Outdoor Safety Bracelet

Design Document

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1 Introduction

1.1 Problem and Solution Overview

Caretakers have a constant responsibility to keep track of whoever they are watching. Whether it be children, the elderly, or anyone else that needs constant supervision, keeping an eye on them can be a full-time job. If the caretaker looks away for even a moment they might lose track of their dependent and depending on the situation, this could be incredibly dangerous.

Our objective is to make this job easier by creating a device that will track and report location and situational information to the supervising person. Specifically, we want to be able to track a dependent using GPS, collect information about motion and impact using an inertial measuring unit, and use a sensor to detect water. These components will fit in a comfortable, tamper-proof wristband/bracelet for easy wearability and comfort. The information will be sent using RF communication at 915 MHz to a receiver possessed by the caretaker. The receiver will be able to view multiple linked dependents' information on a screen and therefore constantly keep track of the dependent or dependents within a large radius. Additionally, the caretaker and dependent can communicate in some way if necessary. The bracelet has a help button that will alert the supervising person that the bracelet wearer needs help. The monitor has a button that will trigger a buzzer on the bracelet. The supervising person and the bracelet wearer can discuss what to do when the buzzer sounds prior to separating.

Many GPS tracking devices on the market require a monthly subscription to a service because they utilize SIM cards for wireless communication almost anywhere. Other devices utilize Bluetooth for shorter range communication. Our device will utilize 915 MHz RF to be able to communicate over long distances without the need for a monthly service. Additionally, our device is not just for tracking location, but also sends situational information like water contact and motion information. This information can be important in understanding more precisely where a dependent is or information about an event that happened.

According to NamUs, an organization that provides services to help locate missing people, over 600,000 people go missing each year in the United States and a lot more around the world [1]. With the availability of technology like GPS, it is possible to help lower these numbers by creating tracking devices for people who are susceptible.

GPS has been used for location systems and navigation for over 20 years. It has gotten so advanced that newer modules released in 2018 can locate to within 30 cm. Current tracking devices are either very short range or require an additional monthly purchase. Our idea is to create a long-range tracking system that can also provide situational information. This way a caregiver can feel less stressed about constantly watching their dependent. Whether at the park, in a city, or even on one’s own property, this device will be incredibly helpful to keep track of dependents and keep them safe.

