4 Design

4.1 Design Content

The initial design comprises three components: a wearable device, an interface for user interaction, and a dog collar device that receives a signal and notifies the dog to take action. The combination of these components detects PTSD hyperarousal episodes and notifies the service animal of the episode. It is also within the scope of the project for the veteran to turn the device off and on.

4.2 Design Complexity

1. The design consists of multiple components/subsystems that each utilize distinct scientific, mathematical, or engineering principles.
2. The problem scope contains multiple challenging requirements that match or exceed current solutions or industry standards.

The wearable device needs to consist of sensors collecting biological data, processing and analyzing the data, and then responding accordingly based on the given information. There are not many existing research studies on the early prediction of these episodes, and non-invasive, continuous monitoring of the vitals of ambulatory (active, self-moving) individuals has already proven to be a challenge for the medical industry, with a limited number of accurate, reliable devices within a reasonable cost.

The wearable device also needs to be able to be updated with a new and improved algorithm for detection as well as remotely send discrete commands to a service animal. The wearable device should also have a long-lasting battery since it will be worn all day and is critical to obtaining vitals critical to the system's functionality.

The dog collar device should be discrete, and be able to subtly receive messages and interact with a service animal. Additionally, the dog collar device should have a long-lasting battery life since it is designed for everyday usage, and it is crucial to the success of the design.

Considering 2 modes of user interaction with varying capabilities and at least one form of wireless communication, we will need to address wireless communication, compression/serialization of data, and effectively design an IoT distributed system with at least 2 nodes.

4.3 Modern Engineering Tools

For asynchronous collaboration with the team, we utilized Figma as a tool for diagramming and traditionally visual activities, Gitlab for task management, and Google Drive for file/artifact organization.

In order to conduct focused, thorough preparation for the project, we used several activities commonly used as tools to produce effective collaboration and idea generation among engineers.

As an approach for user-specific and problem-specific research, we used journalistic mapping to brainstorm the problem, identify the context for its usage, and properly frame our user research, market research, and other research to be done.

After conducting research, we performed user-story mapping (commonly done in Agile Scrum teams to define clear use cases and purpose for tasks) to generate user-focused problem statements. This enabled us to identify tasks our system should perform, specific to our target users, and the desired outcome/benefit that arises from that statement. The result of this tool is a clear definition of the tasks and main facets of the engineering problem we aim to solve.

Following the problem redefinition, we are iteratively creating designs for the various components. Figma is to be used primarily for UML, context, and other high-level designs.

For hardware design we will use Altium for designing PCBs.

In our software design, we will utilize Gitflow, with the provided Gitlab as a version control platform. Additionally, we will use GCC as a C compiler (needed for embedded software design) if needed, ISU provides servers for any backend software that we need (none are present in our current design), and the developer's choice for which IDE we will use. Our platform/tool of choice for any mobile software is not defined yet. Any other languages, frameworks, or tools we need to use will be decided on later.

4.4 Design Context

Area	Description
Public health, safety, and welfare	**How does your project affect the general well-being of various stakeholder groups? These groups may be direct users or may be indirectly affected (e.g., solution is implemented in their communities)** The wearable cannot be harmful to the user. The dog's wearable device should not be disruptive to the dog or anybody in its proximity. The veteran's quality of life would be drastically improved if PTSD episodes can be preemptively handled.
Global, cultural, and social	**How well does your project reflect the values, practices, and aims of the cultural groups it affects? Groups may include but are not limited to specific communities, nations, professions, workplaces, and ethnic cultures.** We have chosen to use a vibration motor to signal the dog as opposed to something like a shock or a noise, as those are not considered very ethical options in our culture and the culture that will use it. Our device, upon success, will add to the modern research and development in utilizing wearable devices for continuous improvement of users' daily lives by aiding in the prevention of potentially harmful/painful situations and uplifting members of the community in need of assistance for improving their daily quality of life.
Environmental	**What environmental impact might your project have? This can include indirect effects, such as deforestation or unsustainable practices related to materials manufacture or procurement.**

	The wearable device will likely be 3D printed using plastic once we move further in our prototyping. Plastic is generally not a very sustainable resource, so we aim to use recycled or other more sustainable 3D printing filament options.
Economic	**What economic impact might your project have? This can include the financial viability of your product within your team or company, cost to consumers, or broader economic effects on communities, markets, nations, and other groups.** Our product should be relatively affordable. We plan to use relatively cheap sensors and other components. It needs to be affordable because our main audience, veterans, generally are not very wealthy and the device is meeting a medical need. Also, a charity may be funding these devices for some people, so we would like to not put undue financial strain on them.

