SAFE SIGNAL

A REALTIME POST-TRAUMATIC STRESS SYNDROME DETECTION DEVICE

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Client: America's VetDogs
Mentors: BAE Systems
Faculty: Dr. Mohamed Selim

SDMAY25-13

https://sdmay25-13.sd.ece.iastate.edu/

DEFINED GOAL

01 America’s VetDogs along side BAE Systems are looking to develop a solution for detecting onset post traumatic stress disorder (PTSD) symptoms through physiological data and alert a service animal of the Veterans state to provide immediate comfort.

02 Hinder the development of a PTSD episode for the veteran.

BAE SYSTEMS

EST. 2003
AMERICA’S
VETDOGS®

CONSTRAINTS

01 Wearable For Both The Service Dog and Handler.

02 Physiological Data Requirements: Heart Rate And Blood Pressure Monitoring.

03 Alert Device For Service Animal Is Humane And Discrete.

04 Effectively Detect Onset PTSD Symptoms.

SOFT CONSTRAINTS

01 Operates on a rechargeable battery system

02 Provides basic system-level on/off functionality

03 Designed for at least 8 hours of operation

04 Architecture allows for easy integration of additional motors

05 Dog architecture fits inside dog vest

ACCOMPLISHMENTS

01 Blood pressure & heart rate data acquisition via photoplethysmogram

02 Developed printed circuit boards (PCBs) to achieve a wearable/stand alone design

03 Pseudo PTSD algorithm

04 Built mock PCB via breadboard for risk mitigation

05 Plan for future iterations

5

DESIGN

Modular Hardware Design Approach

PARTS LIST AND USES

01 ESP32 S3 Wroom-1
- Data processing and includes integrated serial to uart bridge

02 MAX86150
- Photoplethysmogram (PPG) → sensing blood pressure and heart rate

03 DC Eccentric Rotating Mass Motor (ERM)
- Non invasive and non disruptive vibration alert device

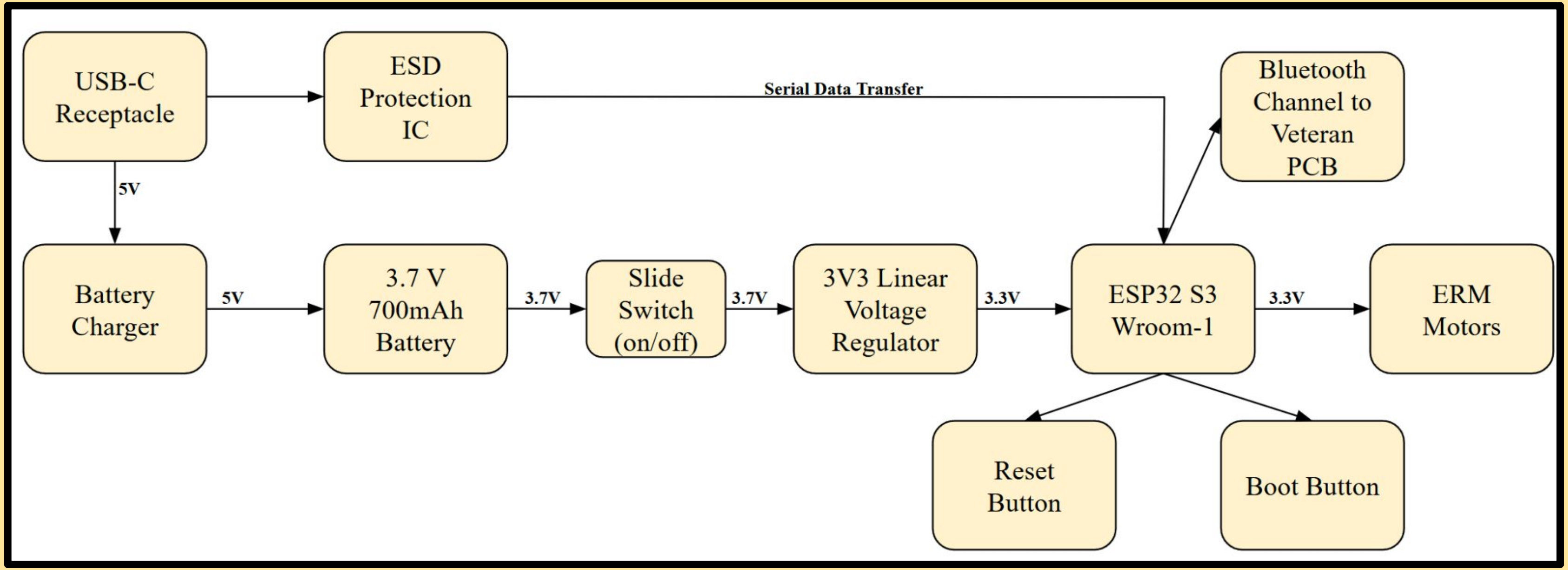
04 Battery Charger Integrated Circuit
- Charges our 3.7v 700mAh battery from USB-C (5v)

