Autobrake Bicycle

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1 Introduction

1.1 Problem and Solution Overview

Currently, the traffic laws for bicycles are often incomprehensive and, therefore, potentially unsafe. In 2018, 857 people in the United States died in bicycle accidents. That number was the highest since 1990 [3]. In 2016, about 71% of deaths due to bicycle accidents occurred in urban areas and 30% occurred at intersections [4]. It was recommended that all bicyclists should wear a helmet but no state has so far announced such a law to rule that, which caused the tragedies.

Furthermore, as one of the important methods of transportation in the world, the bicycle has never acquired equal attention to its development as other vehicles, like the car and the motorcycle. While autonomous driving has become a mainstream in the development of vehicles, many cars have installed intelligent driving assistance like lane-keeping, blind-spot detector, auto-parking. Motorcycles also have riding assistance products. All these products help avoid traffic accidents and therefore protect drivers and riders. However, similar kinds of products are barely seen on bicycles. With an aim to protect bicyclists, we decided to create a riding assist for bicycles and thus to lower the risk of a bicycle accident at crossing roads. In this project, we plan to build an autobrake system that will force the bicycle to stop at STOP signs. The STOP sign is such an important traffic signal that anyone who learns to drive will be taught about rules relevant to it. Bicyclists, however, do not need a license to ride legally and thus may lack such kind of safety awareness. This project will therefore help solving this problem by first, reminding the cyclist about the STOP sign and second, forcing the brake if no action is taken, which means the cyclist does not take any action to slow down. The product should be easy to install and have an affordable price.