4.5 Prior Work/Solutions

There is no wearable technology commercially available on the market today for PTSD event detection. However, there have been recent efforts to design such a device. In 2022, a project funded by Texas A&M University developed a method of detecting PTSD hyperarousal episodes using heart rate and body acceleration. They tested 4 separate machine learning algorithms and found that using the XGBoost optimized gradient descent optimizer algorithm, they were able to predict PTSD episodes with over 83% accuracy and an AUC (area under the ROC curve) of 0.7%. Their algorithm had several key constraints that our group was not faced with. First, they limited their design to currently off-the-shelf commercially available devices to maximize the potential user group's size. As a result of this limitation, they were constrained to utilize only basic heart-rate sensors and body acceleration, the second major limitation that we are not constrained by.

A separate senior design group from 2022-2023 had this project proposed by BAE and attempted to use a smartwatch, cross-platform Flutter app, and custom collar device. We talked to some of the group members on the project. In this conversation, we asked about what vitals they used, what challenges they encountered in their work on the project, what some of their design/platform decisions were, and several other questions. Apple devices are not compatible with many Bluetooth devices, commercially available heart-rate sensors have very high-level APIs limiting access to more raw data, and continuously measuring blood pressure in a non-invasive way, especially with mobile individuals, is a challenge fresh to the medical research community. This information will significantly impact our platform decisions and sensor decisions.

Citations

Sadeghi M, McDonald AD, Sasangohar F (2022) Posttraumatic stress disorder hyperarousal event detection using smartwatch physiological and activity data. PLoS ONE 17(5): e0267749. https://doi.org/10.1371/journal.pone.0267749

Gilbert, Stephen B.; Civitate, Anthony; Kelly, Jonathan W.; Thompson, Frederick; Smith, Alisha; Kopecky, Ken; Winer, Eliot; and de la Cruz, Julio, "Comparing Training Performance With Vibrotactile Hit Alerts vs. Audio Alerts" (2013). Industrial and Manufacturing Systems Engineering Conference Proceedings and Posters. 91. http://lib.dr.iastate.edu/imse_conf/91

T.-Y. Li, W.-C. Tsai, and S.-F. Lin, "Non-invasive Recording of Parasympathetic Nervous System Activity on Auricular Vagal Nerve Branch,"

4.6 Design Decisions

We currently do not have data available to create an algorithm for detection, and that may become available as we continue to research and build a relationship with our client. We are approaching this problem in several ways.

We decided that our best course of action would be to focus on making a minimal viable product (MVP) for the hardware functional as soon as possible.

In addition to building a simple first iteration of the hardware for quick feedback, we reached out to 2 separate entities (the DOE lab at ISU, and researchers in the project funded by Texas A&M) requesting access to their data for review.

We determined that WiFi would not be a great avenue to support the communication of data between our devices, and we would prefer to use radio communication with ASK (Amplitude-shift keying) modulation for communications between the wearable and the feedback device because it is a common and well documented way to send "ping" signals from one device to another. This protocol is used in many applications including garage door openers, and home automation systems. For communication between the wearable device and a user's mobile device, we plan to use Bluetooth LE as it is widely supported and relatively simple to implement.

We also decided that the main computation power needs to happen on the user's wearable device and should not rely on the user's phone device. This will limit the potential communication errors and potential reliabilities. In addition, this will make the device more discrete.

