Backpack Buddy: Wearable Nighttime Safety Device

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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

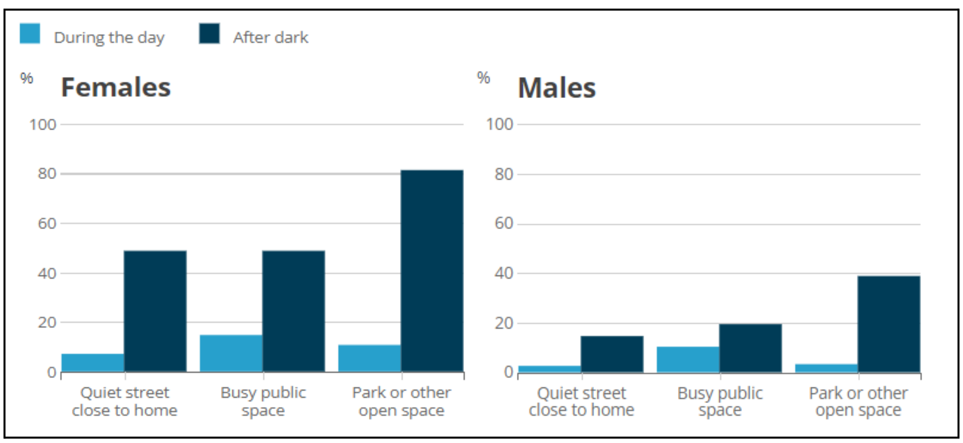
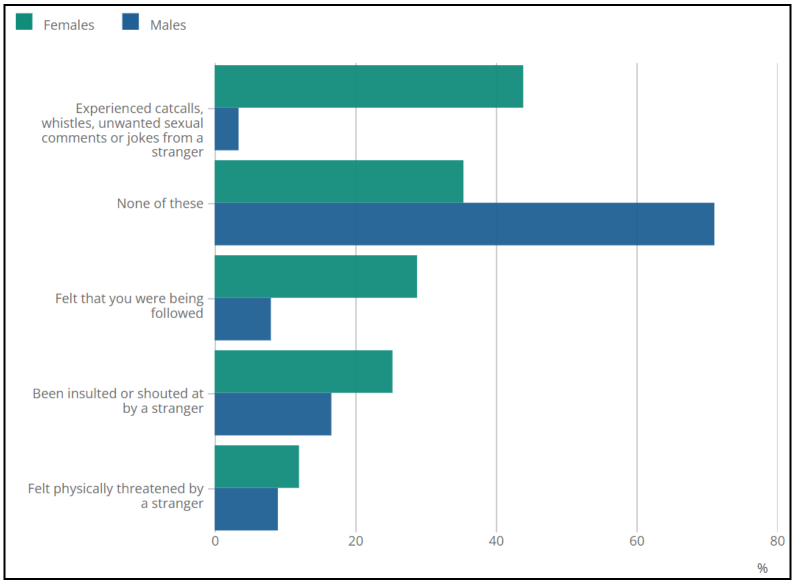


Figure 2: Percent of men and women experience harassment



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.

