3.0 DESIGN APPROACH

The SafeStep shoe's components include the battery; microprocessor; Near-field communication (NFC) tag; Bluetooth module; and temperature, audio, and gyroscope sensors. The design approach selected satisfies the constraints and requirements for the subsystems: Software, Sensor Integration, Communication, and Power Systems. These requirements are that the product achieves an IP 67 rating, fits size constraints, meets budget and time, sustains a battery life of 24 hours, and meets temperature, audio, and position goals set.

3.1. Design Options

Throughout the design process, many variables have been considered, ranging from power requirements to end-user lifestyle. These were challenges that any design team must overcome before creating a product. Some design considerations taken for the SafeStep can be found in the following section.

3.1.1. Design Option 1

Initially, the leading design option was a self-recharging shoe, utilizing piezoelectric discs to transfer kinetic energy into voltage. The shoe would have utilized a battery alongside the piezoelectric discs to regulate voltage for the microcontroller and sensor components. This idea was rejected as the piezoelectric disks would not have provided enough voltage to make a noticeable difference in battery life as well as the target consumer being less likely to walk distances far enough to charge the battery on a day-to-day basis.

3.1.2. Design Option 2

The second iteration of design options removed the kinetic recharging component from Design Option 1 due to the impracticality of the piezoelectric discs. This decision was made in tandem with the change in the target audience, from younger children to the elderly. The SafeStep is now only battery-powered, with a microcontroller using data input from multiple sensors throughout the shoe. With the switch to only battery power, the SafeStep still maintains a charge that lasts 24 hours of normal use. The removal of piezoelectric discs allows the SafeStep to retain more comfort and support in the sole of the shoe and reduces potentially dangerous electrical discharge. The exclusion of piezoelectric discs allowed the team to focus on the safety and durability of the primary components.

3.2. System Overview

This section provides an overview of the design and functionality of the SafeStep shoe and how each component interacts with each other's.

The following Figure 3-1 introduces a very high-level overview of the design. It shows the inputs of the design of the system as a whole and what is expected to be output.

Figure 3-1: The SafeStep System at a Glance (Level 0)

Figure 3-1 is a very high-level overview of the inputs to the SafeStep shoe to the outputs of user alerts to the smartphone app.

Figure 3-2 introduces the Level 1 diagram of what the design will look like. This breaks it down into the inputs received into the system, the overall components used in the design, and the outputs expected from the system.

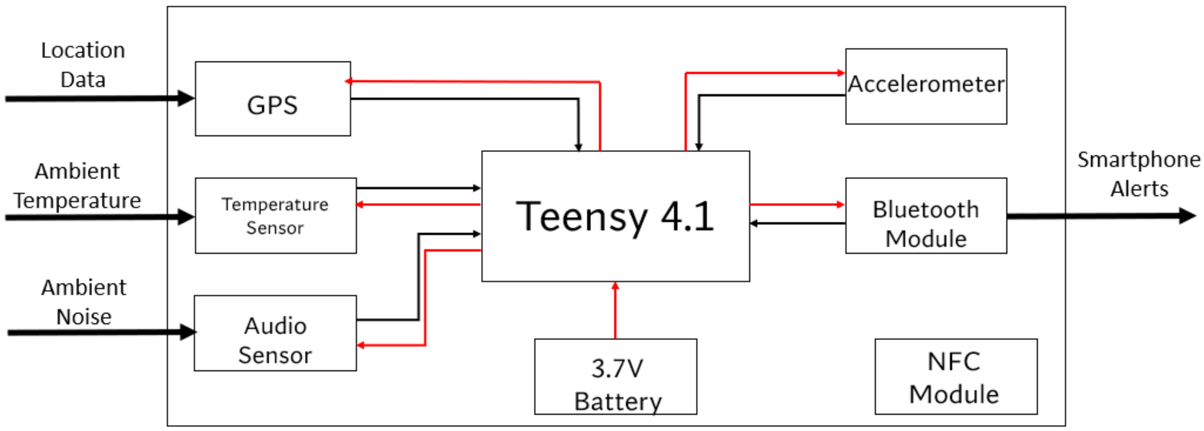

Figure 3-2: The SafeStep System Functionality (Level 1)

Figure 3.2 features the connections between each component and how they interact with each other.

The figures presented in the section above display the overall design selected by the team.

3.2.1. Microcontroller: Teensy 4.1

For the SafeStep, a microcontroller is utilized. to facilitate data collection from the subsystems and to manage Bluetooth communications with the user or caretaker's smartphone. The main considerations for microcontroller selection were operating voltage, amount of onboard flash memory, and the number of general-purpose input/output (GPIO) pins. Table 3-1 provides a comparison of the options considered.

Table 3-1: Microcontroller Options

Product	Memory	Pin Count	Operating Voltage	Dimensions	Cost
Requirements	>= 512 KB	> 40 GPIO	< 3.7 V	Small as possible	< $50
Teensy 4.1 [1]	8 MB	55 GPIO	3.3 - 5.0 VDC	60.9 (L) x 17.8 (W) x 4.1 (H) mm	$ 31.50
Raspberry Pi 4 [2]	1 MB – 100 GB	40 GPIO	3.5 - 5.5 VDC	85.0 (L) x 56.0 (W) x 4.5 (H) mm	$ 35.00
Arduino Due [3]	512 KB	66 GPIO	3.3 - 13.8 VDC	101.5 (L) x 53.3 (W) x 18.6 (H) mm	$ 48.40

For the SafeStep, Teensy 4.1 (shown below in Figure 3-3) serves as the microcontroller for the product. Out of all considered options, the Teensy 4.1 has a usable amount of memory, this is important because it allows Walking Alive to write code that can fully support all subsystems. The small size of the Teensy 4.1 allows for flexibility in positioning. The 55 GPIO pins allow for abundant connections to sensors and power. The

Teensy platform is easily programable via the Arduino IDE. For these reasons, the Teensy 4.1 is the ideal microcontroller for this project.