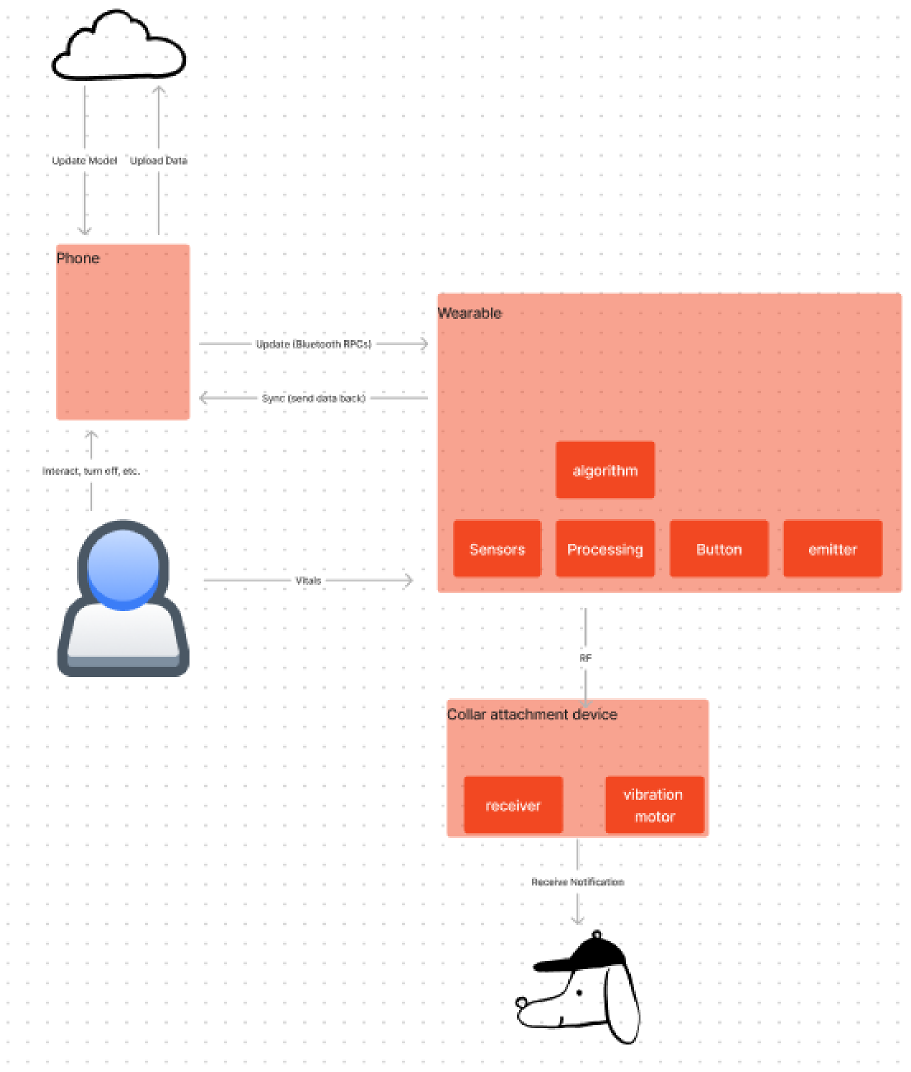
4.7 Proposed Design

As a group we have been able to determine the core parts of our design that include a wearable device by the user, a device attached to the service animal, and a phone to sync data from the wearable device.

We have purchased parts for assembling a simple PPG device, as well as an evaluation kit for the MAX86150 (an integrated PPG, SPO2 sensor). This device showed a pattern of similarity between the ECG output, and PPG raw sensor values (integrated red and IR output from a photo-diode).

4.7.1 Design #0 (Initial Design)

Design Visual and Description



The Collar Device

The collar device receives a signal to tell the dog to go to the veteran. The dog is trained to go to the veteran and notify them of their potential oncoming episode. This device functions similarly to a pager and will buzz whenever signaled by our user's wearable.

The Wearable Device

The wearable device has the core functionality. Sensors record vitals, and it processess the signals to be useful. The algorithm is located in the wearable for early PTSD detection. A button is located for control of the wearable device, an emitter sends signals to the dog device upon detection. The wearable device also sends its stored history of vitals and timestamps for PTSD episodes to the phone when available.

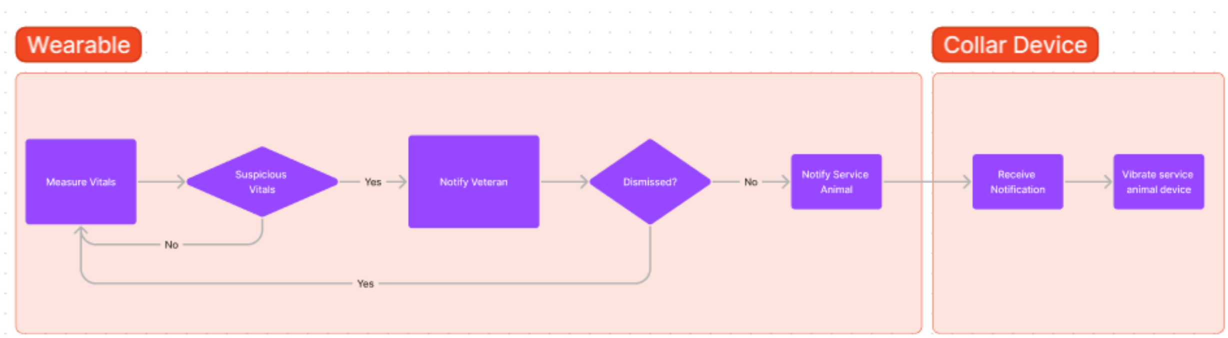
The Phone Application

A phone application sends configuration information to the wearable. This allows the user to turn off and on the device. The application communicates with the wearable via Bluetooth when available. This application is NOT required for the main functionality of the wearable itself.