05 Fixed Linear 3.3v Voltage Regulator
- Steps down 3.7v (from battery) to 3.3v (for S3)

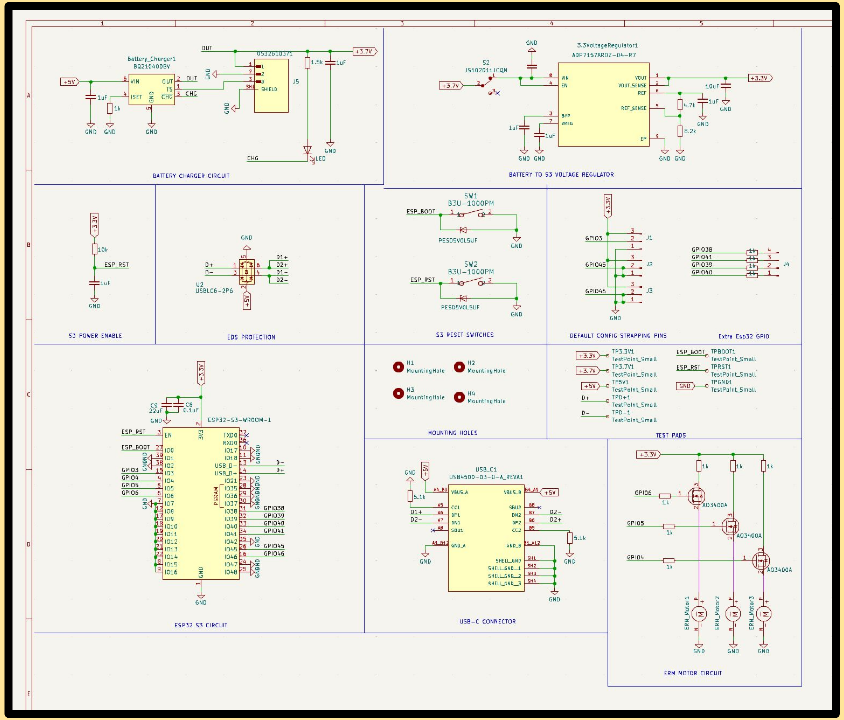
06 USC-C Receptacle Including ESD Protection Integrated Circuit
- Allows for software upgrades and power charging

