a flashing light draws more attention than text on a screen. Second, bike riders sometimes wear headphones, making auditory signals pointless. The display is controlled using PWM signal to drive transistors on the LEDs. *Figure 3* illustrates the placement of the display on the bicycle.

The entire system is powered by a rechargeable battery. A maximum power point tracker (MPPT) control system is used to charge a battery using a Renology solar panel [7]. Additionally, the batteries can be recharged independently of the solar panel if a user uses more power in one day than is generated by the solar panel. The battery provides power to the radar sensor, microcontroller, and LED display.

The battery is comprised of 2 lithium-ion 18650 cells [8], connected in series. The combined cells produce a final nominal voltage of 7.4V. This battery pack feeds into a buck regulator [9] which produces a regulated 5V rail to power our sensor and LED display. Using the 5V rail, a linear regulator [10] produces a stable 3.3V rail for the microcontroller. The battery system powers the LED display, microcontroller, and radar sensor. The worst-case power draw for these three components was measured to be 2.3W. With a total usable capacity of 13Wh, the battery system will be able to supply the system's worst case power draw for over 5 hours.

A ~2 m wiring cable [11] is routed from the back of the bike to the handlebars to provide power and control signals to the LED. All mounts for the electronics are 3D printed. As the radar sensor uses a 24 GHz transmitter, it can be placed behind plastic for weatherproofing and still function as expected. The placement of the display is shown in *Figure 3*.

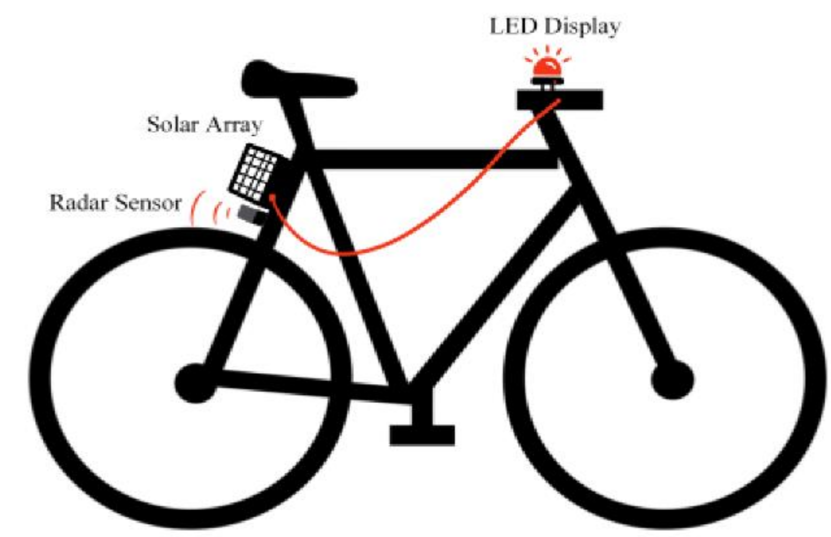


Figure 3. Component Placement on Bike

Comparison to Existing Products

There are several products on the market that address similar problems of bike safety and prevention of car and bicycle crashes. On the low-tech side of products, bike mirrors can be mounted to a bicycle and are relatively affordable and accessible [12]. However, like car mirrors, these mirrors can have blind spots and require a rider to constantly scan for oncoming cars. It was found that collision detection systems in cars have reduced bodily harm claim frequency by

27 percent [12]. The car detection systems are more robust than the bike sensor proposed but similarly use sensors to notify drivers of incoming cars and or pedestrians and have a clear advantage over mirrors for safety [12]. *Table I* summarizes differences between the current products on the market and scholarly articles and their respective prototypes.

Table I. Similar Existing Products

Commercial Product or Literary Paper Reference Number	Similar Completed Prototype [13]	*Garmin* Varia ™ [14, 14]	Bike Mirror [15]
Purpose	Detecting cars from behind and turning onto bike	Detects oncoming cars from behind and alerts rider	Provides visibility of objects behind rider
Sensors	Sonar Radar	Radar	None
Connection from Sensor and Alert	None	Bluetooth	None
Cost	500	200	~$20
Range	6m	140m	~60m
Alert	None	*Garmin* Edge	None

Radar collision detection products for bicyclists exist on the market, including the Varia ™ by *Garmin*, a radar car detection system [14]. The Varia ™ by *Garmin* uses a bike seat mounted radar with a 20° FoV (field of view), a battery life of 6-16 hours, and sensing range of 140 m for vehicle speeds of 10-160km/hr. It also can detect up to 8 cars. The radar communicates via Bluetooth to the *Garmin* Edge device, a GPS computer with an LCD screen mounted on the front of the bike [14]. The Varia ™ by *Garmin* is one of the only radar devices for vehicle detection on the market.

This capstone project is a novel idea, in its power source and simplicity of signaling to bike rider. Unlike the *Garmin* product, our project design would not need to be connected to another separate display system. *Garmin*'s products require the customer to buy both the sensor and the main bike navigation control. If a customer bought both the Varia ™ sensor, Edge device, and the associated mounting kits, the cost would be around $500 [14] - the Sentinel also costs 500 dollars. Unlike the Varia ™, the rider would not need to order multiple parts or worry about connecting each component together. The simplicity of the capstone LED display also reduces the amount of data being presented to the rider. Unlike the Varia ™, the capstone project will be solar powered.

Previous Coursework

The previous course work in both computer engineering and electrical engineering will be vital in the success of this project. The Fundamentals courses (ECE 2630, ECE 2660, ECE

3750) taught circuit design, PCB design, and circuit construction. They also taught key project design skills: meeting specifications, systematically recording results, verifying, and debugging. This process was practiced over and over in labs and final projects. These skills are essential to organize the design challenge, tackle technical tasks, and work coherently as a group. The solar panel system and corresponding PCB design rely heavily on these courses. Secondly, the Intro Embedded Computer System course (ECE 3501 and ECE 3502), and the Advanced Embedded Systems course (ECE 4501) taught the concepts of programming Microcontroller Units (MCUs). Programming MCUs will be essential in processing incoming radar data and communicating that information to the lighting display, as well as controlling the scheduling for all these processes to occur seamlessly. The Electromagnetic Energy Conversion (ECE 3250) course and its concepts of maximizing power and efficiency will be used to create a low power system that can run on a small solar panel. Lastly, the Science, Technology, and Society courses (STS 1500, STS 2000, and STS 4500) have explored the greatest engineering inventions and their impact and place in society. These teachings will help to better design the bike sensor not only to meet the purely technical requirements but to create a device that navigates the societal factors: ethical, environmental, and economic, that will determine the effectiveness of the design in society.

Constraints

Design Constraints

CPU Limitations

The microcontroller selected was the Texas Instruments MSP430F5529 [5]. This is a powerful MCU with capabilities of having a 25MHz clock speed as well as multiple peripherals that are capable of UART and pulse width modulation (PWM). However, the group's task was to conserve power, which limited the clock speed to 8MHz. This decision was made as there needed to be a tradeoff between power consumption as well as selecting a clock speed fast enough to create a stable baud rate for the UART connection.

Software Limitations

In terms of software, the group used KiCAD for designing the circuits as well as the printed circuit boards (PCBs). Texas Instruments' integrated development environment (IDE), Code Composer Studio (CCS), was used for writing the necessary C code, flashing the code onto the MSP430, and debugging purposes. CCS is a very powerful software and was useful throughout most of development; however, debugging became troublesome as the register window cannot read values on the MSP430 unless the code execution is paused. This can make analyzing program execution quite troublesome.

PuTTY 0.76 SSH [16] was used in order to interface with the radar sensor. This was done by connecting the sensor to a laptop via a USB cable. Once connected, the user can type commands into the PuTTY terminal that are then used to reconfigure the sensor settings. The list of commands can be found in the sensor API interface [17].

Solar and Power Constraints

Solar constraints are mainly rooted in the limited solar irradiance available on Earth. At the equator in ideal conditions, about 1kW/m^2 of solar irradiance is available, but at Charlottesville's latitude, this can drop to under 300W/m^2 during the winter. This created three primary constraints – choosing a large enough solar panel, harvesting and processing energy in an efficient way, and consuming as little power as possible. Fundamentally, any device that relies on energy harvesting must be conscious of its power consumption. This makes developing a power budget for the device more challenging than it would otherwise have been.

Manufacturing Limitations

Sentinel used a commercially available OmniPreSense OPS243-C-FC-RP radar sensor. The size of the OmniPreSense sensor determined how big our final PCB was. Furthermore, the Sentinel prototype interfaced with the MSP430 via header pins instead of an embedded chip on the PCB, which would reduce size and cost. Furthermore, our team only had access to 3D printers to fabricate our project. In the future access to tools such as drills and laser cutters would be beneficial.

Economic and Cost Constraints

The budget provided for the UVA Electrical and Computer Engineering Capstone was $500. The budget is the main limiting factor on what kind of and how many sensors we could buy for our project. Once cost reduction to our system is we were able to get microcontrollers for free and we were able to 3D print several mounts for our project.

Physical Mounting Constraints

The sentinel faced several physical mounting constraints. Firstly, the front mount and back mount need to be rigid and unmoving. Additionally, the 3d Printed boxes needed to have a footprint smaller than the printing footprint of the Ender Pro 3 printer [18]. The printed circuit boards needed to fit inside the boxes and have correctly placed screw holes. Next the waterproof connecter [19] had to have a correctly sized hole for waterproofing and enough room to place wires within the entire 3d printed enclosures. The front box printed box needed to accommodate mounting adhesive patch from the bike mounting kit [20]. For time saving and material aging purposes the walls of the enclosure could not be more than .2 inches. The back box needed to accommodate the thickness of the MSP, power board, and sensor. The bicycle rack needed to be a universal fit for standard bicycles.

External Standards

UART: (Universal Asynchronous Receiver-Transmitter) - A UART implements serial communication asynchronously between a transmitter and a receiver device [1].

NEMA3: outlines the waterproofing standard for outdoor electronics. Casings must protect against windblown dust, rain sleet and snow [21].

IPC Standards for PCB Design: IPC-2221A sets standards for the part and track spacings on the PCB designs [22]. IPC-A-600F sets acceptance criteria for PCBs, including board edges, material, holes, plating, and solder mask [23].

Tools Employed

Hardware

In order to test our circuits and connections, the group used National Instruments' VirtualBench [24]. Every member of the group has had to go through numerous classes that have taught us how to properly use this device. As a result, the Virtual Bench was used to collect all information necessary for signal verification.

The Sentinel product has many enclosures that were created in order to properly protect the device. As a result, the group printed these enclosures using the Ender 3D Pro [18] printer.

To make the enclosures weather resistant and obtain a professional level of appeal, the Universal Laser Systems PLS6.150D laser cutter [25] was used to precisely cut the plexiglass necessary to place on the casing of the system devices.

Software

Julia Rudy and Brandon both used Texas Instruments' Code Composer Studio [26] integrated development environment (IDE) in order to develop the code base for the system. They chose this IDE as it provides extensive debugging tools as well as a sense of comfort as both have used the tool before.

Rex chose to use *KiCad*, ver. 5.1.10 [27] for circuit design and PCB layout. This software was chosen as Rex has done numerous internships and personal projects that have caused him to use this development tool.

Solidworks [28] was used in order to create the 3D models that needed to be printed. Cura Ultimaker [29] was used for setting up 3D prints from the models designed in Solidworks.

PuTTY 0.76 SSH [16] was used to read sensor data via USB connection on a laptop.

Environmental Impact and Sustainability

The power source for the sensor will be a mono-crystalline solar panel. Solar panels offer a renewable source of energy, however, the creation of said panels can be energy intensive. Unlike multi-crystalline panels, mono-crystalline panels offer higher efficiency: 16-22% commercially compared to 15-18% of multi crystalline cells [30]. The production of the panels requires a significant input of energy, water, and rare materials [31]. If solar panels are improperly disposed, they can leach into the soil and create pollutants to water sources [32]. Studies have found solar panel's environmental benefits outweigh the initial costs. Solar panel companies also have recycling programs to properly dispose the panels. Some of these companies in the US include: 3 R Recycling, Cleanlites Recycling, and Echo Environmental

[33]. The use of recycling programs can reduce the amount of waste. Following the EPA's guidance on the disposal of solar panels can help to increase the benefits of using solar panels [34].

Another aspect of the environmental impact of the design is the plastic enclosure of the mounting. 3D printers are highly specialized machinery and require several electronic components and energy to run. These factors are countered by high use of the machine and studies have shown that specialized prototyping can reduce waste; however, this is all dependent on specific use and materials used in the print. One of the major sources of waste for 3D prototyping is unusable prints [35]. As a team we will carefully plan the print to reduce error and the possibility of having to reprint the prototype.

Health and Safety

Sentinel's primary goal is to help those with hearing impairments. Our group must make sure that our system is extremely reliable. If the system partially works, in the sense that it detects oncoming vehicles most of the time, the user may become extremely reliant on the system. This could be problematic if our system degraded over time and malfunctioned, leading the user to not know about the oncoming vehicle. Which in turn, would lead to many accidents and cause our system to become a liability rather than an assistive tool.

The 95^{th} percentile human reaction time as used in car crash reconstruction is 1.6 seconds [36]. Conservatively estimating this number to be 2 seconds with a speed difference of 50mph (22.352 m/s) between a bike and an oncoming car, we find that our notification system must be able to detect objects when they are approximately 40 meters away. Therefore, our system will be designed to warn riders of approaching cars when they are at least 40 meters away. Another safety concern is the power wire getting caught in the wheels of the bike. The project's power cable will run alongside the brake cable of the bike to prevent the wire from getting caught. Another safety concern is if the electronics are not waterproof, presenting a shock hazard. Therefore, all electronics are waterproofed using NEMA standards [21].

Ethical, Social, and Economic Concerns

Ethical issues surrounding this project are heavily linked to the health and safety section seen above. When creating a device with the intent to protect the safety of people, the engineers responsible for the design must be extremely thorough. This project also caters to those who are hearing impaired. Over 360 million across the world suffer from some form of hearing loss [37]. If our group does not properly design and test the system, then our consumers could face the risk of being severely injured.

Lastly, if an accident occurs when this device is in use. The question arises of who or what party is responsible. Companies like *Garmin*, have similarly weighed this ethical dilemma and as a result have issued all customers a disclaimer about the customer's responsibility for safe bike riding practices [38]. Since our device would not be making any autonomous driving choices also, the customer is fully in control of their bicycle and the driving decisions they make. We will make a similar disclaimer to those who use our bike sensor.

Intellectual Property Issues

Our project is patentable. The most similar product to the Sentinel is the Varia by Garmin with patent number US10393872B2 [39]. However, the Varia is not solar powered, meaning the Sentinel has an independent claim that varies it enough from the Varia design to be patented. The Sentinel is the only solar-powered rechargeable car detection. Other products with similar functionality to the Sentinel exist such as patent US10748435 [40] and US8952799B2 [41] which use proximity sensors to detect oncoming obstacles**.**

Patent US10748435 is an obstacle avoidance system provided to assist a pilot in avoiding obstacles. The obstacle avoidance system includes a set of proximity sensors and a pilot interface device. The set of proximity sensors detects nearby obstacles by emitting a signal and receiving a reflected signal from an obstacle." [40]

Patent US8952799B2 "is a method and system produce a warning signal to warn a driver of a vehicle about a potential obstacle crossing behind the vehicle for example, as the vehicle is backing out of a parking space." [41].

Both patents deal with obstacle detection and notification. However, neither are used for bike riders, only other motorized vehicles like planes and cars.

Detailed Technical Description of Project

System Overview

Sentinel is a solar-powered car detection system. A solar panel mounted to the back of the bike provides power to the system. A radar sensor mounted to the back of the bike detects how far away obstacles are. This data is communicated from the radar sensor to the microcontroller via UART in JSON packets. The microcontroller parses the JSON packets. Based on how close the obstacle is to the bike, the microcontroller sets the frequency of LEDs mounted at the front of the bike.

Hardware

Power PCB and Solar Interface

The core of the power PCB is formed by an Analog Devices LT3652 maximum power point tracker (MPPT) integrated circuit. The output of the solar panel is fed into the MPPT as shown in *Figure 4*.

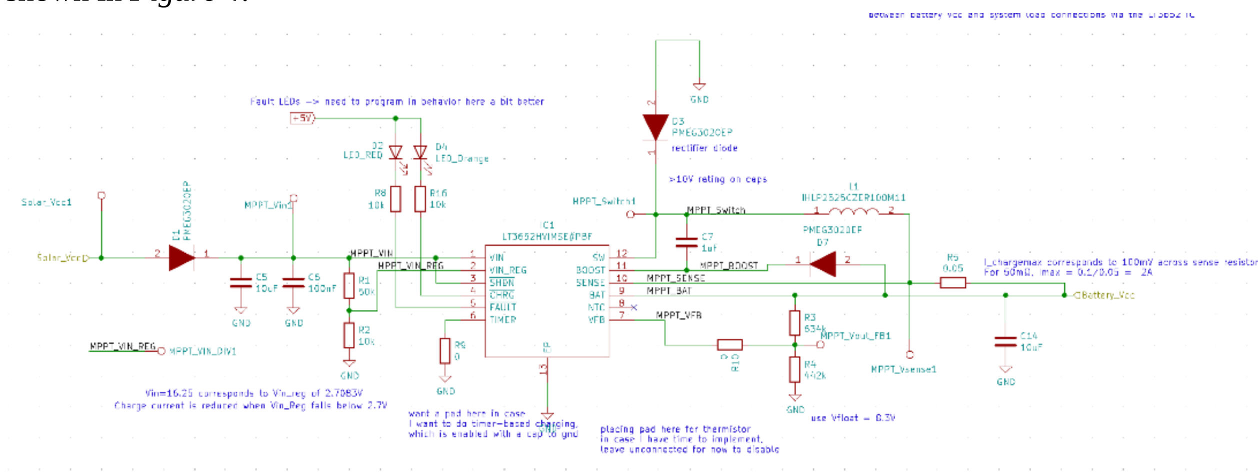


Figure 4. MPPT Circuit Schematic

This circuitry modulates the current draw from the solar panel in order to maximize its output power. It accomplishes this by varying the switching duty cycle through the inductor L1. It delivers power into two lithium-ion 18650 battery cells, which are wired in series to create a nominal voltage of 7.4V. The LT3652 circuit intelligently charges these battery cells as a function of their state of charge, preventing overvoltage, overcurrent, and undervoltage conditions.

