Backpack Buddy: Wearable Nighttime Safety Device

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ECE 445 Design Document – Spring 2023

Team #8

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1. Introduction

1.1 Problem and Background

The Office for National Statistics asked adults in the UK about their feelings of personal safety when they are walking alone at night. Many had responded that their fear of being assaulted when the sun goes down increases dramatically. In Figure 1, we can see that 80% of women and 40% of men feel unsafe when walking alone in large open outdoor spaces in June 2021 [1]. In addition, many of these feelings of discomfort were validated by various experiences of harassment. The Opinions and Lifestyle Survey (OPN) in Figure 2 showed that 28% of women and 16% of men had experienced at least one form of harassment from June 2020 to June 2021. Of adults aged 16 to 34 years, 58% of women had experienced harassment, compared with 24% of men [1].

Figure 1: Adults felt less safe walking alone in all settings after dark than during the day

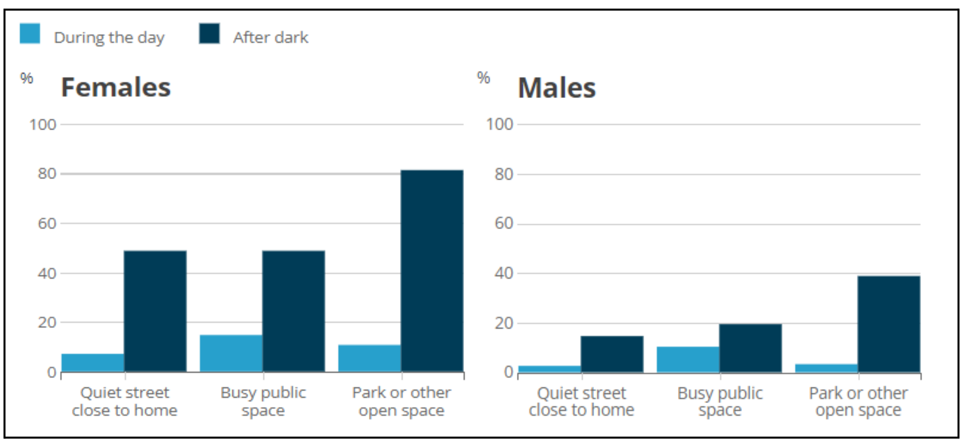
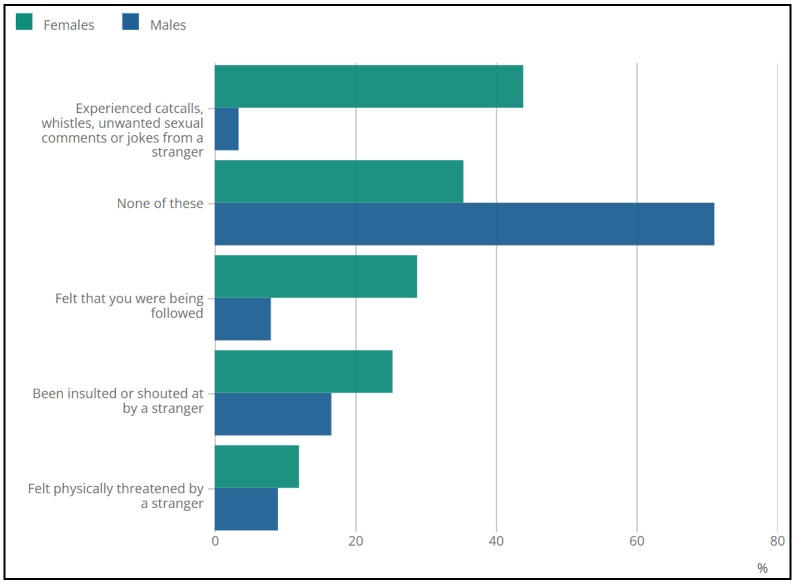


Figure 2: Percent of men and women experience harassment



For many college students, walking home late at night is a common occurrence. While there are safety resources available for students (free transit, emergency buttons, etc.), walking home late at night is often unavoidable or the most convenient way home. When the sidewalks of residential areas are empty at night, the risk of getting approached or followed from behind is dangerous. In cases like these, time to escape or defend yourself is the most critical line of defense. The Backpack Buddy aims to reduce this fear by providing time for the user to check their surroundings and get to a safe place if needed.

