3. DESIGN APPROACH

VitalWeave seeks to be a comfortable and discreet solution for continuous health monitoring using a wearable garment. By incorporating sensors into a lightweight shirt, the system is intended to enable real-time tracking of vital signs without interfering with the user's daily routines. The goal is to develop a product capable of capturing key health-related data—such as ECG signals, blood pressure, and respiration patterns—while also detecting falls and transmitting this information wirelessly to a device for easy access.

To reach this goal, a few different design concepts were considered based on their potential to meet the project requirements. The current VitalWeave design was chosen after considering various ideas including sensors, system configurations, and integration method. The focus is to achieve a balance between accuracy, comfort, and practicality. Key requirements—such as precise vital sign tracking and dependable fall detection—guided many of the early decisions. A budget of $1000, compact design, and low power consumption using consumer-grade batteries have also shaped the approach to development. In addition, safety and durability were considered to ensure the product is appropriate for everyday use.

The following sections describe the current design path selected for VitalWeave and explain how each subsystem is intended to fulfill the project's goals as development progresses.

3.1. Design Options

During VitalWeave's initial development, there were many different designs to consider when brainstorming. The team's main objective for the project was to allow seamless health monitoring with low intervention from the user. In today's market, the Apple Watch is one of the most common methods to track health data. However, the Apple watch requires a good bit of user involvement and know-how with Apple products. This presents a barrier to elderly users, which is something that was taken into consideration when creating design options. With this in mind, two primary design options considered are described below.

3.1.1. Design Option 1

One early design that was considered was an all-in-one machine that would sit by the user/patient's bed. This would allow for much easier management of devices as they would all be in one central container. A main benefit of this would be its low cost, as it would most likely have the same hardware as our current design, but without the special clothing and wiring requirements. Due to its low cost, it would also be mainly targeted at the education sector. It would allow teachers and professors to purchase one and bring them to class for demonstrations and allow for their students to use them as well.

The main disadvantage of this design however is that there are many products on the market that are like it, and does not offer much of a competitive advantage compared to them. Due to its design only allowing usage when in bed, it is also very restricting to the user/patient. Therefore, the team decided to return to our roots and focus our next option on ease-of-use.

3.1.2. Design Option 2

After the team ruled out making a smart watch, the other design was a non-invasive compression shirt. By focusing on making the system fit on a compression shirt, constant monitoring of the user's vitals is possible. It also promotes a healthier lifestyle, as the user does not have to remain sedentary when using VitalWeave. With the sensors being so close to the user, the design can better clarify signals and get more accurate readings and results. This also opened the door to more subsystems being implemented. With this design, implementation of a blood pressure monitor in the arm and fall detector along the hips is possible.

The main advantage of this design is the freedom it gives the user. By making VitalWeave an around-the-clock health monitoring shirt, the user can focus more on their lifestyle without having to take time out of their day to check vital signs. The shirt helps promote a non-invasive everyday way to monitor health. This design also improves the accuracy of the subsystems, mainly the fall monitor. The closer the fall detector can be to the user's center of gravity the more accurate it can be. The main concern with this design is maintaining the user's comfort with the intricacy of the wiring. Since this design is limited to a shirt, the wiring is expected to be more complex than usual, and the goal is to make it as comfortable as possible. Also, since this should be an easy-to-use product, the shirt must be machine washable, and the sensors must be easily removable. Although the product has become more complex, this is the best solution given our constraints and budget, since it is non-invasive and provides around-the-clock monitoring.

3.2 System Overview

At a basic level, VitalWeave will record the users' ECG and respiratory rate, with a fall detection system and manual blood pressure monitoring. This data will be sent to the user interface and archived for future use. Figure 3-1 shows a simple diagram of how VitalWeave functions.