Figure 3-3: Teensy 4.1 [1]

In Figure 3-3, the pin holes are open on either side of the unit. The lack of installed pins allows for maximum flexibility in the design of the SafeStep.

3.3. Subsystems

The prototype for the SafeStep Shoe includes four subsystems. Subsystem 1 is the power system that includes the charging, storage, and distribution of power within the shoe to other subsystems. Subsystem 2 is the communication subsystem, which features Bluetooth connection and NFC connection with smartphones. Subsystem 3 is the software portion of the SafeStep. This features the internal software programming of the microprocessor and the writing to NFC and Bluetooth protocol. Subsystem 4, the last subsystem, features all sensors. These sensors communicate with the microprocessor and take in data for temperature, audio, and position of the wearer.

3.3.1. Power System

The SafeStep shoe requires that the power system provides enough voltage and amperage to sustain the electronics of the shoe for at least 24 hours. The power system requires a component to charge the rechargeable battery and distribute power to the system.

Table 3-1: Charging Module Options

Product	Input Voltage	Charge Current	Dimensions	Cost
Requirements	>= 4 V	<= 1 A	Small as possible	<= $10
Makerfocus TP4056 Charging Module [4]	5 V	1 A	260 (L) x 170 (W) mm	$9.00
NiMH Rechargeable Battery Charger [5]	5 V	231 mA - 240 mA	30 (L) x 15 (W) x 4 (H) mm	$9.00
Battery Charger Module [6]	1 V-5 V	1 A - 1.5 A	500 (L) x 500 (W) x 20 (H) mm	$8.55

The Makerfocus TP4056 Charging Module (shown in Figure 3-4) was chosen for the power system charging module. Though most of these modules were similar in size, the chosen module allowed the most flexibility with placement and space. The charging module features back-charging protection to keep the microcontroller and battery safe. The device utilizes the full charging ability of the battery. The device features a very common input cable as USB-C cables are used around the world.

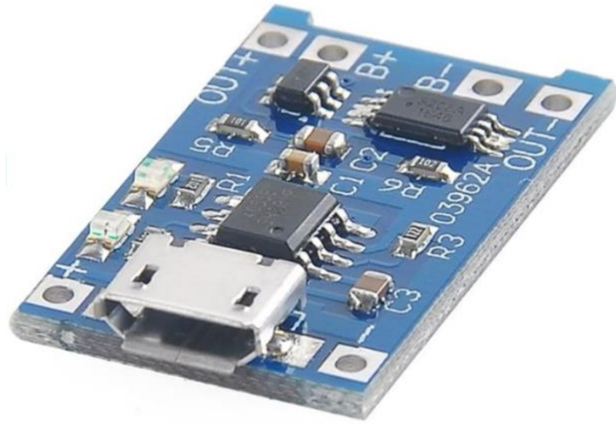

Figure 3-4: Makerfocus TP4056 Charging Module [4]

The Makerfocus TP4056 charging module breakout board will be connected to the battery to allow for charging from USB-C cables.

The power subsystem uses this main component to charge the battery. This helps satisfy the requirement of the power subsystem to last a full day of use. This charging module provides protection and a common cable connection to provide safety and ease of use to the design.

3.3.2. Communications System

For communications between a mobile device and the SafeStep product, a Bluetooth module has been chosen. Bluetooth is the only widely supported NFC protocol for inter-device communication. The Bluetooth module is placed on the side of the SafeStep product to limit material inference. A list of possible Bluetooth modules is provided in Table 3-3.

Table 3-3: Bluetooth Transceiver Options

Product	Operating Voltage	Data Rate	Range	Connection Pins	Dimensions	Cost
Requirements	<= 3.7 VDC	> 9 kB/s	> 10 m	< 6	Small as possible	< $10
DX-BT24-A [7]	3.5 - 5 VDC	10 kB/s	< 15 m	6 pins	37.5 (L) x 15.7 (W) x 4.0 (H) mm	$ 7.40
HC-06 [8]	3.3 VDC	10 kB/s	< 15 m	4 pins	43.0 (L) x 16.0 (W) x 7.0 (H) mm	$ 9.49
HC-05 [9]	3.7 - 6 VDC	9.6 kB/s	< 7 m	6 pins	27.9 (L) x 15.2 (W) x 2.5 (H) mm	$ 9 .99

The HiLetgo HC-06 Bluetooth module (shown in Figure 3-5) is used to facilitate communications for the SafeStep. The Bluetooth module occupies fewer pins on the microcontroller. The number of pins utilized is important because the microcontroller has many pins occupied by sensors. The HC-06 operates on 3.3 volts of electricity. A Bluetooth module that does not require step-up or step-down transformers is vital for the space constraints within the system. The minimum Bluetooth module range for the SafeStep is 10 meters to provide a level of safety for the wearer and caretaker. For these reasons, the HiLetgo HC-06 is the best choice for the project.

Figure 3-5: HiLetgo HC-06 Bluetooth Transceiver [8]

In Figure 3-5 the HiLetgo HC-06 is shown.

To store emergency contact information, an NFC device is utilized because the device does not require power to store, maintain, or read the stored data. Most modern smartphones natively support NFC technology. By using this technology, emergency contact information is available even if the system has lost power. The NFC is placed on an easily accessible portion of the SafeStep product. A list of NFC devices considered is shown below in Table 3-4.