1.2 Visual Aid

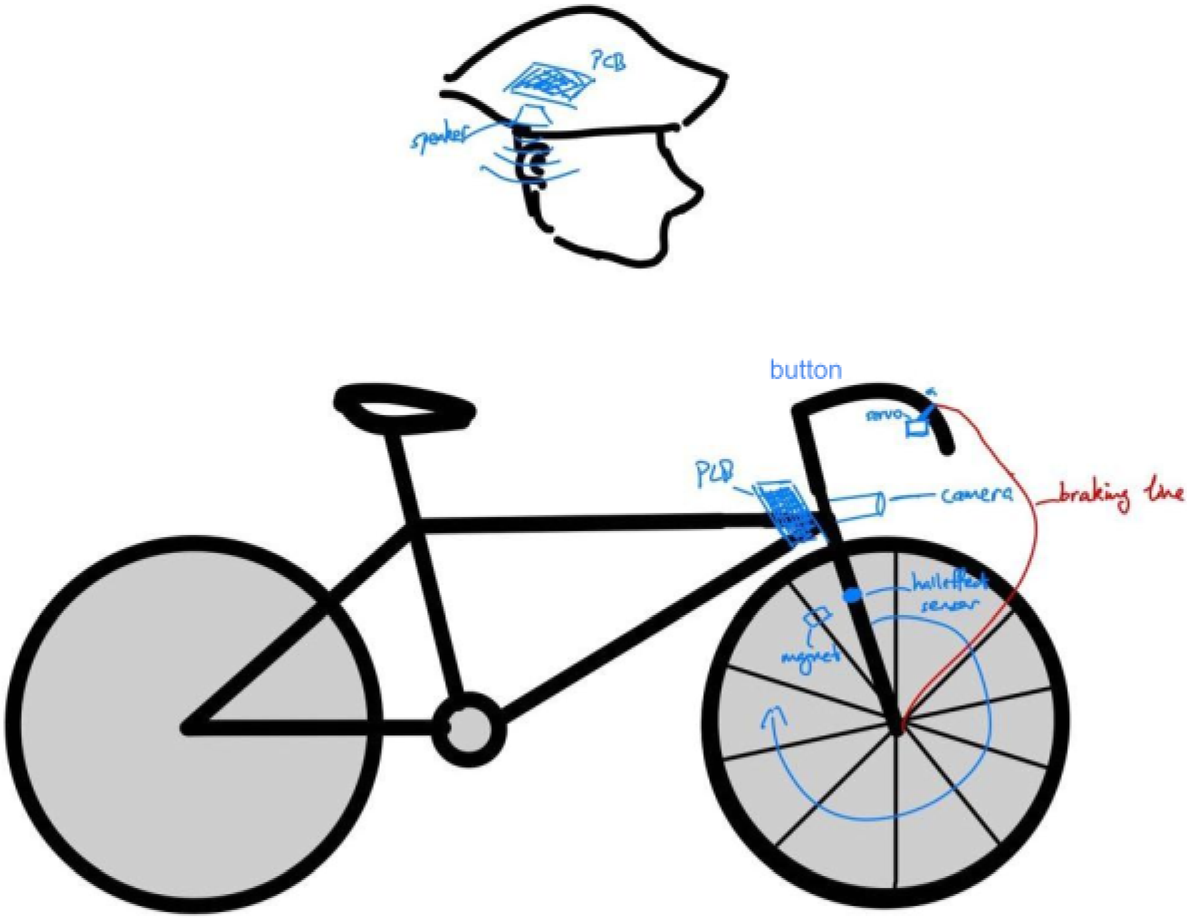


Fig.1 Visual Aid

We will install a camera module as an ‘eye’ on the bicycle to capture frontier images as well as a hall-effect sensor on the wheel for speed measurement. These two sensors are wired and will be wireless connected to the speaker on the helmet. Once the camera detects a STOP sign, the speaker will generate warning sounds as a reminder. Then, when the STOP sign is closed enough, if still no action has been taken by the bicyclist, in which case the speed of the bicycle is not slowing down, the autobrake will be triggered to force the bicycle to stop. A servo will be used to tighten the braking line. There will also be a button whose execution is of the highest priority to turn on/off the autobrake system. This is especially designed to prevent accidents due to false-positives, so that if the autobrake is triggered under inappropriate conditions, the bicyclist can turn it off manually and keep riding forward. This button will be installed on the handlebar and thus can be easily accessed by the thumb.

1.3 High-Level Requirements

- The speaker must ring for three seconds to remind the bicyclist when a STOP sign shows up within 15 meters in the front.
- While the STOP sign is within 5 meters, the autobrake must be triggered if and only if the speed of the bicycle is above 10km/h.
- The false-alarm rate must be no more than 15% and the autobrake can be disabled with one-click to avoid accidents due to false-alarms.