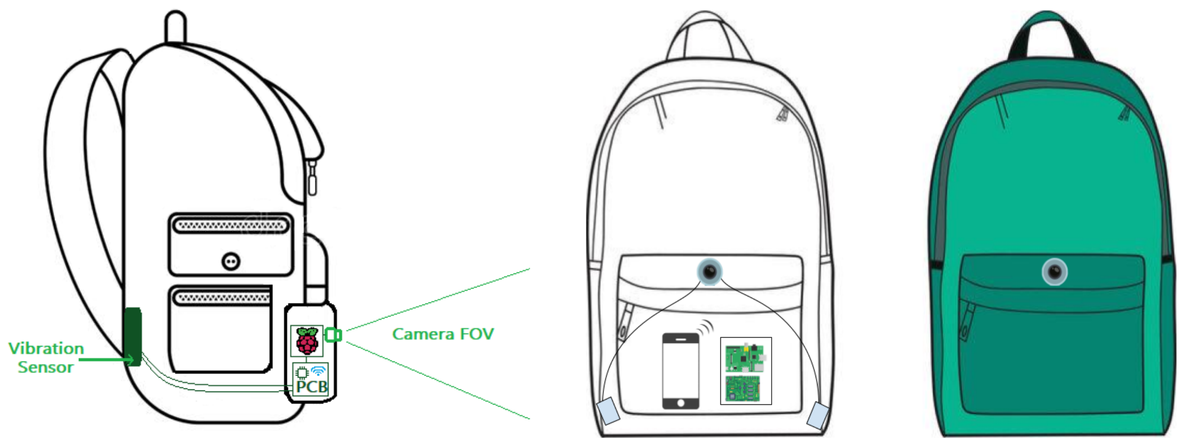
1.2 Objective and Solution

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

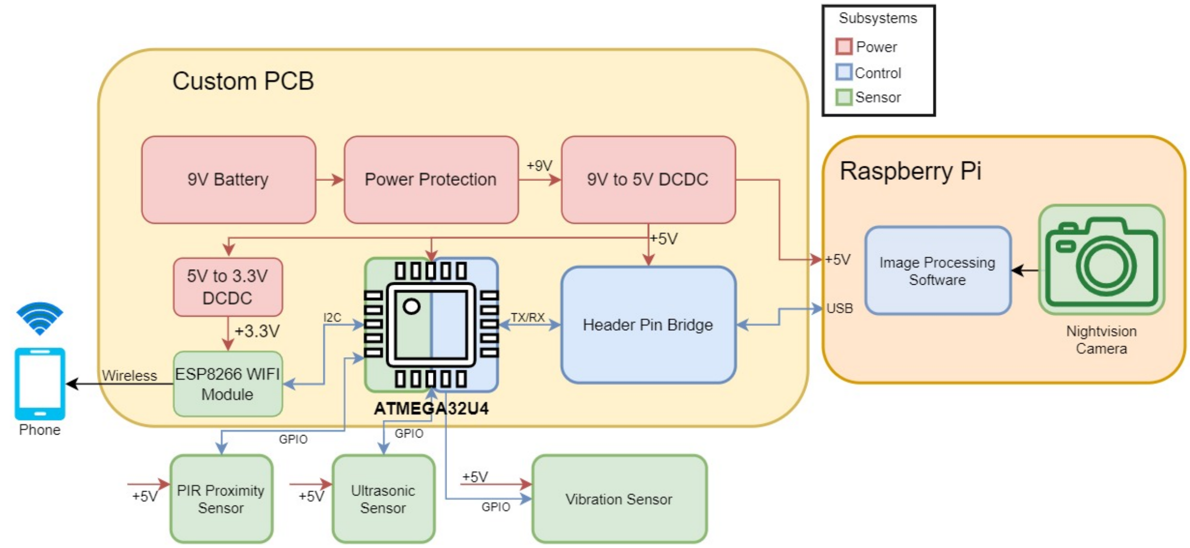
1. Distinguish pedestrians from other moving objects at a rate of 5 frames per second
2. Alert the user with haptic feedback if a pedestrian is less than 3 meters away
3. Send emergency alerts to given emergency contact if a pedestrian is within 30cm

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 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 testpoints and LED indicators for each block that allows us to quantifiably measure if our systems are working.

2.2.1 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.

2.2.2 Power Protection

The voltage 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 versatile to the voltage changes in the batteries used. The 9V power will also be regulated with a tolerance of +/- 0.25V

2.2.2 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 +/- 0.3V tolerance to power all devices. Additionally, the wifi module requires a 3.3V operating voltage so another DCDC converter will be used for this.

2.3 Sensor Subsystem

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

2.3.1 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.

2.3.2 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.

2.3.3 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.

2.3.4 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.

2.4 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.

2.4.1 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.

2.4.2 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.

Subsystem Requirements and Verification Table

Requirement	Verification Procedure
Power Subsystem outputs 5V, 3V3	Probe circuit at testing points. When unable to probe test points, we will connect the relevant voltage sources to indicator LEDs
Image processing algorithm distinguishes humans from other moving objects	Apply algorithm on a live camera-feed with people. Test on stationary objects, moving objects, and a moving platform.
Sensor subsystem activates image processing algorithm if movement is detected	Apply movement in front of PIR sensor, should initiate image processing algorithm
User is able to detect when there is a person behind them	Vibrational feedback actuators turn on when microcontroller detects people walking behind user. The user should be able to feel the haptic feedback on their back.
Emergency text is sent to pre-selected number	Phone with the relevant phone number receives message upon figure approaching the device too closely

2.5 Tolerance Analysis

2.5.1 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.

2.5.2 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.

2.5.3 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. 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.

4. References:

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