Table 3-4: NFC Options

Product	Storage	Dimensions	Cost
Requirements	> 100 Bytes	Small as possible	< $5
Adafruit NTAG203 Micro [10]	144 Bytes	15.6 (L) x 6 (W) x 0.7 (H) mm	$2.95
13.56MHz RFID/NFC White Tag [11]	144 Bytes	25 (L) x 25 (W) x 0.9 (H) mm	$2.95
NTAG203 Chip [12]	144 Bytes	25.0 (L) x 25.0 (W) x 0.7 (H) mm	$2.95

The Adafruit NTAG203 Micro NFC tag (pictured in Figure 3-6) is utilized to provide emergency contact information for the SafeStep. The project requires that an NFC device be able to store at least 100 Bytes of data. All of the NFC devices listed utilize the NTAG203 chip, with the primary difference being the antenna sand enclosure size. The NTAG203 Micro was deemed to be more suitable for the SafeStep as it meets the storage requirements while being smaller than the other NFC options.

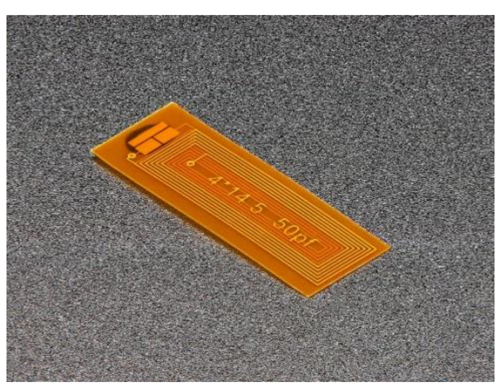

Figure 3-6: NTAG203 Micro NFC tag [10]

The NTAG203 Micro is attached to the back of the SafeStep to facilitate easy access to emergency contact information.

The communications subsystem serves to link the SafeStep with the caretaker's device. This link carries GPS and sensor data to provide accurate information to the app. The communications system also carries emergency contact information via an NFC tag. The communications system is vital for the integration of both the app and the SafeStep device.

3.3.3. Software System

The SafeStep utilizes a smartphone application to interface with the shoes and monitor data. The mobile application is page-based, consisting of the status page, location page, information page, and settings page. The mobile application is built on .NET MAUI, the successor to Xamarin Forms, and features full support for both Android and iOS. The modern flexibility and support of .NET MAUI, as well as feature-rich community plugins, make it an easy choice for cross-platform applications. Due to internal .NET MAUI restrictions, the SafeStep mobile application only supports Android 5.0 (API 21) or higher, and iOS 11 or higher. These operating system versions were released in 2015 and 2017 respectively. As such, most modern smartphones likely meet or exceed these requirements and should not pose a significant challenge to users. The mobile application uses local notifications to avoid the need for constant network connectivity. Because of this requirement, the mobile application does not utilize backend cloud servers, such as Firebase, for notification services.

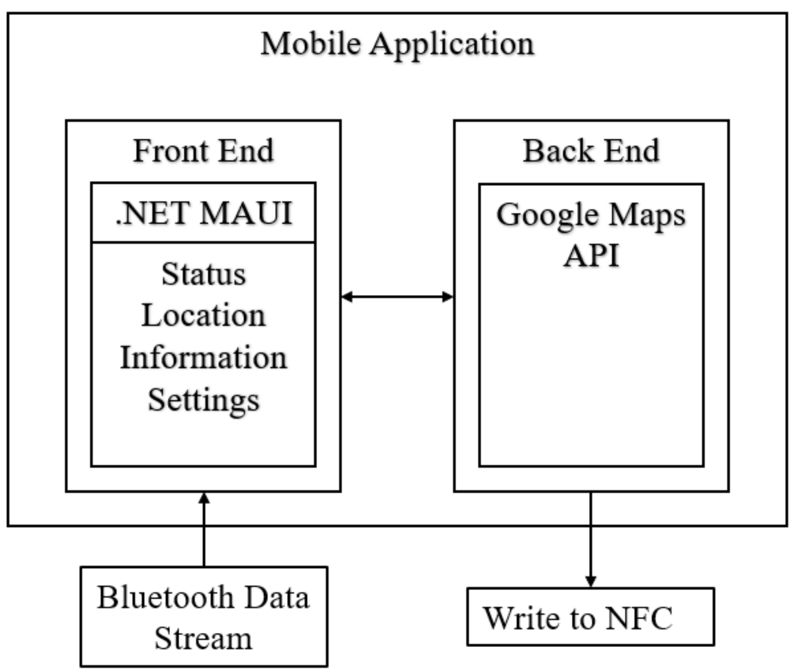

Figure 3-7: Mobile Application Architecture Diagram

In Figure 3-7, the mobile application architecture is shown. The application provides an easy interface with the SafeStep to increase convenience for the end user.

The status page displays the shoes' most recently reported battery life, decibel readings, and temperature readings. These values are determined by the various sensors' location throughout the SafeStep and reported to the mobile application via Bluetooth connection. The location page displays a map of the most recently reported location of the SafeStep, as well as the current location of the smartphone. The location services are provided by the Google Maps API as it has widespread support and integration with .NET MAUI. The location services do not require a constant internet connection to work, however, an internet connection is required for the initial setup. These pages can be seen in the following figure.