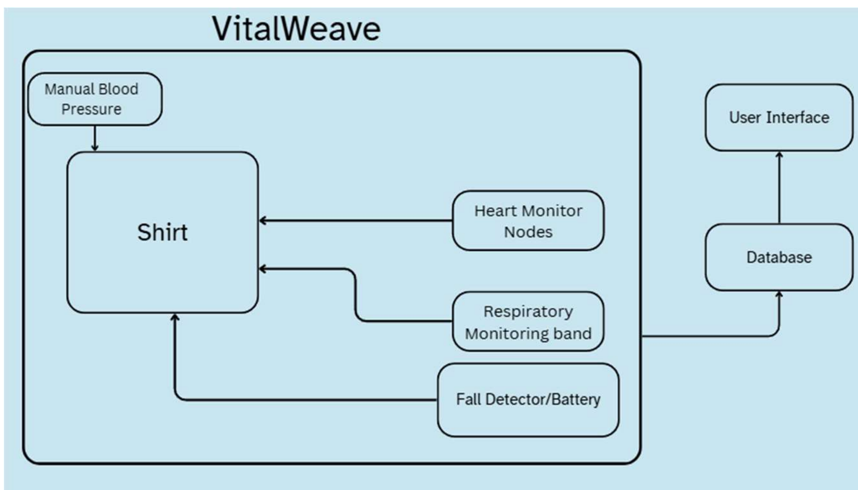

Fig. 3-1: Basic VitalWeave System Overview (Level 0)

Figure 3-2 shows a more in-depth view of the functionality of VitalWeave. The data collected from the fall detection, ECG, breathing and blood pressure subsystems are fed to the microcontroller which then sends the data to the UI application where it can be reviewed at any time.

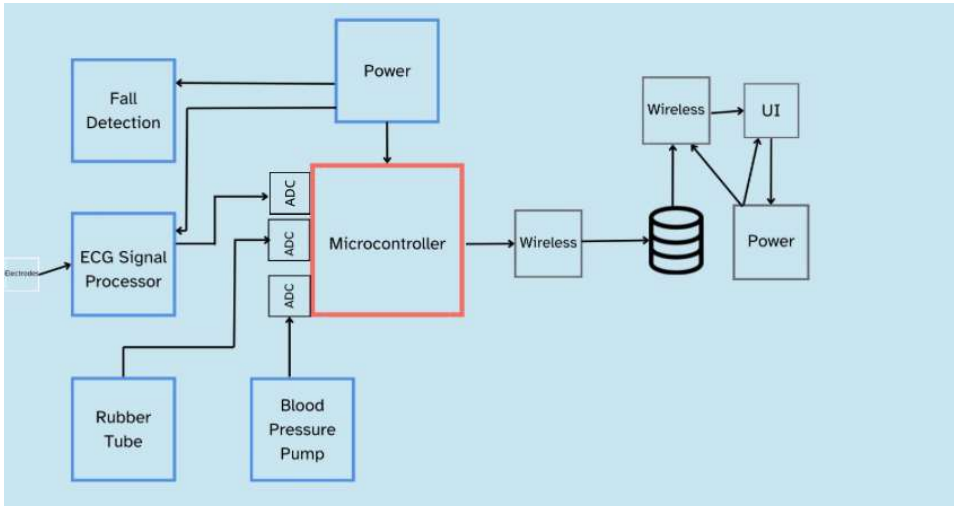

Fig. 0-2: Vitalweave System Functionality (Level 1)

The VitalWeave is designed to operate autonomously except for the blood pressure monitoring subsystem which will need to be manually activated.

3.2.1 Microcontroller

For VitalWeave, several microcontrollers were considered to handle the desired functionality. Our main concerns were cost, size, power consumption, and Wi-Fi and Bluetooth capabilities. Table 3-1 helps highlight these issues, as well as the choices considered.

Table 3-1: Microcontroller Options

Processor	**Cost ($)**	**Size (mm)**	**Power Consumption**	**Wi-Fi**	**Bluetooth**
Requirements	**< 20**	**< 30 x 30**	**Power Modes**	**Yes**	**Yes**
ESP32[1]	8	25 x 18	Low	Yes	Yes
ESP8266[2]	6	24 x 16	Low	Yes	No
Arduino Nano 33 BLE [3]	25	45 x 18	Low	No	Yes
Raspberry Pi Pico W [4]	6	51 x 21	Ultra-low	No	No

The ESP32 was chosen since it was the best fit. It was relatively cheap and very compact. It also had low power consumption, as well as Wi-Fi and Bluetooth capabilities. Figure 3-3 illustrates the selected microcontroller.