1.2 Visual Aid

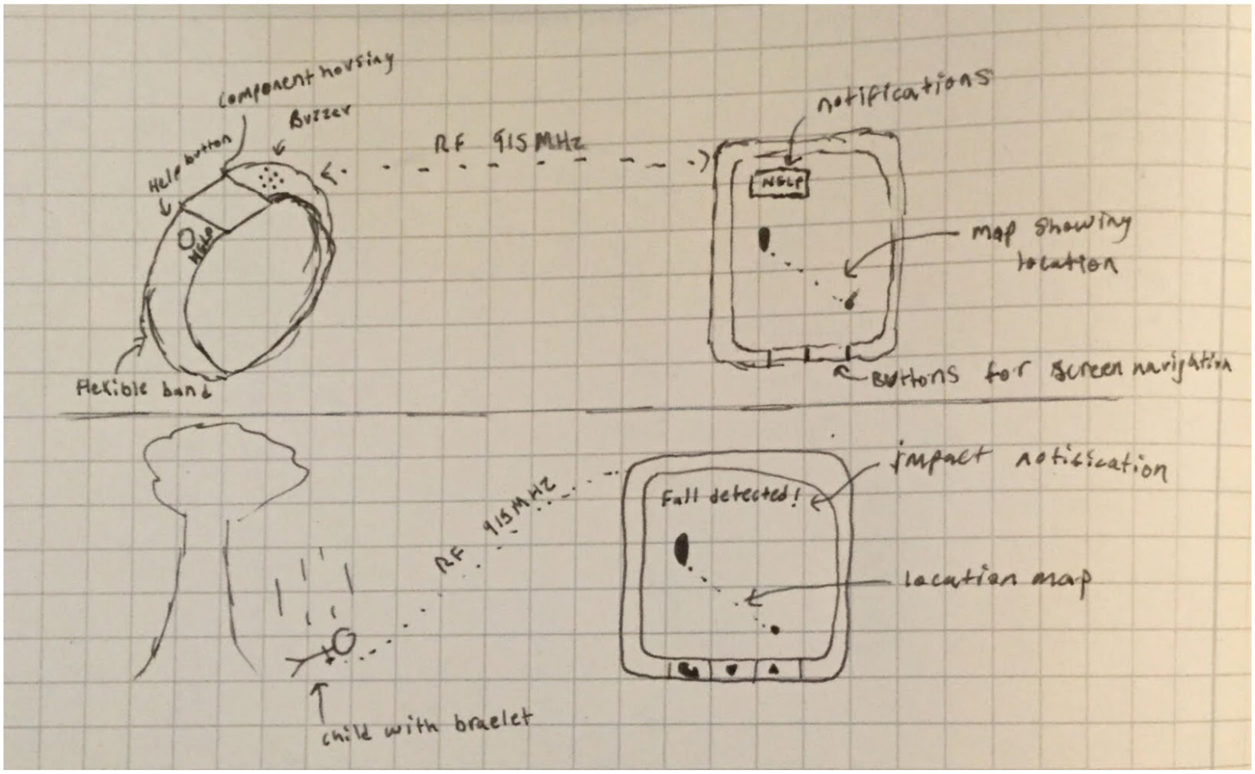

Fig. 1: Visual Aid

1.3 High-level Requirements

- Bracelet must be able to detect if wearer has had a fall from 1 meter or higher or comes in contact with water as
- Bracelet should be able to immediately send an alert to monitoring device when bracelet has detected danger
- Bracelet must be able to track location and communicate back to monitoring device for distances up to 500 meters

2 Design

There are two parts to this design. The bracelet is the device that is carried by the dependent and the monitoring device is possessed by the caretaker or supervising person. Within the bracelet are all the components that “monitor” the dependent and report situational as well as locational information. The sensor unit contains three sensors: the GPS module, IMU, and water detection module. These three sensors are powered by a 3.3V coming from the voltage regulator. They all communicate with the bracelets MCU through different communication protocols that will be described below. The MCU then packages the information in the necessary way to be sent over RF communication by the transceiver. Additionally, the bracelets UI block contains a help button to report that the dependent needs help and a buzzer which can be triggered by the monitoring unit.

The monitoring unit is a device that displays information about the bracelet. It shows location on a map as well as the distance between the two devices. The monitoring device will consist of a screen, buttons, control unit and power unit. The control unit will be responsible for receiving information from the bracelet and formatting it to be displayed by the screen. A GPS module is also used in the monitoring device to show the location of both devices on the map and to calculate relative distances. The monitoring device will also be able to signal the bracelet by sending a message to trigger the bracelets buzzer.