The 18650 battery cells are then fed into a buck regulator, as shown in the schematic in *Figure 5*.

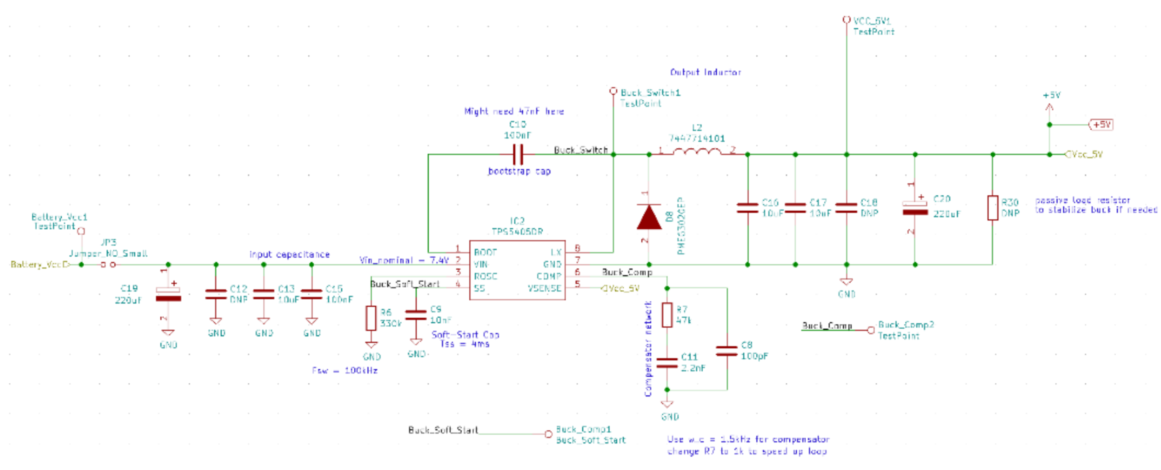


Figure 5. Linear Regulator Circuit

The voltage of the batteries varies throughout their state of charge, sometimes swinging even under 7 volts or over 8 volts. Because the radar sensor requires a stable 5V rail to operate, this buck regulator is needed to create a stable 5V rail. Using a Texas Instruments TPS5405 integrated circuit, this circuit utilizes the varying battery voltage to create a fixed 5V output. Finally, this 5V output is fed into a linear regulator as shown in *Figure 6*

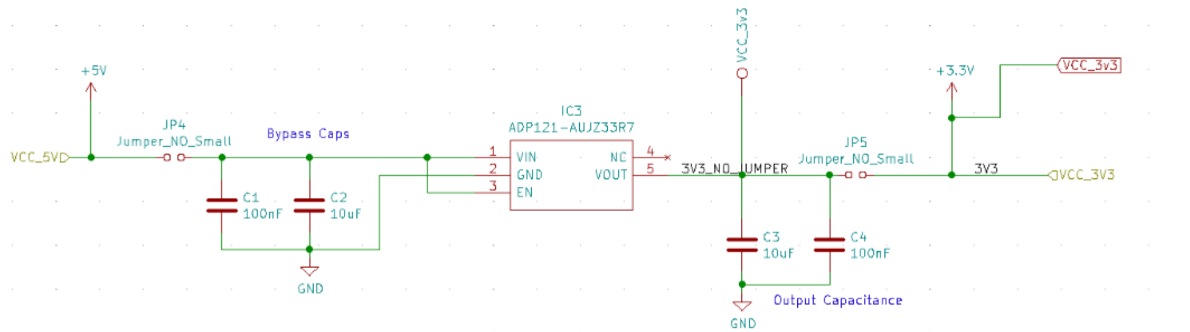


Figure 6. Linear Voltage Regulator Circuit

This linear simply creates a stable 3.3V rail to power the microcontroller. In addition to producing each of the power rails, the power PCB also drives the LEDs in the display board. It accomplishes this with the BJT driver circuit shown in *Figure 7*.

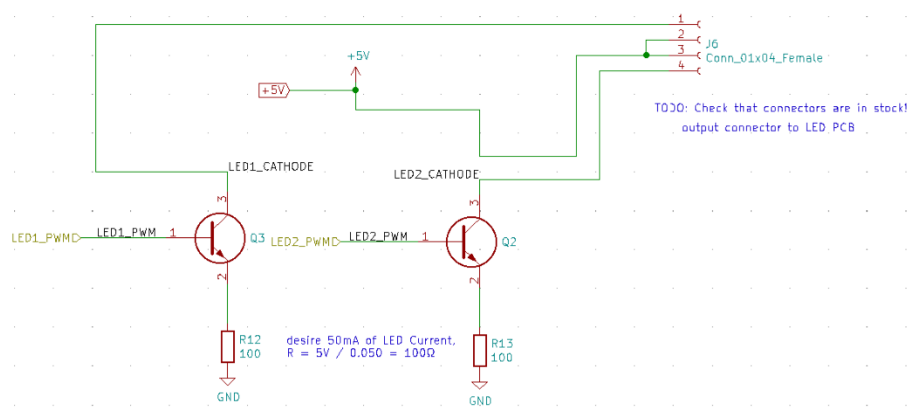


Figure 7. LED Driver Circuit Schematic

The base of each BJT connects to a PWM output of the MSP430 microcontroller. When the micro sets the voltage high, the BJT conducts and allows current to flow from base to emitter. Thus, a current flows through the LED determined by a current-limiting resistor located on the display board. When the voltage is set low, the BJT does not allow current to flow and the LEDs remain off. The power board and display board connect through the connector J6 pictured in the schematic above.

Finally, the power board has pin headers which allow it to interface with both the MSP430 microcontroller and the radar sensor. It also routes the required traces from the radar sensor to the MSP430, such as the UART RX and TX lines which carry information from the sensor to the microcontroller. A 3D render of the completed circuit board is shown in *Figure 8*.

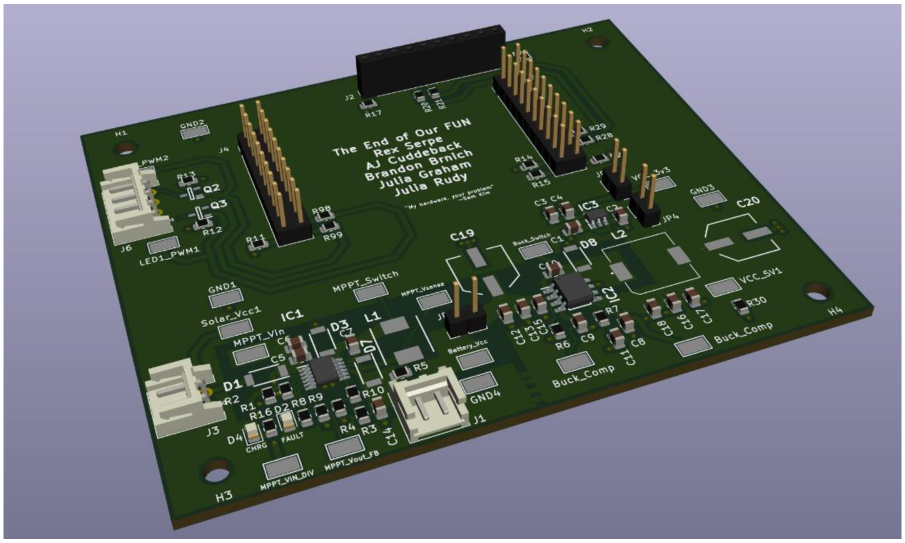


Figure 8. 3D Render of PCB Layout

Sensor

To properly read data from the sensor and obtain the information necessary to create the Sentinel, an interface needed to be created such that data could be passed from the sensor onto the MSP430. This was done by creating headers located at the top of our PCB board seen in *Figure 8*. After connected to the header pin, traces were made from the transmitter (Tx) pin of the sensor to the receiver (Rx) pin of the MSP430 header. As a result, data was able to properly flow between the sensor and our microcontroller.

Product Mounting

The physical mounting of the sensor and the LEDs are critical to the functionality of the Sentinel. There were many considerations to be taken into account. Firstly, the enclosure of the Sentinel needs to be waterproof according to NEMA Standards [21]. Secondly, the mounting needs to be rigid and sturdy to accommodate the solar panel [7], LED display, and sensor [6] on a moving vehicle. The mounting most basically consists of a front mount and back mount.

Front LED Mount

The front mount consists of a 3D printed enclosure as detailed in Figure 7, Heyco 3245 waterproof wire connector [19], jacketed wire [11], SimbaLux Acrylic Sheet Clear Cast Plexiglass top [42], 4 screws which attach the plexiglass to the printed enclosure [43], M3 screws to attach the front LED circuit board to the enclosure, flex tape [44] to further waterproof the box, and the Sincetop Bike Mount device [20]. The jacketed wires connect on each end to the PCB through a JST connector [45]. The first design step was to rigorously measure the associated components and determine design parameters. The size of the mounting adhesive from the mounting kit was measured as well: this product is shown in *Figure 23* [20]. The front box was designed to have the respective PCB board sit inside the box while discretely connecting to the waterproof connector. In the creation of the 3D box Figure 9. Side

View of Front Mount, the thickness of the walls needed to be modified in later revisions of the 3D print to reduce the required time for printing. The box was created using the Creality Ender 3 Pro printer [18]and Overture PLA Filament material [46]. Once the final revision of the box was created, the plexiglass [42] was cut using a laser cutting machine in the Architecture school [25]: this cutting was aided by DWG drawings created in Solidworks [28] [47]. The various components of the box were secured together using 3m screws from the connection of the PCB to box, Krazy glue [48]was used to provide further support to the waterproof connector joint, and Flex Tape [44] was used around the top edge of the box to ensure a tight waterproof seal. Lastly the enclosure was connected to the bike with the Sincetop Bike Mount [20].

The Front LED Mount is pictured in Figure 9 and Figure 10. The front mount is a 3D printed PLA box, with a flat piece of plexiglass screwed onto the top. The LED Display is screwed to the inside of the mount. A Heyco 3245 waterproof wire connector [19] is used to waterproof the wire connection on the bottom of the mount. In future renditions, the 3D print would include a lip around the seam of the plexiglass, to prevent water from getting in.

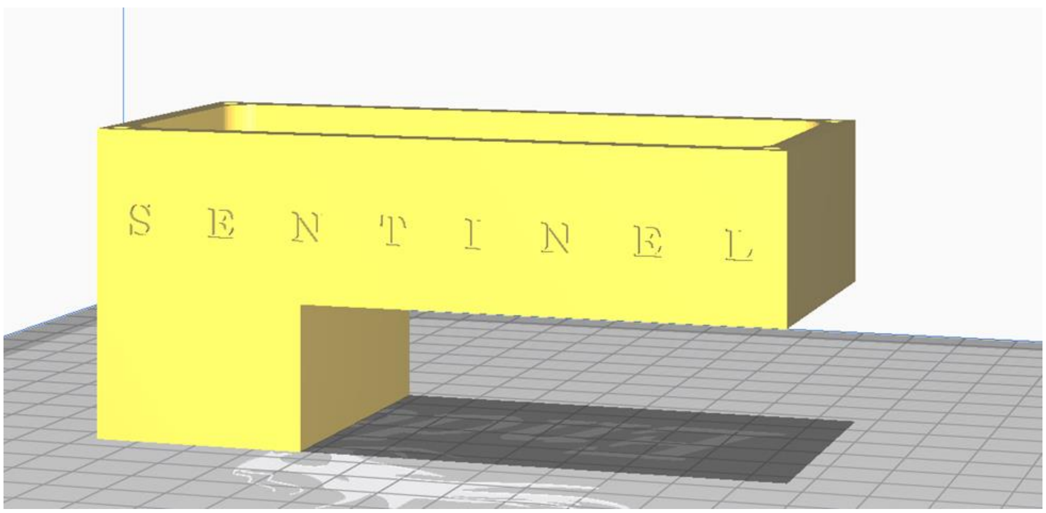


Figure 9. Side View of Front Mount

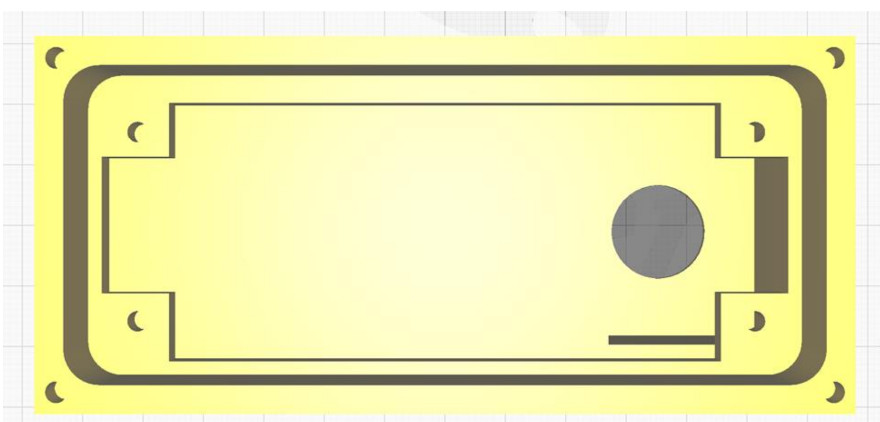


Figure 10. Bird's eye view of LED front Mount

Back Mount

The back mount consists of a 3D printed enclosure as detailed in *Figure 11*, waterproof wire connector [19], jacketed wire [11], plexiglass top [42], 4 screws, M3 screws, flex tape to further waterproof the box, zip ties [49], bike rack [50], and Krazy glue [48]. The jacketed wires connect on each end to the PCB through a JST connector [51]. The first design step was to rigorously measure the associated components and determine design parameters. The x y and z dimensions of the sensor [6], power PCB, and MSP connection were measured. Additionally, the size of the battery pack was also measured. The 3D printed PLA box was designed to have the sensor facing the rear and to sit inside the box while allowing room for connection to the waterproof connector. In the creation of the 3D box, the thickness of the walls needed to be modified in later revisions of the 3D print to reduce the required time for printing. The box was created using the Creality Ender 3 Pro printer [18] and Overture PLA filament [46]. Once the final revision of the box was created, the plexiglass was cut using a laser cutting machine in the Architecture school: this cutting was aided by DWG drawings created in Solidworks [28]. The various components of the box were secured together using 3m screws for PCB to box, Krazy glue [48] was used to provide further support to the waterproof connector joint, and Flex tape was used around the top edge of the box to ensure a tight waterproof seal. Lastly the enclosure was connected to the bike with the zip ties [49] to the bike mount [50].

The Back Mount is pictured in Figure 11. In future renditions, the 3D print would include a lip around the seam of the plexiglass, to prevent water from getting in. Additionally, the assembly process is shown in Figure 26.