2 Design

2.1 Block Diagram

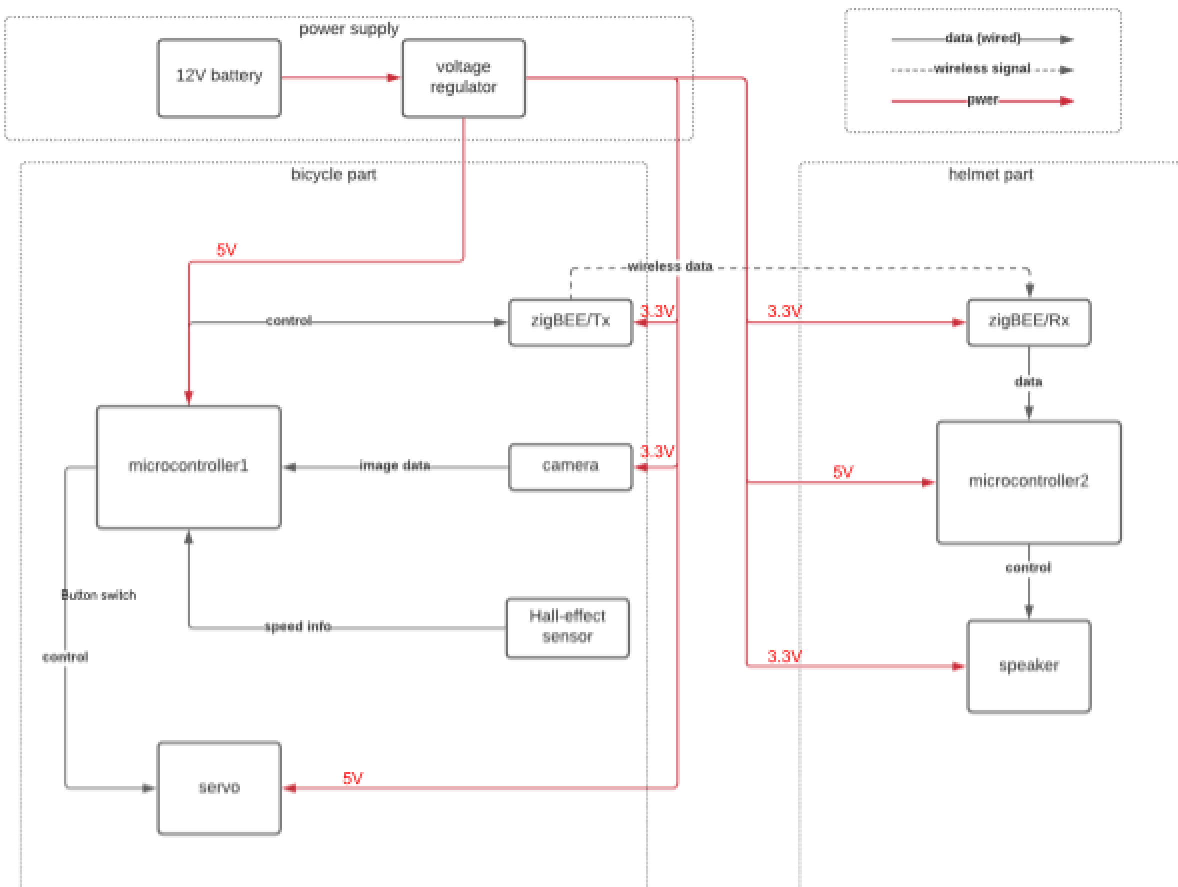


Fig.2 Block Diagram

The autobrake bicycle project is split into two parts: the detection and braking system on the bicycle and the warning system on the helmet. These two parts will be wireless connected with zigBEE module, which can have a transmission distance of 10 meters even with the lowest power supply. We plan to use a camera module OV7670 and the 'template match' algorithm to detect a STOP sign. We can also determine the distance of detection by adjusting the size of convolution kernels. Once a STOP sign is detected, it will send a signal to the helmet, and the speaker will remind the cyclist about the STOP sign. We will also measure the speed of the bicycle so that if the speed is higher than some value while the STOP sign is closed enough, which means the cyclist does not take action after hearing the reminder, the autobrake will be triggered.

2.2 Power Supply subsystem

2.2.1 Regulators

The regulators LD1117 and LC7805CV will lower a voltage of 12V from the battery and supply stable power to other subsystems as shown in Fig.2.

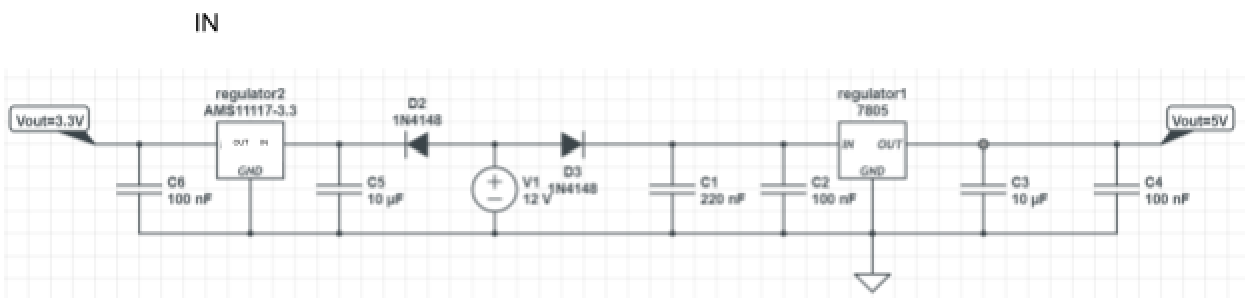


Fig.3 power supply circuit

Requirements	Verifications
1. The two regulators must be able to have a stable 3.3V+/-5%, 5V+/-5% output voltage at 12V input. 2. The LC7805CV should be able to operate stably at 6mA+/-15%.	1. Build the circuit shown in Fig.3. Power it with a fully charged 12V battery. 1. Verify the output voltages as defined in Fig.3 with a voltmeter. 2. Connect the right part in parallel with an 1kohm. Verify if the current is 5mA+/-5% and the voltage is still 5V+/-5%.

2.3 Control Units

2.3.1 Microcontroller

The microcontroller, ATmega328P, will receive image input from OV7670, process it and run the template match algorithm to determine if a STOP sign is captured. It sends control signals to the zigBEE module, servo, and the speaker.

Requirements	Verifications
1. Each I/O port reads/writes reasonably under 5V power supply.	1. Connect 5V to VDD and GND to GND. Wire microcontroller with USB port. 1. Connect it to PC. 2. Connect each pin to GND with a 1kohm resistor. 3. Program the chip to iteratively write to and read from each port, use voltmeter to verify the result.

2.3.2 Enable/Disable Button

A button switch is installed on the handlebar where the cyclist can easily access it with a thumb. The button should decide whether the autobrake system is turned on.

Requirements	Verifications
1. The button can be pressed without strain	1. Push the button and verify if it is pressable.

2.4 Wireless Connection

2.4.1 XBEE module

XBEE can operate at 2.4GHz at 3.1+/-0.3V. The transmitter can send 250,000 bytes per second to a receiver within 30m in urban areas. We only need to use a pair of XBEEs to build point-to-point wireless connections and send 1-bit messages (1: STOP sign detected, 0: else) between the helmet and the bicycle, which are only 1m+/-50% apart. XBEE can work from -40 to 85 celsius degrees, which means it will not be constrained by extreme climates.

Requirements	Verifications
1. 1-bit messages are sent from transmitter to receiver at 3.3V power supply.	1. Connect 3.3V to VCC and GND to GND on both the transmitter and the receiver. 1. Connect Tx and Rx to the microcontroller. 2. Program the microcontroller to periodically send 1-bit messages from the transmitter to the receiver. 3. Log the data read on the receiver and ensure that the receiving time has no more than 0.1s lag.