Functionality

Describe how your design is intended to operate in its user and/or real-world context. This description can be supplemented by a visual, such as a timeline, storyboard, or sketch.

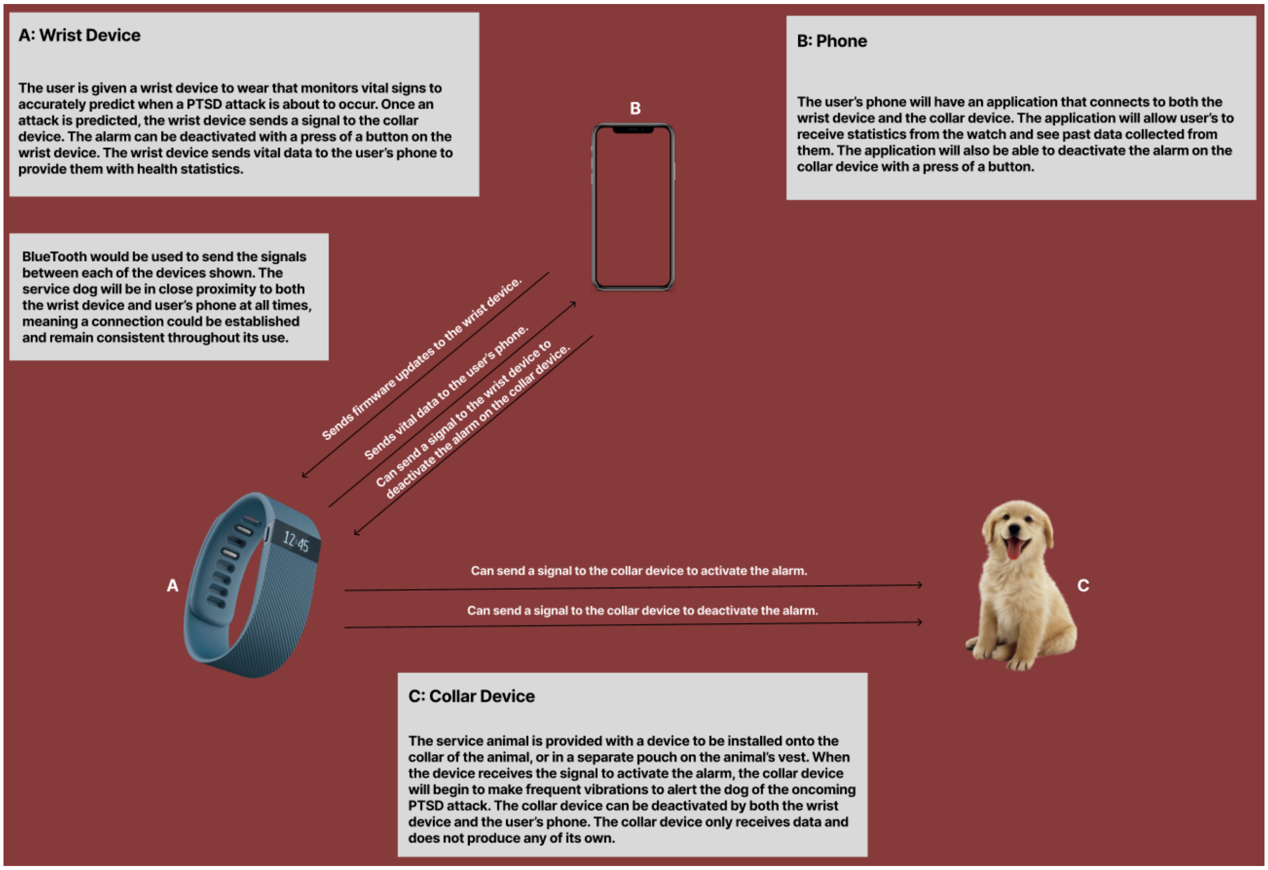
The wearable device and the collar device combine to provide the core functionality of the system. The user will depend on this system when they leave their home with their service animal. This means that the platform exists in every context that the veteran leaves home. Utilizing a wearable device attached to the user's wrist provides access to measure multiple vitals (cardiovascular activity, respiratory system activity, nervous system activity). Additionally, if the user needs to discreetly interact with the device, it is in a location that is almost always easily available. Using a simple interface for interacting (buttons, a small screen), the user can quickly complete their interaction and return to their prior activity.