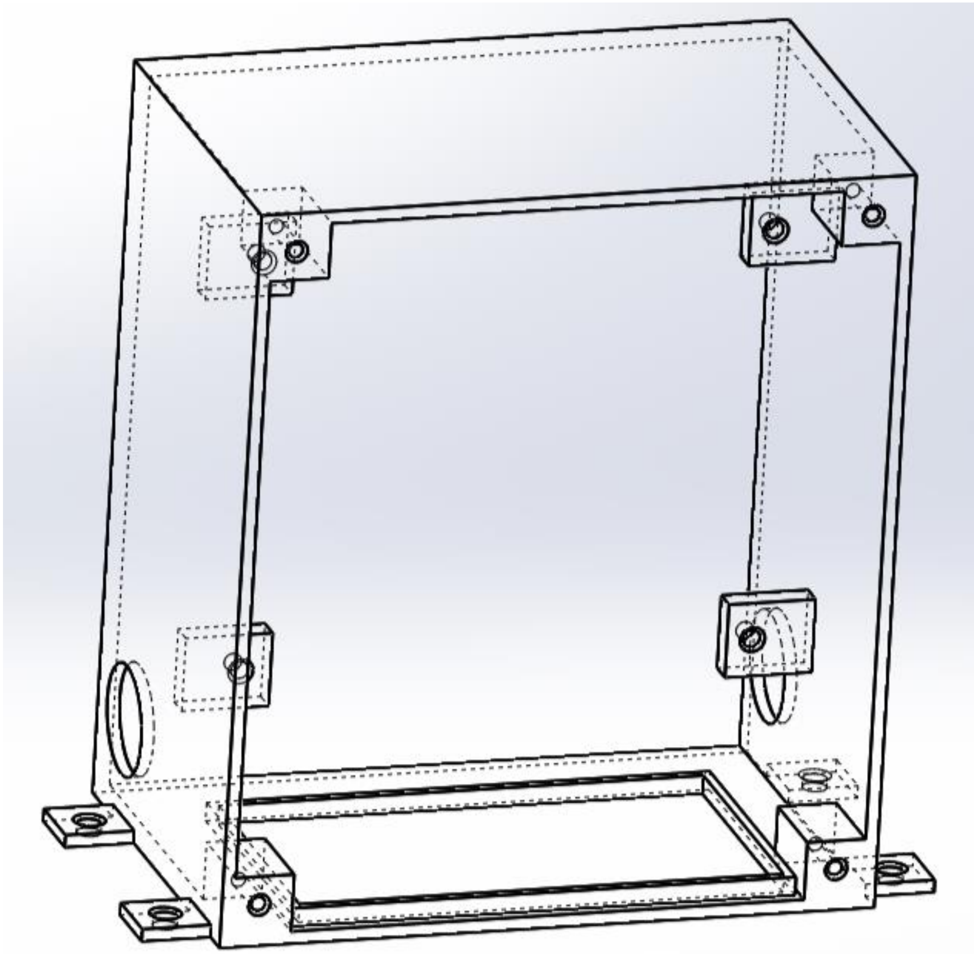


Figure 11. Side View of Back Mount Printed Box

Bike Rack Installation

The last portion of the mounting was to secure the bike rack [50] onto the back wheel. The bike rack [50] [11]was chosen because it fits most standard bicycle sizes. The screws that came with the bike rack were insufficient to ensure a sturdy connection. Additional nuts and bolts: size 6 and 8 were used to create a rigid connection [43]. The bike rack [50] is pictured in Figure 12. Also shown is the final product of the mounting to the struts of the bike. Additionally, the Solar Panel [7] was attached via plexiglass [42] and zip ties [49] to the rack.

Figure 12. Bike Rack [50]

Firmware

UART

To read incoming data from the radar sensor, UART needed to be configured on the MSP430. To begin this configuration, the respective I/O ports for the transmitter (Tx) and receiver (Rx) needed to be identified. Referring to the sensor datasheet [6], it can be seen on page 26 that the pins 3.4 and 3.3 correspond to the Rx and Tx for UART, respectively. These pins then needed their SEL bits set to 1 to enable the UART module function. Next, the respective UART registers needed to be configured such that the specifications for communication amongst the sensor and MSP430 were the same. Looking at the datasheet of the radar sensor, each data packet is configured to have 8-bits, one stop bit, and no parity bit. The MSP430 is specified to have this same configuration by setting the CTL0 register to have bits UCPEN and UCSPB set to zero. In doing so, the MSP430 knows each packet will have no parity bit and only one stop bit. Continuing with the configuration, the baud rate for the MSP430 must be set such that it is the same as the sensor. From the sensor datasheet, it can be seen it can handle baud rates ranging from 9600 through 230,400. The MSP430 is also capable of achieving this range of baud rates. However, to balance power consumption and efficient transfer of information, the group selected a baud rate of 115,200. This is an extremely quick baud rate and can be maintained with the 8MHz clock signal the MSP430 is using. To obtain these baud rates, registers UCA0BR0 and UCA0MCTL needed to be configured based on the following equations found on page 950 of the MSP430 datasheet:

$$N = \frac{f_{BRCLK}}{BaudRate}$$

$$UCA0BR0 = INT\left(\frac{N}{16}\right)$$

$$UCBRS = round[\left(N - INT(N)\right) * 8]$$

The value given from the UCBRS is what needs to be loaded into the UCA0MCTL register. From these equations, the following values are obtained:

$$N = \frac{8000000}{115200} = 69.4444$$

$$UCABRO = INT(69.444) = 69$$

$$UCBRS = round[(69.444 - 69) * 8] = 4$$

Once these values were found and their respective registers were set, the last part of the UART configuration was to enable interrupts to occur when the Rx buffer was full. This was done to allow the group to configure an interrupt service routine (ISR) to occur every time data was sent from the sensor to MSP430.

Within the ISR, the bit values taken from the register were cast into characters. Once the character representation was obtained, it was compared to the open bracket, '{', to indicate if this is the beginning of packet or not. If the character is an open bracket, then the index into the buffer would be set to 0 to signify the start of the JSON packet. In this conditional, a global Boolean is set to tell the periodic thread that parses the JSON packet that the buffer is not ready to be parsed yet. This precaution is taken to prevent parsing invalid strings which would lead to improper functionality of the system. Furthermore, another Boolean is set to true to tell the ISR that any data after this can be placed in the buffer. From this point forward, any data can be read into the buffer up until the closing bracket, '}', is detected. When the closing bracket is detected, it is placed in the buffer, and the buffer ready conditional is set to 1 to indicate to the periodic decode thread that this buffer is full and ready to be parsed.

When the code was first written, upon each interrupt triggered on the Rx pin, data would be copied into the buffer if it found itself within the two brackets. However, this is inefficient and waste clock cycles as data is constantly being written; due to the buffer ready conditional, this could cause the frequency of the LEDs to never change as it could always block it.

Therefore, another conditional was introduced into the UART ISR. This conditional was set via the periodic decoder thread to indicate that another was ready to be received. As a result, a JSON packet is placed into the buffer and decoder every 50 milliseconds.

JSON Parser

Figure 13 shows a flow chart of the period interrupt implemented. This interrupt waits until the buffer is finished copying the JSON data. If the buffer is ready (buffRead ==1), then the interrupt decodes the JSON data located in the buffer. The jsmn.h library [52] was used to parse the JSON data. The interrupt checks if the moving average of range data is within an experimentally determined threshold. This is to filter out any unexpected jumps in data. If the data is within the threshold, the sensor's range value reading is mapped to a LED blinking frequency as seen in Table II. The closer the car is to the rider, the faster the LED will blink. The flag buffReady is set to 0 to indicate the buffer is no longer ready. The wantData flag is set to 1 to indicate that a new buffer of data is ready to be filled.

Table II. Distance from Bike to LED Frequency

Distance From Bike (m)	**LED Frequency**
0 - 5	Fast Blinking
5 - 15	Medium Blinking
15 - 30	Slow Blinking
30 and above	LEDs are off

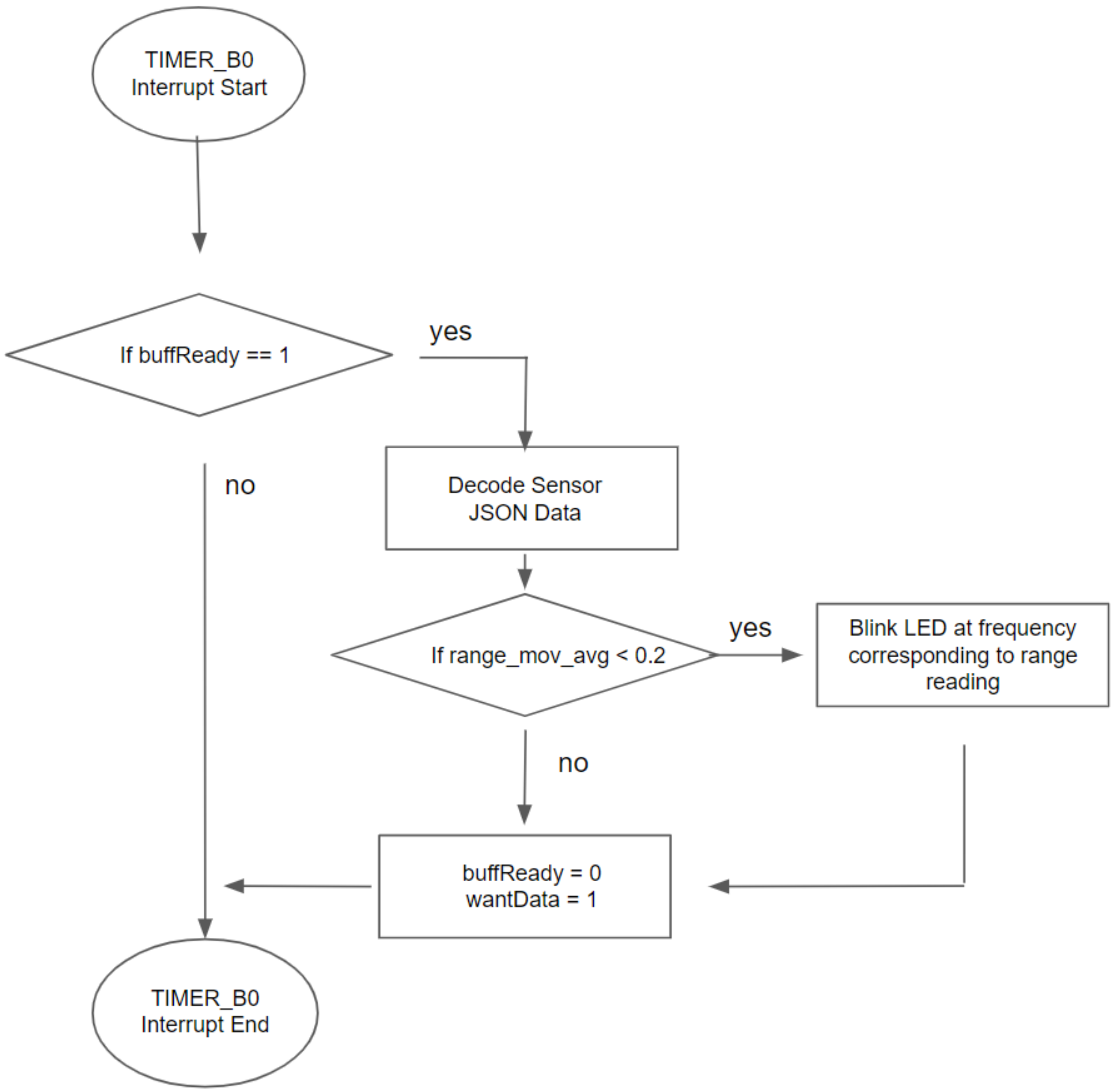
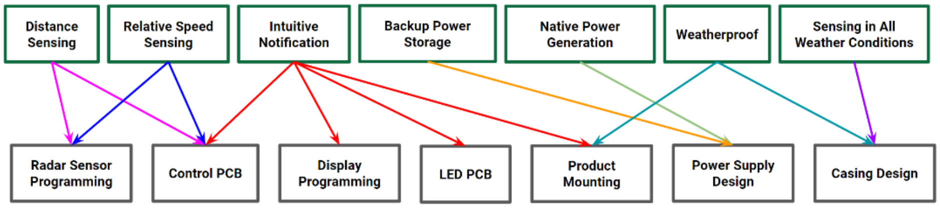


Figure 13. Software flow diagram for TIMER_B0

Project Timeline

Figure 14 shows the project task objectives broken into technical deliverables. The table outlines the team's primary and secondary responsibilities as described in the project proposal. It is important to mention that some responsibilities did shift as the project progressed. Specifically, Rex's primary role became to design both the power supply as well as the PCB for it. The reason for this is that the two tasks were so similar that having one team member design the system and another build the PCB would prove to be extremely inefficient. Therefore, the group decided to shift AJ's primary role to overall system level design and testing.



Team Member	Primary Responsibility	Secondary Responsibility
Brandon	Radar Sensor Programming	Control PCB and Display Programming
AJ	Control PCB and LED PCB	Product Mounting
Julia G	Casing Design and Product Mounting	Power Supply Design
Julia R	Display Programming	Casing Design and Radar Sensor Programming
Rex	Power Supply Design	LED PCB

Figure 14. Project Task Deliverables and Primary and Secondary Responsibilities

Figure 15 shows the initial Gantt chart for the project. *Figure 16* shows the final timeline. Many projected deadlines were shifted to later in the semester as we waited for components to arrive (product mounting and waterproofing). Furthermore, decoding the sensor data took longer than expected. Overall, tasks were able to be completed in parallel and on time once all the components arrived.

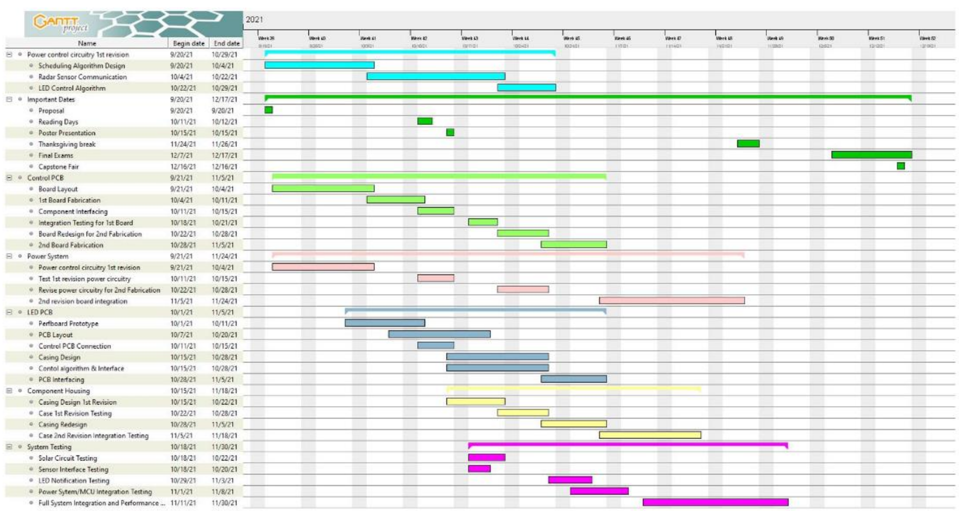


Figure 15. Initial Gantt chart from project proposal

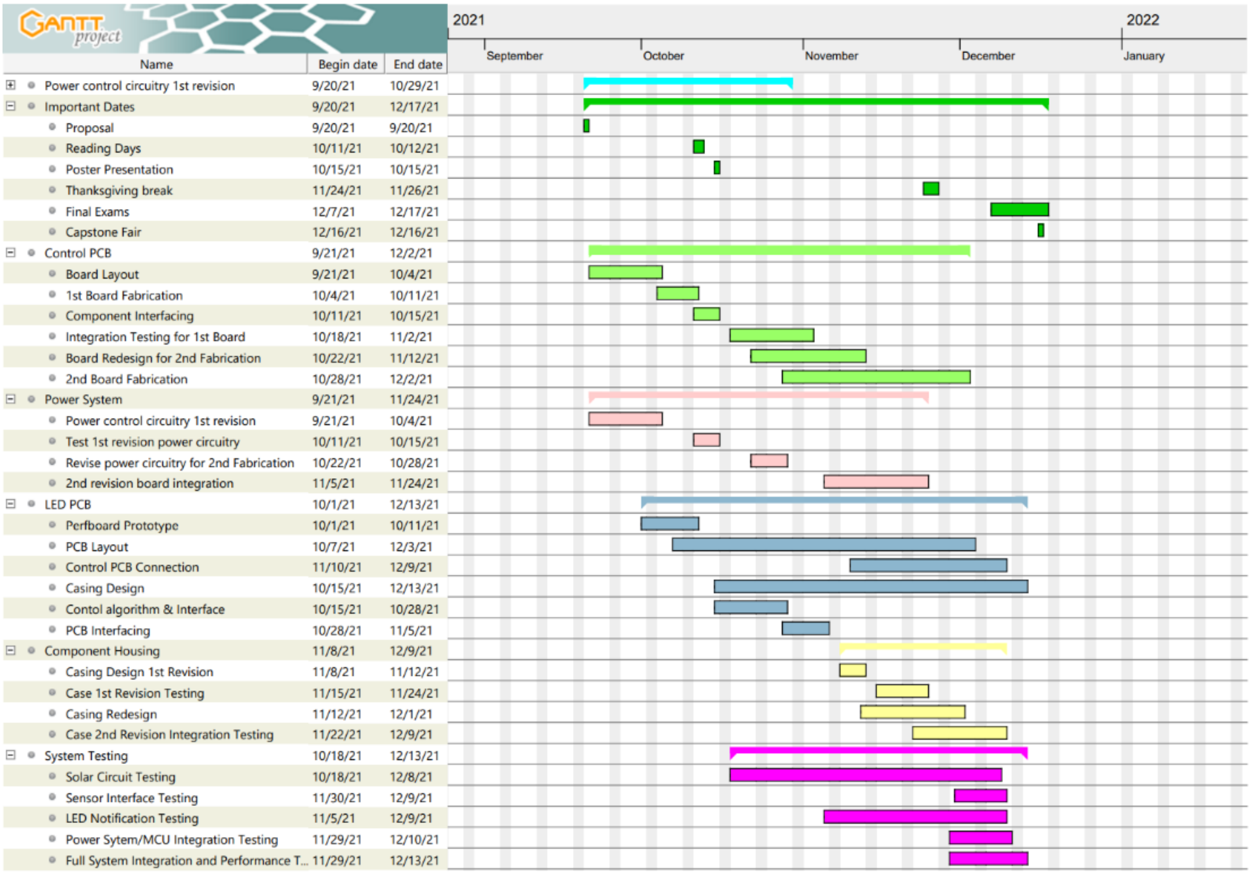


Figure 16. Final Gantt Chart

Test Plan

Metric Testing

Distance Sensing

Testing the distance is used to determine areas where the sensor is susceptible to signal noise and to establish the outer limits of our sensor's ability to detect objects. This information is used to set the sensor range filters and the bounds of our distance to flash frequency map for our notification algorithm.