OVERARCHING DESIGN

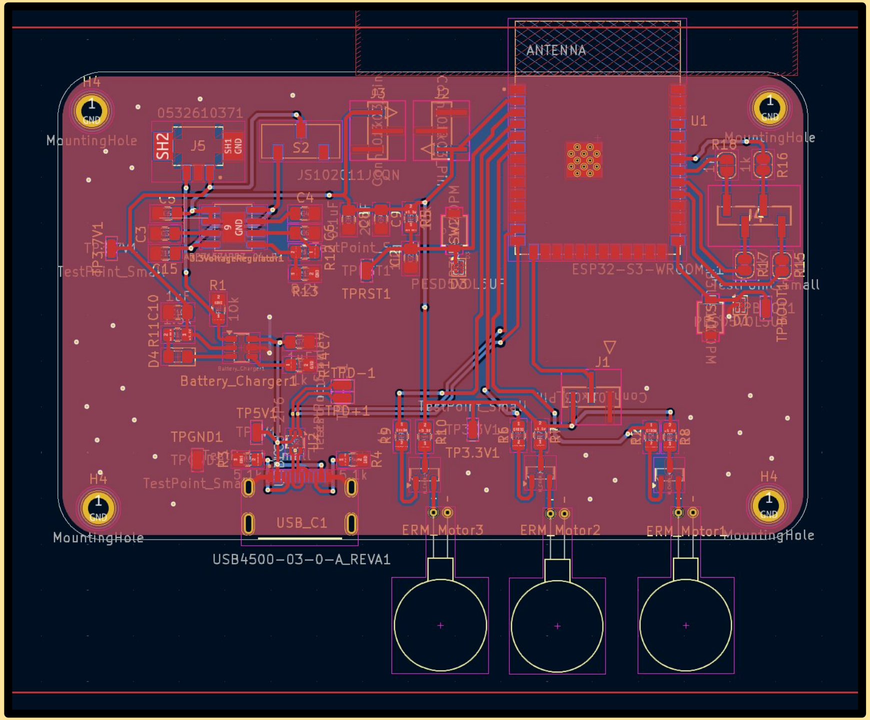
Dog Side



DOG SIDE

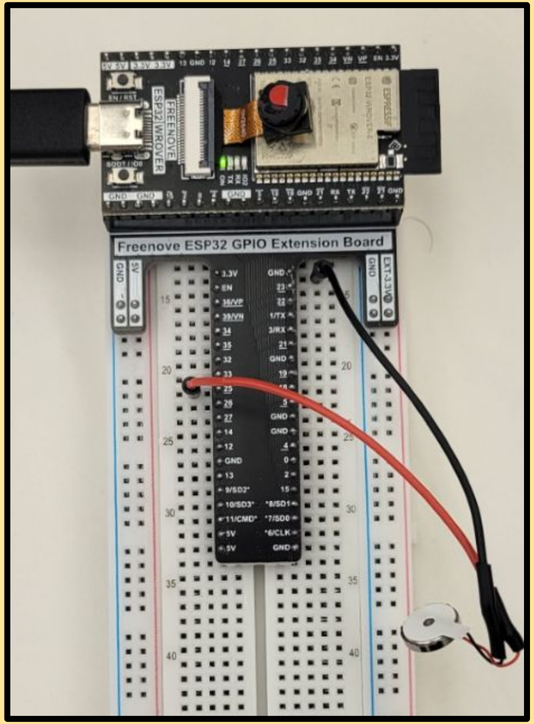


KiCad Schematic

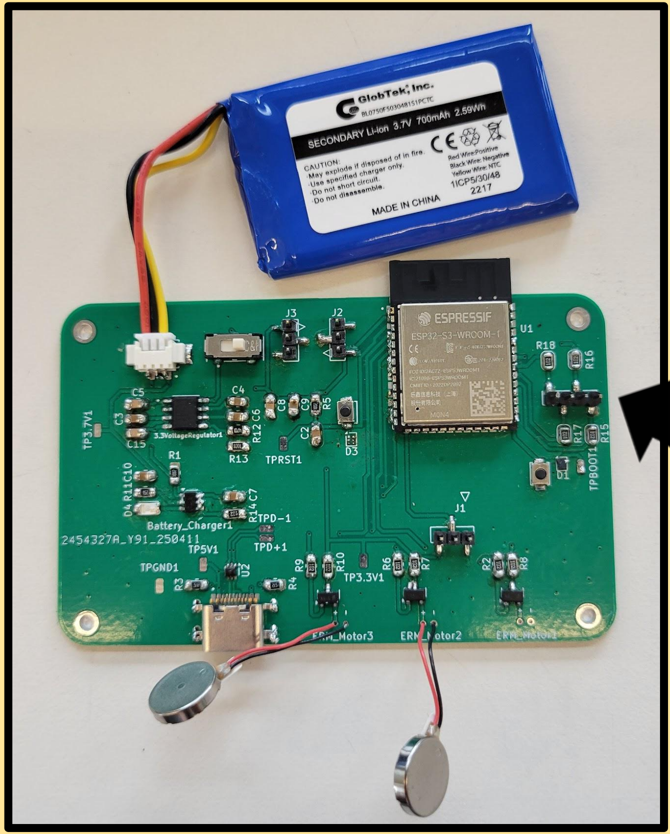


KiCad PCB

DOG SIDE



Previous Design

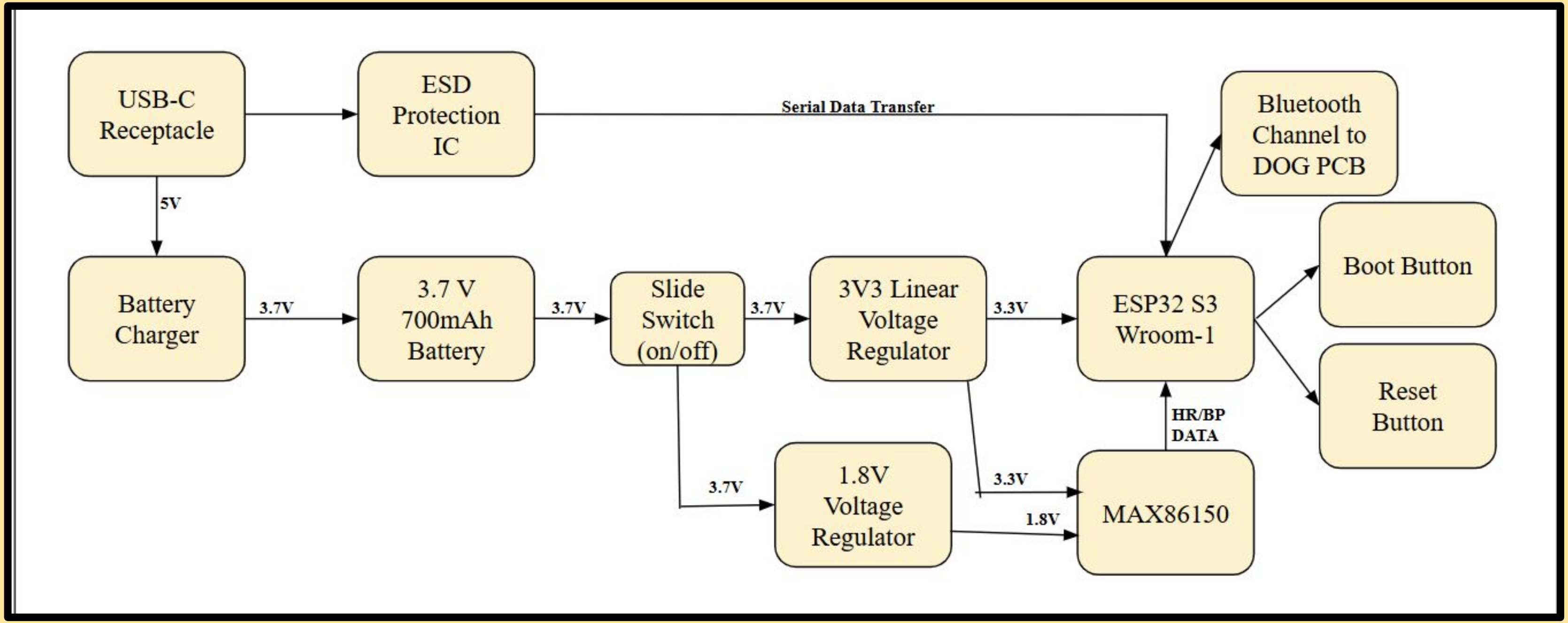