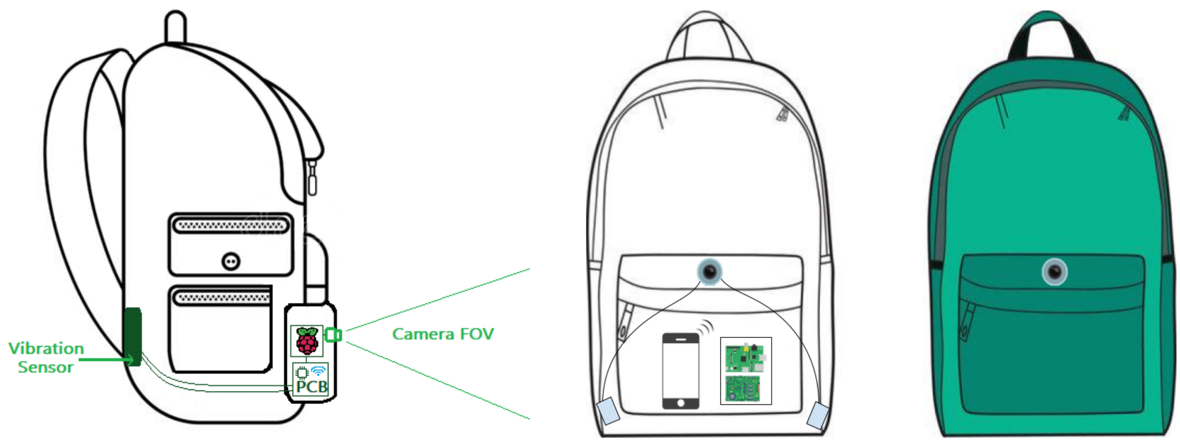
1.2 Objective and Solution

We plan to create a wearable system that monitors the walkway behind the user and discretely notifies them of another pedestrian's presence. The system should be able to distinguish a pedestrian (versus other moving objects) in low light conditions and alert the user if the pedestrian is either maintaining a close distance or on an intercept course. The device will use a night-vision camera and image processing to detect pedestrians in order to alert the user through haptic feedback. In addition, the user will also have the option to input an emergency contact, which the device will send an alert text to upon incident detection.

1.3 Visual Aid

The physical backpack will include an extra pouch to house the PCB and Raspberry Pi. At the top of the pouch, there will be a circular hole (or holes) for the night-vision camera. Our goal is to make this hole as discreet and secure as possible. The more secure the camera is to the backpack, the less shaky the camera footage will be and the more accurate our algorithm will predict a pedestrian. On the sides, the device will contain wired connections to our vibration sensors that will be placed closest to the user’s back.

Figure 3: Visualization of the physical design



1.4 High-level Requirements List

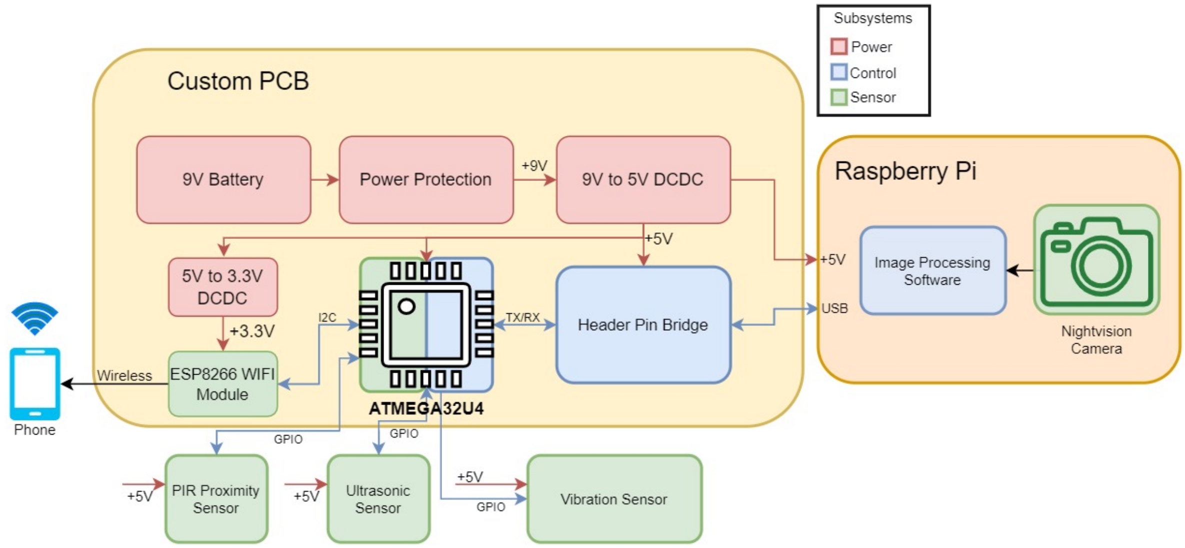
1. Distinguish pedestrians from other moving objects at a rate of 5 frames per second
2. Alert the user with haptic feedback if a pedestrian is less than 3 meters away
3. Send emergency alerts to given emergency contact if a pedestrian is within 30cm