Testing sensor performance requires measuring how the sensor measures the presence of cars in its field of view. This test requires a car with a hatchback to serve as the observation point, an additional car to serve as the test subject, a parking lot with standard space markings, a tape measure for taking distance measurements, a computer and serial communication client for reading the data, a USB cable, and the sensor. The serial communication client we used is PuTTY version 0.76 [16] and a detailed description of measurement configuration can be found in

Appendix . This procedure is repeated in both sunny and rainy/cloudy weather to verify that the sensor can perform in a variety of weather conditions.

To make consistent distance measurements we lined the sensor up with the border of a parking space and measured the width of the parking space to allow for quick calculation of observation position. For each measurement, we counted the full number of parking spaces within that distance and then measured the remainder of the distance from the last parking space line. For example, to measure 10m we counted three 2.72m parking spaces and finished by measuring an additional 1.84m to reach 10m (as shown in *Figure 17*).

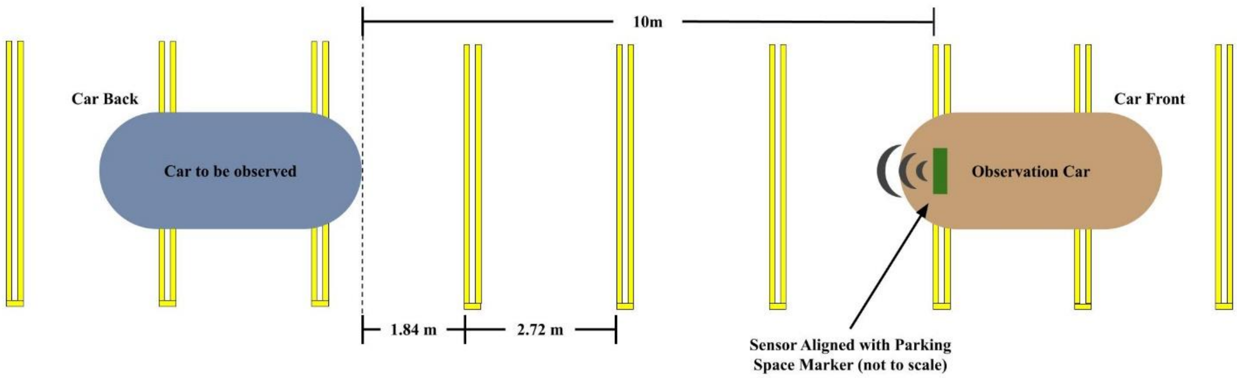


Figure 17. Experimental Setup for Sensor Measurement Testing

In the lab we noticed noise near the sensor so we first started by placing the car 10m away from the sensor to determine what noise near the sensor might prevent it from reading properly. With nothing directly in front of the sensor it consistently read 0.9m rather than picking up the car set at 10m. To rectify this problem, we set a filter at 1.5m at which point we started measuring the car at 10m. We then took measurements at 1.6m, 10m, 20m, 30m, and 40m to verify that the sensor reading scaled with car position and could detect cars at 40m, the maximum range of the sensor [6].

Our initial plan was to test in both rainy and sunny weather. During distance testing for rainy weather, however, the rain stopped and yielded a fully overcast sky. Rather than stopping the experiment, we continued to take measurements to determine if the sensor would exhibit consistent behavior despite the change in environment. The resulting data was consistent both within the rainy/cloudy weather experiment and across the rainy/cloudy and sunny weather experiments. A complete table of the data can be found in *Table VII* in

Appendix . The data are graphed in *Figure 18*.

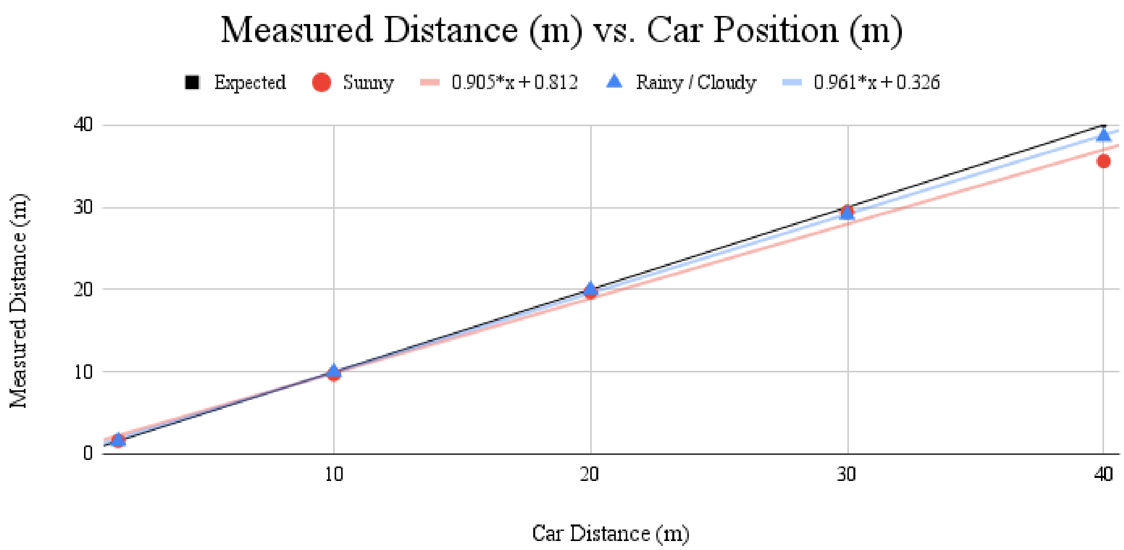


Figure 18. Measured Distance vs. Car Position for Sensor Validation

The data from both experiments show that the sensor provides measurements which have both a consistent and nearly linear trend and a low amount of absolute error.

Finally, we placed the car closer than 1.5 meters away from the sensor to observe the behavior of the sensor when the target object falls within the bounds of the distance filter. When observing objects closer than 1.5 meters, the distance measuring fluctuated greatly between near (2-5m) and far (20-30m) distances. To counteract the erratic measurements, we implemented a moving average filter to prevent the display from notifying the rider based on invalid data. The design and verification of the moving average filter is described in the intuitive notification metric test plan.

Speed Sensing

Testing for speed sensing uses the same physical setting and instrumentation as distance testing. Measurements are taken by placing the target car 60m away from the observation car. Phone communication is maintained between the driver of the target car and the team member in the observation car to inform the observer when the target car reaches its target velocity. This allows the observer to record the sensor reading for a known car velocity. Measurements are taken at 10, 14, 20, 24, and 25 miles per hour. Given that the distance measurements were accurate and consistent between weather conditions (as described in distance sensing testing) and the notification algorithm is based only on car distance (as described in the intuitive notification test plan), the experiment was only conducted in rainy/cloudy weather.

The speed sensing showed a linear relationship between the car speed and measured speed, with the caveat that the car speedometer consistently read around 3.5 mph faster than the measurement from the sensor. The full results can be found in **Error! Reference source not found.** in

Appendix and are summarized in *Figure 19*:

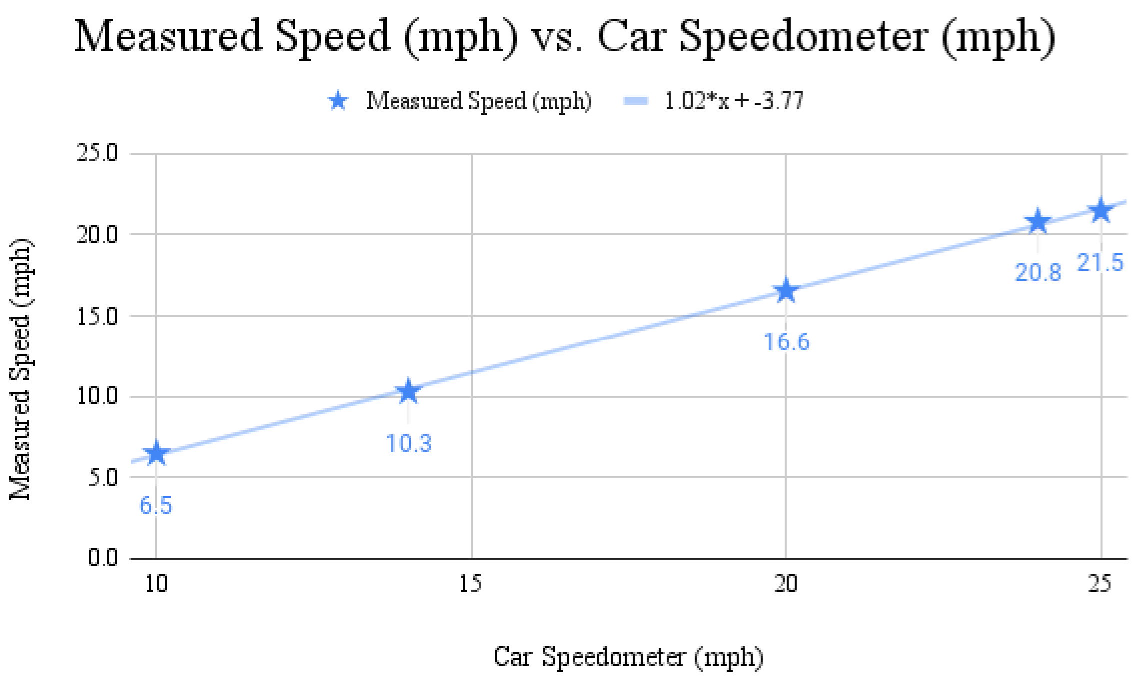


Figure 19. Measured Speed vs. Car Speedometer for Sensor Validation

The offset between the measured speed and car speedometer does not pose an issue for the performance of our sensor as a constant offset between speedometer and actual speed is not an unusual characteristic of European cars [53]. The target car was a 2004 BWM s5 which, as a European car, can be reasonably expected to have that performance. Furthermore, as long as the offset is consistent it can be adjusted for in software.

Intuitive Notification

Notification Algorithm Design Validation

The notification system for our product was designed explicitly because of end-user feedback to determine what type of notification would be considered intuitive. To determine the appropriate algorithm for notification of approaching cars we began by first identifying what a possible signal might look like. We determined that a reasonable initial notification algorithm would flash slowly if the detection of the approaching vehicle was not urgent, and flash quickly if the presence of approaching vehicle was urgent. Rather than deciding a-priori what kind of sensor data corresponds to an "urgent" signal, we elected to conduct a survey of frequent cyclists to determine how they would intuitively interpret a light display with a changing flash frequency.

The survey contained two videos of a lightbulb with a changing flash frequency wherein one video captured an increase in flash frequency and the other captured a decrease in flash frequency. For each video, participants were first asked to identify if and how the signal was changing in urgency and then asked to describe the motion of the car described by the notification signal. After asking participants to describe the signal we asked a series of demographic questions to provide context to our responses if we obtained inconsistent results. A full copy of the survey is included in

Appendix .

The results of the survey showed that most respondents could identify that the signal was changing urgency, as shown in *Figure 20*:

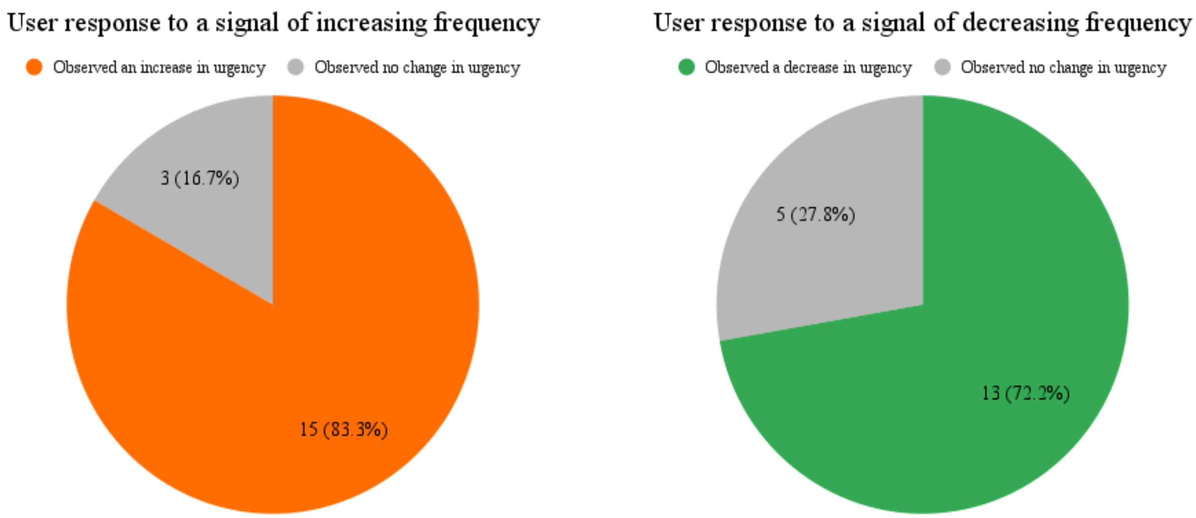


Figure 20. Responses from 18 target users asked to identify if a signal was changing urgency

While fewer respondents could identify when the signal was getting less urgent, it is preferable that the users err on the side of seeing notifications as urgent as it is better to avoid a collision that might happen than to fail to avoid a collision that does. Additionally, all target users that responded that the signals were changing in urgency associated the change in urgency with a change in distance with only a few associating the change in urgency with a change in speed as well as distance. The breakdown of these responses can be found in

Appendix .

Following the completion of the survey, we determined that the most intuitive algorithm for our system would be one that maps the distance of approaching objects to the period of the light bulb flashes. The resulting notification displays a slow flash frequency when cars are far away from the device and a fast flash frequency when they care close to the device.

When performing field testing, it was found that under 1.5m range readings, the sensor would read sporadic unexpected range readings. A moving average of range readings was implemented to ignore any readings that were drastically unlike recent samples. (A moving average keeps track of the average change in data over time). If the moving average was less than 0.2, It means that the data being read was relatively stable and was not counting any extraneous sporadic data. By pointing the sensor at a stationary wall, it was experimentally determined that readings with a moving average of under 0.2 m filtered out any unexpected jumps in data since the LEDs would always blink at the fastest frequency when an object was within 1.5 meters.

Notification Algorithm Performance Verification

Testing UART Communication

Prior to creating the intuitive notification display, the group needed to first verify that data was being properly read into the MSP430 via the UART protocol. This test was done by first connecting the Tx pin of the radar sensor to the Rx pin (3.4) of the MSP430. Once this was done, the radar sensor was connected to a 5V power supply. It is important to mention that for this test, the radar sensor cannot be connected via USB. Once a USB connection is made from the sensor to another device, the communication protocol switches and UART is ignored. Therefore, the battery supply was used to power both the radar sensor and MSP430 for the purposes of the two sharing a common ground. The group found the signals to be a bit noisy when reading the oscilloscope when the MSP430 was powered by the computer.

In order to verify, the code needed to be reconfigured such that when an interrupt was triggered by the Rx data buffer being filled, the data was placed into the Tx buffer rather than being placed into the buffer for parsing. Once this is done, an oscilloscope can be placed on both the Tx pins on the sensor and MSP430 (pin 3.3). The results of this test can be seen on *Figure 21* where two separate square waves should appear. These square waves represent the bits of information being sent from the sensor to the MSP430. When looking at these waveforms, the waveform reading the Tx pin of the MSP430 should lag slightly behind that of the radar sensor. This is because there is a delay between the MSP430 receiving the data and waiting for the Tx buffer to be free.