Current Iteration

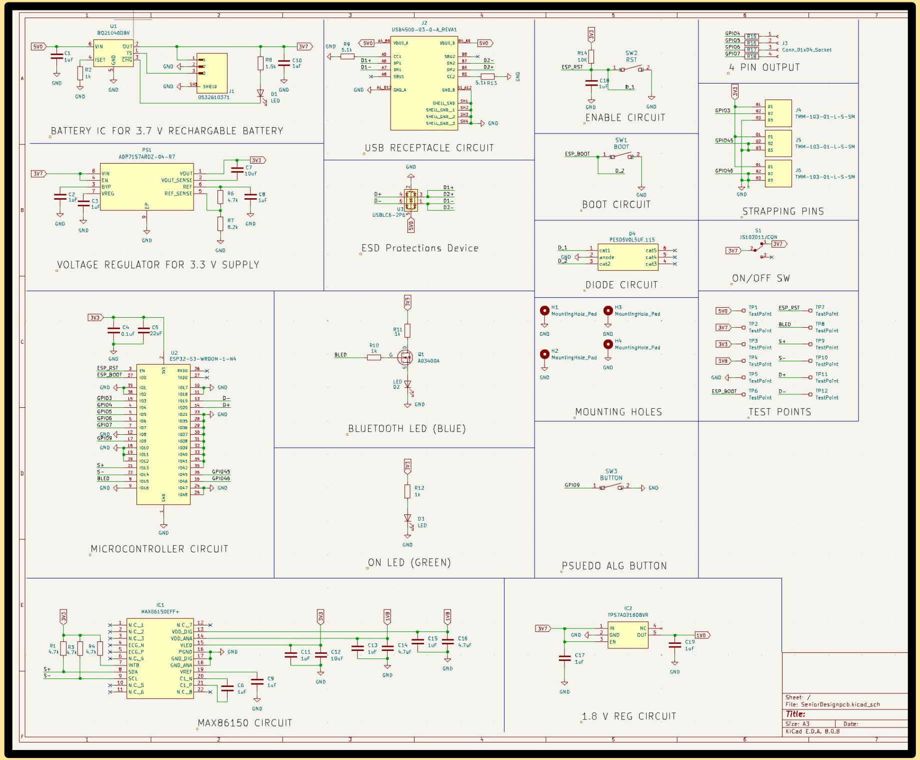
Additional Motors

OVERARCHING DESIGN

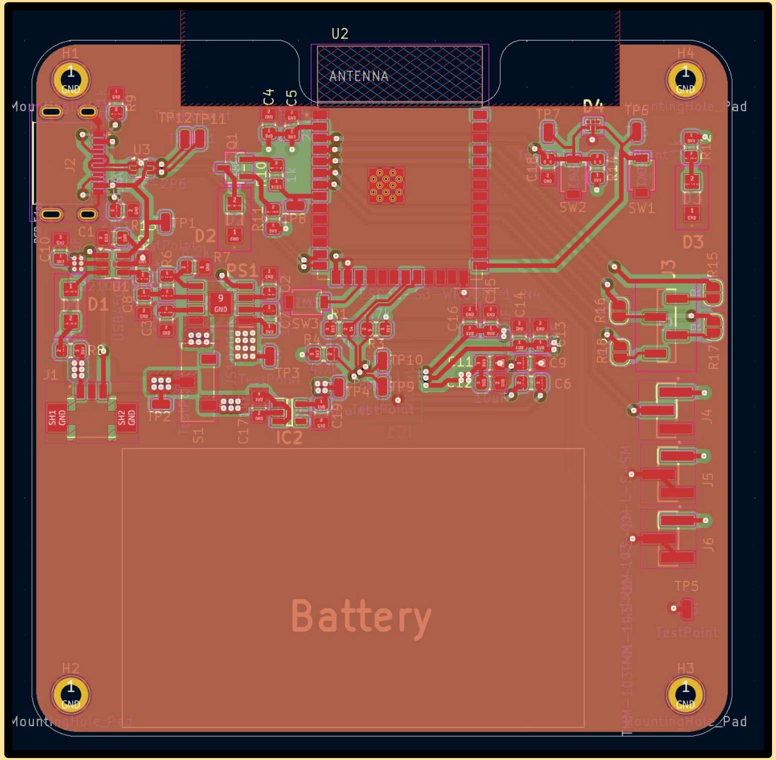
Veteran Side



VETERAN SIDE

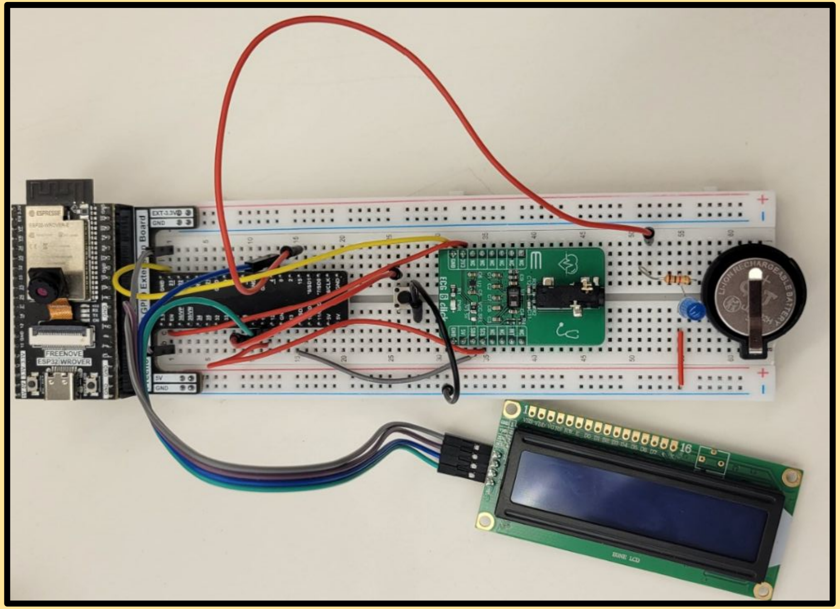


KiCad Schematic