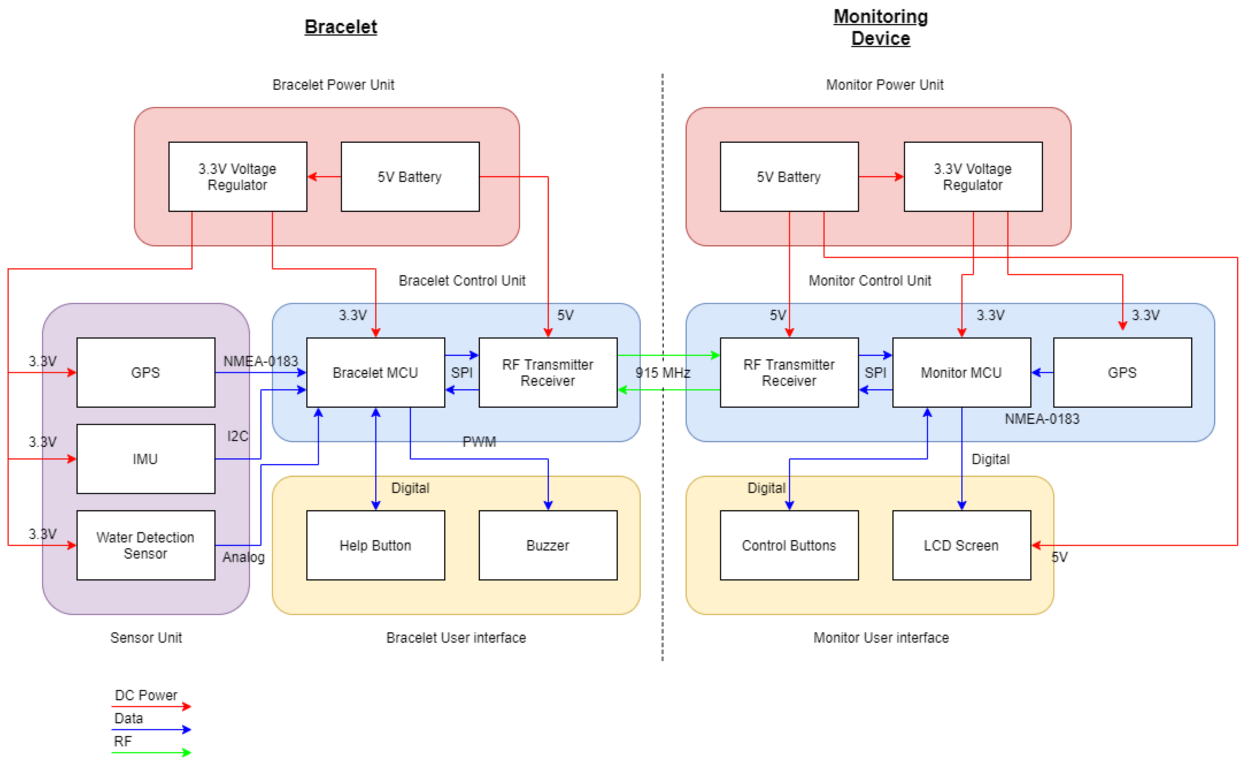

Fig. 2: Block Diagram

2.1 Power Units (Bracelet and Monitoring Device)

The power units will power all the modules in both devices. This unit will consist of a battery and a voltage regulator to step down the voltage for components that run on lower voltages.

2.1.1 5V Battery

Requirements	Verification
1. Battery must provide steady 4.75-5.25V with 0.2mA current draw for at least 4 hours	1. a. Using multimeter, verify a new 5V battery supplies between 4.75-5.25V b. Apply 0.2mA current draw against battery for 4 hours c. Measure output voltage after 4 hours to ensure it is still within 4.75-5.25V range

2.1.2 Voltage Regulator

The voltage regulator is responsible for stepping down the voltage and ensuring a safe voltage range to power the lower voltage modules. If the voltage leaves the safe range, there is a risk of damaging some components.

Requirements	Verification
1. Voltage regulator must provide 3.3V±5% from a 4.75-5.25V voltage source	1. a. Measure the voltage regulator output voltage using a multimeter. b. Verify the voltage is within 3.3V +/- 5%.

2.2 Bracelet Control Unit

The bracelet control unit is in charge of receiving data from the sensors, repackaging that data, and sending it through RF communication to be interpreted by the monitoring device.

2.2.1 Bracelet MCU

The Bracelet MCU is responsible for talking to the sensors and collecting the data that they gather. It will need to be able to communicate over several protocols including NMEA-0183, I2C, and SPI.

Requirements	Verification
1. MCU must include I2C, SPI peripherals 2. MCU must have at least 2 digital IOs and at least 1 analog IO 3. MCU must have at least 1 PWM output	1-3. Review MCU datasheet to verify that all peripherals and IOs are included on device

2.2.2 Bracelet RF Transceiver

For the RF transceivers we will use the RFM69HCW module that communicates at 915MHz. This is a small module that can communicate across fairly large distances. The module contains the ability to encrypt data with AES-128 bit encryption. The 915MHz band falls under the industrial, scientific, and medical (ISM) band and therefore, does not require a licence from the FCC [3].