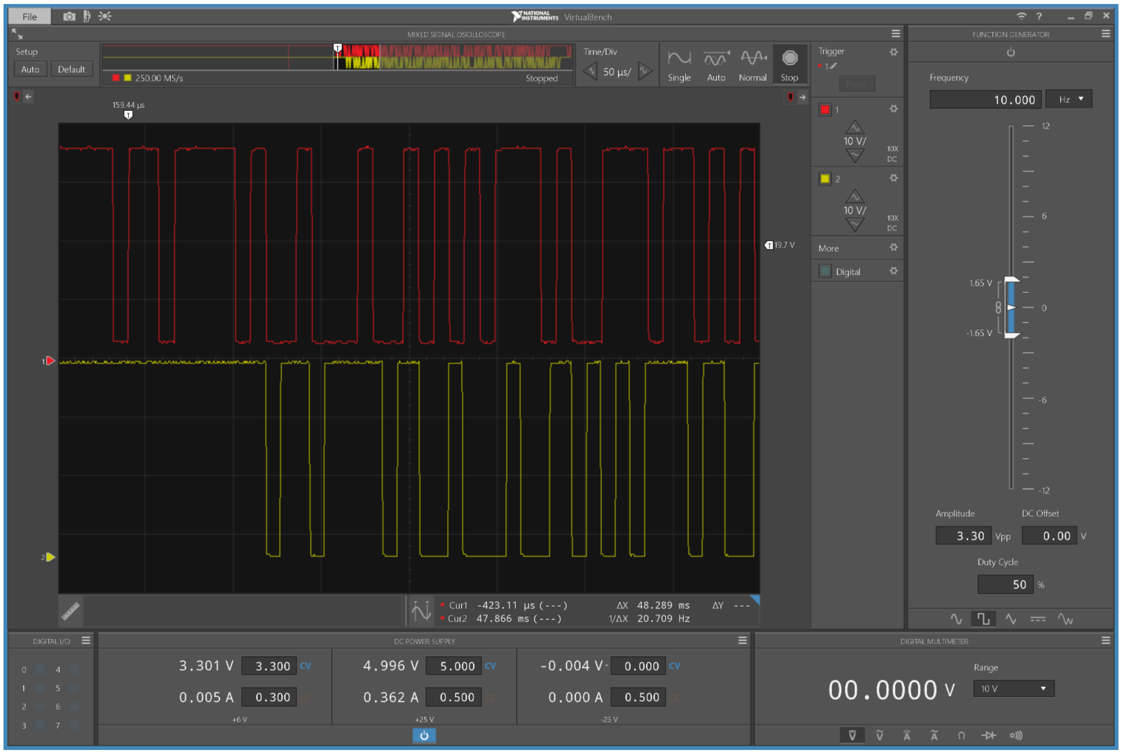


Figure 21. UART verification displaying data transfer

After verifying that the UART connection between the radar sensor and the MSP430 is made, testing that the data is properly placed in the translation buffer needs to be done. This test is done by connecting the Tx pin of the sensor to the Rx pin of the MSP430. The ISR of the Rx pin on the MSP430 is also adjusted to copy the given data into a buffer. Lastly, the MSP430 should be connected to the user's laptop running CCS to use the expressions window. After the system is configured, code execution can begin, and the user can look at the translation buffer. When looking at this buffer, the user should be able to see JSON data where each index in the buffer corresponds to a respective character in the JSON string.

Testing the JSON Parser

The jsmn.h header file JSON library parser was used to parse the incoming JSON data from the Rx data buffer. The Rx data buffer is a pointer to a JSON string with the following key value pairs:

"{\"unit\": \"m\", \"range\": range_reading_as_a_float}"

The sensor was held from the wall at varying distances and the float value from the range reading was compared to the in-life distance. The JSON parser was overall able to properly extract a float reading from the JSON string.

The frequency at which the UART buffer data is read is controlled by a periodic timer, TIMER_B0. TIMER_B0 is configured to run at a 20 Hz frequency. *Figure 22* shows the LED being turned on and off for port pin 2.4 with a 20 Hz frequency, confirming the interrupt's timing.

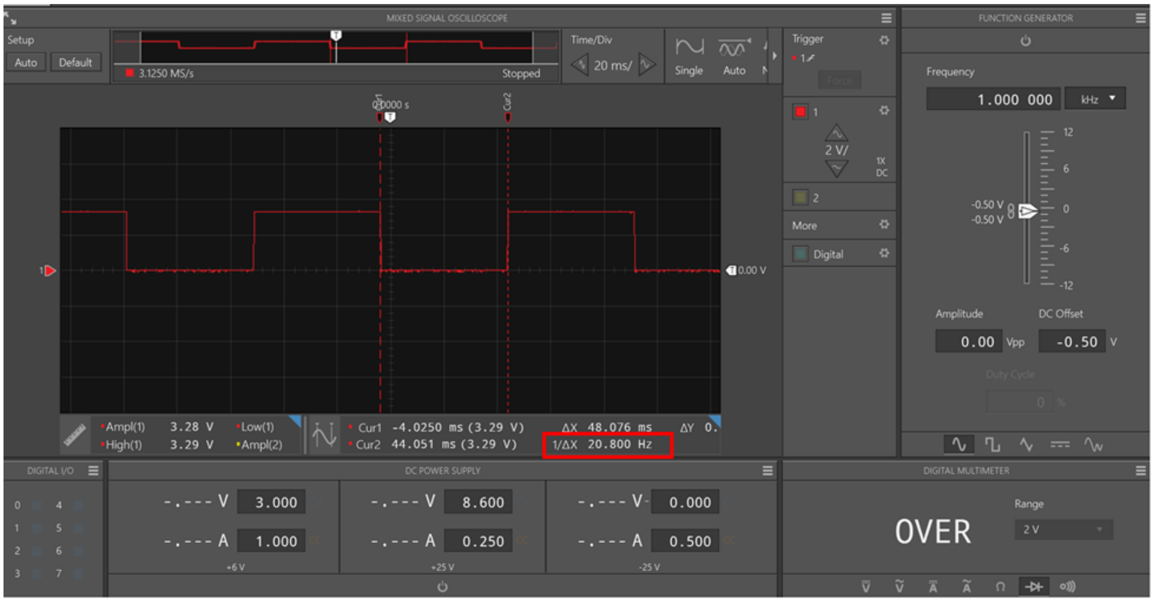


Figure 22. TIMER_B0 interrupt PWM signal with a 20 Hz Frequency

Weatherproof Testing

NEMA3 standards [21] requires the Sentinel to be resistant to mist and rain. A paper towel was placed in each of the 3D encapsulations. Once these enclosures were properly sealed, each of them was placed under a sink faucet for a 30 second duration. After this period ended, the enclosures were opened, and the paper towel was removed. Each of the paper towels taken from the 3D printed models came out completely dry. Photos from this testing can be found in Appendix Test Plan.

Electrical Component Testing

Verifying MPPT Functionality

The MPPT functionality of the assembled board needed to be verified. To test this, a fluorescent bulb was placed at a fixed distance from the solar panel and run into the MPPT. Originally, the circuit was not functioning effectively and significant amount of current was being dissipated in the MPPT circuit. However, by switching to a catch diode with a lower forward voltage, the efficiency was improved significantly. Ultimately, the MPPT tracker was able to operate at an efficiency of nearly 90%.

Verifying Voltage Regulator Functionality.

Both the 5V switching regulator and 3.3V linear regulator needed to be verified. The linear regulator functioned perfectly out of the box, as it was a very simple integrated circuit effectively only containing two passive components. However, the 5V switching regulator was unstable with low input voltage at startup with low load. This was improved by adding additional bulk capacitance to the input and output of the regulator, as well as a small bias load.

Final Results

Summary of Success Metrics

Each of the deliverables outlined in the objective tree (*Figure 1*) corresponds to a metric by which the success of this project is evaluated. *Table III* provides a summary of the project success metrics and their corresponding point values.

Table III. Summary of Project Success Metrics

	0	1	2	3	4	5
Distance Sensing	Cannot detect any objects	Can detect the presence of an object up to 5m away	Can detect the presence of an object up to 10m away	Can detect the presence of an object up to 20m away	Can detect the presence of an object up to 30m away	Can detect the presence of an object up to 40m away
Relative Speed Sensing	Cannot detect when a car is approaching too fast	Can very rarely detect when a car is approaching too fast	Occasionally can detect when a car is approaching too fast	Can sometimes detect when a car is approaching too fast	Can detect when a car is approaching too fast most of the time	Can detect if a car is approaching too fast
Intuitive Notification	Does not alert based on sensor data	Very rarely alerts based on sensor data	Occasionally alerts based on sensor data	Sometimes alerts based on sensor data	Mostly alerts based on sensor data	Always alerts based on sensor data
Backup Power Storage	No backup power storage	Backup power for up to 30 minutes of use	Backup power for up to 1 hour of use	Backup power for up to1 hour & 30 minutes of use	Backup power for up to 2 hours of use	Backup power storage giving 2 or more hours of use
Native* Power Generation	No native power generation	Power generation for up to 15 minutes of use	Power generation for up to 30 minutes of use	Power generation for up to 45 minutes of use	Power generation for up to 1 hour of use	Native power generation for 1 or more hours of use
Weatherproof	Is not waterproof		Can withstand low levels of water (mist)			Can withstand rain
Sensing in all weather conditions	Does not work in any weather conditions	Works in sunny weather conditions	Works in partially cloudy weather conditions	Works in cloudy weather conditions	Works in rainy weather conditions	Can provide full capability in a variety of weather conditions

*Native power generation requirements define how long the system can run off one full day of solar charging.

After a point value is assigned to the implementation of each objective based on the metric table, the points are totaled to determine the final score of the project. The conversion from point values to letter grade as written in our initial proposal can be found in *Table IV*.

Table IV. Conversion from point value to letter grade

Points	Grade
32	A
27	B
21	C
17	D

Fulfillment of Objectives

Distance Sensing

Based on the results of our sensor testing, we have fulfilled the metric item “can detect the presence of an object up to 40m away.” While the sensor never reported a reading of 40m or greater, it did detect the presence of the car when it was 40m away meaning that it would still trigger the display from a physical distance of 40m. As the exact sensor measurement is abstracted in encoding distance data as a flash frequency, it is sufficient for our purposes to simply detect the presence of a car 40m away. Furthermore, the accuracy of the distance sensing is better as the sensor is closer to the detected object where accuracy is more important. Finally, as our notification algorithm is relative, the exact values of the distance are abstracted away when converting car distance to display flash frequency. Therefore, the resulting score for this metric as defined in the rubric is 5 points.

Relative Speed Sensing

From the results seen in the speed sensing section of the report, the conclusion can be reached that our product is able to properly detect the relative speed of the oncoming vehicle. From the graph seen in *Figure 19*, the speed that the sensor is reading is off by a constant offset of about 3.7MPH. However, as previously explained, a constant offset is both not unexpected nor is it problematic or the system. Therefore, we can justify that our device can properly detect if a vehicle is approaching too fast.

Intuitive Notification

Based on the results of our sensor testing, we have fulfilled the metric item “always alerts based on sensor data.” Our notification algorithm was developed through user-focused design validation and tested sufficiently to show that the firmware correctly obtained readings from the sensor and actuated the LED display based on those data. The functionality of the LEDs switching frequency based on object distance is best seen in the demo video, submitted for consideration alongside this paper.

Backup Power Storage

The capacity of our battery pack is 13.32Wh. This number is still achieved even by conservatively limiting the battery state of charge to between 20% and 80% to improve lifetime.

The power consumption of the system was measured at 2.3W with the display illuminated, which represents a worst-case consumption. A capacity of 13.32Wh can supply 2.3W for about 5.8 hours, which is more than sufficient to fulfill our metric of 2 or more hours of power storage.

Native Power Generation

A power budget analysis estimated a worst-case power consumption of 2.294W, and characterization of the real system showed a true power consumption of 2.3W. System tests also revealed a 4.3W peak power production under realistic conditions. From a power budget analysis, we have determined that the system can generate 2.35Wh of energy from our solar system on a worst-case day, which will be sufficient to power the system for 1.02 hours. Given our power generation capability of about 4.3W and peak power consumption of 2.3W, this hour of battery life can be recovered easily within one hour of charging even in less-than-ideal conditions.

Weatherproof

To create a robust and durable system, the Sentinel needs to be resistant to multiple weather conditions. The results of our paper towel waterproof testing showed that our boxes could withstand heavy amounts of moisture. Therefore, we have determined that our product is able to withstand rain providing the group with a score of 5 in this category.

Sensing in all Weather Conditions

Given that the results of our distance testing showed consistency between rain and overcast weather within one single experiment as well as consistency between rain/clouds between two experiments, we have determined that our system can accurately sense cars in cloudy, sunny, and rainy weather conditions. Based on our metrics, the ability to accurately sense cars in a variety of weather conditions awards us with a score of 5 for this metric.

Final Grade

Following testing of all our metrics, we have received the highest possible score in each objective category. This results in a final score of 35 for the completion of our project.

Table V. Summary of objective categories and points awarded totaling 35 points

Metric	Qualification	Points Awarded
Distance Sensing	Can detect the presence of an object up to 40m away	5
Relative Speed Sensing	Can detect if a car is approaching too fast	5
Intuitive Notification	Always alerts based on sensor data	5
Backup Power Storage	Backup power storage giving 2 or more hours of use	5
Native* Power Generation	Native power generation for 1 or more hours of use	5
Weatherproof	Can withstand rain	5
Sensing in all weather conditions	Can provide full capability in a variety of weather conditions	5

According to the point value to letter grade conversion in *Table IV*, our project meets the highest point value possible in the “A” range.

Costs

Table VI outlines the final total cost of the project at 585.57 dollars. Sentinel went over budget, mostly due to the cost of the radar sensor ($229). Furthermore, many components were bought for time-efficiency instead of being 3D printed, such as the bike mounts. Sentinel's cost in the future could be drastically reduced if the RF layout and power PCB were manufactured on the same chip.

Table VI. Final Total Cost of Sentinel

Solar	**Component**	**Quantity**	**Cost per Line Item ($)**
	Solar Array	1	40
	Battery	1	10
Sensors			
	OPS243-C-FC-RP	1	229
LED Display			
	LED	1	5
	Misc. Wire Connection	-	15
3D Printing			
	Filament	-	50
	Plexiglass	2	23
	Handlebar Mount	1	18.93
	Waterproof wire connectors	5	15
MCUs			
	MSP430G2744IDA38	1	0
PCBs			
	2 boards, 2 send outs	2	66
Power Components			
	Order 1	1	45.86
	Order 2	1	36.98
	Order 3	1	15.91
	Order 4	1	45.05

Future Work

The main improvements to be made to the system are centralized on the idea of extending the display system that was described in this paper. Limiting the product to just using LEDs for notifying the cyclist leads to difficulties in describing more extensive information than immediate danger. For example, our current product can distinguish that there is an object approaching and intuitively notify the rider based on this information. However, if there are multiple vehicles in the vicinity, then there is no mode to notify the user of this case. Furthermore, despite the location of the vehicle in the field of view of the sensor, the display will give the same indication and not provide any indication of direction. While our product properly alerts cyclists of oncoming vehicles, the states could be extended to provide more useful information.

Furthermore, more of the computational power of the microcontroller could be utilized by connecting our product to the internet of things (IoT). By connecting this product to the IoT, data could constantly be tracked and analyzed to provide cyclists with more information about the routes they take for their routes. For example, by tracking the number of cars detected on a cyclist's commute, we could offer alternative routes that are known to have a fewer number of vehicles during that time of day.

There are also many improvements that could be made to the power system. One such improvement would be to add a passthrough circuit to the MPPT such that the solar panel could supply the power regulators instead of the power when sunlight was present. This could increase the overall efficiency of the system. Additionally, the switching frequency and component selection in the 5V regulator could be further optimized to increase efficiency. Both improvements would reduce power consumption and increase battery life. Finally, the radar sensor could be optimized for power consumption. Because it represents the primary power consumption in the circuit, this could reduce solar panel area size and required battery capacity, reducing both size and weight.