2.5 Sensors

2.5.1 Camera

We will use CMOS OV7670 as our camera module. OV7670 can generate images with resolution of 640*480 at up to 30 fps for VGA. It directly outputs 8-bit raw RGB data and is easy to manipulate. The camera will capture live images in front of the bicycle and send the image information to the microcontroller.

Requirements	Verifications
1. Provides images with resolutions of 640*480 with 3.3V power supply.	1. Power the module with the regulated 3.3V power supply. 1. Connect the camera module to Arduino and then connect the Arduino to the computer through USB port. 2. Upload images to the computer and verify their clearness.

2.5.2 Hall-effect sensor

The hall-effect sensor, US1881, will be installed on the wheel for speed measurement. A small piece of magnet will be placed on the wheel hub so that while the wheel rotates, every time the magnet passes the hall-effect sensor, the microcontroller will record it and computes RPM based on the frequency, from which the speed is estimated.

Requirements	Verifications
1. The magnetic switch opens and closes in different magnetic fields	1. Connect 5V to the VDD pin and GND to the GND pin. 1. Connect a 1kohm resistor in series with an LED to the output pin. 2. Place a magnet next to the hall-effect sensor and then remove it. 3. Confirm if the LED turns on/off in this process.

2.6 Electrical Auto-Brake

In general, there are three main types of bicycle brakes that are still being used: V-brake, Disc Brake, and C-brake. Each type of brake has its own benefits and disadvantages.

V-brake advantages: Simple structure; Cheap price; Easy for maintenance; Light in weight.

V-brake disadvantages: This type of brake may lose feedback from riders' fingers especially when the brake has not been maintained for a long time. The braking time should not be too long for this type of brake since it uses the friction between bicycle wheels and the brake pads to stop the bike. If the braking time is too long for this type of brake system, the brake pads may be burnt due to the heat generated.

Disc Brake advantages: It has better strength and is adaptive to more environments and different weathers.

Disc Brake disadvantages: It has much bigger weight and a more complex design. Thus, it is more difficult to be maintained and repaired. This type of brake is also afraid of oil and besmirch.

C-brake: In general, C-brake is just another version of V-brake, they share exactly the same method for braking. The only difference is their metal part design: V-brake has a V shape and C-brake has a C shape. Such design leads to the difference in torque and eventually, V-brake has a better stopping force compared with C-brake.

In conclusion, the best brake type to be utilized in this project is the V-brake. It has a simple structure, which makes it easy to be modified or adding an electrical control device into it. It is also the cheapest bicycle brake that could be found on any shopping website. Some shops even have V-brakes that could be sold so cheap as under 4 dollars each.

2.6.1 Brake Module

The brake is the physical interface between the auto-brake system and actual bicycle. The rest part of the system only controls when and how to trigger this module while the brake module itself only needs to stop the bicycle.

Requirement	Verification

1. A modified V-brake that could be triggered by a signal sent from the control system.	1. Receive signal from the control system. 1. The signal could trigger the brake to work. 2. Some electrical devices make the brake pads clip and stop the wheel. 3. The force is big enough to stop the bicycle even if it is running very fast.

2.7 Executors

2.7.1 servo

ROB-11965 servo will be able to generate a torque 5~6kg*cm at 4.8~6V input voltages. It will be used to push the brake

Requirements	Verifications
1. Must be powerful enough to push the brake	1. Power the servo with 5V and fix it to the brake line. 1. Ensure that the brake can be triggered by the servo

2.7.2 speaker

The magnetic buzzer, CEM-1203 will be used to generate warning sounds on the helmet. We select it because it has two long terminals which can be easily soldered to the PCB.

Requirements	Verifications
1. Must generate sound that is loud enough to get people’s attention.	1. Power it with 5V and make sure it is loud enough.