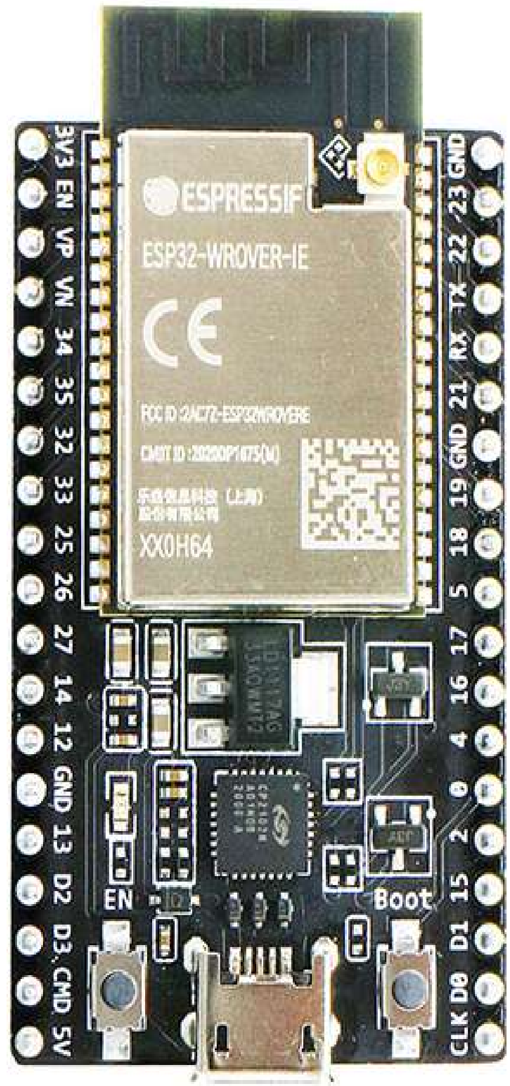

Fig. 3-3: ESP32 Microcontroller [1]

VitalWeave processes various health signals and transmits that information through Wi-Fi and Bluetooth to the user, while keeping battery consumption to a minimum. The microprocessor should be small enough to fit soundly in the battery compartment of the suit. The ESP32 checks all these boxes with its effective use of battery consumption. A key factor in choosing the ESP32 was the product's size and price. Since we offer an everyday use product, the product needs to be able to be taken apart easily. The best way for us to remove the microcontroller easily is to place it in a separate compartment. The price point also helps in case a replacement is needed, given that we have already had to order some. With the playtesting required for this product, inexpensive devices are needed to maintain the budget low.

3.3 Subsystems

The design for VitalWeave is split into five different subsystems. Below is a brief description of each one.

1. The ECG signal subsystem monitors the ECG signals of the user and alerts irregular activity.
2. The respiratory monitoring subsystem keeps track of the user's breathing rate and establishes a baseline for each user.
3. The fall detection subsystem monitors a user's speed and orientation to proactively track any major falls that can result in injuries.
4. The blood pressure subsystem enables the user to measure their blood pressure at any given moment with the press of a button.
5. Our database helps every user keep track of all the activity the system detects, and enabling the user to be able to keep an accurate record of their health.

3.3.1 ECG Signal

In order to monitor heart activity and health, VitalWeave must be able to acquire ECG signals from the user. The traditional method of acquiring these signals in a medical setting would be to use wet ECG electrodes, which are disposable sticky nodes that the user would have to change after every use. Because of the inconvenience of changing these nodes after each use, VitalWeave utilizes copper tape attached to the shirt to conduct and transfer ECG signals. This allows for a slimmer and comfortable design, while still maintaining function equal to the traditional wet ECG nodes.

To filter and convert these ECG signals from analog to digital, creating an ADC circuit from scratch was one of the top considerations, as it would allow for easy troubleshooting and customization. However, this option was considered very risky, as it would require much more time and money compared to alternatives. Instead, VitalWeave utilizes a prebuilt ADC to acquire and filter these ECG signals. This ADC will then be connected to the ESP32, where it will analyze and display the signal. Table 3-2 shows the different options that were considered for this ADC.