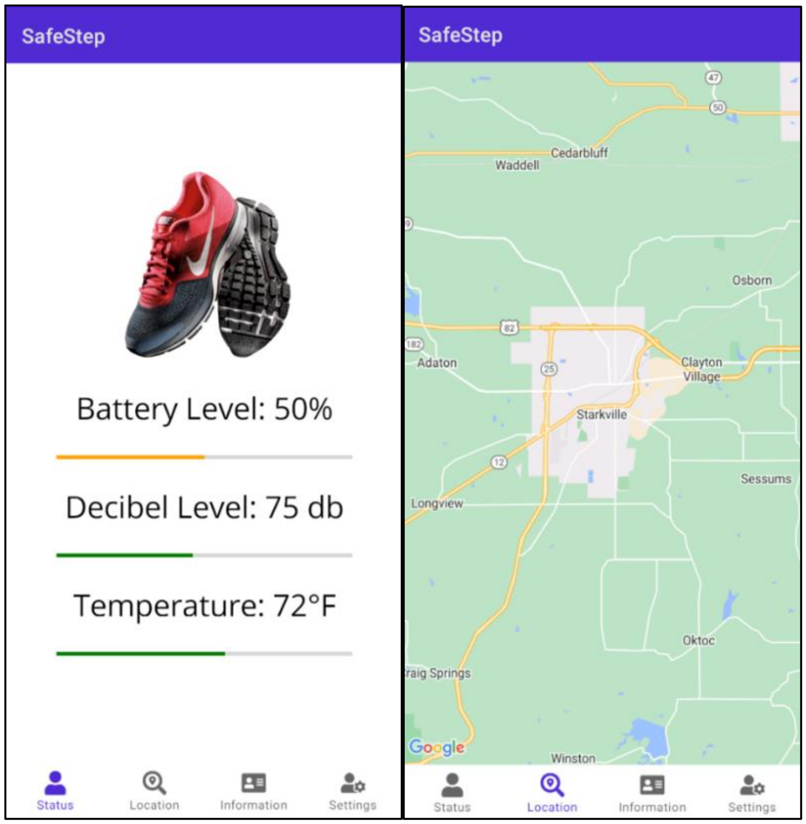

Figure 3-8: Mobile Application Graphical User Interface Mockup – Status and Location

In Figure 3-8, the app mockup for both the status and location page is shown. As these images are just a mockup, they are subject to change. The page on the left depicts the status page, showing the current battery level, decibel level, and temperature, with color-changing status bars beneath the readings. On the right, the location page displays a map of the user's current location as well as the location of the SafeStep.

The information page displays the last written emergency contact information to the NFC tag within the SafeStep. The information page also allows the user to update the emergency contact information on the NFC tag. The settings page allows the user to change basic app settings, such as toggling notifications for certain triggers. A mockup of these pages can be seen in the following pages.

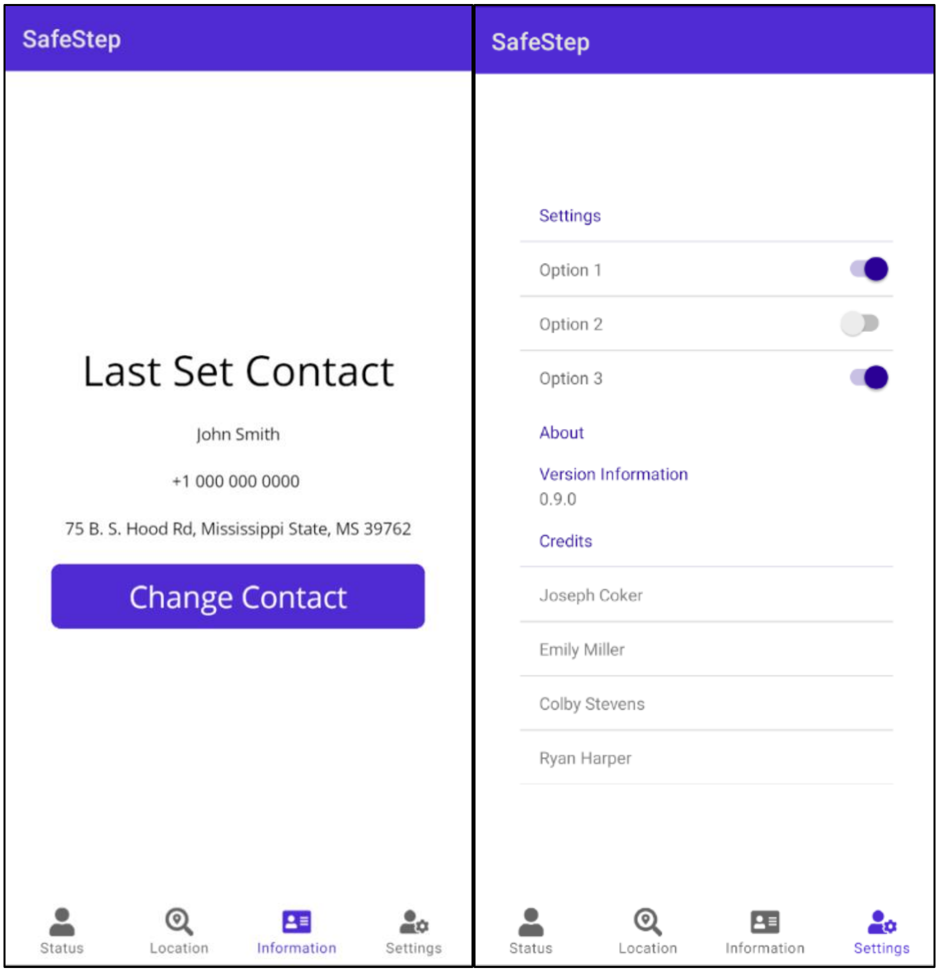

Figure 3-9: Mobile Application Graphical User Interface Mockup – Information and Settings

In Figure 3-9, the app mockup for both the information and status pages is shown (also subject to change). The page on the left displays the information page, showing the last set of contacts. An NFC tag is used to store the information, and changing the contact requires user input and tapping the smartphone to the NFC tag. On the right, the settings page is shown. The settings page gives the user options to change how the app operates, as well as showing the app version and credits.