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Appendix A

Figure 23. Handlebar mount for LED Display

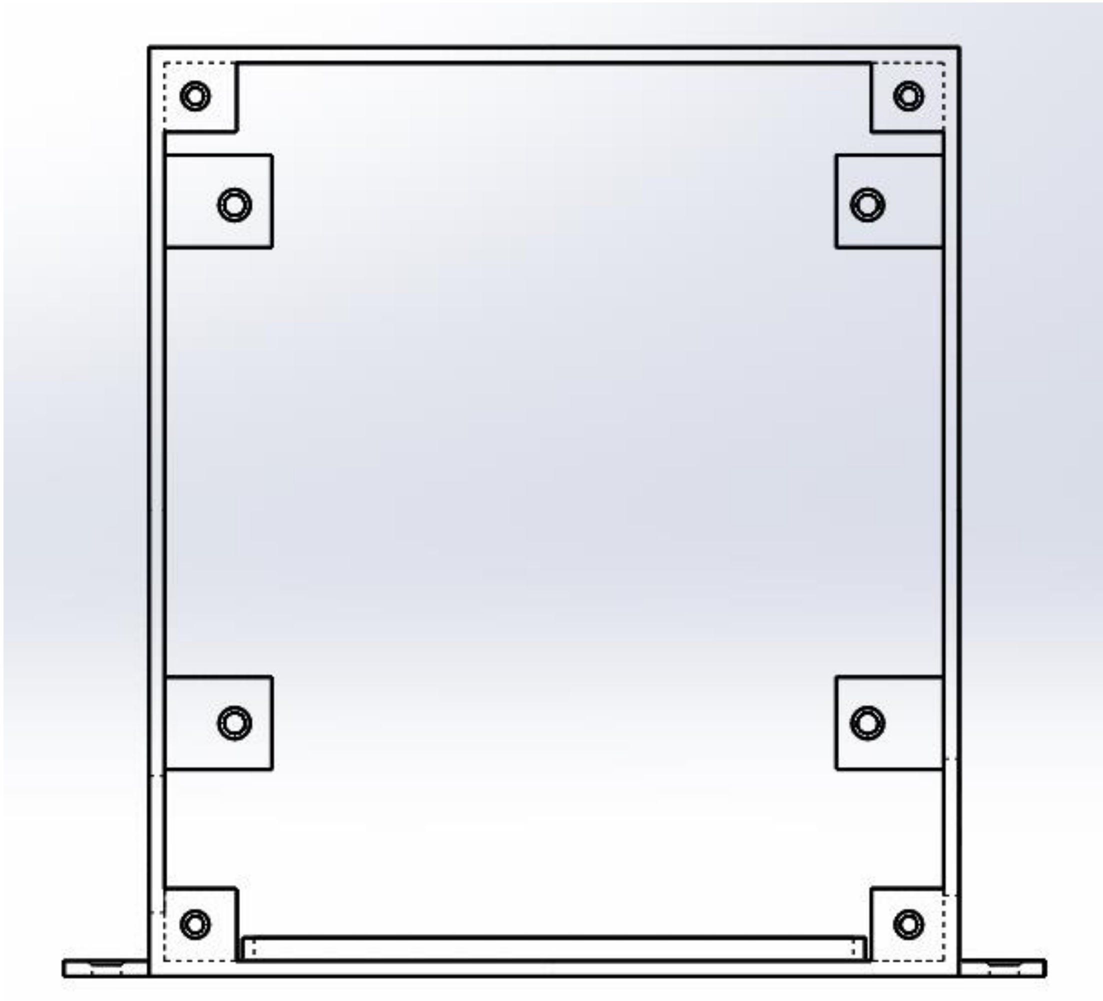

Figure 24. Back View of Back Mount Printed box

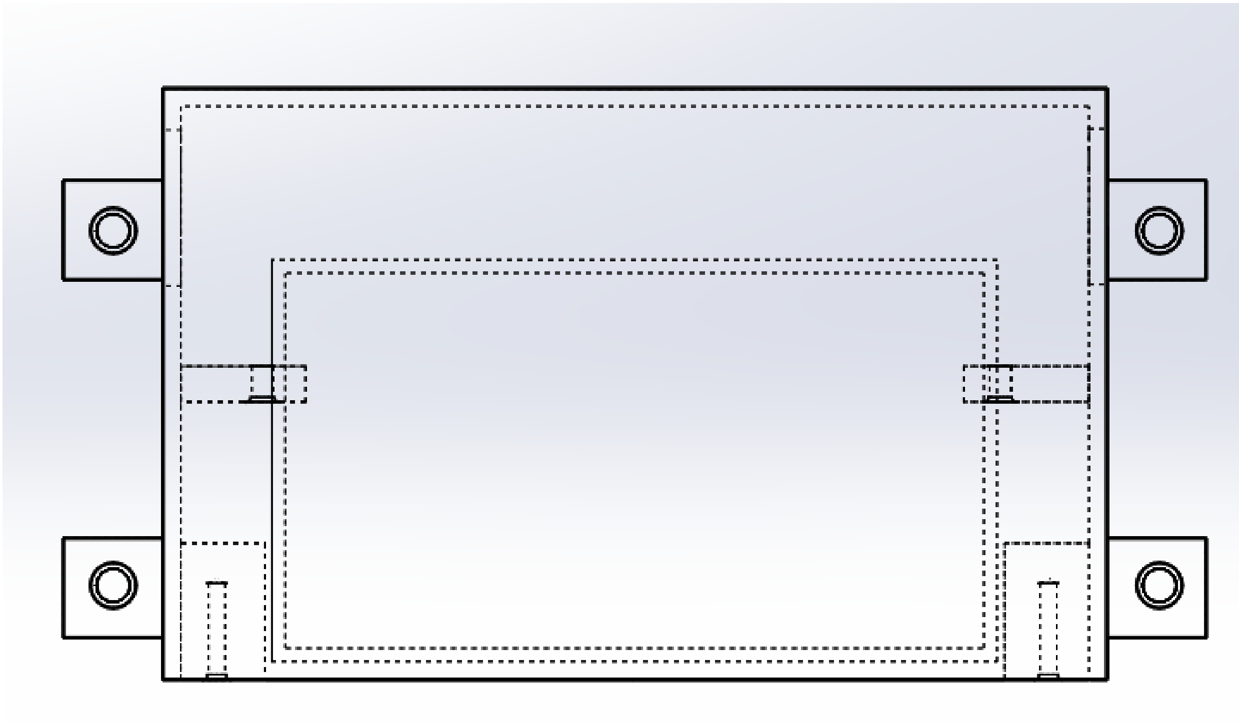

Figure 25. Top View of Back box

Figure 26. Construction of Back Box

Figure 27. Securing of Bike Rack

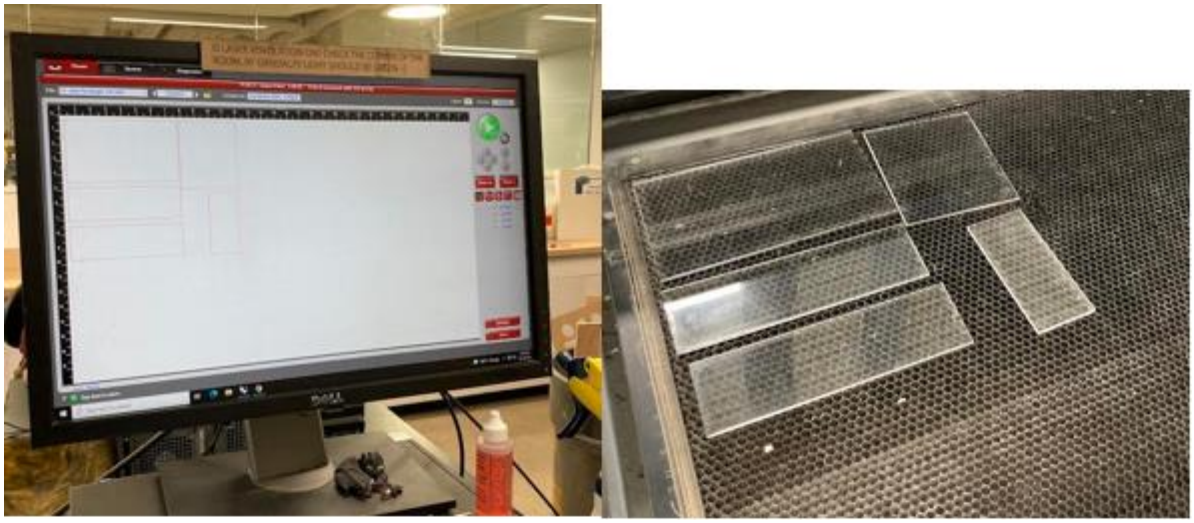

Figure 28. Laser Cutting Process

Appendix B

Sensor Testing Configuration

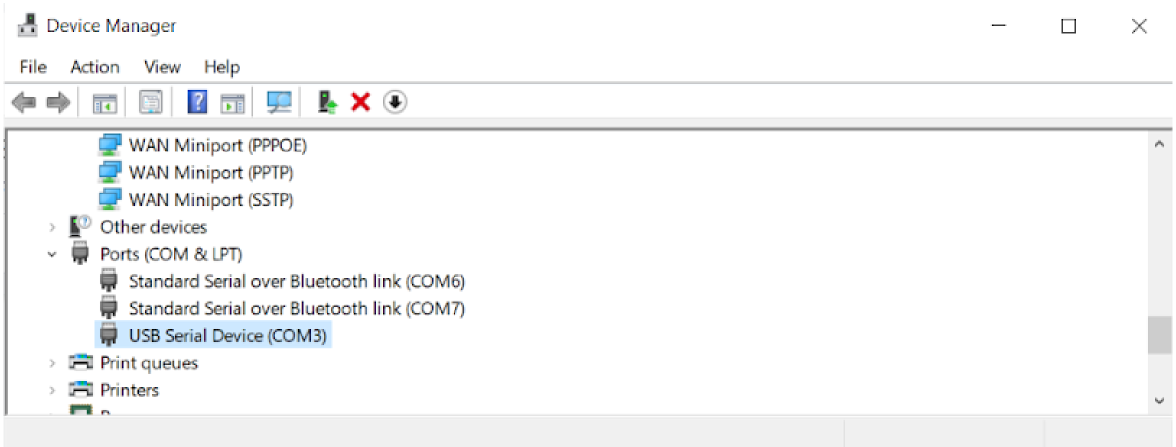

Figure 29. Identification of the sensor in Windows Device Manager

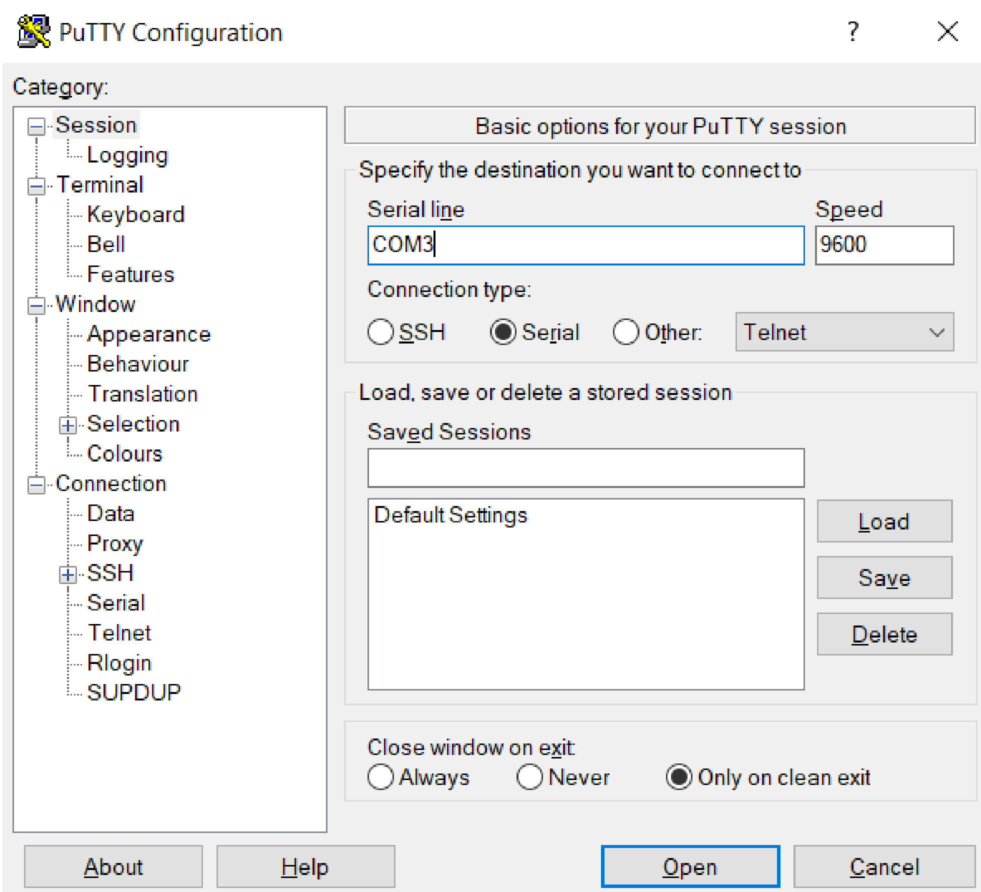

Figure 30. Default configuration to read OPS 243-C sensor data via PuTTY terminal

Distance Sensing

Table VII. Distance sensing verification data

	Measured Distance (m)		Absolute Error (m)		Percent Error (%)	
Car Position (m)	Sunny	Rainy/Cloudy	Sunny	Rainy/Cloudy	Sunny	Rainy/Cloudy
1.5	1.6	1.6	0.1	0.1	6.7	6.7
10	9.7	10	0.3	0	3	0
20	19.7	20	0.3	0	1.5	0
30	26.4	29.1	0.6	0.9	2	3
40	25.6	38.6	4.4	1.4	11	3.5

Speed Sensing

Table VIII. Data for sensor speedometer verification

Car Speedometer (mph)	Measured Speed (m/s)	Measured Speed (mph)	Difference (mph)
10	2.9	6.5	3.5
14	4.6	10.3	3.7
20	7.7	16.6	3.4
24	9.3	20.8	3.2
25	9.6	21.5	3.5