How well does the current design satisfy functional and non-functional requirements?

Our design will satisfy the requirement to make sure that the alert feature for the dog is subtle. We plan to use vibration, which is one of the most subtle options for an alert. Most likely, only the dog will be alerted, and potentially, a bystander near the dog will notice. Additionally, our intended form for the wearable is to be a wrist-worn device and, therefore, subtle.

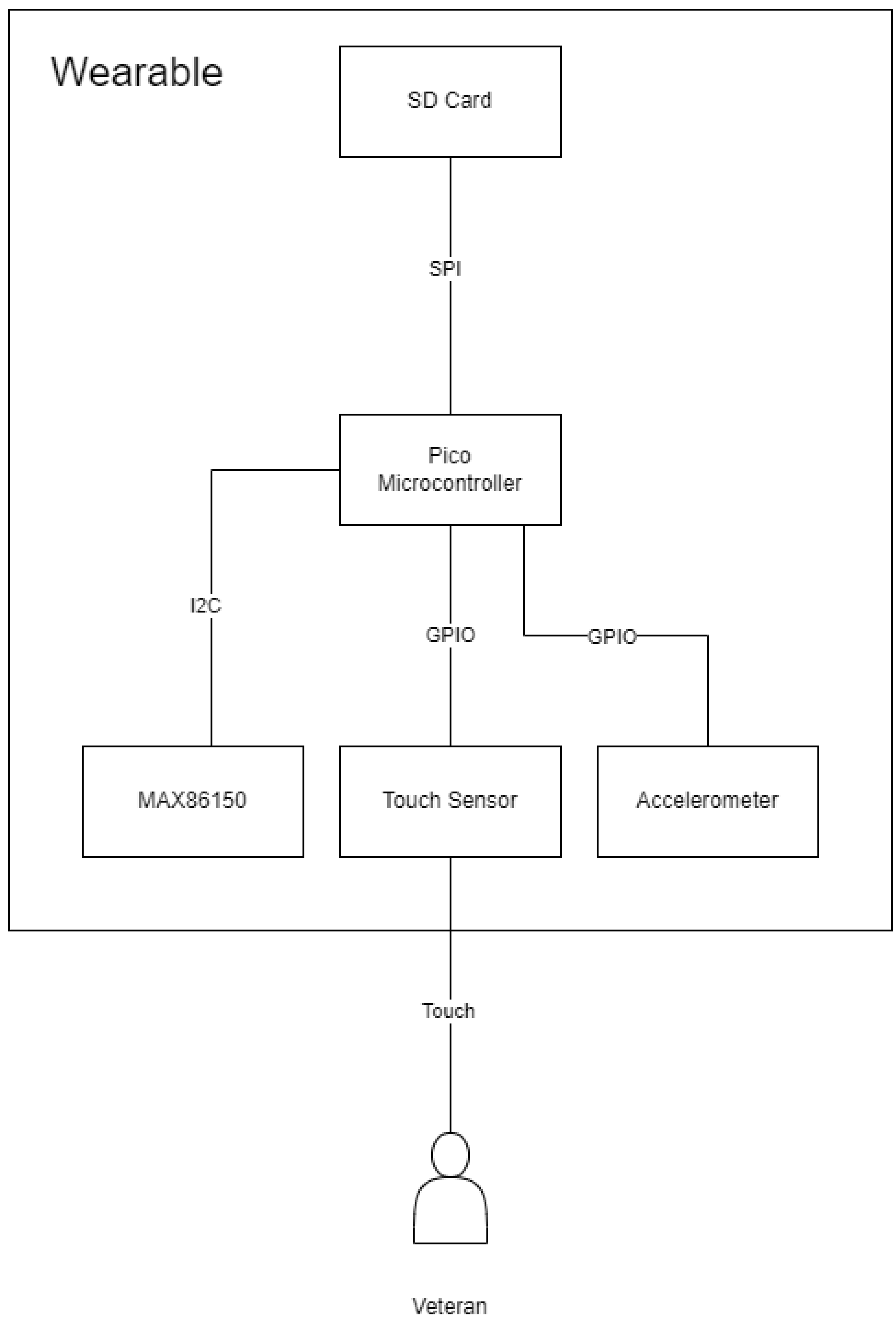
4.7.2 Design #1 (Design Iteration)



Changes from Previous Iteration:

This design iteration builds on the previous initial design by outlining the key features that each device will have as well as how they will interact with each other. The core devices mentioned within the diagram are the Wearable Device, Collar Device, and Phone Application.