An integral part of the software subsystem is the microcontroller software. The microcontroller utilizes the Arduino IDE to interface with the sensors and sends the data over Bluetooth to the mobile application. The SafeStep has a battery life of 24 hours which is made possible with the sleep mode. An overview of the microcontroller software architecture is found below.

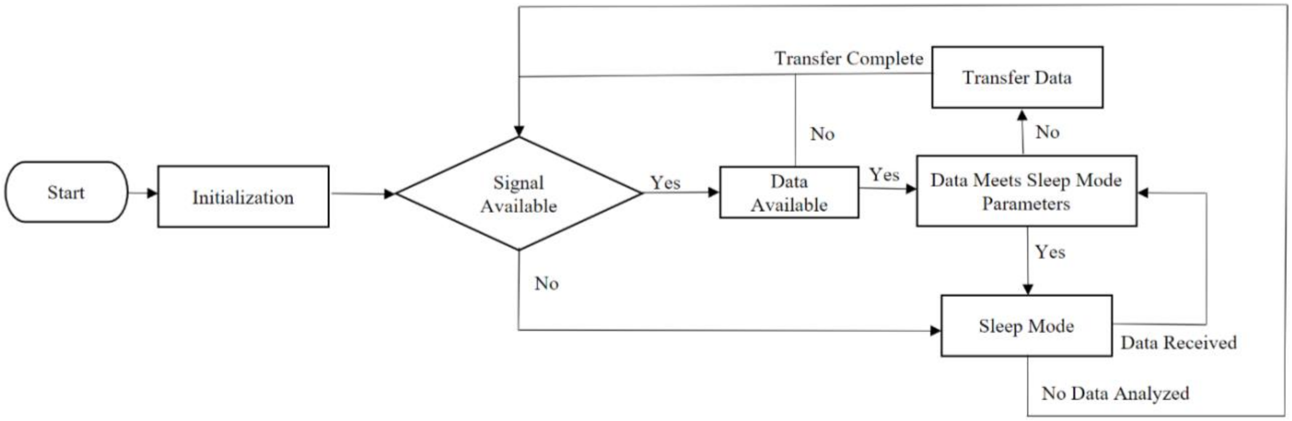

Figure 3-10: Microcontroller Software Architecture Diagram

In Figure 3-10, there an overview of the microcontroller software architecture is shown. The key takeaway is the sleep mode, which helps extend the battery life of the SafeStep.

The software systems put in place for the SafeStep are required for all the sensors, controllers, and communications to operate as intended and allow the user or caretakers to have accurate information.

3.3.4. Sensor Integration System

The SafeStep integrates five types of sensors within each shoe: a temperature sensor, a humidity sensor, a global positioning system (GPS) module, a gyroscope sensor, and an audio sensor. Each sensor takes in an array of data from the environment and the sensors work in conjunction with the radio module to send real-time environmental data to the app.

For the temperature and humidity sensor, the team considered having two separate sensors within the shoe that monitor temperature and humidity separately, but due to size constraints, a combined module has been selected. Table 3-5 lists the temperature and humidity sensors that were viewed.

Table 3-5: Temperature / Humidity Sensor Options

Product	Temperature Range	Humidity Capability	Dimensions	Cost
Requirements	18 °C to +27 °C	Largest Range	Small as possible	< $12
HiLetgo DHT11 Temperature Humidity Sensor [13]	-40 °C to +125 °C	0-99%	11.94 (L) x 27.94 (W) x 7.2 (H) mm	$9.99
Si7021 Temp. and Humidity Sensor [14]	-40 °C to +125 °C	0-80% RH	17.8 (L) x 15.3 (W) x 3.0 (H) mm	$10.95
AM2320 Temp. and Humidity Sensor [15]	-40 °C to +80 °C	0-99% RH	12.1 (L) x 4.5 (W) x 23.7 (H) mm	$3.95

For the temperature and humidity sensor, the AM2320 Temperature and Humidity Sensor was chosen. The AM2320 has a wider range of relative humidity percentage, as well as the temperature range is within the required range for the SafeStep Shoe. Although it is not the smallest option on the list, it is the most affordable option and since we would prefer to keep each shoe relatively inexpensive, it would be best to choose the least expensive option.

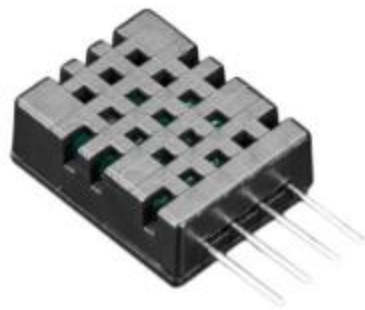

Figure 3-11: AM2320 Temperature and Humidity Sensor [15]

In Figure 3-11, the four pins shown in the image are voltage input, serial data, ground, and serial clock. The device uses I2C to communicate with the microcontroller and is placed behind mesh fabric to limit data from being skewed.

Due to the temperature sensor and humidity sensor not being placed in an area with full access to the environmental air, the temperature sensor data may be skewed. To accommodate this issue, the team decided that thermistors be placed along the outside of the shoe to monitor ambient temperature and compare data with the temperature and humidity sensor data. Listed in Table 3-6 are thermistors that were viewed.