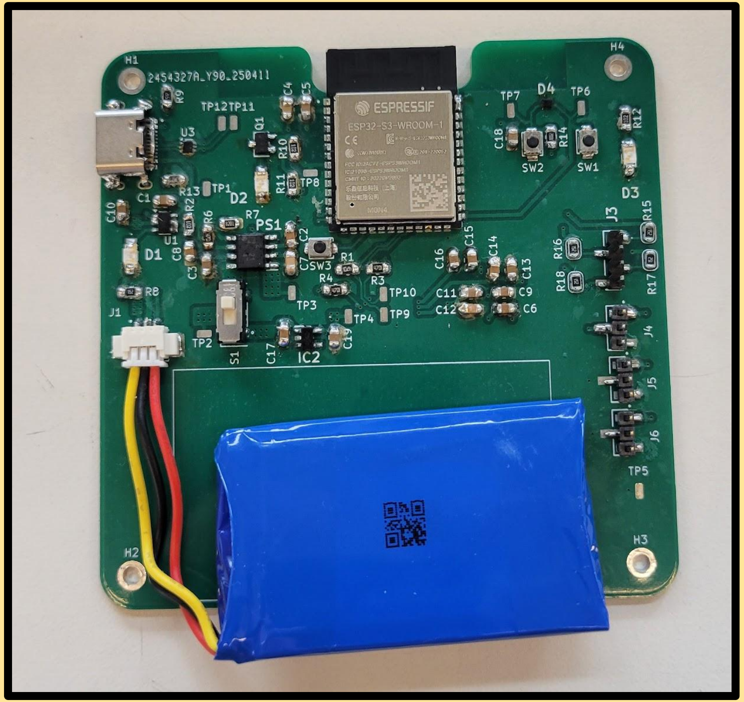


KiCad PCB

VETERAN SIDE



Previous Design



Current Iteration

13

SOFTWARE DESIGN

PHOTOPLETHYSMOGRAM

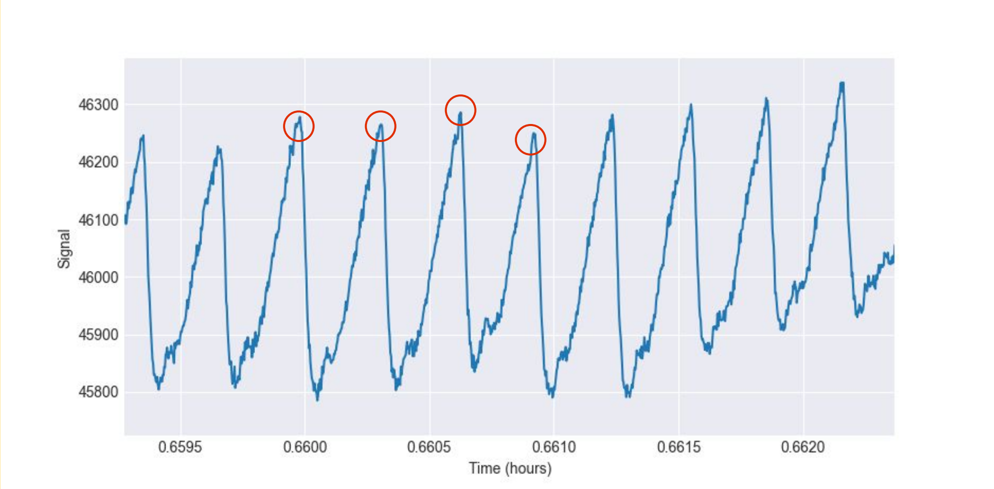
01 Write our custom configuration to initialize MAX86150 registers.