4.7.3 Design #2 (Design Iteration)



Changes:

Following Design Iteration 1, we identified several unsolved problems. Firstly, there is no data available to us for designing any kind of algorithm for predicting the onset of symptoms. Additionally, relying on a phone for dismissing alerts, and interacting with the device causes another point for breakdown in the system. The phone could die, be incompatible, or have numerous other issues beyond our control. This caused us to attempt to create an iteration of our design more decoupled from the phone.

To solve these issues, we decided to break the device into multiple design stages. The lack of available physiological data on PTSD symptoms currently presents a significant challenge for designing any algorithm for predicting the onset of symptoms. Additionally, the main goal of Agile (our main project management style) is to produce shorter development cycles, more frequent releases, and allow early feedback. Below is an outline of each design stage:

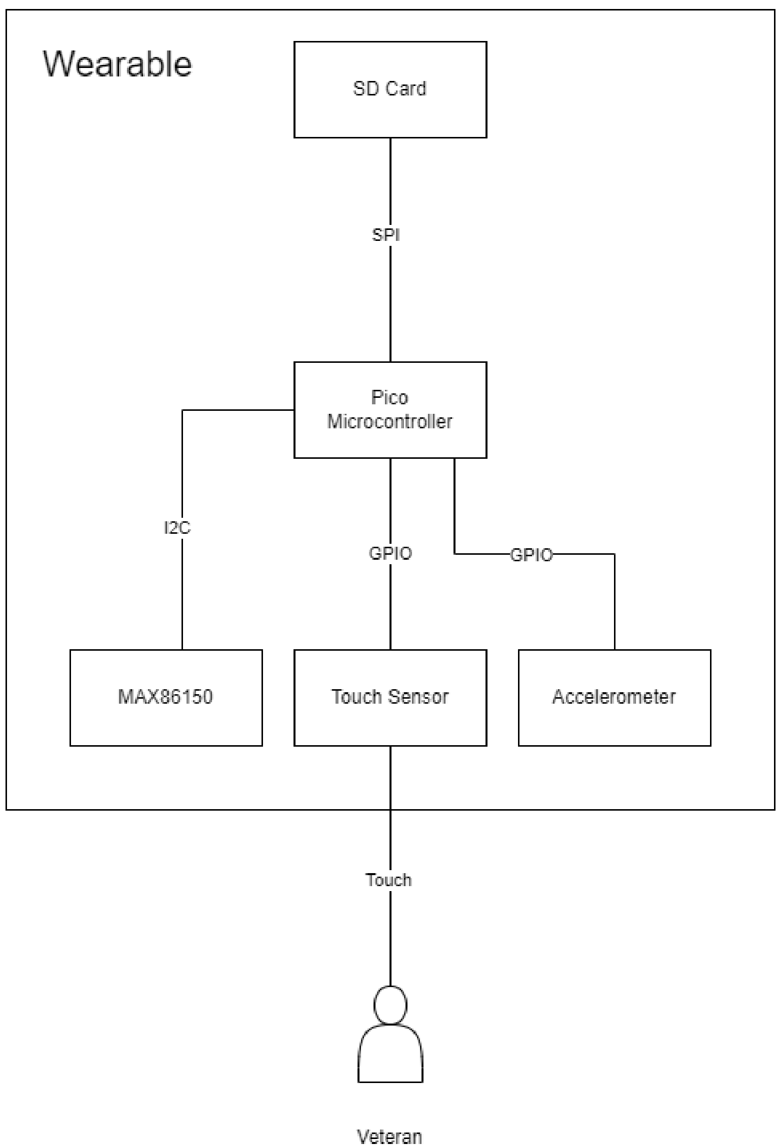


Figure 4.7.3.1: Design Stage 1: Wearable for data collection

In the first stage our device will collect data. We will design a device that stores vitals and event timestamps (on a button press). This will be distributed to Vetdogs, and we will collaborate with them in the collection of PTSD episode data.