2. Design

2.1 Block Diagram

The design shown in the block diagram shows two primary components: a custom PCB and a Raspberry Pi. The purpose of the Raspberry Pi will only be for image capture and processing. The data is then sent from the Pi to our PCB where the microcontroller will make future decisions about sending haptic feedback or triggering the automated phone text message system.

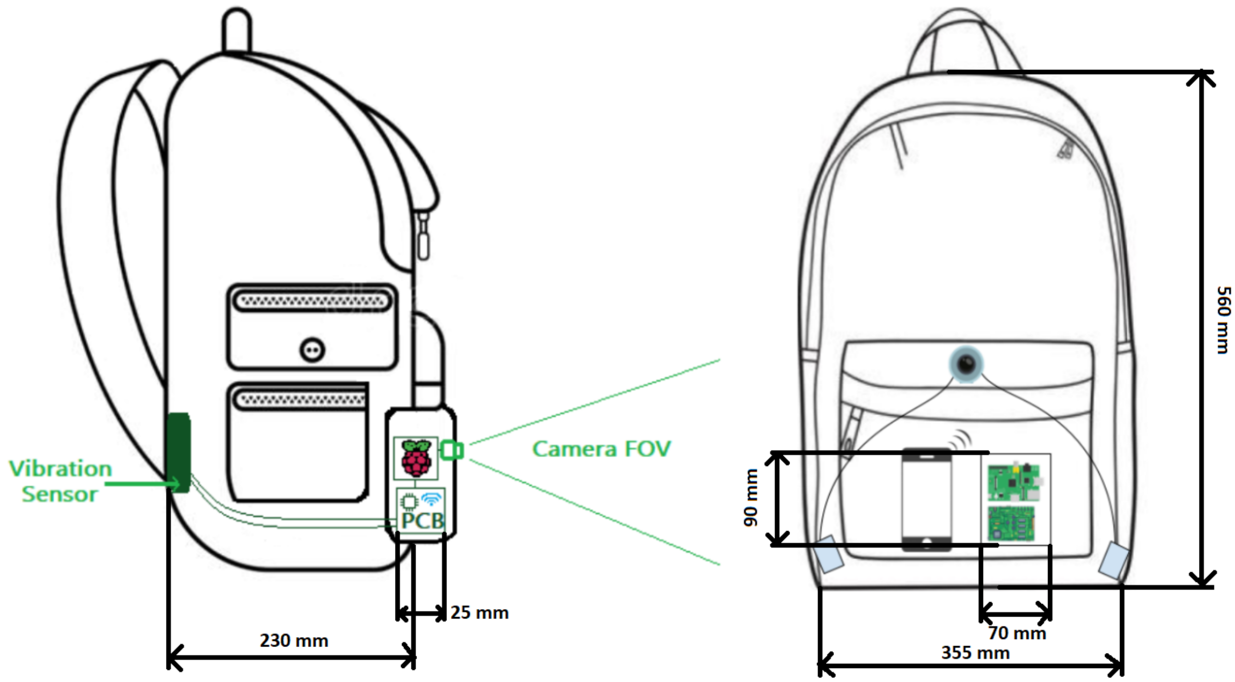
Figure 4: Block Diagram



2.2 Physical Design

The entire device will sit inside of a standard backpack, approximately sized 560 x 355 x 230 mm. The device's main board will fit within a 90 x 70 x 25 mm enclosure fixed to the bottom of the backpack, and will have an additional similarly sized enclosure housing all of the relevant sensors. These sensors will protrude from the rear side of a backpack and the haptic feedback actuator will be fixed to the user-side of the backpack, see Figure 3.

Figure 5: Physical Design



2.3 Power Subsystem

The Backpack Buddy draws its power from a rechargeable 9V battery configuration. This will be the component that ensures that all of our devices have the necessary power to run while performing their respective functions. To verify our system is working, we will create test points and LED indicators for each block that allows us to quantifiably measure if our systems are working.

2.3.1 9V Battery

The 9V battery will power all other components in our design. Having a 9V supply allows the board components to draw less current from the cells leading to a longer power-on time. We will be using Li-ion cells that will need to be properly connected in a series-parallel configuration to supply the power we need.