Table 3-2: ECG Signal ADC Options

Product	Operating Voltage (V)	Dimensions (mm)	Weight (g)	Cost ($)
Requirements	**< 3.3**	**< 40 x 40**	**< 25**	**< 30**
AD82832[5]	2 – 3.5	36 x 28	18	21.50
ADS1292R[6]	1.7 – 3.6	5 x 5	2	12.64
AFE4490[7]	2 – 3.6	6 x 6	2	19.91

The AD8232, shown in Figure 3-4, was chosen as the option best suited for the subsystem's goals and restrictions. The AD8232 benefits from a strong community and extensive documentation, especially for the Arduino IDE, making configuration straightforward. Due to its design not being a traditional open PLC board and not a pre-made breakout board, it will allow for easier troubleshooting at the cost of size. The alternatives simply do not have nearly enough documentation or supply compared to the AD8232.

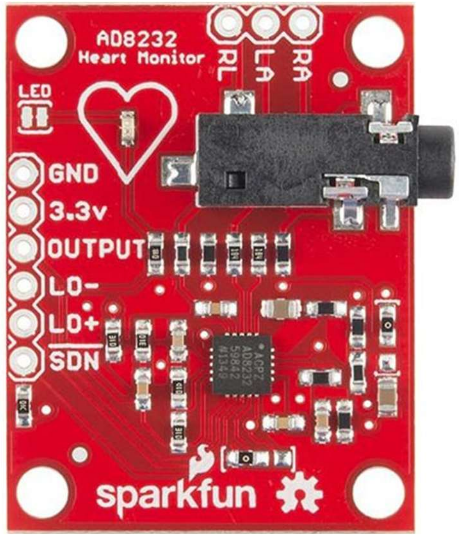

Fig 3-4: SparkFun AD8232 [5]

3.3.2 Respiratory Monitoring

The Respiratory Monitoring Subsystem detects the change in resistance of a rubber conductive cord. This change in resistance is used to get the user's respiratory rate of breaths per minute. The user will relax and breathe normally, and a number will increase every time a change in resistance is detected for a minute to get the user's average respiratory rate. If this average respiratory rate increases or decreases to a certain number of breaths per minute (below 12 and above 20), the user will be notified. The subsystem is comprised of the rubber conductive cord and the code.

The rubber conductive cord is the backbone of the respiratory subsystem, as its change in resistance is used to obtain the user's breaths per minute. Table 3-3 shows the different options for a rubber conductive cord that were considered.

Table 3-3: Rubber Conductive Cord Options

Rubber Conductive Cord	Resistance (Ω)	Length (m)	Price ($)
Requirements		**1**	
Conductive Rubber Tube Hose Black Silicone Tubing (Amazon) [8]	80-400	1	11.00
1m Flexible Stretch Sensor Cord (RobotShop) [9]	350-400	1	9.99
Conductive Rubber Cord Stretch Sensor (Adafruit) [10]	350-400	1	9.95

The Conductive Rubber Tube Hose Black Silicone Tubing from Amazon (shown in figure 3-5) was chosen as a secondary option because the first choice, the Conductive Rubber Cord Stretch Sensor from Adafruit, got lost in transit and has not yet arrived. With not enough time to reorder the same part, the alternative from Amazon was chosen instead. When this cord is stretched, its resistance will increase. This increase in resistance is detected to count when the user breathes and calculates respiratory rate.

Fig. 3-5: Conductive Rubber Tube Hose Black Silicone Tubing [8]

Figure 3-6 shows how the code of the respiratory monitoring subsystem works.

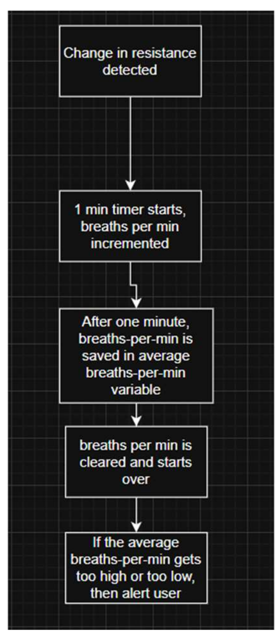

Fig. 3-6: Code flowchart

The code detects the change in resistance of the rubber cord. Every time this change is detected, the respiratory rate increases by one. After one minute, the respiratory rate is saved in another variable as the user's average respiratory rate and is repeated. If this average gets lower or bigger, then the user is alerted to relax. The programming language utilized will be C++ or Python.