02 Poll the device to see if there is data available.

03 When device indicates data is available, read raw 19 bit IR value to ESP32.

04 Repeat 02 and 03 until 600 samples have been collected, use these to detect heart beats & blood pressure.`

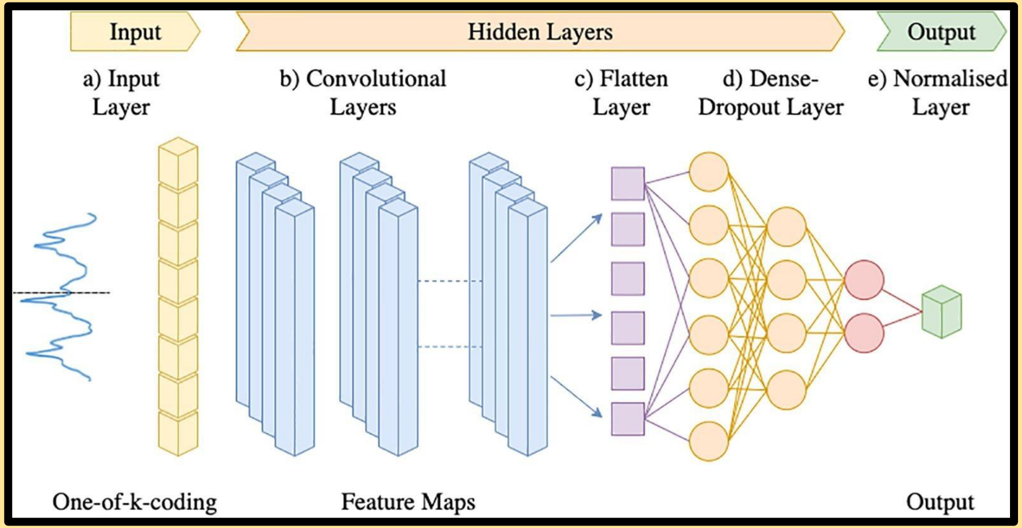
HEART RATE DETECTION



- Peaks correspond to heart beats.
- Need way of reliably detecting these beats.
- **Solution: MSPTD:** Consensus most accurate beat detector

- Look for samples whose value is greater than all nearby values, average the time between these values to find heart rate.

BLOOD PRESSURE DETECTION



Motivation - Blood pressure (BP) data essential for accurately detecting PTSD episodes

Challenge - Current research around BP detection from PPG data is still in early stages; no great algorithms exist.

Solution - Using publicly available health data, train a 1 dimensional convolutional neural network (CNN) to recognize BP.

- Using some publicly available tools and data, we were able to generate a novel CNN architecture that uses context-specific constraints and optimizations to estimate a users blood pressure
- Our solution is able to perform this task without incurring large energy costs and timing overhead, a common problem among machine learning models.

Blood Pressure Detection (2)

01 From the 600 samples collected from PPG, take a subset of 210 samples for pre-processing.

02 Normalize RAW PPG values by subtracting each sample by mean and dividing by standard deviation.

03 Calculate the first and second derivative of the PPG waveform, giving the neural network more features.

04 Run our pre-processed input through three consecutive convolutional layers to produce feature maps.

05 Finish with mean layer and two fully-connected layers, final output is blood pressure estimate.

DETECTION ALGORITHM

Real Time Processing - The algorithm gets a constant stream of data for processing

Rolling Buffer - A circular buffer is used to ensure that the oldest data is replaced as new data is collected

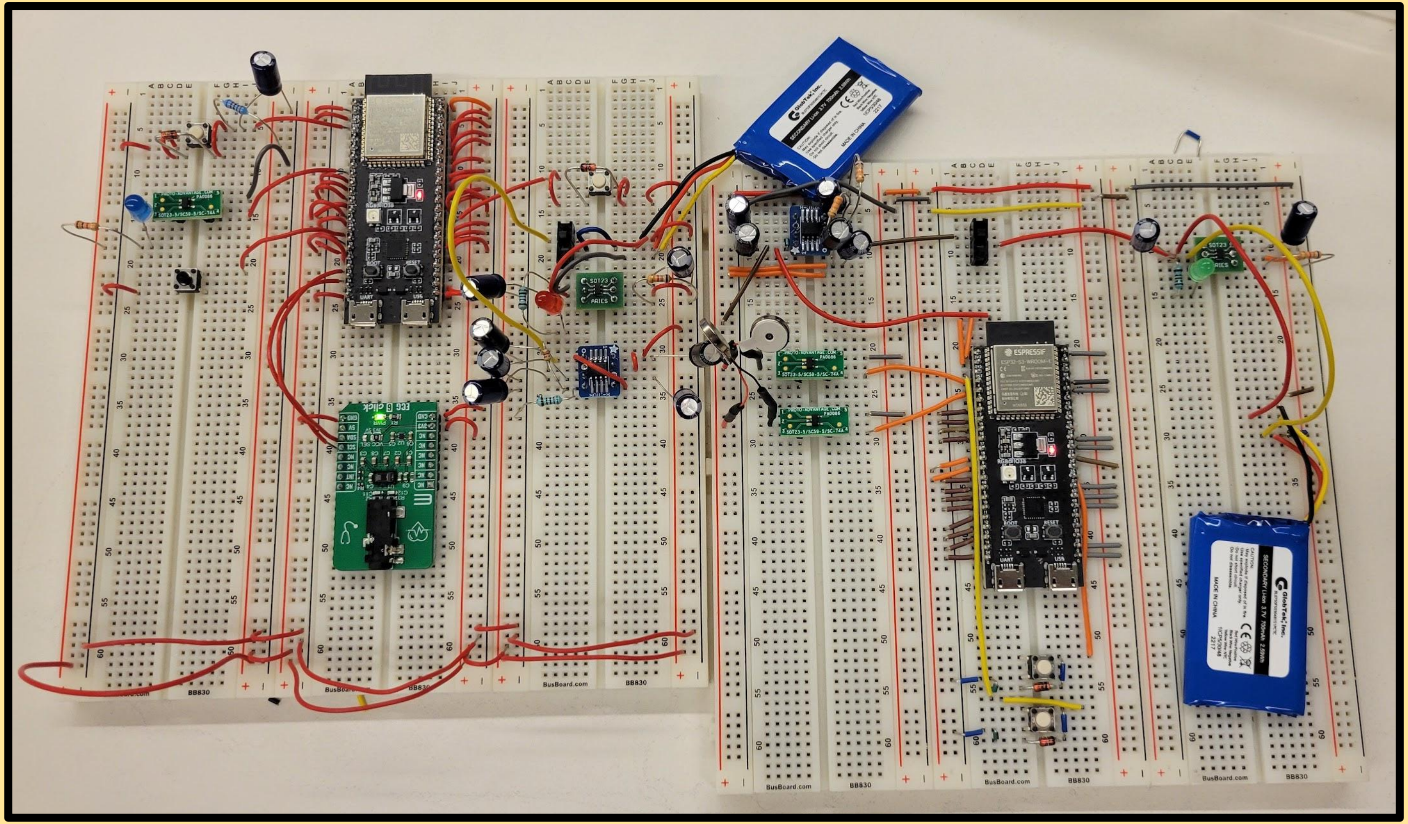
Baseline Calculation - Baseline stats are calculated using the data that's in the buffer. These include average BPM, standard deviation, and root mean square.