2.3.2 Power Protection

The current coming from the battery power supply will be varying so this power protection circuit will ensure the output of the battery is constant protected 9V power. This allows our PCB to be immune to the current spikes in the batteries used. The 9V power will also be regulated with a tolerance of +/- 10%. If the circuit draws too much power, we will have a 4A fuse break the circuit.

2.3.2 DCDC Converters (5V and 3.3V)

Many of the components on the PCB require a 5V power solution. This step down converter will produce a constant 5V output with a +/- 10% tolerance to power all devices. We decided to use the SI-8050Y because of its ability to supply up to 8A. Our project uses a Raspberry Pi 4 that can draw up to 3.5A. Other components also require various other amounts of current that we estimate up to another 1.5A. Additionally, the wifi module requires a 3.3V and at least 100mA so we chose the LM3940 3.3V DCDC converter for this purpose.

Table 1: Power Subsystem Requirements and Verification

Requirement	Verification Procedure
9V +/-10% Power Protection circuit ensures battery does not experience sudden surges in voltage in current leading to an undervolt situation	• Plug battery configuration into the PCB. With a DMM, we will able to probe the voltage coming out of the protection circuit • Connect an LED from the output of the converter to GND for quick visual verification
SI-8050Y buck switching regulator for 5V +/- 10% conversion and up to 8A output	• Probe circuit voltage and current at testing points • Connect an LED from the output of the converter to GND for quick visual verification
LM3940 LDO for 3.3V +/- 10% output and at up to 1A output	• Probe circuit voltage and current at testing points • Connect an LED from the output of the converter to GND for quick visual verification

2.4 Sensor Subsystem

The sensor subsystem is the primary I/O of our project. If an object comes within range of the motion sensor, the motion sensor is used to toggle the camera. The camera will then communicate with the raspberry pi for image processing and subsequent haptic feedback to the user. If a collision is detected with the sensors, the wifi module will send an SMS to a predefined contact.

2.4.1 Motion Sensors

Once the device is powered and mounted properly, the passive infrared sensor constantly searches for any object behind the user. If the object comes within 5 meters of the user, it toggles the night-vision camera to turn on. An additional ultrasonic sensor will turn on with the night vision camera, and will be used to detect whether or not someone comes into contact with the user. The sensors being used operate on 5V power. This component can be validated by being connected to our microcontroller which can read the I/O signals produced by these components; we will also connect an indicator LED to the PIR.

2.4.2 Night-Vision Camera

The night-vision camera is toggled by the proximity sensor detecting an object. Once it turns on, the camera continuously sends image data to the Pi through the USB interface. These images are then used for processing to trigger the vibration sensor as well as the wifi module. This component can be validated by connecting the output to an external monitor and ensuring image capture is available.

2.4.3 Vibration Feedback Actuator

When the system detects a person within a certain range of the user, the vibration actuators toggle in the users backpack to alert them that there is someone approaching them. Our plan is to use two of these vibration actuators so the user can receive stronger feedback or directional feedback. This component can be validated when user can feel vibration through a backpack.

2.4.4 Wifi Module and Phone

When the system detects a person on an immediate collision course with the user using the PIR and ultrasonic sensor, the wifi module will send a predefined alert message to an emergency contact through a webserver. The webserver will then send an SMS message to a predefined emergency contact through an external web server after being pinged by the wireless module. The wireless module we will be using is the ESP8266 which operates at 3.3V. This component can be validated if we can successfully initiate an SMS message to the emergency contact.

Table 2: Sensor Subsystem Requirements and Verification

Requirement	Verification Procedure
HC-SR501 Passive Infrared Sensor makes initial detection from 5m +/- 0.5m away	● Pedestrian walking towards PIR turns on indicator LED ● Modify sensitivity of PIR and repeat tests
HC-SR04 Ultrasonic Sensor measures depth with person 30cm +/- 10cm away	● Use the ATMEGA32U4 Arduino Dev Kit to read sensor data ● Verify sensor detects correct depth within tolerance
MakerFocus Raspberry Pi 4 Camera Night Vision Camera works in Low Light Conditions (in between last light and first light)	● Connect camera to external monitor for live video output ● User is able to distinguish most objects with live camera feed ● Test between sunset and sunrise (+/- 30 minutes)
Vibrating Mini Motor Disc for vibration generation that produces noticeable haptic feedback through a standard canvas backpack	● Connect motor to microcontroller ● When an object is detected within 3m away the microcontroller will supply the motor with 5V ● Verify user is able to feel vibrations through backpack
ESP8266 Wifi Module can send emergency message to Phone within 5 minutes	● Independently Power using breadboard setup ● Determine programmability to ping a webserver to send a text message to any preset phone number

	• Test functionality with ATMEGA32U4 microcontroller • Test integration with entire system

2.5 Control Subsystem

The control subsystem applies the image processing algorithm and subsequently controls the I/O sensors and actuators. The Raspberry Pi will analyze the live camera feed of the walkway and determine if a pedestrian is on a collision or otherwise threatening course (based on speed and angle). The ATmega microcontroller will aid in communication between all sensor modules.