3.3.3 Fall Detection

The Fall Detection System detects if the user falls while wearing the device. This is done by taking the user's speed and positioning and monitoring drastic changes in both. Whenever VitalWeave detects a fall, it will prompt the user to confirm or deny the alert. Afterwards, the subsystem will notify the database of what happened in order to keep track of these accidents. This subsystem consists of an accelerometer, a gyroscope, and a buzzer used to verify the transmission of a signal.

The accelerometer and gyroscope are critical components for the fall detection system. A few options considered for this task can be found below.

Table 3-4: Fall Sensor Options

Sensor	Price ($)	Accelerometer	Gyroscope	Power Consumption (Active Mode)
Requirements	**<10**	**Yes**	**Yes**	**<5 mA**
MPU6050[11]	6	Yes	Yes	~3.9 mA
MPU9250[12]	15	Yes	Yes	~3.5 – 9.3 mA
ADXL345[13]	7	Yes	No	~140 µA

With its lower power consumption and inexpensive price, the MPU6050 sensor, shown in Figure 3-7, was chosen for the project. The sensor will help detect sudden changes in the user's orientation and speed. This information will then be compared to code and help verify if a fall is detected. A push button will also be used to confirm this fall, as well as a buzzer to properly demonstrate the transmission of this signal. The push button was chosen to help manage false negatives, and the buzzer is a temporary solution before integration happens.

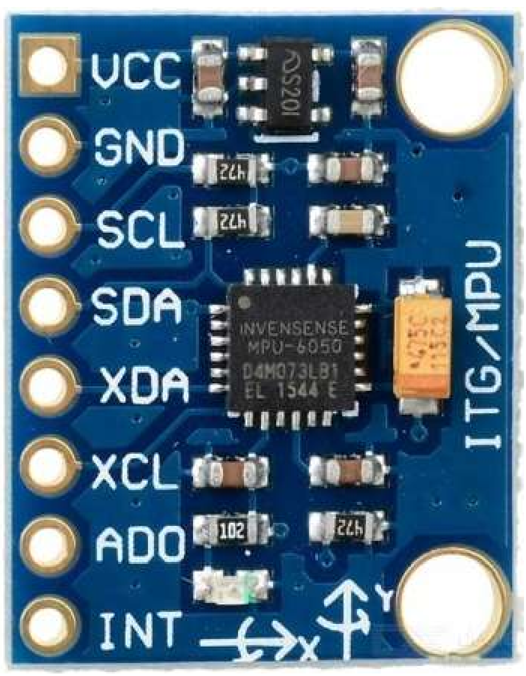

Figure 3-7

Figure 3-8 demonstrates how the code for the fall detections system will work.