2.8 Detection Algorithm

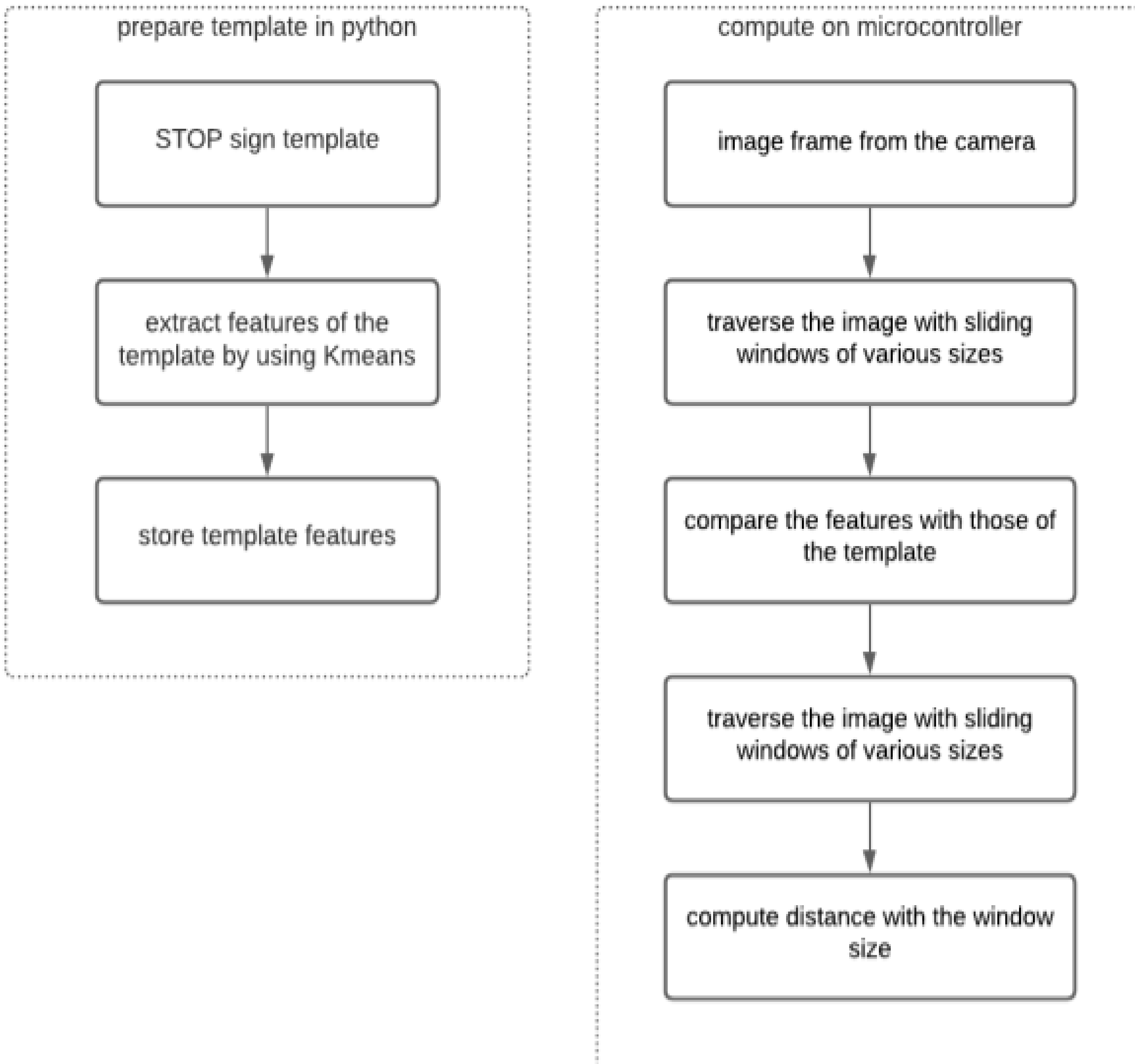


Fig.4 Software design

2.9 Schematics:

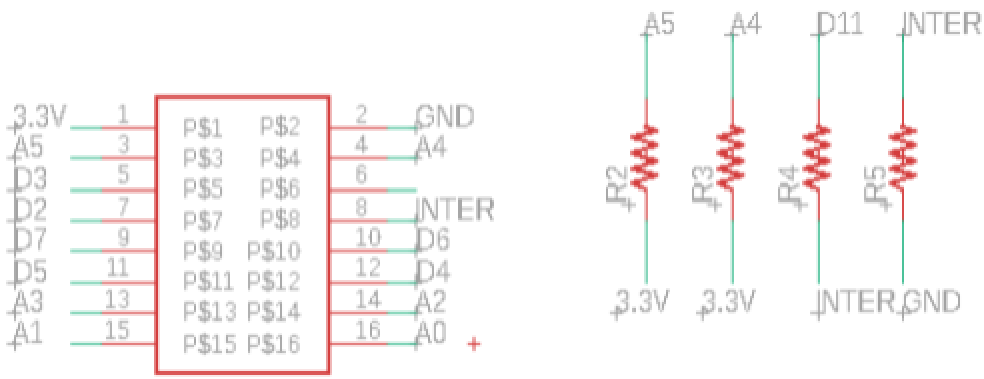


Fig.5 camera module