Requirements	**Verification**
1. Must be able to communicate with RF transceiver at 915MHz 2. Must be able to communicate data up to 500m	1. Check on SDR radio device if there are transmissions at 915MHz when device is transmitting. 2. Separate two transceivers 500m apart and see if communication still occurs.

2.3 Bracelet Sensor Unit

The bracelet sensor unit contains all the monitoring components for the bracelet. Each sensor has its own communication protocol.

2.3.1 Global Positioning System

The GPS module will provide location coordinates to the MCU. The GPS communicates with NMEA-0183 which is a common communication protocol for marine electronics. This module requires 3.3V for power and will be attached to an antenna that is embedded in the bracelet.

Requirement	**Verification**
1. Provides accurate location data to ±0.00001° 2. Location data includes cardinal direction and GPS coordinates 3. GPS module updates location data at least 1 time per second (≥1*Hz*)	1. a. Place GPS module connected to Arduino in location where coordinates and direction is known b. Have GPS output NMEA data to Arduino and print coordinates/directions to monitor c. Read data and verify accuracy against the known coordinates/direction 2. a. Place GPS module connected to Arduino in location where coordinates and direction is known

	b. Have GPS output NMEA data to Arduino and print coordinates/directions to monitor c. Read location data and verify that it includes cardinal direction (N/S/E/W), degree of direction, and coordinates 3. a. Connect GPS module to Arduino and send location data to microcontroller b. Print location data to monitor with timestamp included c. Read timestamps to verify that location is being updated at least at 1 Hz

2.3.2 Inertial Measurement Unit

The IMU will provide force information about the bracelet and by extension the bracelet wearer. Software will be written to interpret the information provided by the IMU and to determine whether a larger impact has occurred. The IMU component communicates using the I2C protocol.

Requirements	Verification
1. Built in accelerometer is able to sense free falls at an acceleration of 1g ±5% 2. Built in accelerometer is able to sense standing falls, rapid changes in acceleration greater than 50% of 1g	1. a. Connect IMU to Arduino and program microcontroller to record and save all output data b. Package IMU+Arduino in encasing that will ensure circuitry's safety upon impact c. Drop package from various heights and record IMU data in Arduino d. Review data and verify that IMU outputs when free fall or sudden stops are detected within 1g ±5% acceleration range 2.

	a. Connect IMU to Arduino and program microcontroller to record and save all output data b. Package IMU+Arduino in encasing that will ensure circuitry's safety upon impact c. Drop package from various heights that mimic typical height of the human wrist and record IMU data in Arduino d. Review data and verify IMU outputs a delta in acceleration greater than 50% of 1g before, during, and after fall

2.3.3 Water Sensor

The water sensor module is an analog sensor that will output a high signal to MCU if water is detected. Software will be created to interpret the incoming signal and determine if there was a significant event. The sensor outputs an analog signal and will be converted by the MCU's ADC.

Requirements	**Verification**
1. Sensor must be able to detect a delta in temperature ≳2℃ 2. Sensor must be able to detect a delta in pressure of at least 2%	1. a. Connect sensor to Arduino and program microcontroller to record and save all output data b. Package sensor+Arduino in waterproof encasing that will ensure circuitry's safety when submerged in water c. Place package in water and record data in Arduino at least 10 times e. Review data and verify that sensor outputs a delta of temperature that is ≳2℃ 2.

	a. Connect sensor to Arduino and program microcontroller to record and save all output data b. Package sensor+Arduino in waterproof encasing that will ensure circuitry's safety when submerged in water c. Place package in water and record data in Arduino at least 10 times d. Review data and verify that sensor outputs a delta in pressure of at least 2%

2.4 Bracelet User Interface Unit

2.4.1 Help Button

The purpose of the help button is to allow the bracelet wearer to communicate with the supervising person. The button will trigger a help message to be sent to the monitoring device.

Requirements	Verification
1. Must be debounced to prevent multiple inputs. 2. Must be reliable and respond correctly to a press.	1. Hook up the button to an oscilloscope and verify no bouncing in the resulting signal. 2. Press the button 1000 times in rapid succession and verify the button was reliable.