Table 3-6: Thermistor Options

Product	Temperature Range	Tolerance	Length	Cost
Requirements	+18 °C to +27 °C	+/- 10%	80 mm	< $10
Adafruit 10k Ohm Thermistor [16]	-30 °C to +125 °C	+/- 1% at 25 °C	25 mm	$0.95
Epoxy Coated 10k Ohm Thermistor [17]	-40 °C to +125 °C	+/- 0.2% from 0 °C to 70 °C	76 mm	$8.49
Ametherm 10k Ohm Thermistor [18]	-40 °C to +150 °C	+/- 10%	38 mm	$3.03

The Epoxy Coated 10k Ohm Thermistor was chosen as the best choice for thermistors, this is placed on the base of the shoe. They are sturdier than the other thermistors due to the epoxy and have a much smaller tolerance for the temperature range.

Figure 3-10: Thermistor [17]

Figure 3-10 shows the epoxy-coated thermistor which is placed within the rubber sole of each shoe for accurate data collection.

For the GPS, a power-efficient, MTK3333-based module has been chosen. The GPS module allows the SafeStep to track the wearer and report back to the smartphone app for location tracking. Listed in Table 3-7 are possible GPS options.

Table 3-7: GPS Options

Product	Navigation Power Consumption	Power	Dimensions	Cost
Requirements	<= 30 mA	< 3.5 VDC	Small as possible	< $30
Adafruit Ultimate GPS Breakout [19]	20 mA	3.3-5.5 VDC	25 (L) x 35 (W) x 6.6 (H) mm	$28.16
Adafruit Flora Wearable Ultimate GPS Module [20]	30 mA	3.0-4.3 VDC	15 (L) x 15 (W) x 4 (H) mm	$24.95
Adafruit Mini GPS PA1010D [21]	30 mA	3.3-5.0 VDC	25.5 (L) x 25.4 (W) x 8.2 (H) mm	$29.95

Ultimately, we decided that navigation power consumption was the highest priority. As such, we went with the Adafruit Ultimate GPS board. The lower navigation power consumption, 20 mA, combined with the MTK3333 chipset's built-in sleep mode allows us to extend the battery life of the SafeStep. The dimensions are slightly larger than the others listed in Table 3-1, however, the team decided that the potential power savings are worth the tradeoff. The size difference may be reduced once custom-printed circuit boards are created.

Figure 3-12: MTK3333 Adafruit GPS [19]

Figure 3-12 shows the Adafruit Ultimate GPS Breakout board featuring all the through-hole soldering ports.

The gyroscope is required to function in a power-efficient manner and to detect the wearer if the user falls. The gyroscope, with accompanying software, can detect with 60% accuracy if the wearer were to fall. The power-efficient manner requires that the gyroscope consumes enough wattage to allow for a 24-hour lifespan of the device. Listed in Table 3-8 are possible gyroscope options.

Table 3-8: Gyroscope Options

Product	Sensing Ranges	Power	Dimensions	Cost
Requirements	+/-2g, +/_4g, +/-8g	<= 3.5 V	Small as possible	< $15
Adafruit 1032 3-Axis Gyroscope Breakout Board [22]	+/-250, +/-500, +/- 2000 degrees/sec.	3.3-5 V	30.65 (L) x 19.11 (W) x 3 (H) mm	$12.50
Adafruit Triple-Axis Accelerometer [23]	+/-2g, +/-4g, +/-8g	3.3-5 V	21 (L) x 18 (W) x 2 (H) mm	$7.95
DFRobot SEN0142 Gyroscope [24]	+/-2g, 4g, 8g, 16g +/-250, +/- 500, +/-1000, +/-2000 degrees/ sec.	3-5 V	14 (L) x 21 (W) x 2 (H) mm	$9.90

One of the reasons that the Adafruit Triple-Axis Accelerometer was selected was due to the precision of the accelerometer. As well as the form factor of the module provides more flexibility in placement on the shoe due to the size constraints of The SafeStep. The sensing ranges for all products were similar in most respects, allowing for the module to not be a factor besides the general constraint.

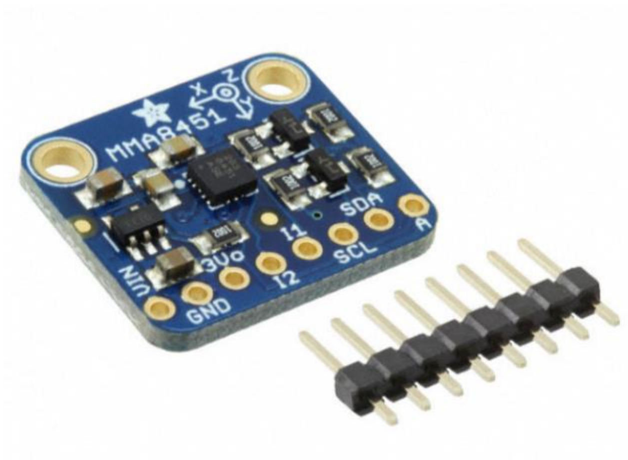

Figure 3-13: Gyroscope [23]

In Figure 3-13, the Adafruit Triple-Axis Accelerometer is displayed along with through-hole pins.

For the audio decibel-level sensor, a sensor that can use analog is preferred to allow flexibility in sending data whether it be from a threshold or a spectrum of decibel levels. Table 3-9 shows various options for the audio decibel-level sensor.