Intuitive Notification

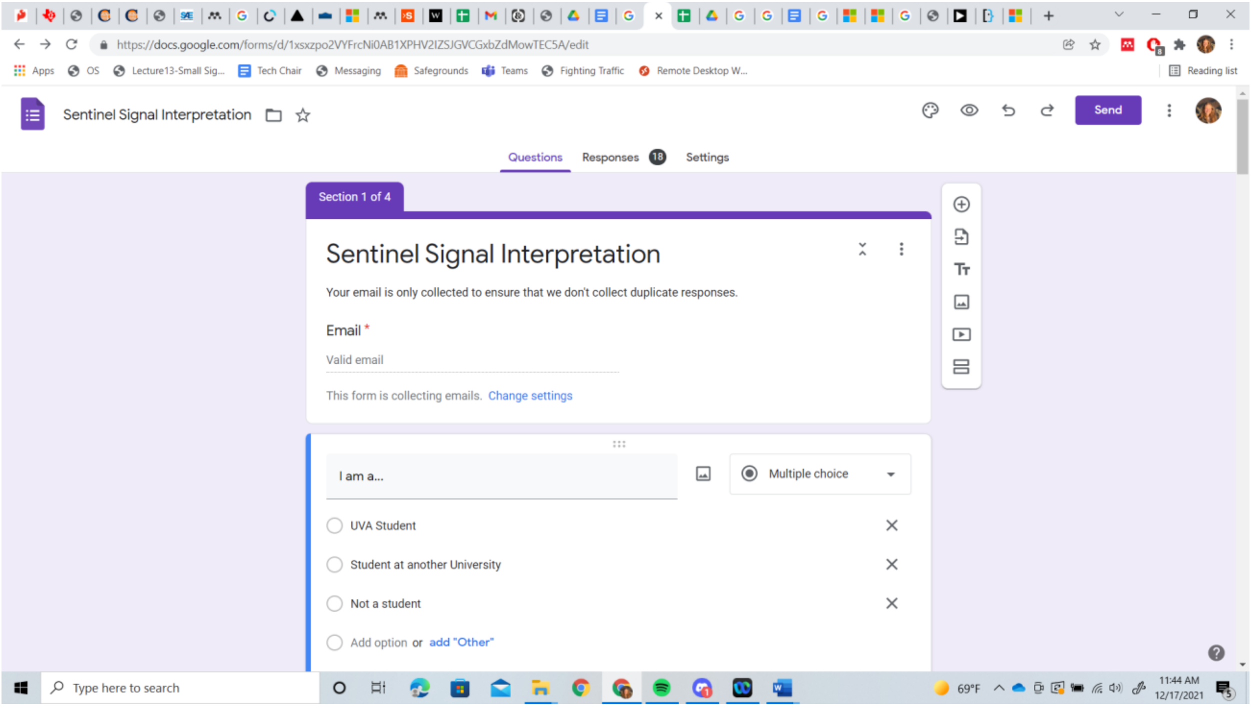

Figure 31. Initial survey questions

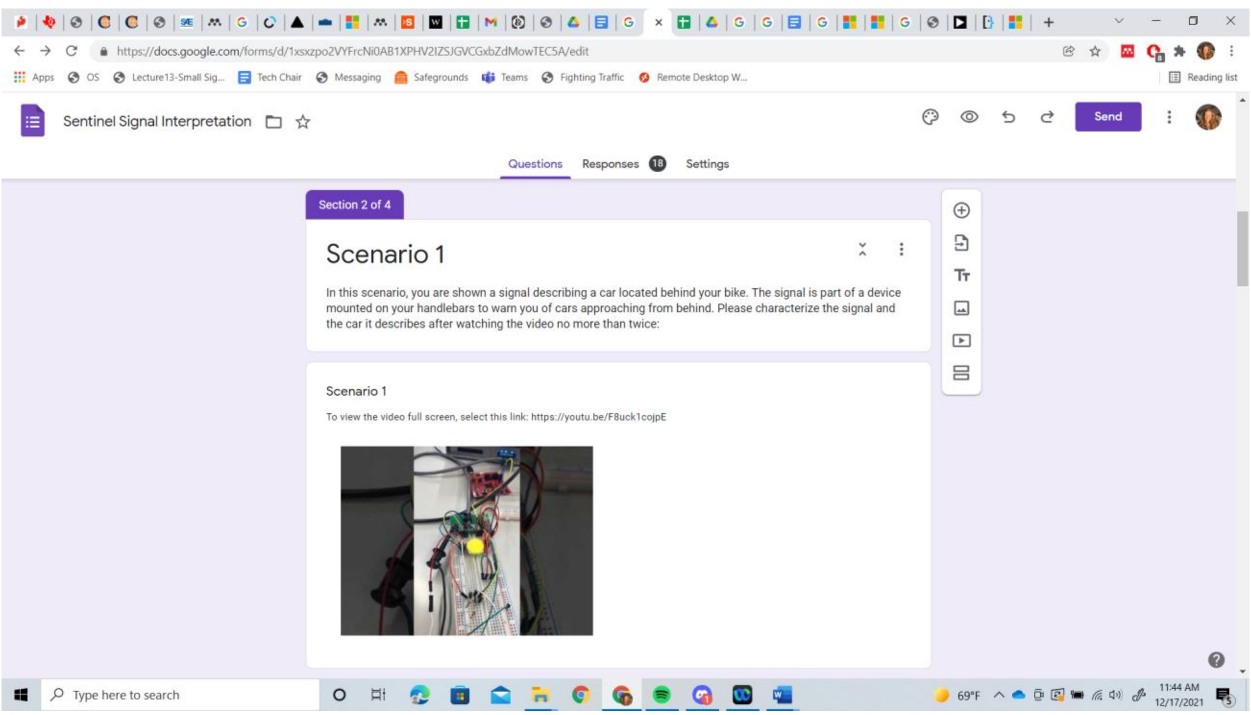

Figure 32. First scenario setup in survey

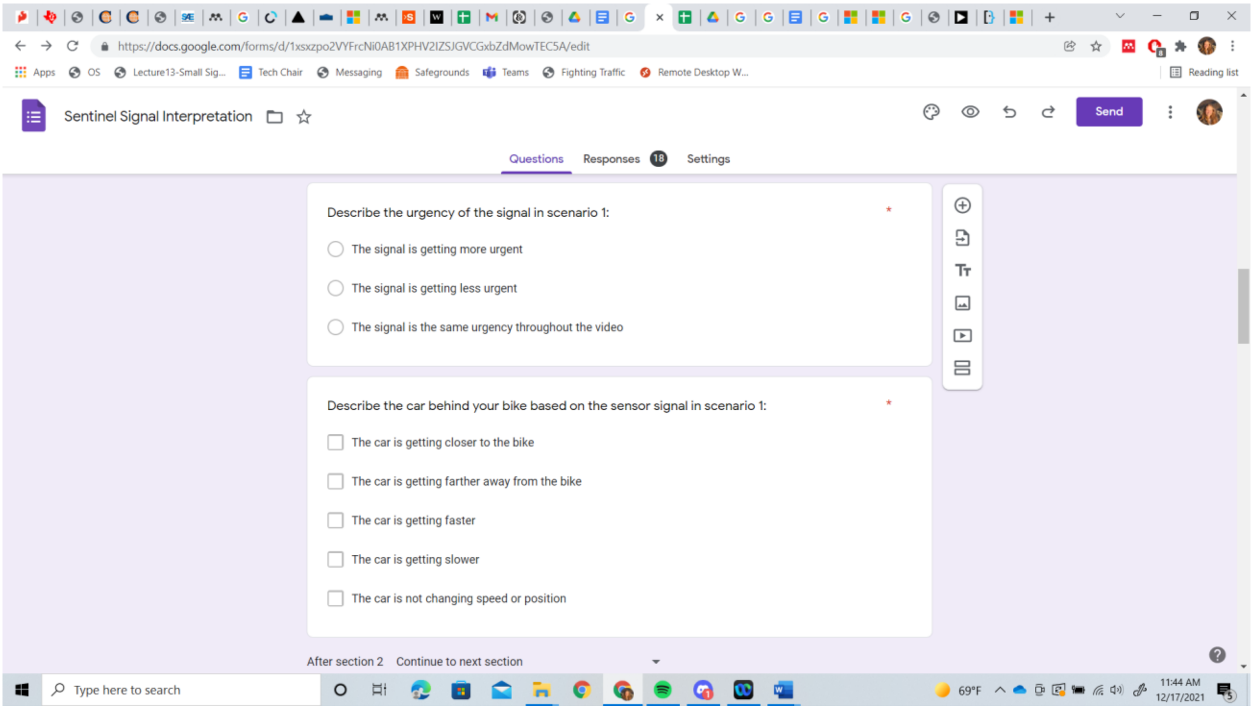

Figure 33. First scenario questions in survey

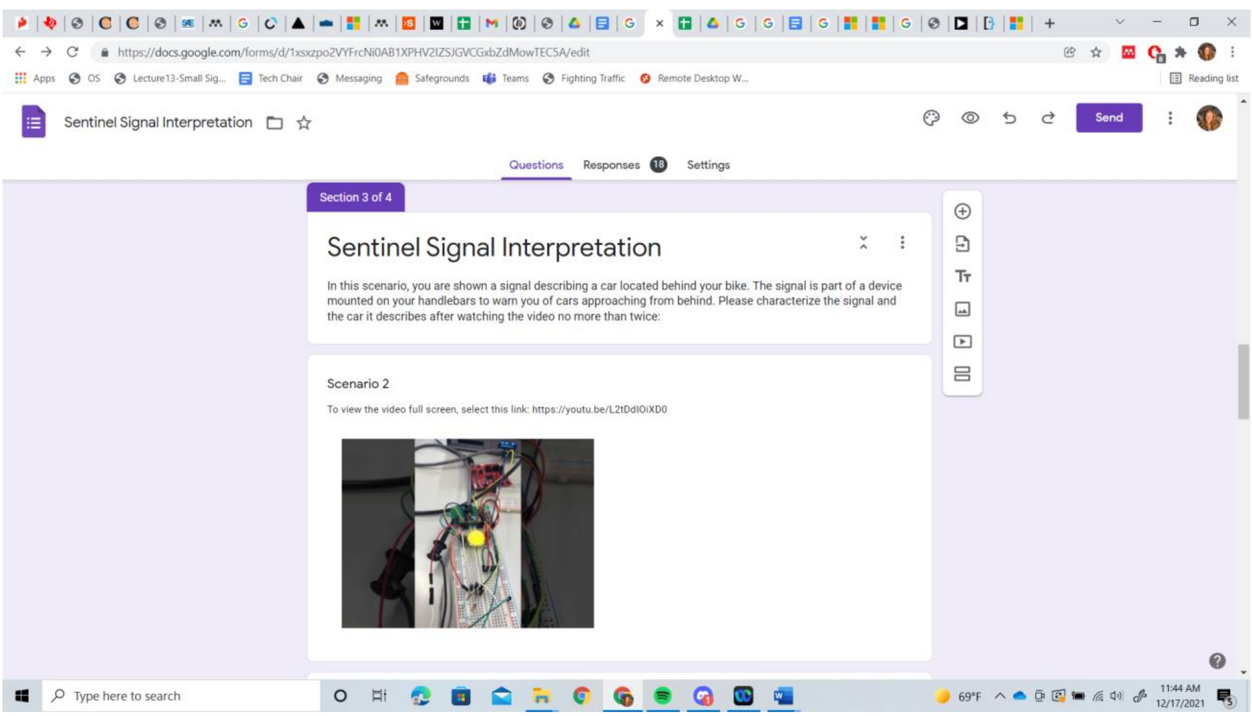

Figure 34. Second scenario setup in survey

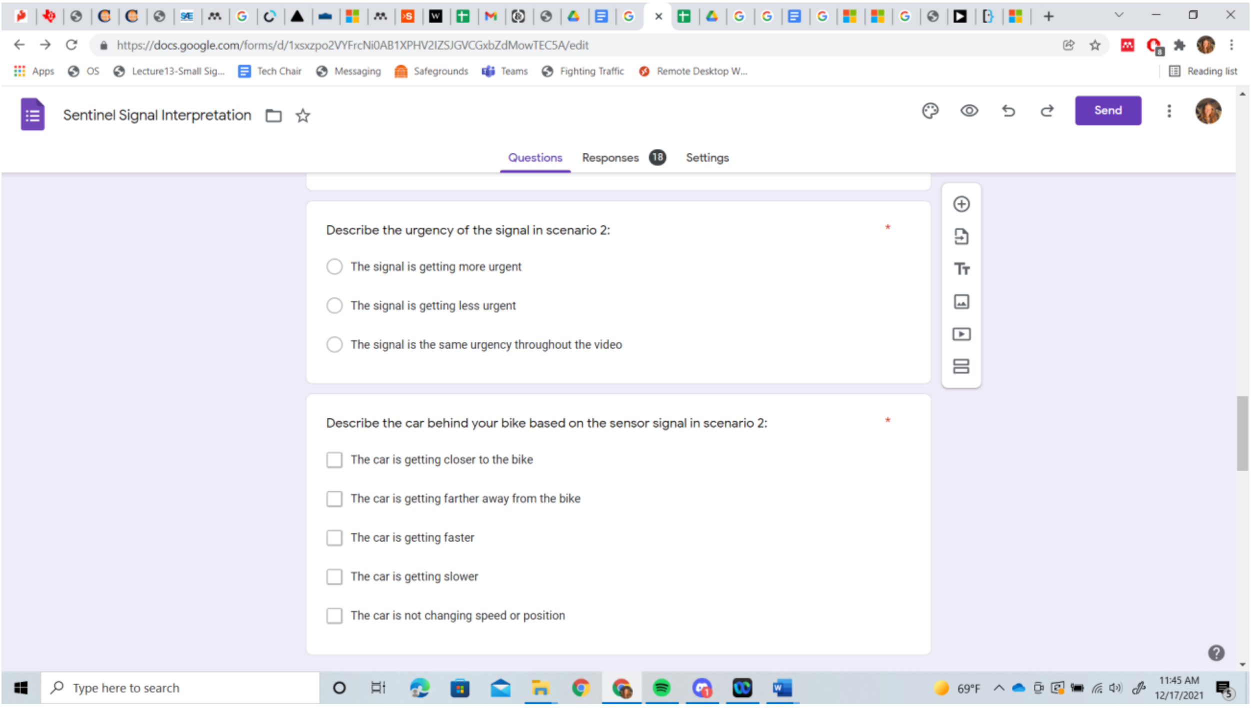

Figure 35. Second scenario questions in survey

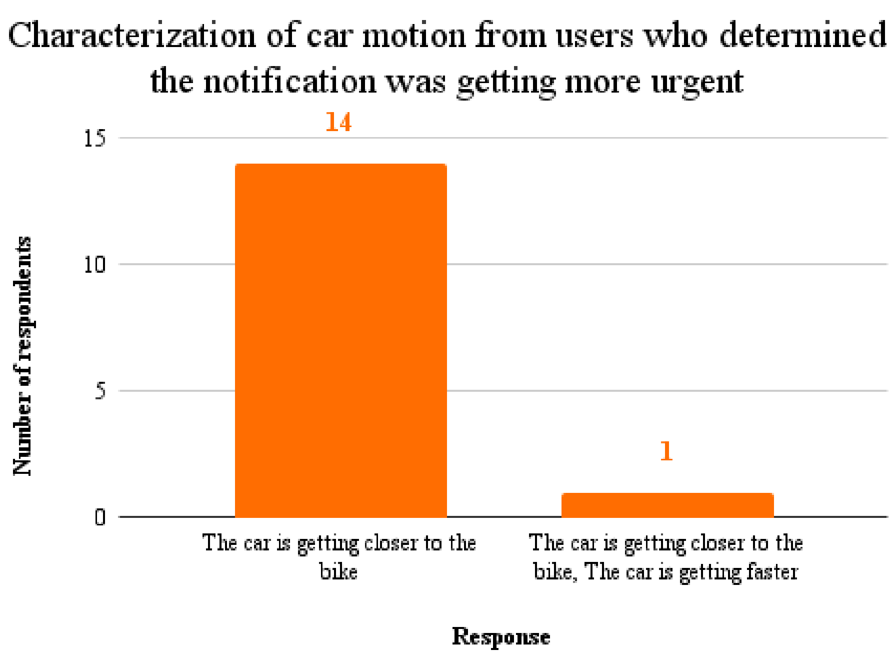

Figure 36. Characterization of car movement for a signal of increasing frequency/urgency

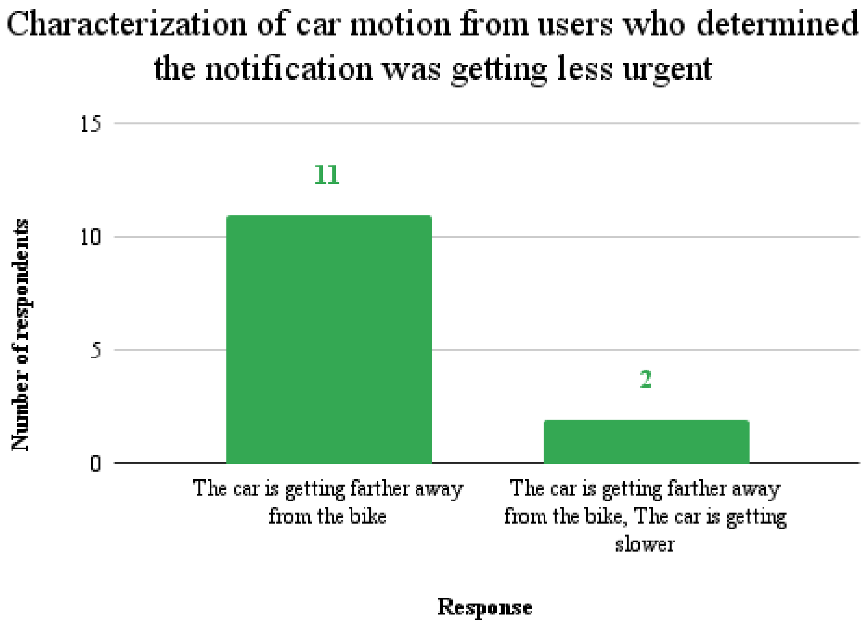

Figure 37. Characterization of car movement for a signal of deccreasing frequency/urgency

Waterproof Testing

Figure 38. Back Box Waterproof Testing with Napkin

Figure 39. Front Box Waterproof Testing with Napkin

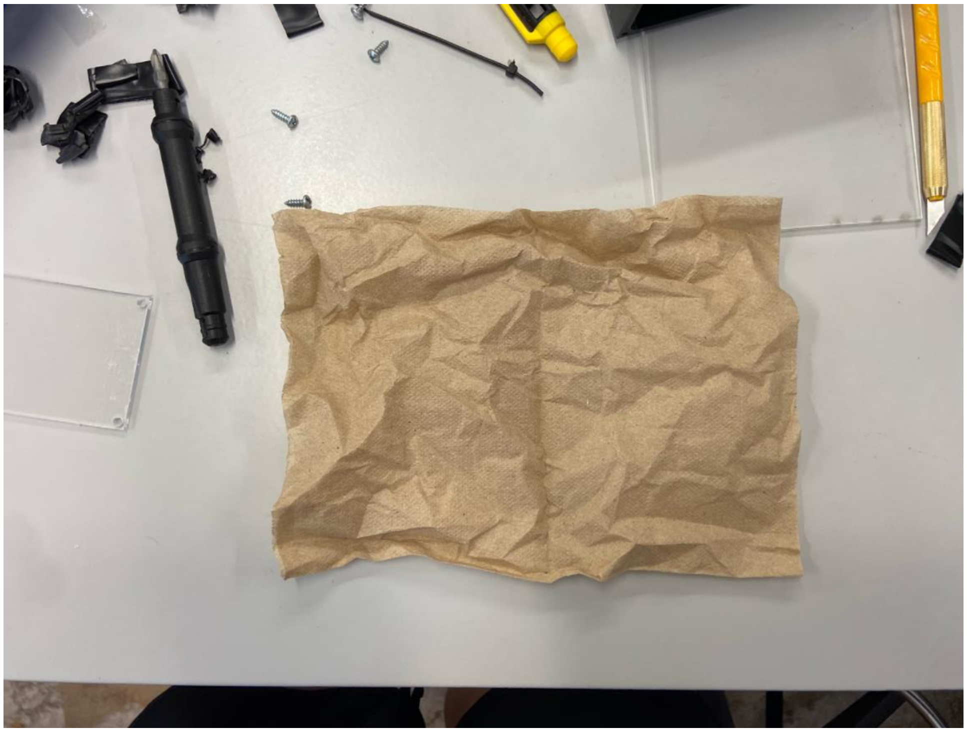

Figure 40. A Dry Napkin After Removing it from the Front Box

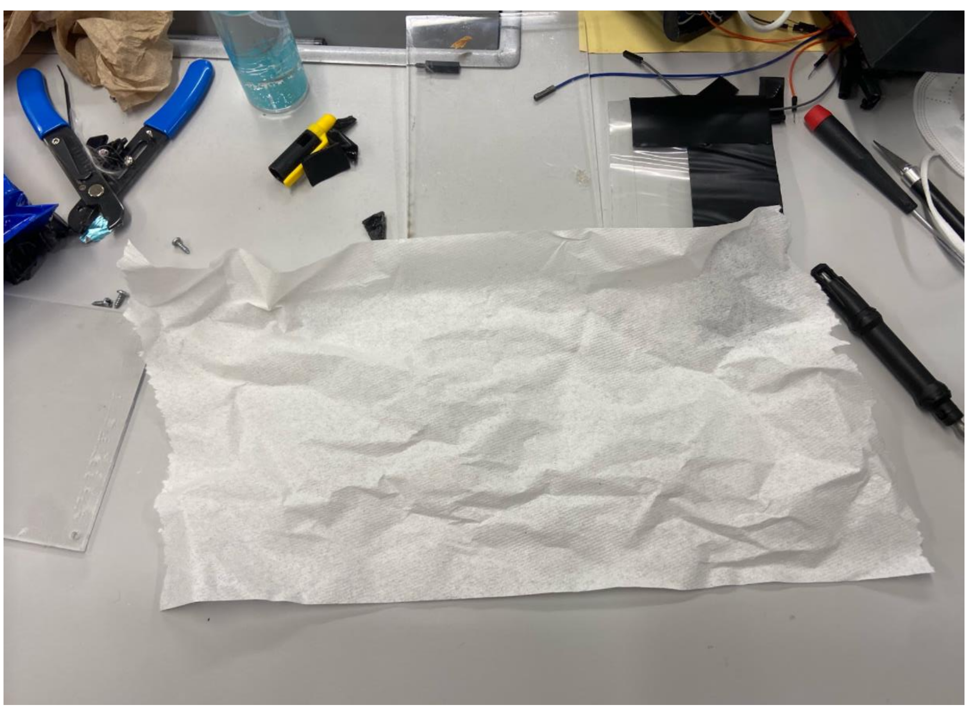

Figure 41. A Dry Napkin After Removing it from the Back Box

Robotic Police in the United States: A Divisive Innovation

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

Julia Rudy

Spring 2022

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Advisor

Travis Elliott, Department of Engineering and Society

STS Research Paper

Introduction

In recent years, there has been an increasing presence of robotics in the United States public sphere, finding its way even into the police force. In this paper I will discuss through the lens of the actor-network theory why autonomous robotics should not be used for lethal force or surveillance. More specifically, autonomous robotic policing should not be implemented in the United States. The morality of autonomous lethal force is gray at best. Furthermore, police, politicians and civilians often do not want robotics in the public sphere to begin with.