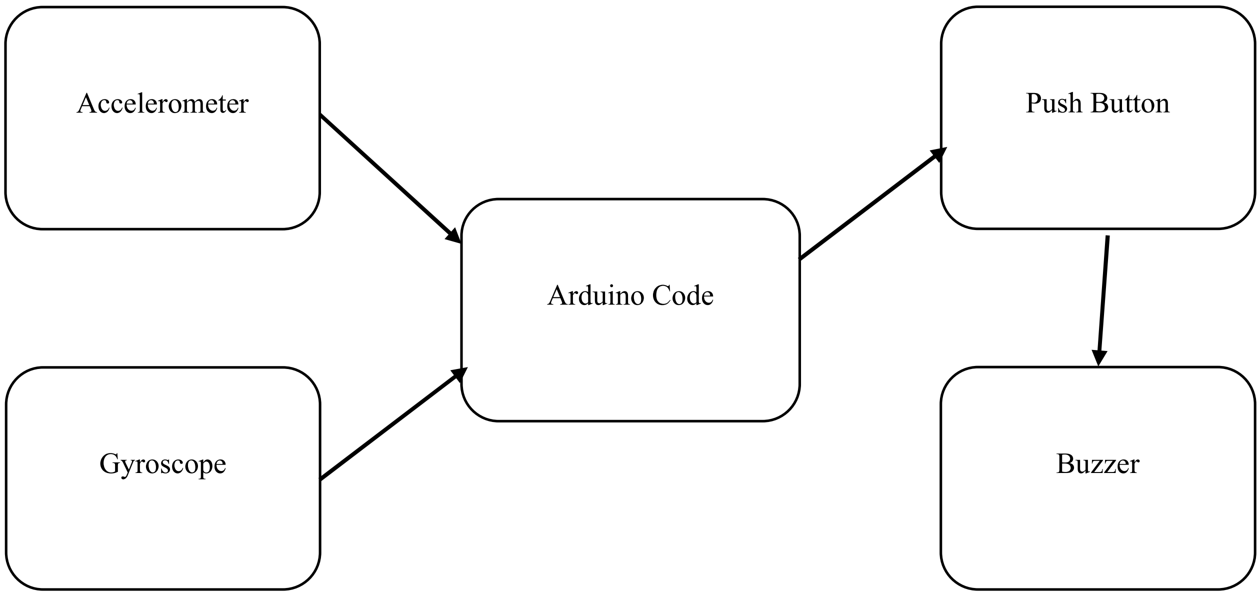

Figure 3-8: Sensor Code Flowchart

The sensor constantly monitors the user's speed and positioning, and stores the information into the Arduino code for comparison. If a sudden change is detected the program will wait and verify internally in the code before proceeding. Afterwards, a secondary verification will be sent to the push button to confirm or deny a fall. If the user fails to confirm or deny the fall within 1 minute, a fall alert will be sent to the buzzer. The buzzer will then activate, demonstrating the alert signal was sent. Afterwards, the user can press the push button to stop reset the system.

3.3.4 Blood Pressure Monitoring

The Blood Pressure Monitoring Subsystem uses a standard cuff and pump system integrated with a heart rate monitor sensor to semi-manually take the user's blood pressure. This system will be sewn into the sleeve. The user is responsible for inflating the cuff and slowly releasing the air using the valve on the pump while the sensor is programmed to accurately read the systolic and diastolic numbers and record them.

The most important piece of equipment for this subsystem is the sensor, as accurate heart rate readings are essential to blood pressure monitoring. Table 3-5 shows a number of potential heart rate sensors that were considered for this project.

Table 3–5: Potential Heart Rate Sensors

Sensor	Size (mm)	Price ($)	Input Voltage (V)	Weight (g)
Requirements	**<30 x 30**	**<20**	**<6**	**<20**
SEN0203[14]	28 x 24	16.00	3.3 - 6	10
PulseSensor[15]	15.8 x 15.8	24.99	3 – 5.5	10
Comimark Heart Rate Pulse Sensor[16]	118 x 79	7.99	3.3-5	7.3

The SEN0203 Heart Rate Sensor [14] was chosen for its small scale, low price, and low input voltage. It will be able to detect the users heartbeat while he or she inflates the arm cuff to record his or her blood pressure. Figure 3-9 shows the SEN0203 sensor.

Figure 3-9 SEN0203 Heart Rate Sensor [14]

A few different options were considered for the cuff and pump. The cuff needed to be a convenient size that could fit most users. Also, since the user will only be required to inflate and deflate the cuff, a simple and affordable cuff and pump will suffice. Table 3 – 6 shows some options for possible cuff and pumps (sphygmomanometers).

Table 3–6: Potential Sphygmomanometer

Cuff and Pump	Size	Price ($)
Requirements	**Adult (22 - 42cm)**	**<20**

Primacare DS-9197-BL [17]	Adult	14.13
PARAMED Aneroid Sphygmomanometer [18]	Adult	17.95
Santamedical Adult Deluxe Aneroid Sphygmomanometer [19]	Adult	19.94

The Primacare DS-9197-BL [17] from Amazon comes with an adult sized cuff and pump, as well as a stethoscope (which will not be needed) for a reasonable price. The SEN0203 will be able to simply and comfortably be incorporated with the cuff so that the user can easily take his or her blood pressure without having to use a stethoscope. The Primacare pump and cuff are depicted below in Figure 3-4.