OV7670

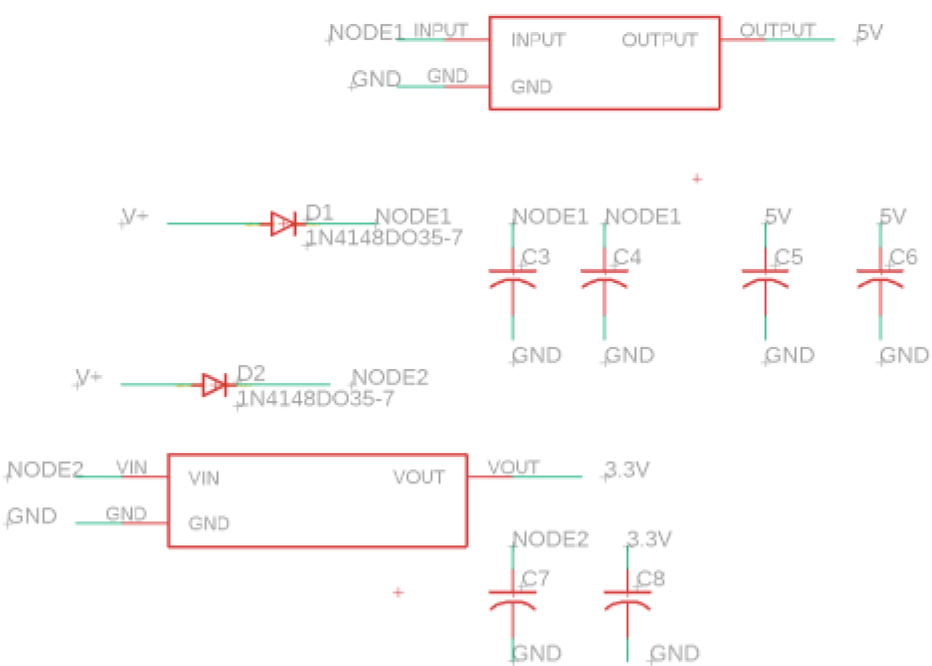


Fig.6 5V/3V power supply

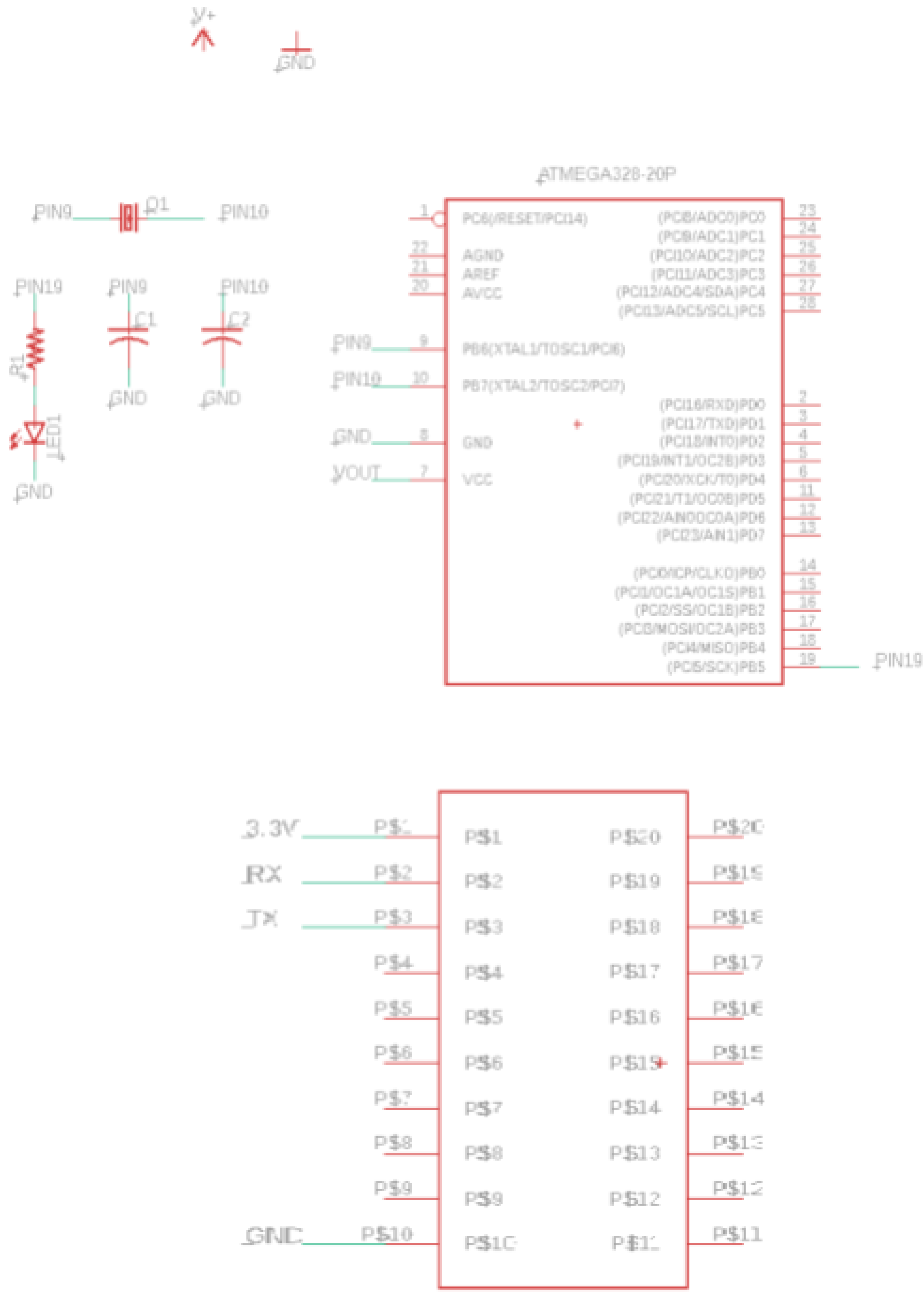
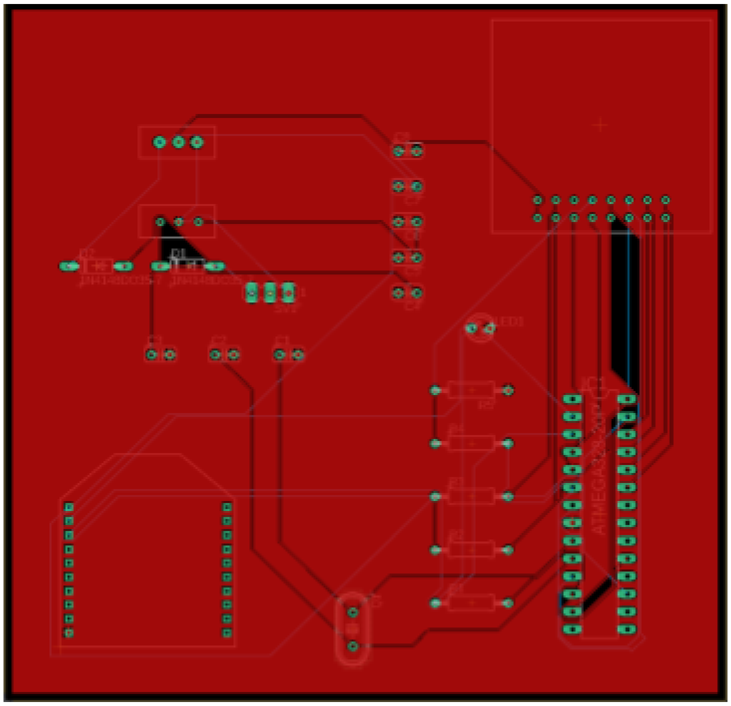