2.5.1 Raspberry Pi Image Processing

The Raspberry Pi receives an image from the camera, applies filters for image processing and pedestrian detection based on the raw image taken from the night-vision camera. This data is then sent to ATmega over USB serial interface for post-processing. One potential way we would implement this is using the "You Only Look Once (YOLO)" algorithm [2]. The advantage of using this algorithm is that it provides image classification and localization real time. This way, the device will be faster to respond to potential threats. Another parameter we are taking into consideration is the light level outside. This algorithm is intended to work during the night, so we will ensure that our image processing will still occur with reasonable accuracy at a light level that goes along with at least 30 minutes before sunrise and 30 minutes after sunset.

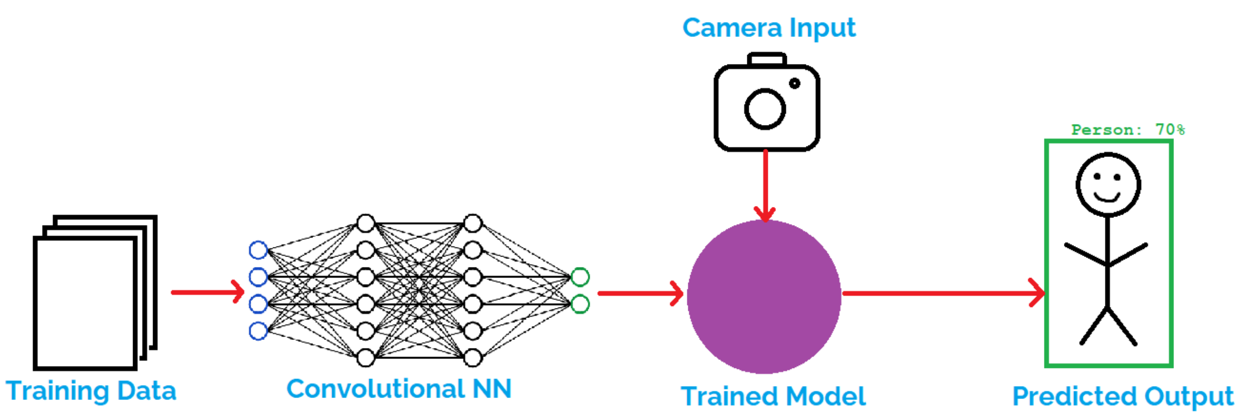


Figure 5: Image Processing Workflow

2.5.2 ATMEGA32U4 Microcontroller

The microcontroller is responsible for taking in all the sensor inputs and sending its respective signals to where they need to be delivered. We plan to use the ATMEGA32U4 due to its compatibility with the Arduino IDE and the availability of a development board for testing. Additionally, it contains enough GPIO pins for the project as well as works in a 5V operating system range.

Table 3: Control Subsystem Requirements and Verification

Requirement	**Verification Procedure**
Image Processing Algorithm identifies people with the similar accuracy as the YOLO algorithm +/- 5% at a rate of 4-6 frames per second	● With a stationary camera, perform object detection on objects stationary objects ● Algorithm should be able to determine which objects are people and which objects are non-people (not relevant whether it can properly identify what non-people objects are) ● Camera is stationary, objects are moving at average walking speed (2.5 - 4 mph) ● Algorithm should be able to determine which objects are people ● Camera is on a moving platform to simulate walking, objects are moving toward the camera at average walking speed
Microcontroller sends correct I/O signals to each subsystem within 1 second	● Flash the MCU with a program that drives pins to high and measure output with a DMM as well as have LED indicators ● Verify PWM signal pins with an oscilloscope ● Verify that each sensor is able to work with the same functionality on the dev kit and custom PCB