Heart Rate Change - If there's a sudden change in heart rate, it is detected by a change in these stats, and relayed back to the system

TESTING

RISK MITIGATION

Breadboard implementation of PCB design



BREADBOARD VS PCB

01 Fixed Grounding issues with unused GPIO pins

- tied pins to ground. Consequently, serial data could not pass. The line was stuck low.

02 Fixed mosfet circuits (ERM motor and Bluetooth LED circuits)

- not a large enough voltage difference between Vgs and Vds. Resulting operation in triode region versus saturation

03 Order/receive soldering mask

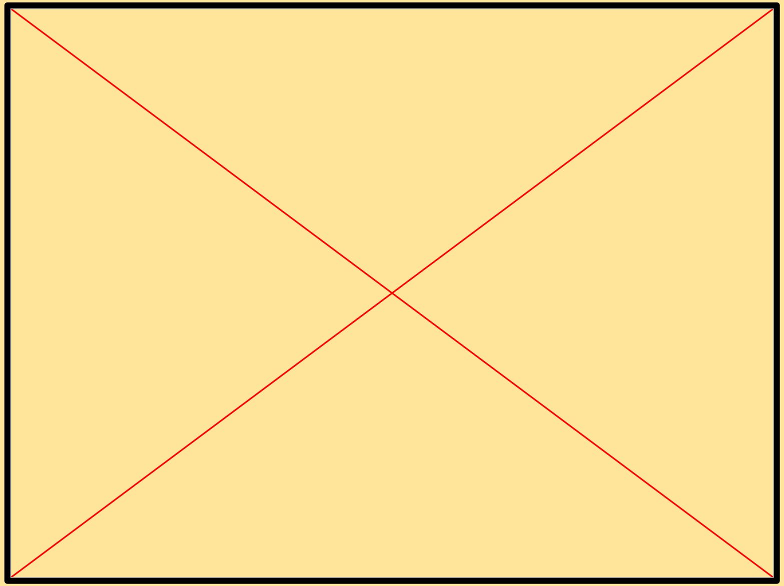
- mitigate shorts, correctly connect grounding planes, and cleaner soldering job