Table 3-9: Audio Decibel-Level Sensor Options

Product	Digital / Analog	Power	Dimensions	Cost
Requirements	Analog	< 5 V	Small as possible	< $15
DigiKey SEN-14262 Sound Sensor [25]	Analog	3.5 – 5.5V	46 (L) x 25 (W) mm	$13.25
DEVMO Sound Sensor [26]	Both*	4-6 V	32 (L) x 17 (W) x 8 (H) mm	$12.99

Adafruit 1713 Sound Sensor [27]	Analog	1.7–5.5 V	25.4 (L) x 14.22 (W) mm	$7.95

**The digital decibel reading is dependent on the sensitivity set by a potentiometer to signify that it is above a certain threshold.*

Ultimately, the DEVMO Sound Sensor was chosen for its capability to send digital data and analog data. This module allows for dynamic implementation, using both analog and digital I/O from the sound module to transfer data. It also fits within the power range desired, and the size of the module is relatively the same as the other options given.

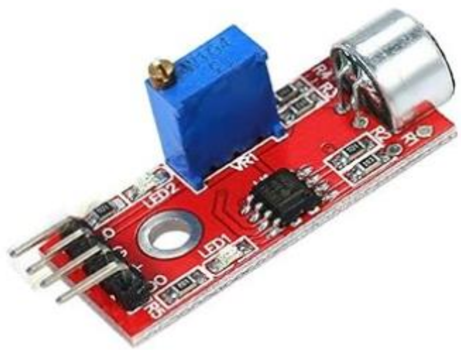

Figure 3-14: Audio Sensor [26]

In Figure 3-14, the four pins shown signify the digital input/output, voltage input, ground, and analog input/output. The sensor is placed on the top of the shoe to measure ambient sound for the user.

3.4. Level 2 Prototype Design

In the next phase of design, the subsystems will move from the outside of the shoe to the inside of the sole and padding throughout. The primary challenge is fitting all the components and sensors within the shoe and maintaining a reasonable level of comfort. Because of the space limitations, we are exploring options for custom-printed circuit boards to combine various sensor components. This allows us to reduce the physical size needed for sensors within the shoe, increasing the reliability and comfort of the SafeStep.

3.4.1 Level 2 Diagram

The Level 2 diagram provides a view of all the low-level components used in the final design of the SafeStep shoe. It displays all the power and data connections between each component as well as the enclosure or the shoe that all these components will fit into. The input conditions of the environmental data and the output of smartphone alerts are provided in the diagram as well. This approach of low-level components was chosen due to the space efficiency and power consumption along with the optimization of environmental monitoring.

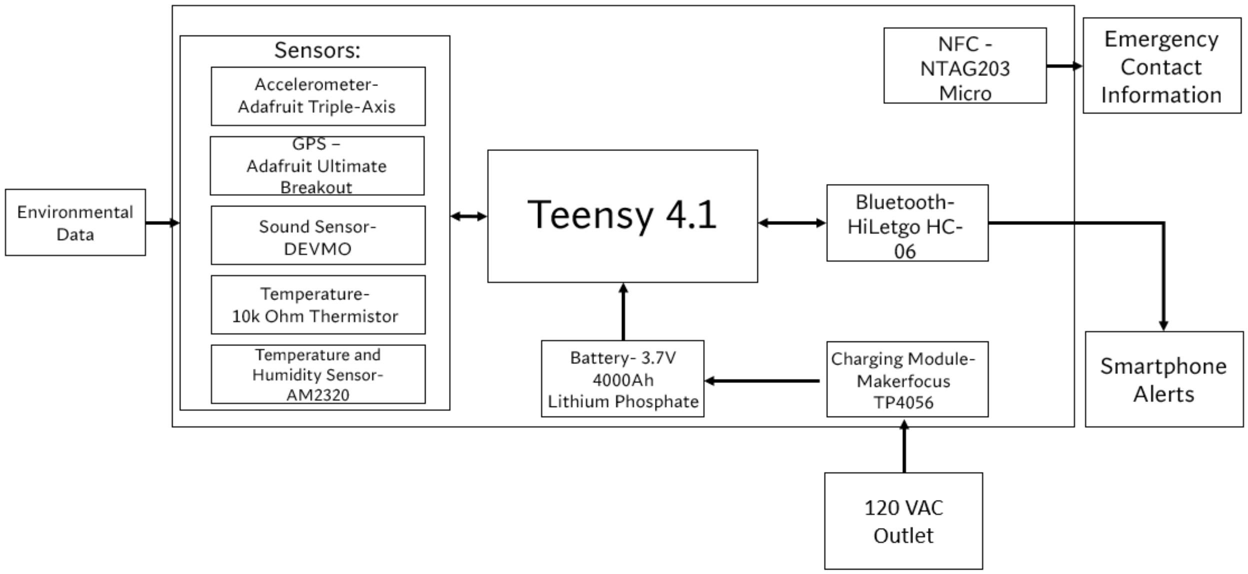

Figure 3-14: The SafeStep shoe Level 2 diagram

The overall design of the system can be seen in Figure 3-14. This provides the low-level architecture of the design to allow for easy transparency of the components chosen and how they interact with each other. These components were chosen for the requirements provided. These components will be tested following the evaluation criteria.

References:

[1] P. J. Reisner, "Teensy® 4.1," PJRC, https://www.pjrc.com/store/teensy41.html.

[2] "Raspberry Pi 4 Model B specifications," Raspberry Pi, https://www.raspberrypi.com/products/raspberry-pi-4-model-b/specifications/.

[3] "Arduino Due," Arduino Online Shop, https://store-usa.arduino.cc/products/arduino-due.

[4] "TP4056 Charging Module with Battery Protection 18650 BMS 5V Micro USB 1A 18650 Charging Board (Pack of 10)," MakerFocus, https://www.makerfocus.com/products/10pcs-tp4056-charging-module-5v-micro-usb-1a-18650-lithium-battery-charging-board (accessed Nov. 03, 2023).