2.6 Circuit Schematic Diagrams (Work in Progress)

2.6.1 Power Subsystem Schematic

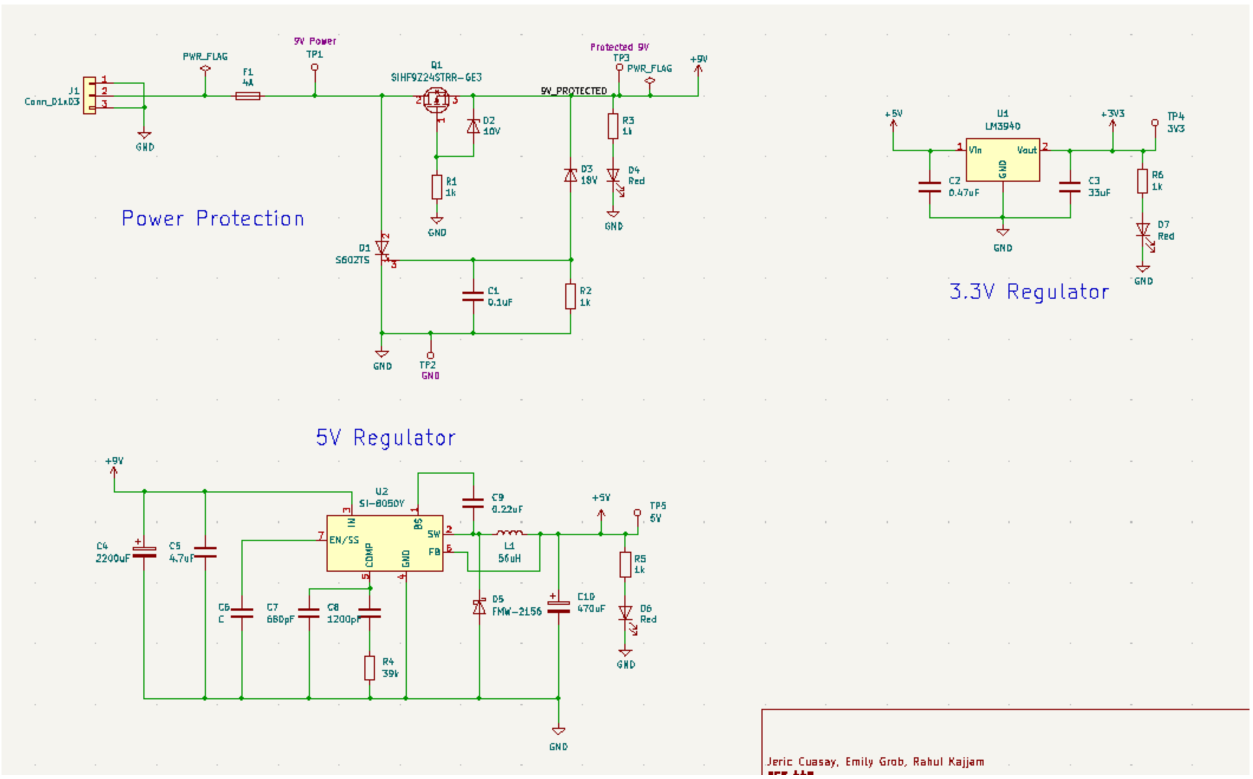


Figure 6: Power Circuit Schematic

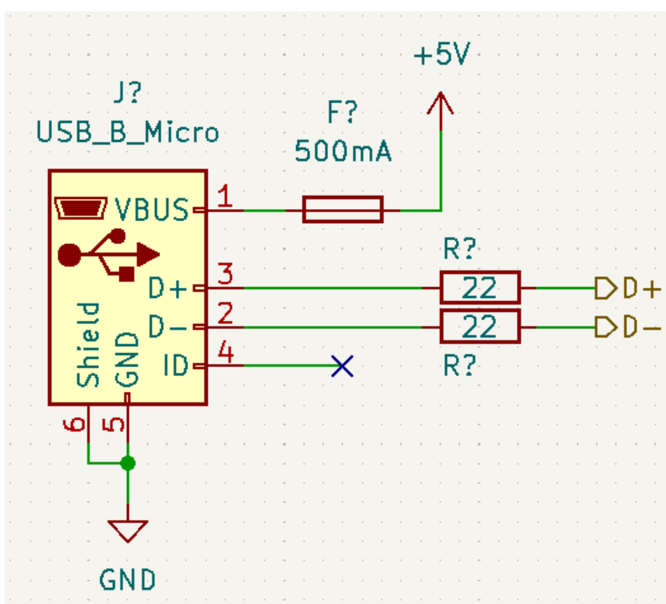


Figure 7: USB Programmer Circuit

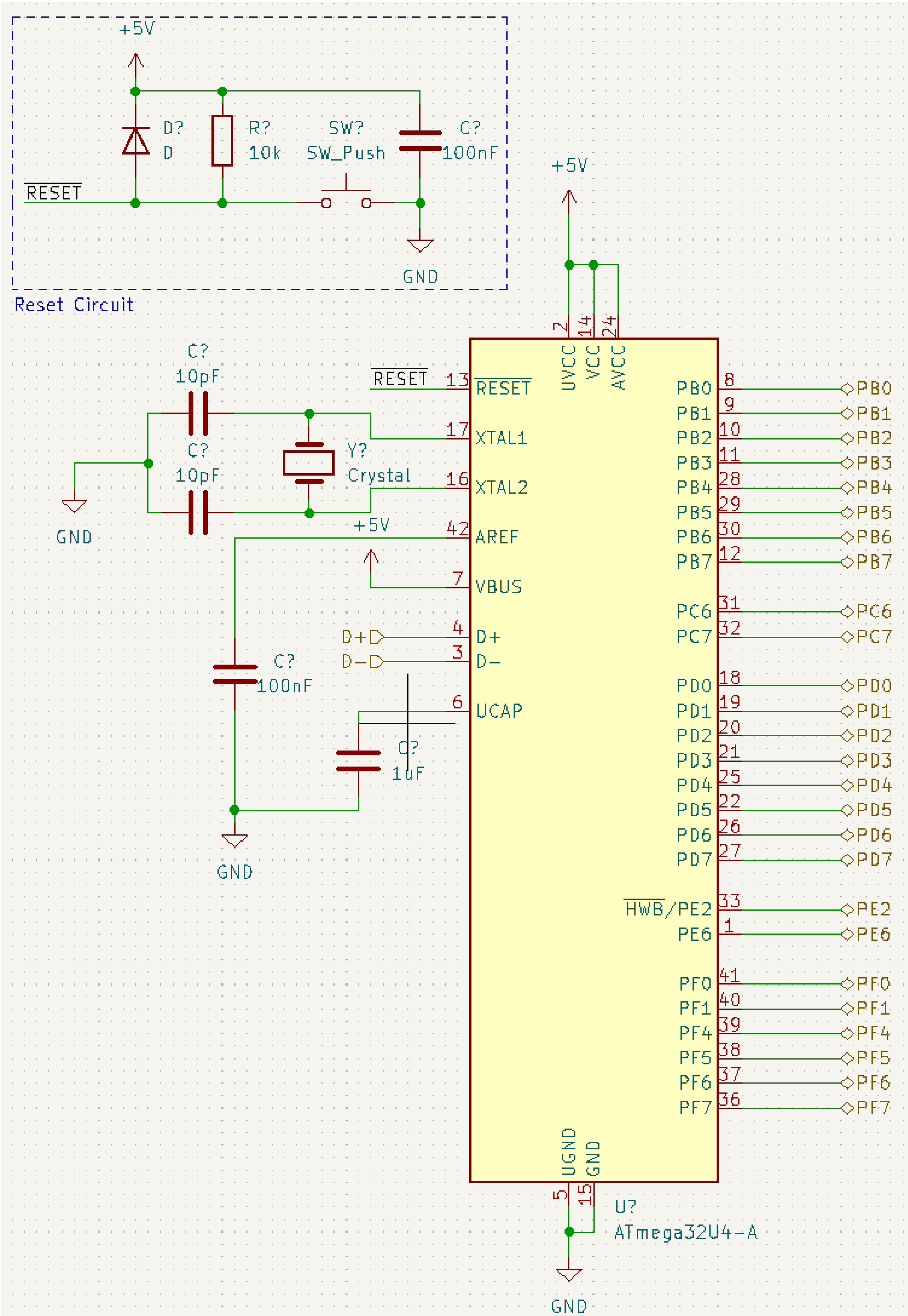


Figure 8: Microcontroller Schematic

2.7 Tolerance Analysis

2.7.1 Battery Selection

For our power subsystem, we have chosen a 9V battery to accomplish our needs. There could be a possibility that this will not be enough, so we will have our entire power subsystem account for multiple battery voltages, and still deliver the proper amount of power to each component.

2.7.2 Wifi Module Chip

One component that poses a risk to our project is the interfacing through the wifi module chip on our PCB. There could be multiple issues with getting the PCB connected to the phone using the I2C protocol. If it doesn't work out, then another solution would be to use the internet provided through the wifi chip integrated with the Raspberry Pi.