2.4.2 Buzzer

The purpose of the buzzer is to allow the supervising person to communicate with the bracelet wearer. This can be a signal to return to a predetermined location, or stay where they are. The supervisor and bracelet wearer would discuss what this signal meant before parting ways.

Requirements	Verification
1. Must be at least 70 db (sound of multiple people talking) in volume.	1. Use audio equipment to test noise level.

2.5 Monitoring Device Control Unit

2.5.1 Monitoring Device MCU

The monitoring device MCU is responsible for all GPS related calculations as well as IMU computation. For this reason we chose to use a 16 bit MCU instead of an 8 bit.

Requirements	Verification
1. MCU must include SPI peripherals 2. MCU must have at least 2 digital IOs	1-2. Review MCU datasheet to verify that all peripherals and IOs are included on device

2.5.2 Monitoring Device RF Transceiver

Refer to Section 2.2.2

2.5.3 Monitoring Device GPS

Refer to Section 2.3.1

2.6 Monitoring Device User Interface

2.6.1 Monitoring Device Buttons

The monitoring device will utilize two buttons. One button will be used to turn the device on and off. The other button will be used to trigger the buzzer on the bracelet.
Refer to Section 2.4.1

2.6.1 Monitoring Device Screen

The screen of the monitoring device will display a map showing the location of the monitoring device itself as well as the location of the bracelet. Additionally the screen will show attributes of the bracelet as in the distance between the two devices, signal strength, and sensor information.

Requirements	Verification
1. Screen must be able to be visible in the sun and withstand the heat and UV light.	1. Take the screen in the sun and see how it operates.

2. Screen must be reliable and able to display everything correctly.	2. Trigger notifications and check to see if the screen gets updated correctly.