Actor-Network Theory

Science and Technology Studies (STS) strive to explain the relationships between technological systems and society. STS is often analyzed through “frameworks” or different perspectives that aim to explain these relationships. Actor-network theory is a sociotechnical framework that states that everything in the social and natural world exists in an ever-evolving network of relationships (Latour, 2005). It is an influential theory that strives to understand human’s relationships with inanimate objects. The three major authors that created actor-network theory describe it as:

> …a disparate family of material-semiotic tools, sensibilities and methods of analysis that treat everything in the social and natural worlds as a continuously generated effect of the webs of relations within which they are located. It assumes that nothing has reality or form outside the enactment of those relations. Its studies explore and characterize the webs and the practices that carry them. (Law 2009).

The framework suggests inanimate objects and processes influence social situations as much as humans do.

In this paper, the actor-network theory will be used to explain robotics’ relationships to society, primarily robots' role in police organizations. Robots are important actors or “source of action” in the actor-network theory in that they have “emerged from social interests ... and it thus has the potential to shape social interactions”. Namely, robotic use in police forces have emerged to increase safety of police forces (keep officers out of harm's way) but by nature of being inanimate, shape how different policing systems are enacted and how the public responds to them.

Even though robots are inanimate objects, they have the capabilities to create and shift social networks. A main way that robotic use can be seen via the actor-network theory is how they enhance the power dynamics of a social network. The groups who are in power are the ones who can afford buying high-end robotics. Consequently, these robotics allow the groups in power to stay in power.

For example, drones offer police untapped surveillance powers; with the use of drones, police can monitor you at your apartment window, 5 stories above the ground, as seen recently in China (McMorrow, 2022). The majority of the public are at the mercy of how larger institutions use the robotic devices. These power dynamics become even more dangerous if autonomous lethal systems are introduced. Those countries that have the funds to afford lethal robotic systems controlled by AI are the ones who will be able to maintain power through brute force.

Therefore, through the actor-network theory analysis, the purpose of this paper is to show how the use of robotic systems in the public sphere should be severely restricted.

Background

For the purposes of this paper, a "robot" is an "engineered machine that senses, thinks, and acts, thus being able to process information from sensors and other sources, such as an internal set of rules, either programmed or learned, that enables the machine to make some 'decisions' autonomously" (Lin et al.2011). Robotics are prevalent in U.S. industry. In 2020, the International Federation of Robotics (IFR) estimated 2.7 million industrial robots were in use worldwide (Heer, 2020). Industrial robots are used for manufacturing and performing repetitive tasks such as disassembly of electric vehicle batteries.

While not as common as industrial settings, robots are a growing presence in public spaces around the U.S. For example, in 2018 DoorDash launched self-driving robots to deliver food across Silicon Valley (Robinson, 2018). An increased public presence of robots presents unique opportunities and challenges. Robots have the potential to enrich daily lives, but raise concerns about the increased commercialization and surveillance of public spaces. As the US moves forward to integrate robots into daily life, policy makers must consider the risks robots pose to both physical and data privacy.

Morality in using AI for Lethal Force

Robotic policing raises ethical questions. There is no standard for coding autonomous robots in situations of moral uncertainty (Lin et al., 2020). If enabled to act in the physical world, police robots would need to be "trained" to deal with infinite case by case situations. Not only that but there is the issue of the court system. Who gets held responsible for an autonomous robot's incorrect decision?

Many robotics companies will not weaponize their tech. Clearpath Robotics "vouched to not manufacture weaponized robots that remove humans from the loop" (Hennessey, 2017). Due to the issue of moral uncertainty, the human rights advocacy Campaign to Stop Killer Robots calls for a ban on fully autonomous weapons systems (Campaign, n.d.). Launched in 2013, the Stop Killer Robots coalition advocates for international laws to regulate autonomous weapons systems.

While many companies vow not to weaponize their tech, the fact that robots are programmable means they could be hacked for malicious intentions. A group of AI experts wrote an open letter to the United Nations Convention on Certain Conventional Weapons (CCW) urging for awareness on the threat of weaponized tech:

> Lethal autonomous weapons threaten to become the third revolution in warfare. Once developed, they will permit armed conflict to be fought at a scale greater than ever, and at timescales faster than humans can comprehend. These can be weapons of terror, weapons that despots and terrorists use against innocent populations, and weapons hacked to behave in undesirable ways. We do not have long to act. Once this Pandora's box is opened, it will be hard to close. We therefore implore the High Contracting Parties to find a way to protect us all from these dangers (110 Writers, 2017).

The group, led by Elon Musk, adds in the letter: "As companies building the technologies in Artificial Intelligence and Robotics that may be repurposed to develop autonomous weapons, we feel especially responsible in raising this alarm" (110 Writers, 2017).

Overall, autonomous systems capable of lethal force should be avoided at all cost. First of all, there is no way to determine how to code an autonomous robot to make moral decisions.

In endless possibilities, even humans have a hard time discerning the right choice. Secondly, the age of AI is relatively new and difficult to regulate.

As seen via the actor-network theory, autonomous AI also poses a unique challenge to society at large. AI is hard to regulate and has untapped lethal potential that could be disastrous. The introduction of autonomous AI as an “actor” will and has already inevitably shaped political and social narratives. For example the introduction of autonomous systems has forced policy makers to address how to regulate AI.

For example , the US National Institute of Standards and Technology (NIST) initiative facilitates discussion between the private and public sectors to create federal standards for reliable and trustworthy AI systems (Greenberg, 2022). Regulating AI is a hard task as the technology is hard to quantify. As Elon Musk, CEO of Tesla and SpaceX, tweeted in March of 2022: “Even some of the best AI software engineers in the world don’t realize how advanced Tesla AI has become.”

The difficulty in regulating a technology that even engineers themselves can not keep up with is a monumental task. However, the bigger problem at hand is the destructive capabilities autonomous systems could have. The construction of lethal systems also means destruction can be automated on a scale larger than ever seen before. Furthermore, the countries that have the funds to afford lethal robotic systems controlled by AI are the ones who will be able to maintain power.

Robotic Police in the United States: A Divisive Innovation

In 2020, the New York City Police Department (NYPD) leased a $94,000-dollar robotic dog “Spot” from Boston Dynamics, a robotics company whose mission is “to imagine and create exceptional robots that enrich people's lives" ("Boston Dynamics", 2021). However, public opposition to Spot forced the NYPD to cancel their lease in 2021.

Public Opposition to Robotic Police

Several democratic politicians, like Mayor Bill de Blasio, oppose the robotic dogs, calling them creepy and unnecessary (Bowman E, 2021). Politicians question how helpful the robot dogs actually are to the public, criticizing the use of taxpayer money on unnecessary projects.

Representative Jamaal Bowman, a first-term Democrat for the Bronx said in a tweet "You can't give me a living wage, you can't raise a minimum wage, you can't give me affordable housing; I'm working hard and I can't get paid leave, I can't get affordable child care, instead we got money, taxpayer money, going to robot dogs?" (Bowman J, 2021). The introduction of robots in the public sphere raises several safety and privacy concerns, particularly for already privacy-vulnerable populations such as the homeless (Thomasen, 2020).

Some people worry the increased surveillance could contribute to the predictive policing of marginalized communities. If not done right, robotic police presence on the streets could inherently make the public space a hostile and cold environment.

As suggested by the actor-network theory, objects and ideas themselves have as much influence on a system as people do. For example, the broken windows theory is a criminological theory that states clear evidence of crime in a community encourages further crime (a broken window is a signal that no one cares). Broken windows-style policing encouraged foot police traffic presence in communities to send a message of safety to the community. This style of policing also encouraged writing of lower level crimes, such as turnstile jumping. It has been shown that a higher number of foot traffic police can increase community trust.

If a broken windows-style policing was implemented with robots, the very opposite message could be sent. Imagine instead of extra policemen walking around your town, dozens of robotic dogs roamed the streets. Spot could provide the same widespread surveillance as its human police counterpart. However, by the very nature that Spot is not alive, a widespread robotic force could give the appearance of a nanny-state, where the public is constantly being watched. New Yorkers also disliked the 'Digidog' Spot. One person tweeted a video of the dog in NYC with the caption "By the time my kids are old enough to watch Black Mirror it's going to be a documentary series" (hellalee, 2021).

The unsettling feeling the community might feel from the robotic force could be due to the uncanny valley phenomenon. The uncanny valley is described as an eerie feeling one experiences in response to almost but not quite human figures. The same feeling is invoked in the almost but not quite fluid movement of robots, such as the robot dog Spot.

The uncanny valley is not the only reason introducing robotics into policing could create tensions between enforcement agencies and the public. Policy makers have to consider how to regulate robotic systems to protect the liberties of all people. If only some people are allowed access to robotic systems, it can lead to further power differentials. In 2016, the US Federal Aviation Administration (FAA) instituted differential regulation of the use of drones over protests.

During the Dakota Access Pipeline Protests (a grassroots opposition to the construction of Energy Transfer Partners' Dakota Access Pipeline in the northern US. Protests) protestors and some journalists were prohibited from using their drone to survey police activity. On the other hand, police were given full access to survey protestors (Eidelman, 2016). Numerous problems could arise if such high tech surveillance gear is limited only to those in power.

Note that this here is yet another example of the actor-network theory in play. By introducing drones into the social system, a new power- dynamic emerged. Journalists who want to give the full story revolving around the Dakota Access Pipeline were denied. Drones shifted the preexisting network of relationships, allowing those already in a position of power, the police shutting down the protests, to maintain a position of power.

Introducing Spot into the NYPD was one of the first instances of police use of robotics in the public domain. It is easy to see why the project got shut down so quickly; a future where the public trusts robots roaming the streets is hard to imagine. People feared the power robotics gave to the police force. Whether or not the robots put to use in New York were ever used for malicious purposes, allowing robotics in public places sets a dangerous precedent.

Counter Arguments

A common argument to support robotic force is the protection of police in dangerous situations. 170 policemen died during their line of duty in 2021 with the lead cause of death being gunfire. Despite this, police forces often do not want weaponized robots. A web-survey study showed law enforcement primarily want robots in order to keep police safe in surveillance based operations, such as assistance in “inspection of hazardous areas” (Nguyen and Bott, 2000). Many police and security robots are used for non- lethal operations such as “scanning for pedophiles ….

reciting warnings and more” (Lin et al., 2014). Consequently, the NYPD supports the use of robotic ‘Digidog’ for non-lethal situations including Frank Digiamacomo, NYPD Technical Assistance Response Unit Inspector (Bowman, 2021).

Even if police do not want lethal force, robotic surveillance should be dissuaded, due to the unsettling tensions it could create between the police and people. An example of these tensions can be seen in the drone usage in China during their Covid-19 lockdowns. Drones were also used to send threatening messages to citizens after a protest over a lack of food due to the extreme Covid-19 policies. In the suburb of Jiuting a drone could be heard saying in a loud robotic voice: "Don't stir up trouble or gather illegally, or you'll be handled according to the law" (McMorrow, 2022).

Another argument to support Spot, as a Boston Dynamics spokeswoman said, is the company's robots were "not designed to be used as weapons, inflict harm or intimidate people or animals … We support local communities reviewing the allocation of public funds, and believe Spot is a cost-effective tool comparable to historical robotic devices used by public safety to inspect hazardous environments" (Zaveri, 2021). While well intentioned, even if the design of the robotic dog was not to cause physical harm, policy makers must be aware of the unsettling image a robotic police dog gives. As discussed before, robotic dogs give off the uncanny-valley effect that makes them creepy. The very presence of robots shifts the public's view of the police negatively. Robotics have no place in a world where the public should be able to trust the police.

Conclusion

Robotics has important implications for the future. While the use of robotics may have good intentions, their capabilities to create an intrusive and dangerous police force are too much of a risk. The indeterminate and unpredictable actions of autonomous systems mean they should not be allowed to use lethal force. In the future, policy makers must make sure that autonomous systems are properly regulated. This means that engineers should never be allowed to design autonomous systems that cause harm. The use of autonomous robotics for police use in any capability also should be banned. Furthermore, the use of robotics, even non-autonomous systems, should be avoided. While non autonomous systems may not be immoral, as seen with Spot in New York City, the public does not trust any form of robotic policing.

In this paper we have discussed through the actor-network theory why robotics should not be introduced in the police force. Robots, as actors in the system, shift the dynamics between public and police, giving the latter too much power. Furthermore, autonomous systems are hard to regulate and have the potential to be extremely dangerous. Robotics can be a very powerful tool, but it should be avoided for any future work with the police.

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A Car Collison Detection System for Bicyclists
(technical research project in Computer Engineering)

Robotic Police in the United States: A Divisive Innovation
(sociotechnical research project)

by

Julia Rudy

November 1, 2021

technical project collaborators:

Brandon Brnich
AJ Cuddeback
Julia Graham
Rex Serpe

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Julia Rudy

Technical advisor: Powell H. Advisor, Department of Electrical and Computer Engineering

STS advisor: Peter Norton, Department of Engineering and Society

Prospectus

General Research Problem

How can the U.S. integrate robotic autonomous systems to improve everyday life in the public sphere?

For the purposes of this paper, a “robot” is an “engineered machine that senses, thinks, and acts, thus being able to process information from sensors and other sources, such as an internal set of rules, either programmed or learned, that enables the machine to make some ‘decisions’ autonomously” (Lin et al.2011).

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While not as common as industrial settings, robots are a growing presence in public spaces around the U.S. For example, in 2018 DoorDash launched self-driving robots to deliver food across Silicon Valley (Robinson, 2018). An increased public presence of robots presents unique opportunities and challenges. Robots have the potential to enrich daily lives, but raise concerns about the increased commercialization and surveillance of public spaces. As the US moves forward to integrate robots into daily life, policy makers must consider the risks robots pose to both physical and data privacies.

A Car Collision Detection System for Bicyclists

How can autonomous sensors be used to reduce bike collisions with cars?

Bicycles are a great means of transportation. They promote exercise, are cost effective, and are environmentally sustainable. However, bicycle riders often have to share the road with cars, which can be lethal. Consequently, our technical research project, “Sentinel” aims to help bicycle riders avoid collisions.

Several collision detection systems for bikes already exist, such as mirrors. Mirrors have a long range of view, but require a rider to constantly scan their field of view. It can also be hard to see objects in the dark. Another detection system is the Varia™ by Garmin. The Varia is a bike seat mounted radar with a 220° FoV (field of view), a battery life of 6-16 hours, and sensing range of 140 m for vehicle speeds of 10-160km/hr. The radar communicates via bluetooth to the Garmin Edge device, a GPS computer with an LCD screen mounted on the front of the bike. The Varia is battery operated. When the batteries run out of charge, there is no way to replace them. The customer has to buy a completely new Varia, which is harmful to both the environment and the wallet.

Sentinel, is a solar-powered bike radar system that alerts cyclists of approaching cars; it also aims to remedy the shortcomings of current solutions on the market. Sentinel aims to warn bike riders of oncoming cars through intuitive LED display mounted on the handle bars of a bike. Since Sentinel is solar powered, the system does not rely on switching out batteries. The LED display also means that riders will be alerted of oncoming cars in the dark.

The system utilizes an OPS243-C-FC-RP radar sensor with an MSP430 microcontroller. Two LEDs mounted on the handlebars will light when a car approaches a biker. It uses a 10-watt solar panel and two Li-Ion 18650 cells.

The project must cost under $500 dollars. Success of the Sentinel is based on five metrics:

distance sensing of an object, relative speed sensing, intuitive notifications, backup power storage, native power generation, weatherproofing, and sensing in all weather conditions. In each of these metrics the goal is to have the sensor provide accurate and meaningful alerts (in a variety of weather conditions). The project is a capstone done in collaboration with Julia Graham, Rex Serpe, Brandon Brnich, and A.J. Cuddeback under the supervision of advisor Harry Powell (ECE department).

Robotic Police in the United States: A Divisive Innovation

In the U.S. how are promoters and opponents of robotic police devices advancing their respective agendas?

In 2020, the New York City Police Department (NYPD) leased a $94,000-dollar robotic dog "Spot" from Boston Dynamics, a robotics company whose mission is "to imagine and create exceptional robots that enrich people's lives" ("Boston Dynamics", 2021).

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While many companies vow not to weaponized their tech, the fact that robots are programmable means they could be hacked for malicious intentions. A group of AI experts wrote an open letter to the United Nation's Convention on Certain Conventional Weapons (CCW) urging for awareness on the threat of weaponized tech:

> Lethal autonomous weapons threaten to become the third revolution in warfare. Once developed, they will permit armed conflict to be fought at a scale greater than ever, and at timescales faster than humans can comprehend. These can be weapons of terror, weapons that despots and terrorists use against innocent populations, and weapons hacked to behave in undesirable ways. We do not have long to act. Once this Pandora's box is opened, it will be hard to close. We therefore implore the High Contracting Parties to find a way to protect us all from these dangers (110 Writers, 2017).

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