Figure 3-10: Prmiacare DS-9197-BL [17]

The chosen pump and cuff meets the requirements of being a size that is compatible with most adults as well as being cost efficient which makes it the best choice for VitalWeave.

3.3.4 Database & User Interface

To display the data given from VitalWeave, an app and database will be used to store that data and display. VitalWeave will support connectivity via Bluetooth to the user's phone. VitalWeave will send its data to the user's phone, where the app will display the data. The app will have a simple UI to make it easier for elderly users to operate. There will be an additional "advanced" tab that will display the data more in depth for other users such as doctors. The user will also be able to store the past 5 minutes of data into a database through a "save" feature under the advanced tab. The database will be stored on an SQL server, while the application will initially be programmed through Android Studio and will later be programmed through

Flutter to support both Android and IOS devices. Figure 3-11 displays what the UI is aimed to look like. On initial startup, it will have a simple UI displaying easy to read measurements and indicators. On the bottom it will have a home, history, settings, and advanced tab.

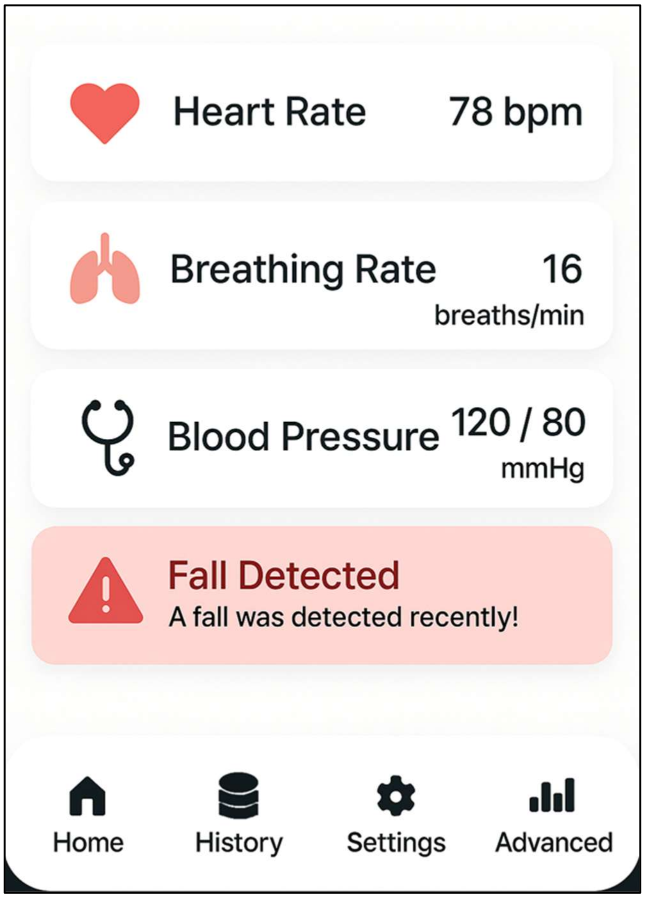

Fig. 3-11: Home screen for VitalWeave app

Figure 3-12 displays the flow diagram for the subsystem. The data from the VitalWeave's ESP32 will be connected to the user's phone, where it will then display the data, and store it if the user wishes to.

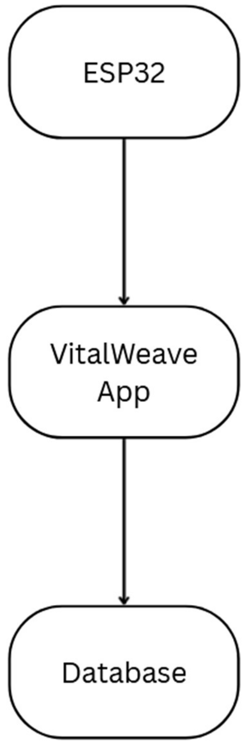

Fig. 3-12: Flowchart VitalWeave App

3.4. Level 2 Prototype Design

As a fully integrated prototype, VitalWeave's components are housed in a compression shirt that is non-invasive, comfortable, and reliable. The compression shirt monitors blood pressure, respiratory rate, fall detection, and ECG signals. This information is sent to a database for the user to track and monitor their health more efficiently.