2.2 Software

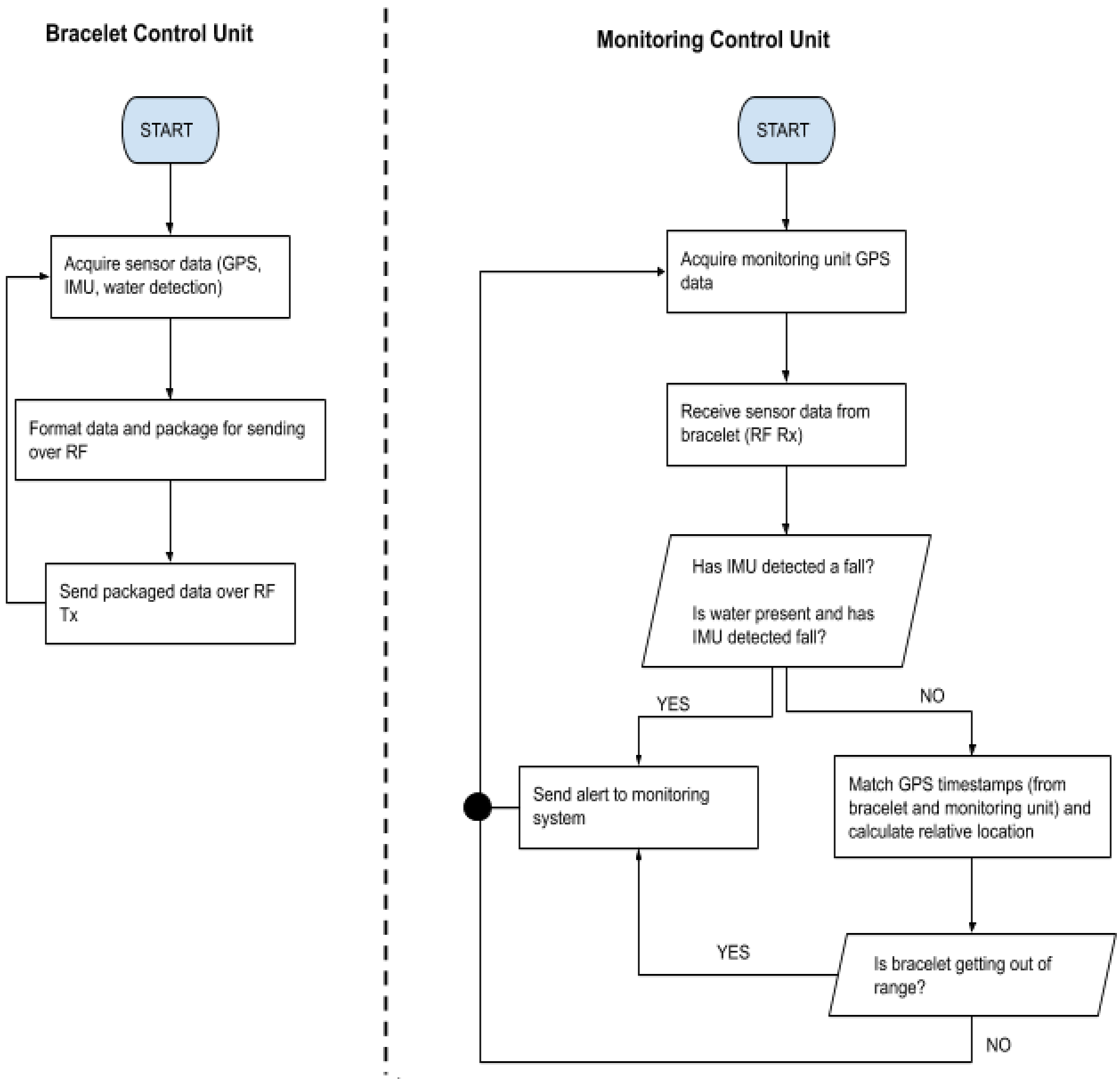

Fig. 3: Software Flow Diagram

3 Tolerance Analysis

One important tolerance we must consider is the measurement of the acceleration using the IMU. We want to be able to report falls both from high heights and just from standing, but we don't want swinging arms, sliding down slides, or other fast movements to trigger a warning. Ideally, the measured acceleration during free fall would be $g = 9.8\frac{m}{s^2}$ but we can't expect exact results. Our plan is to have a 5% tolerance on 1g.

$$a \geq 9.8 * 95\% = 9.3\frac{m}{s^2} \qquad \text{Eq. 1}$$

This will work to detect free fall, but won't necessarily capture someone falling from standing (i.e. tripping). To account for this, we will also take into account rapid changes in acceleration.

$$\Delta a \geq 6\frac{m}{s^2}\text{ ,} \qquad \text{Eq. 2a}$$

$$\Delta a = a(now) - a(-1sec) \qquad \text{Eq. 2b}$$

4 COVID-19 Contingency Plan

In the event that the University transitions to an all online approach, not much will change for our group. We will continue to discuss the project over Zoom. Sam and Seth can work on the physical design and assembly as they will be in proximity to each other and have a soldering iron. Sameeth can continue to program remotely.

Verifying speeds and other electronic testing might be more difficult without an oscilloscope although we have a digital oscilloscope that might be good enough.

In terms of putting together the housing, the band, and the receiver device, we can have parts 3D printed for us and can order all other components online.

If the project becomes difficult to fully complete, breadboard testing/PCB testing can certainly be accomplished. The most difficult part would be actually building housings for the electronics. Verifications would not change. All testing should still be able to be accomplished.

5 Cost

We estimate that it will cost $40/hour, 10 hours/week, over 16 weeks for three people.

$$3 * \frac{\$40}{hr} * \frac{10hr}{wk} * 16wks * 2.5 = \$48,000 \quad \text{Eq. 3}$$

Parts	Prototype	Bulk
Buzzer (PS1240)	$1.50	$1.13
Bracelet MCU (ATmega328P)	$2.01	$1.67
Monitoring MCU (STM32L010F4P6)	$1.40	$0.98
IMU (BMI270)	$5.58	$3.44
GPS x2 (MTK3339)	$29.95	$23.96
Voltage Regulator x2 (LD1117-3.3)	$1.25	$1.00
RF Transceiver x2 (RFM69HCW)digikey	$5.95	$4.99 on Amazon
Battery x4 (CR2450)	$0.79	$0.55
LCD Screen (ESP8266)	$21.49	$21.49
Water Sensor (BME280)	$5.95	$3.24
Button x3 (ALCOSWITCH)	$0.19	$0.16
PCB (PCBway)	$5.00	$0.37
Total	$120.96	$94.90