Fig.7 Atmega328P & XBEE



PCB breakout

3 Cost and Schedule:

3.1 Cost Analysis:

With an estimation of $30/hr, 15hrs/week, 16 weeks for each of us:

$$TOTAL = \frac{30}{hr} \cdot 2.5 \cdot \frac{15hr}{week} \cdot 16weeks \cdot 3 = \$ 54,000$$

Description	***manufacturer***	***part#***	***Quantity***	***Cost***
3V3 regulator	sparkfun	LD1117	2	1.95
5V regulator	sparkfun	LC7805CV	2	0.95
microcontroller	adafruit	ATmega328P	2	5.95
zigBEE	digi-key	XBEE	2	21.95

camera	ebay	OV7670	1	2.45
hall-effect sensor	sparkfun	US1881	1	0.95
servo	sparkfun	ROB11965	1	12.95
mini-speaker	sparkfun	CEM-1203	1	1.95
Bicycle V-brake	JD	-	1	3.5
				total=83.4

The total development cost is $54083.4.

3.2 Schedule

Week	*Schedule*
3/15	Finishing ordering parts for PCB, hall effect sensor, camera module, Atmega microchip, battery(Gary Gong, Taiqing Ling)
3/22	Assemble parts for ATmega328P microchip as microcontroller for the design(Gary Gong,Taiqing Ling, Weichen Qi)
3/29	Starting to write the code for template match algorithm(Taiqing Ling), and assemble the camera module and battery(Gary Gong)
4/5	Finishing the template match algorithm(Taiqing Ling) and assemble parts of hall effect sensor(Gary Gong)
4/12	Start testing for template match algorithm, and adding the feature for false alarm(Gary Gong, Taiqing Ling)
4/19	Mock test for whole project design, and debug the circuits and code(Gary Gong, Taiqing Ling)

4/26	Mock test for whole project design(Gary Gong, Taiqing Ling), and debug the circuits and code(Gary Gong), also start to write the final paper and presentation(Weichen Qi)
5/3	Prepare for final presentation(Weichen Qi, Gary Gong,Taiqing Ling), and wrap up final paper(Weichen Qi)