3.4.1 Level 2 Diagram

Figure 3-11 displays the final prototype of VitalWeave with all subsystems. The VitalWeave shirt will be a close-fitting compression shirt, allowing for accurate data collection.

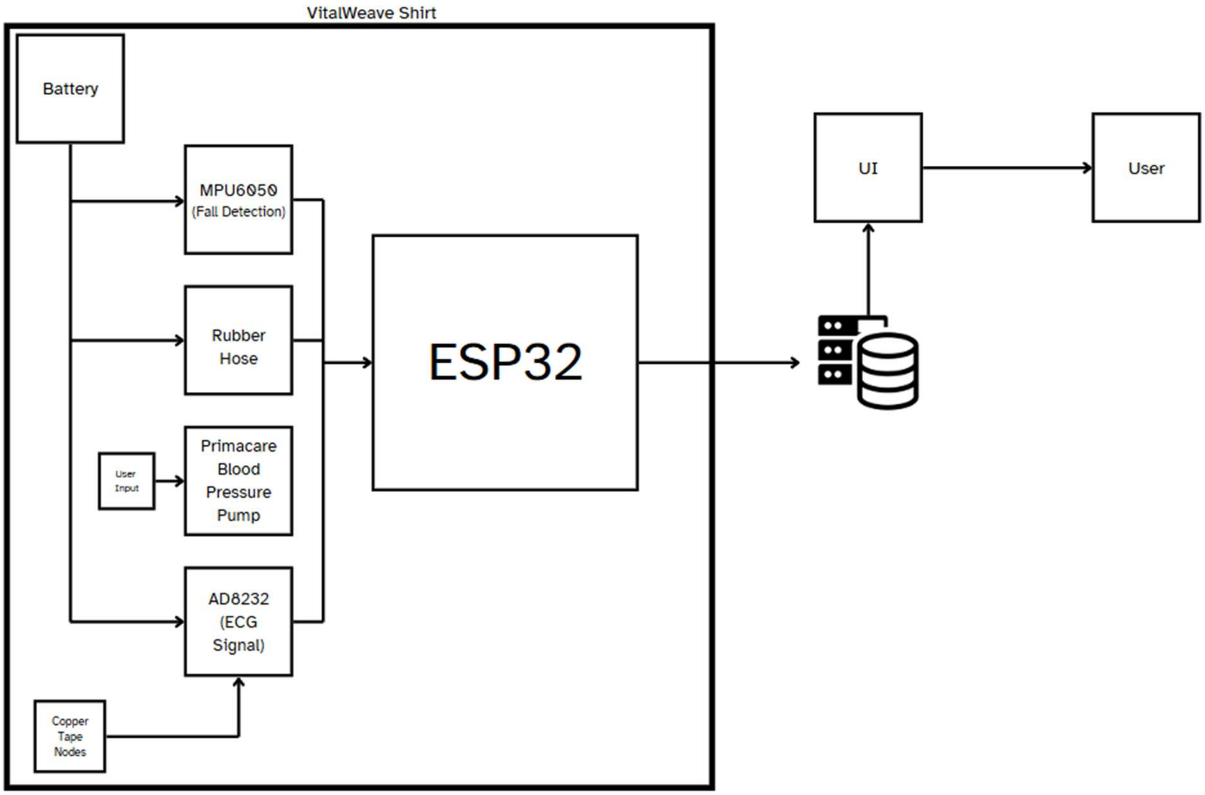

Fig. 3-13: Diagram for VitalWeave (Level 2)

The inputs of the ESP32 consist of data from the MPU6050 accelerometer, resistive rubber hose, and the AD8232. These main sensors, battery, and MCU will be in various places of the user's shirt. The sensors' data will then be sent to the MCU for it to be processed and sent to a server. Once it is loaded into a server, the application will then pull the data from the server and display it for the user.

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