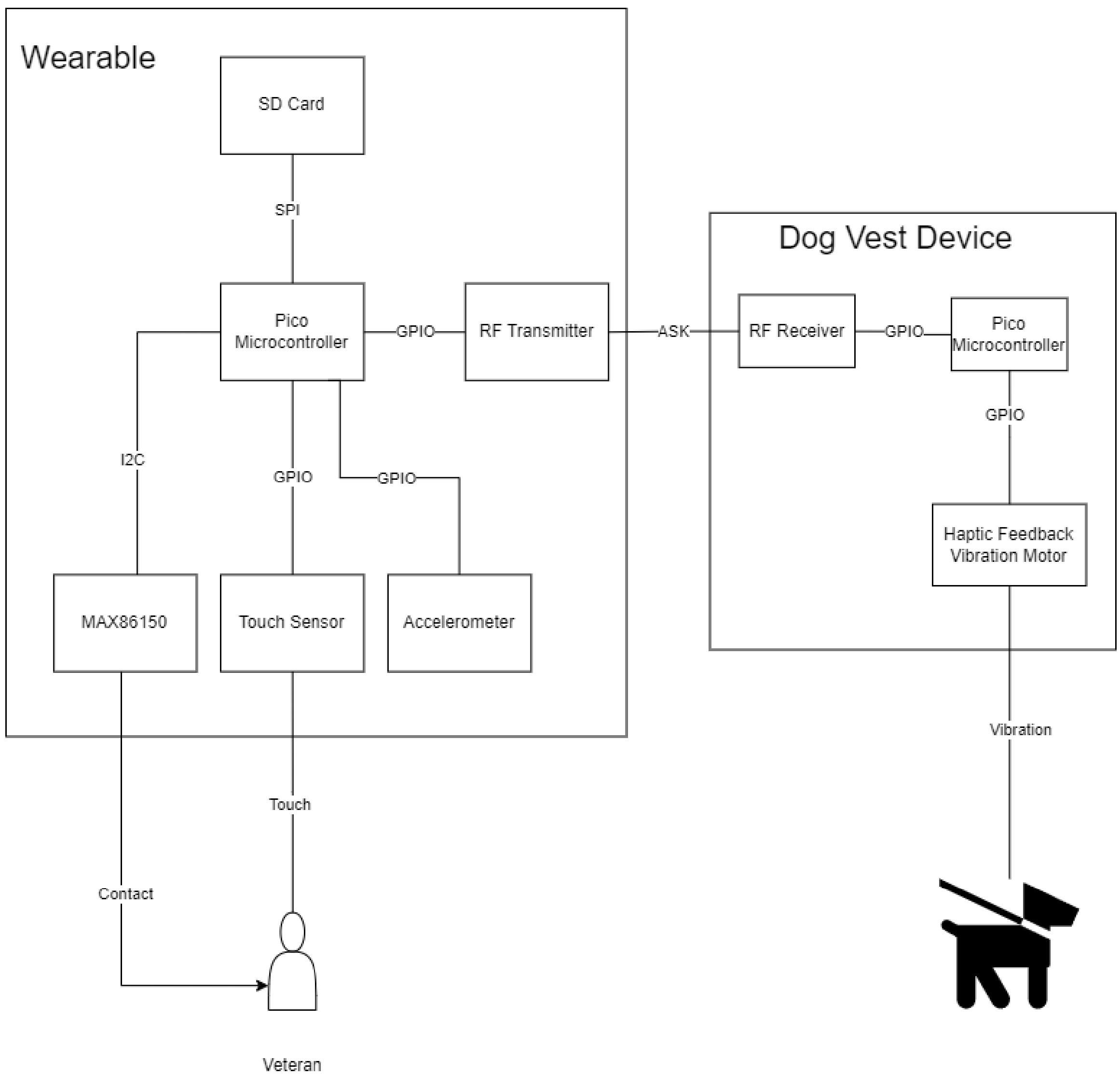


Figure 4.7.3.2: Design Stage 2: Wearable with dog feedback device

In the second stage, we design the dog feedback device, an initial/simple algorithm for PTSD episode symptom prediction, and integrate a means of communication with this onto the wearable device. This stage should collect data, predict PTSD episodes, and alert service animals. The algorithm will be designed using data collected from the first design stage.