[5] "Power Module 1-8S 1.2V-9.6V NiMH NiCd Rechargeable Battery Charger Charging Module Board Input DC 5V More Cost-Effective Electronic Accessories (Color: 4S)," Amazon.com, https://www.amazon.com/1-2V-9-6V-Rechargeable-Cost-Effective-Electronic-Accessories/dp/B0923KH2Z2 (accessed Nov. 03, 2023).

[6] "Battery Charger Module USB TP4056 3.7V 4.2V to 9V 5V 2A Charge Discharge Integrated Step-Up Module,18650 Lithium Li-ion Battery Charger Module(6 PCS)," Amazon.com, https://www.amazon.com/Battery-Charger-Discharge-Integrated-Lithium/dp/B098989NRZ (accessed Nov. 03, 2023).

[7] "Wireless Bluetooth Module RS232 / TTL to UART converter for Arduino," Keyestudio, https://www.keyestudio.com/products/keyestudio-wireless-data-transmission-dailog-14531-chip-dx-bt24-v51-bluetooth-module- (accessed Nov. 03, 2023).

[8] "HC-06 RS232 4 Pin Wireless Bluetooth Serial RF Transceiver Support Module Slave and Master Mode," Shenzhen HiLetgo Technology Co., Ltd, http://www.hiletgo.com/ProductDetail/2156664.html (accessed Nov. 03, 2023).

[9] "HC-05 6 Pin Wireless Bluetooth RF Transceiver Module Serial BT Module for Arduino," Shenzhen HiLetgo Technology Co., Ltd, http://www.hiletgo.com/ProductDetail/2152062.html (accessed Nov. 03, 2023).

[10] Adafruit Industries, "Micro NFC/RFID Transponder - NTAG203 13.56MHz," Adafruit, https://www.adafruit.com/product/2800 (accessed Nov. 03, 2023).

[11] Adafruit Industries, "13.56MHz RFID/NFC White Tag - NTAG203 Chip," Adafruit, https://www.adafruit.com/product/4033 (accessed Nov. 03, 2023).

[12] Adafruit Industries, "13.56MHz RFID/NFC Clear Tag - NTAG203 Chip," Adafruit, https://www.adafruit.com/product/5458 (accessed Nov. 03, 2023).

[13] "HiLetgo DHT22/AM2302 Digital Temperature and Humidity Sensor Module Temperature Humidity Monitor Sensor Replace SHT11 SHT15 for Arduino Electronic Practice DIY," Amazon.com, https://www.amazon.com/HiLetgo-Temperature-Humidity-Electronic-Practice/dp/B01N9BA0O4?th=1 (accessed Nov. 03, 2023).

[14] "Si7021 Humidity and Temperature Sensor Hookup Guide," SparkFun Learn, https://learn.sparkfun.com/tutorials/si7021-humidity-and-temperature-sensor-hookup-guide/all (accessed Nov. 03, 2023).

[15] Adafruit Industries, "AM2320 Digital Temperature and Humidity Sensor," Adafruit, https://www.adafruit.com/product/3721.

[16] Adafruit Industries, "Ultra-Thin 10K Thermistor - B3950 NTC," Adafruit, https://www.adafruit.com/product/4890.

[17] Adafruit Industries, "10K Precision Epoxy Thermistor," Adafruit, https://www.adafruit.com/product/372.

[18] "AmethermACC-004," Rho point Components, https://www.rhopointcomponents.com/product/components/thermistors/ntc-thermistors/ametherm-acc-004/ (accessed Nov. 03, 2023).

[19] Adafruit Industries, "Adafruit Ultimate GPS Breakout - 66 channel w/10 Hz updates," Adafruit, https://www.adafruit.com/product/746.

[20] Adafruit Industries, "Flora Wearable Ultimate GPS Module," Adafruit, https://www.adafruit.com/product/1059 (accessed Nov. 03, 2023).

[21] Adafruit Industries, "Adafruit Mini GPS PA1010D - UART and I2C - STEMMA QT," Adafruit, https://www.adafruit.com/product/4415 (accessed Nov. 03, 2023).

[22] Adafruit Industries, "L3GD20H Triple-Axis Gyro Breakout Board - L3GD20/L3G4200 Upgrade," Adafruit, https://www.adafruit.com/product/1032 (accessed Nov. 03, 2023).

[23] Adafruit Industries, "Adafruit Triple-Axis Accelerometer - ±2/4/8g @ 14-bit - MMA8451," Adafruit, https://www.adafruit.com/product/2019.

[24] "6 DOF Sensor-MPU6050 (SKU:SEN0142)," Digikey, https://mm.digikey.com/Volume0/opasdata/d220001/medias/docus/2204/SEN0142_Web.pdf (accessed Nov. 03, 2023).

[25] "DAOKI 5PCS Microphone Sound Sensor Module AVR PIC High Sensitivity Voice Detection for Arduino with Dupont Cable," Amazon.com, https://www.amazon.com/DAOKI-Microphone-Sensitivity-Detection-Arduino/dp/B087QFYYG5 (accessed Nov. 03, 2023).

[26] "DEVMO 3PCS Mic Microphone Sensor High Sensitivity Sound Detection Module Compatible with Arduino PIC AVR," Amazon.com, https://www.amazon.com/DEVMO-Microphone-Sensitivity-Detection-Compatible/dp/B07S4DTKYH?th=1 (accessed Nov. 03, 2023).

[27] Adafruit Industries, "Electret Microphone Amplifier - MAX9814 with Auto Gain Control," Adafruit, https://www.adafruit.com/product/1713.