2.7.3 HC-SR04 Ultrasonic Sensor

The HC-SR04 Ultrasonic Sensor is a cheap and easily-integratable module, however due to its low-cost design there are accuracy and reliability risks. The functionality of the sensor involves triggering ultrasonic waves which are then reflected after hitting a target. The distance is determined by measuring the time-of-flight from transmission to the reception of the reflected waves. In our application, the object (a walking person) should be relatively slow with respect to the sound wave, so many distance estimations are possible while the object is within the sensor's coverage beam. Multiple distance estimations can be averaged to improve accuracy.
If we consider the distance to a fixed obstacle d_M, the distance to a moving object (a passing person) d, the minimum measurable distance d_m, and the coverage angle Θ. The time T of passing through the coverage area of the sensor can be calculated as follows:

$$T = \frac{2l}{v_p}$$

v_p is the speed of the moving object.

l is half the length of the sensor coverage area: $l = tan(\theta)d$

The time needed for distance measurement, T_p, knowing d can be found as:

$$T_p = \frac{2d}{v_s} + 2t_b$$

Here, v_s is the speed of sound and t_b is the burst length of the ultrasonic signal. If we add a margin of t_m seconds between two successive distance estimations, the equation can be re-written as:

$$T_p = \frac{2d}{v_s} + 2t_b + t_m$$

For our application, the result of the ratio $\frac{T}{T_p}$ will be >>1. Therefore, there should be plenty of time to determine several distance estimations. Averaging of the distance estimations can be used to improve the overall accuracy. [5]

3. Cost and Schedule:

Table 4: Cost Analysis

Part	**MPN**	**Manufacturer**	**Description/Notes**	**Quantity**	**Cost**
Ultrasonic Sensor	HC-SR04	Sparkfun	ultrasonic low range	1	4.50
PIR Sensor	HC-SR501	Xiaohunike	passive infared, longer range	1	8
Night Vision Camera	OV5647	MakerFocus	5MP 1080P camera	1	17.99
3.3V Regulator	LM3940	Texas Instruments	5V to 3.3V, 1A max output	1	2.84
5V regulator	SI-8050Y	Sanken	9-5V, 8A max output	1	2.26
9V Battery	–	EBL	5400mWh Li-Ion	4	23
Microcontroller	ATMEGA32U4	Microchip Tech	5V operating voltage	1	5.68
Vibration Sensor	Adafruit Motor Disc	Adafruit	11000 RPM at 5V (x2)	2	17.70
Wifi Module	ESP8266	Sparkfun	3v3 operating voltage	1	7.50
Backpack	–	Jansport	Standard Lightweight Schoolbag	1	20.00
Total Cost (Materials)	**–**	**–**	**–**	**–**	**$109.47**
Labor	–	–	$38.60/hr for UIUC EE from [7]	144 hrs	5558.4
Total Cost (with Labor)	**–**	**–**	**–**	**–**	**$5667.87**

Table 5: Schedule

Week	Task	Assignee
2/26	Finalize schematic	Jeric
	Refine library for pedestrians	Rahul, Emily
3/5	After receiving components, begin verification	Everyone
	Test algorithm in low-light and various moving conditions. Begin firmware	Rahul, Emily
	Begin testing ultrasonic and PIR in low light conditions	Jeric
3/12	Complete software to distinguish human from other moving object, send corresponding signal to ATmega	Everyone
3/19	Begin integrating subsystems	Everyone
	Finalize datasets for image processing algorithm	Everyone
3/26	Second Round PCB Orders Due	Everyone
	Finalize PCB design and component selection	Everyone
	Individual Progress Reports	Everyone
4/9	Finalize software and firmware components	Everyone
	Team Contracts	Everyone
4/16	Mock Demonstration and debug	Everyone
4/23	Final Demonstration	Everyone
4/30	Final Presentation and Final Paper	Everyone

4. Ethics and Safety:

One ethical issue that needs to be considered in this project lies in the nature of the image processing algorithm. Because our priority is to classify and localize an object in an image quickly, it will be prone to numerous errors. This can result in a higher number of false positives and negatives when recognizing pedestrians. It is important to ensure that privacy is maintained while video may capture someone unknowingly (IEEE Code of Ethics I.1) [3]. To prevent this, we will make sure that the processed image data will not be stored after its use; however, in the case that a figure does approach the user, a divergence can be made where an image can be saved in order to assist law enforcement in the case of emergency.

Additional potential concerns include safety concerns as we are planning on using batteries with chemistry in order to implement portability in our design. To prevent current runaway, we will ensure that the batteries we use are stored appropriately with proper insulation and ventilation. We will also complete all and any relevant trainings provided by the university.

5. References:

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