TESTING MOCK ALGORITHM

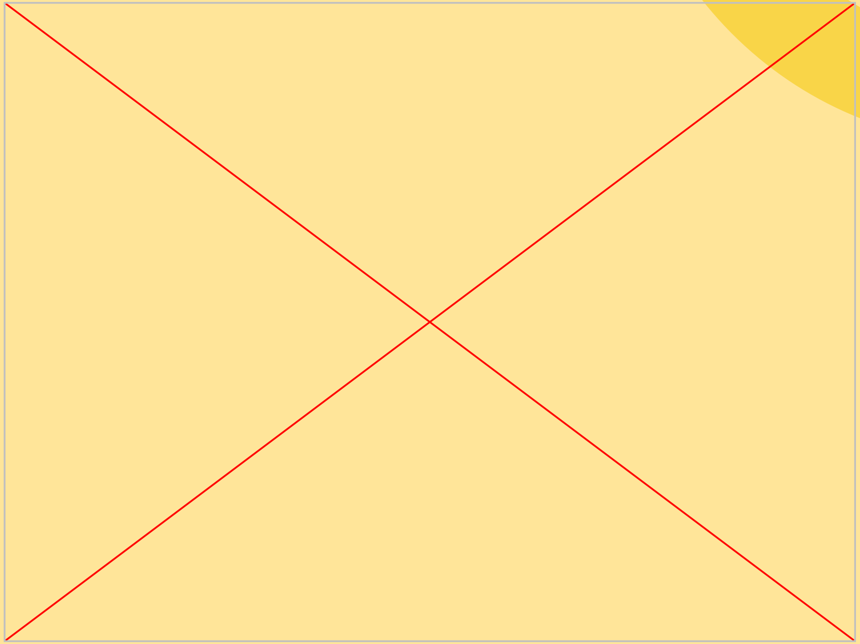
Previous Design

Current Iteration

BLUETOOTH COMMUNICATION



Previous Design

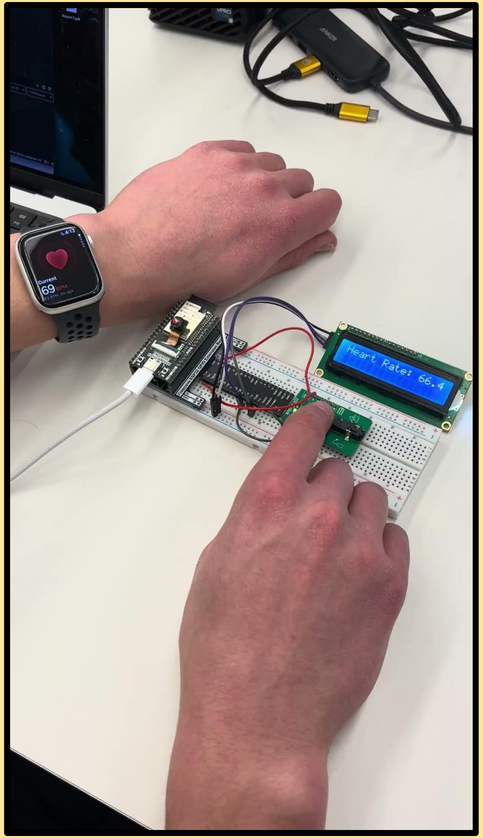


Current Iteration

Heart Rate Monitoring

Avg Simulation bpm:
66.4 bpm

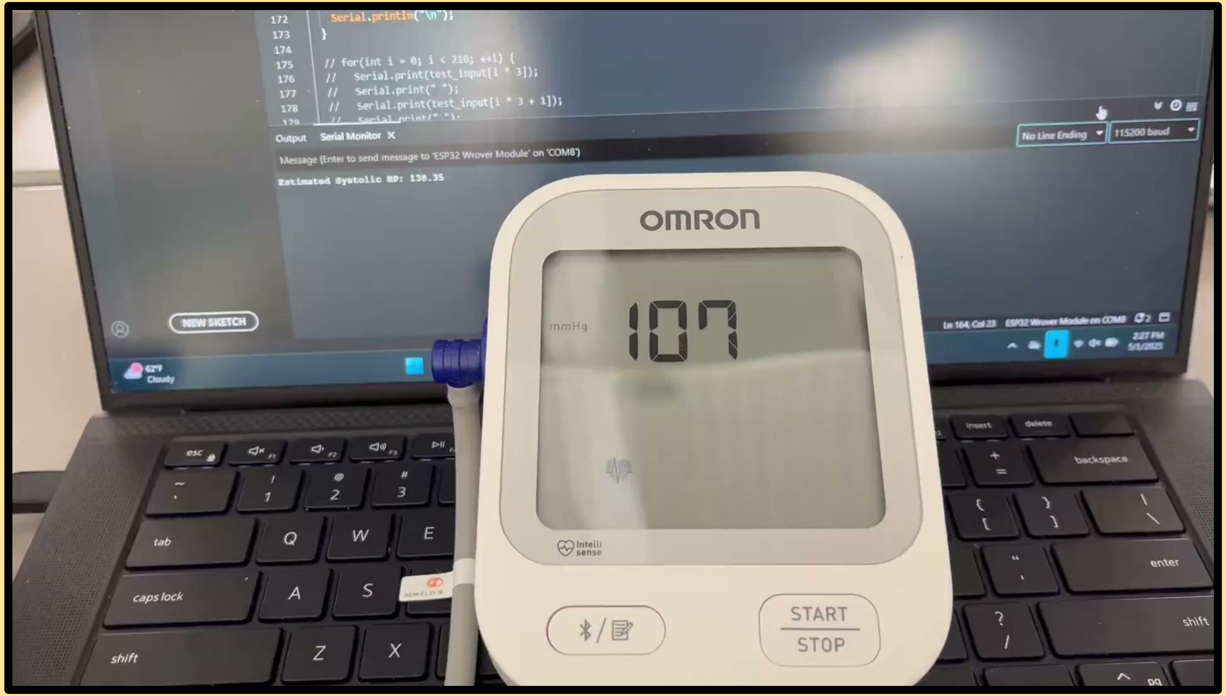
Apple Watch bpm:
69 bpm



Blood Pressure Monitoring

Avg Simulation Systolic BP:
124.9 mmHg

Actual Systolic BP:
133 mmHg



CRUDE TESTING STATS

01 The device takes 6.97 seconds to visual show connection via Bluetooth

03 Bluetooth Connection Lasts at least 30 Feet
- Including through walls

04 Heart Rate Verified With Apple Watch
- Within 5 bpm

06 Blood Pressure verified with medically certified cuff
- Within 20 mmHg

THE NEXT STEPS

FUTURE DESIGN TEAM

01 System and software integration
- Merging Bluetooth, heart rate, and blood pressure source codes

02 Another iteration of PCB design
- Design veteran side to be smaller (watch size)

03 Device housing for dog and veteran PCBs

04 Fine tuning/testing detecting PTSD Algorithm

05 Implementing device security

06 Testing with veterans and their service dogs

SECURITY PLAN

01 Most likely attack vector

- Bluetooth LE vulnerabilities/misconfigurations

02 Handheld hacking devices are a potential threat

03 Review Bluetooth LE code

04 Prioritize security items using organizational checklist/matrix

- See design document

SECURITY ITEMS

Only use necessary BLE services/profiles

Undiscoverable until needed

Explore options for authenticated pairing

QUESTIONS

ENGINEERING STANDARDS

01 IEEE 802.15.1: WPAN / Bluetooth

02 ISO/IEEE 11073: Medical / Health Device Communication Standards

03 IEEE 360-2022: IEEE Standard for Wearable Consumer Electronic Devices

04 IEEE 11073-10407-2020: Health informatics--Personal health device communication Part 10407: Device specialization--Blood pressure monitor