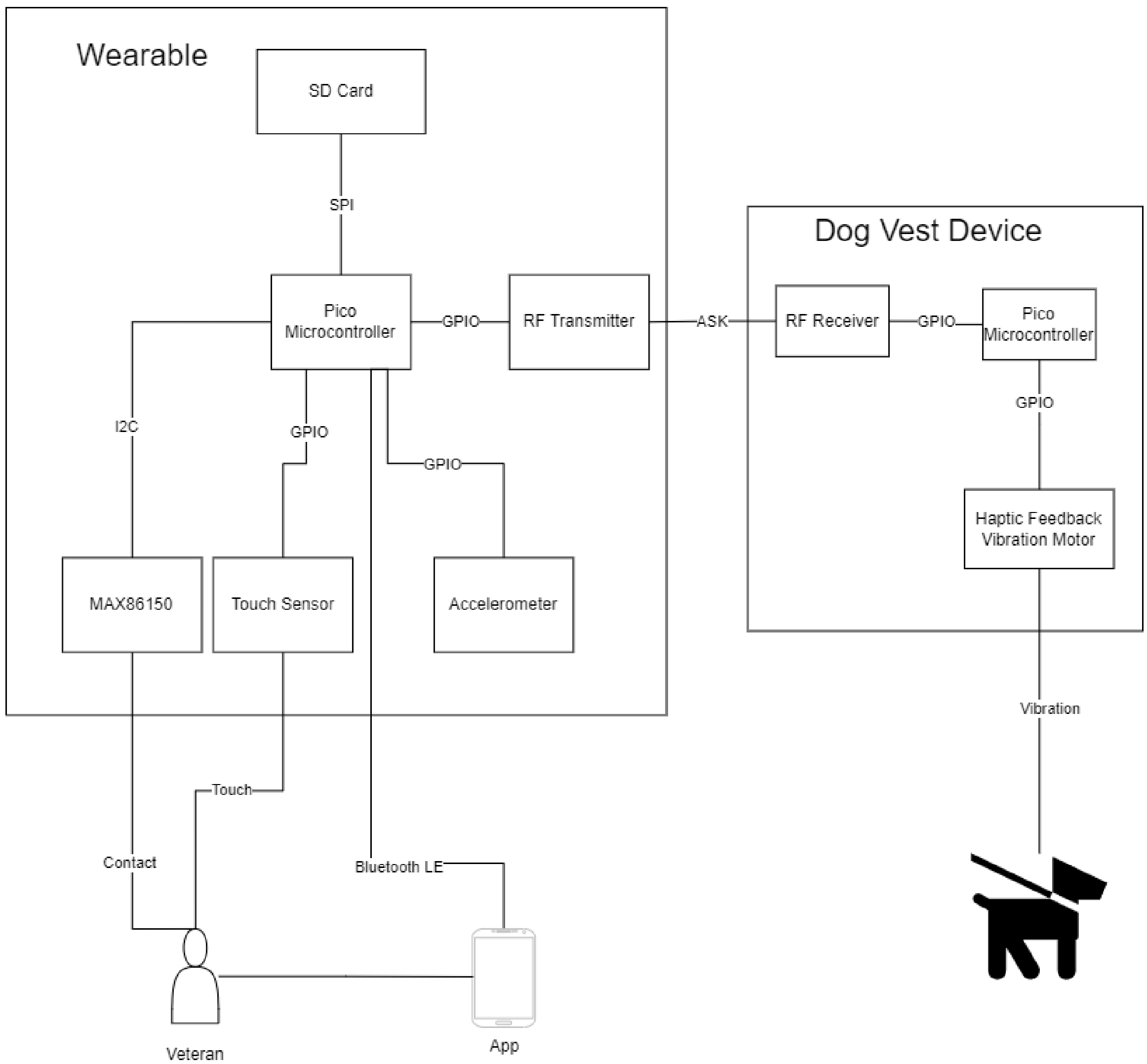


Figure 4.7.3.3: Design Stage 3: Integration of app with wearable

The final design stage integrates an app/UI with the wearable. This stage provides the user with the ability to synchronize the app with the wearable and turn off/on the device.

4.8 Technology Considerations

Bluetooth benefits:

- Connections are long-lived
- Supported by many platforms

Bluetooth limitations:

- Short range
- Requires authorization/handshake

Radio benefits:

- Simple, no handshake
- Longer range

Radio drawbacks:

- More custom work
- Less established procedure

Mobile benefits::

- More processing power
- Built-in support/frameworks

Mobile drawbacks:

- Different hardware by phone
- No custom RF
- Potential compatibility issue

4.9 Design Analysis

As of now, our team does not have any definitive test results to conclude if any of the mentioned designs function correctly or not. With that said, we have many ideas for potential additions to the design for functionality purposes if our current design is successful:

- Implementing additional sensors - there is research on the usefulness of cortisol levels and skin conductivity in measuring stress levels, so we have our eyes on them as a possibility for future feature expansion.
- Add sensing for electro-dermal activity (EDA). Electrodermal activity is a measure of sympathetic nervous system activity, and is reflected as of skin conductance. EDA has been clinically proven as a direct indicator of stress.
- Implementation of a mobile app - this is discussed elsewhere in the document. Display data and act as a control interface that users are already familiar with.