6 Schedule

Date	Sam	Seth	Sameeth
10/04/2020	Work on bracelet	Design bracelet using	Look into software

	electrical schematic	CAD software	requirements of components
10/11/2020	Complete bracelet electrical schematic and work on PCB	Work on receiver schematic and PCB/order parts	Start writing code for bracelet
10/18/2020	Test Circuits	Start assembling bracelet/ test circuits	Continue writing code
10/25/2020	Order PCBs	Assemble all hardware components	Continue writing code
11/01/2020	Solder PCBs	Test Prototype	Adjust code
11/08/2020	Make adjustments	Make Adjustments	Adjust code
11/15/2020	Finalize	Finalize	Finalize
11/22/2020	Prepare Final Presentation	Finish Final Report	Finish Final Report

7 Safety & Ethics

According to IEEE Code of Ethics, “We … in recognition of the importance of our technologies in affecting the quality of life throughout the world, and in accepting a personal obligation to our profession… agree: to accept the responsibility in making decisions consistent with the safety, health, and welfare of the public…” []. As the primary focus of this project is to expand and build on our personal and professional careers, we must uphold and remain consistent in our diligence for safety and ethical decisions. Therefore, as a team, we will ensure that we utilize proper safety precautions in the lab and during testing.

One potential safety issue this project has is that a child will be wearing a bracelet broadcasting their GPS location. According to IEEE Code of Ethics, #1: “to hold paramount the safety, health, and welfare of the public… to protect the privacy of others” [2], we are responsible for protecting all the information traveling through our devices. To prevent strangers from intercepting and interpreting the RF signal, it will be encoded with a known key using AES-128 bit. We intend to do everything in our power to protect all information on both devices from outside interference.

Another safety concern is the use of electronics in a product for children. Although the power supply voltages are low, electrical shocks can still potentially occur.

To protect against this, the bracelet will be tamper-proof and waterproof. This will prevent water and people from interacting with the electronics.

Another concern is with the use of radio frequency communication. The FCC has very clear regulations on the amount of RF energy that can be emitted by a device to limit exposure to human tissue. At high power levels/kg and high frequencies, there is potential to do damage [4]. Because of this potential the FCC decided to regulate the specific absorption rate (SAR) for humans in different contexts. The monitoring device and bracelet fall under the limits for general population/uncontrolled exposure which has a SAR limit of 0.08 W/kg as averaged over the whole body and a peak spatial average SAR for extremities (e.g. hands, wrists, feet, ankles, and pinnae) of 4 W/kg averaged over any 10 grams of tissue [5]. The maximum transmit power of our transceiver is 100mW [6] which averaged over an extremity and body is much less than the FCC limits.

References

[1] The National Missing and Unidentified Persons System (NamUs). [Online]. Available: www.namus.gov/About. [Accessed: 16- Sep- 2020].

[2] IEEE IEEE Code of Ethics (IEEE). [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 16- Sep- 2020].

[3] FCC Rules for Unlicensed Wireless Equipment operating in the ISM bands (Afar Communications). [Online]. Available: https://afar.net/tutorials/fcc-rules/ [Accessed: 1- Oct- 2020].

[4] RF Safety FAQ (Federal Communications Commission). [Online] Available: https://www.fcc.gov/engineering-technology/electromagnetic-compatibility-division/radio-frequency-safety/faq/rf-safety#Q6. [Accessed: 1- Oct- 2020].

[5] 47 CFR § 1.1310 - Radiofrequency radiation exposure limits. (Legal Information Institute). [Online]. Available: https://www.law.cornell.edu/cfr/text/47/1.1310 [Accessed: 1- Oct- 2020].

[6] RFM69HCW Datasheet (Hoperf Electronic). [Online]. Available: https://cdn.sparkfun.com/datasheets/Wireless/General/RFM69HCW-V1.1.pdf. [Accessed: 1- Oct- 2020].