4. Tolerance Analysis

One tolerance of our project is that the detection of the STOP sign and the distance measurements are solely dependent on the image processing algorithm. Considering that almost all STOP signs look exactly the same, instead of introducing a machine learning model, we plan to use 'multi-scale template match' to complete this task. We will first set a STOP sign image as our template and use K-means to analyze its color features. Then we will traverse the video image with multi-scale sliding windows to see if at some point there is a match. Whenever there is a match, the code will determine whether this STOP sign is at a safe distance away based on the sliding window, because intuitively the larger the sliding window, the closer it is. We need to do some mathematics to calculate the real life distance here. Since all STOP signs have fixed dimensions, we can compute its size in terms of pixels. The equation for distance computation is shown below:

$$distance\ to\ STOP\ sign\ (mm) = \frac{size\ of\ STOP\ sign(mm) \cdot image\ size(pixels) \cdot focal\ length(mm)}{size\ of\ STOP\ sign(pixels) \cdot size\ of\ OV7670(mm)}$$

Given that the OV7670 has a pixel size of 3.6um, a 76.3cm octagon STOP sign at 15 meters would take 48+/-1 pixels in length, which should be able to support the template match algorithm.

However, to make accurate calculations, this algorithm requires the STOP sign to be directly facing the camera. Any slight change in yaw would change the image pixels and thus affect the result. The reason why I use this algorithm is that first, it is more complex to introduce other sensors like LiDAR or IR to measure distance, especially when we want to combine it with camera vision, and second, we can tolerate it by setting more strict constraints on the position of the sliding windows. In fact, since the bicycle lane is always the rightmost one on the streets, which is just next to the pedestrian curb, we only want to recognize the STOP sign straight in front of us. Those which are in the left diagonal front or the right diagonal front are probably on other branches, which shouldn't be cared for, and we will consider them as false-alarms. If the bike is braked under false-alarm conditions, it will cause danger which might end in serious consequences potentially. In order to solve this problem, we plan to add constraints on the matched positions to lower false alarm rates. Additionally, we decide to add a button that can disable the auto-braking system when the user declares that he doesn't want to stop. We will notify the user that there is a STOP sign detected 15 meters ahead of the stop sign, then the user can have a 10 meters distance to react to decide whether or not it is necessary to stop. By having this feature, the potential danger caused by false alarm can be minimized to a large extent.

5 Ethics and Safety

The potential danger of our project is the failure to execute the autobraking mechanics or false alarm of the signal. The bicycle would brake at some wrong points which can be a danger to the user of this product. However, we already implement the method to avoid this situation as much as possible by giving the control back to the user. Our project is only an assistant for helping riders identify stop signs when they do not notice the potential danger, which could help avoid accidents in a large context. However, the project is not auto driving related. The project is aimed to lower the risk for bicycle riders instead of letting bicycle riders ride with lower precaution. The user who uses this product may think that they are safe but less aware of the stop sign on the roads. This is not the intention of the project, and can cause serious issues to the traffic safety. Anyway, it is the user's responsibility to be aware of the stop signs and keep following the traffic rules rigidly. On the other hand, the product makes use of the battery as the power supply, but the battery has some possibility to explode due to extreme sunlight or moisture. Therefore, the product cannot be used under some special weather condition. Related information can be found from reference [1].

For ethics, there is low potential that this project will be misused accidentally or intentionally. Our project obeys all the IEEE code precisely. For example, “to avoid injuring others, their property, reputation, or employment by false or malicious actions, rumors or any other verbal or physical abuses”. Our project will be supervised carefully, and it will not be used to harm others in any form or in any circumstances. When we design and test for this product, we will also obey all the traffic laws, and make the testing in a very safe environment to avoid breaches of ethics. I also have some resources on safety about bicycles listed in the reference part.

6 References:

[1] “Lithium Ion Battery Safety,” *Go to EHS*. [Online]. Available: https://ehs.mit.edu/lab-research-program/lithium-ion-battery-safety/. [Accessed: 04-Mar-2021].

[2] T. Stein, “8 Safety Tips for Sharing the Road With Bikers & Cyclists,” *RoadLoans*, 03-May-2019. [Online]. Available: https://roadloans.com/blog/8-ways-to-safely-share-the-road-with-cyclists. [Accessed: 04-Mar-2021].

[3] S. Gustafson, “Why bicyclist deaths are at the highest levels in 30 years,” *Autoblog*, 04-May-2020. [Online]. Available: https://www.autoblog.com/2020/05/04/cyclist-traffic-death-tracking-outside-magazine/#:~:text=Tracking%20news%20databases%20and%20local,trains%20during%20the%20coronavirus%20pandemic. [Accessed: 04-Mar-2021].

[4] “U.S. Bicycle Accident Statistics,” *PennyGeeks*, 31-May-2019. [Online]. Available: https://pennygeeks.com/legal-resources/statistics/bicycle-accidents/#:~:text=Almost%20467%2C000%20individuals%20were%20hurt,reaching%20nearly%20820%20in%202015. [Accessed: 04-Mar-2021].