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Chesto Alarm

Beta Prototype Final Presentation

Somi (Company 4)

ENSC 440 Capstone B, SFU, Fall 2021

Overview

1. Introduction
2. Technical case
3. Business case
4. Risk analysis / Risk management
5. Adherence to standards
6. Demo
7. Self-reflection
8. Conclusion

Introduction

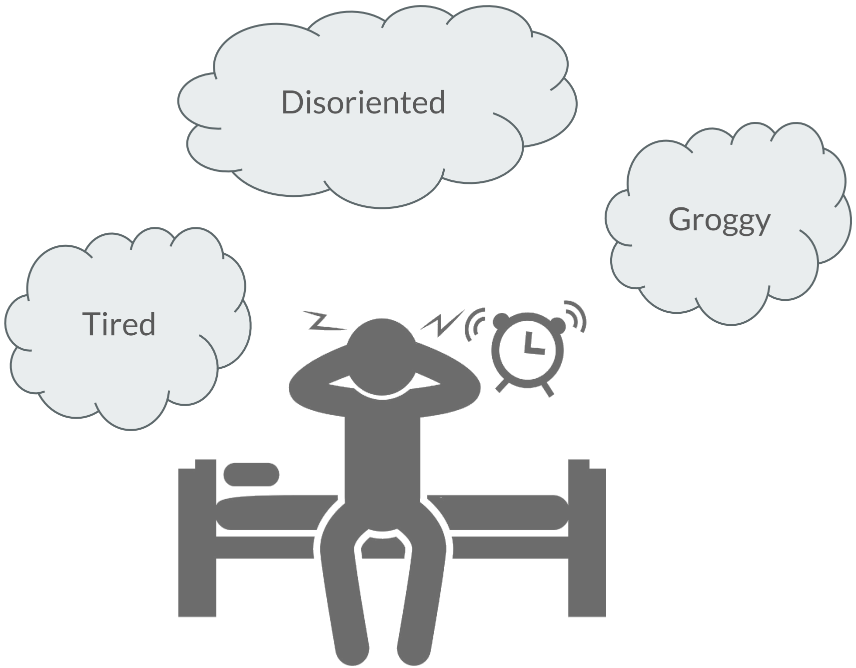
Team Member Introduction

Maple Tan
CEO
Firmware, Hardware

Minji Ju
CTO
Signal Processing

Grace Zhang
CTO
Mobile Application

Motivation behind Chesto Alarm



Do *you* ever wake up feeling tired?

Our Motivation behind Chesto Alarm: Curiosity-driven

- We have all experienced the morning grogginess
- Somewhat knew about smart alarms
- Wanted to get behind the essence of it

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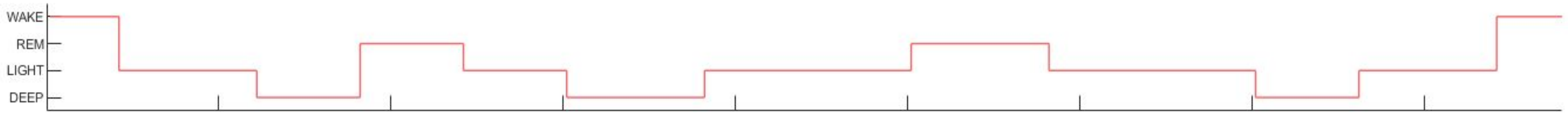
Background

Sleep Inertia: "a period of impaired performance and reduced vigilance following awakening from the regular sleep episode or from a nap" [1]

- Morning grogginess = ***sleep inertia***

- Throughout the night, we go through multiple sleep cycles
    - Each sleep cycle is composed of Wake, Light, Deep and REM sleep stages



- Studies [2][3] have shown that..
    - ***Most sleep inertia effects*** when woken during ***deep or REM*** sleep stages,
    - ***Least sleep inertia effects*** when woken during the ***light*** sleep stages

- Sleep staging is commonly conducted using polysomnography, which involves collection of a series of biometric data, including brain wave activity, eye movement, muscle movement, and heart rate

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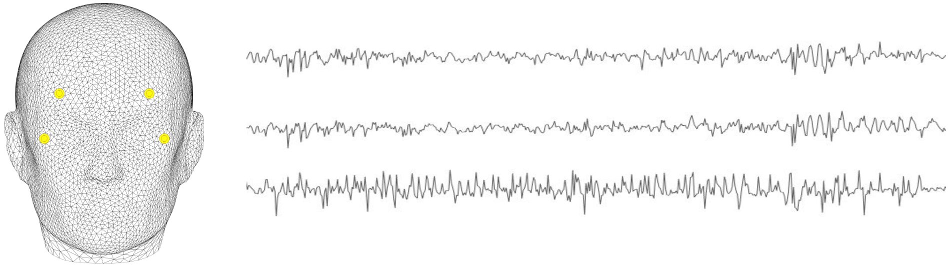
Introducing Chesto Alarm

A smart alarm system that *reduces sleep inertia*

An alarm that considers sleep stages:

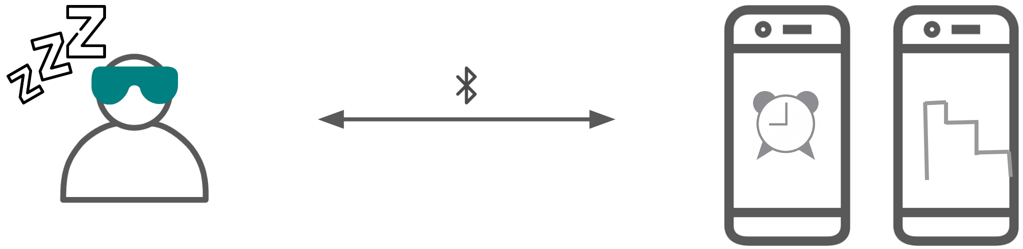
- Finds sleep stages using brain activity and eye movement data



- Rings alarm during light sleep stages

Technical Case

Main Functions / Project Modules



Wearable Device (Eye Mask)

- Collects biometric data (EEG+EOG)
- Analyzes data and classify sleep stages
- Sends sleep stages to mobile application

Mobile Application

- Allows users to set alarm and rings alarm
- Receives sleep stages from eye mask and updates alarm time
- Displays hypnogram

Alarm Logic

User Inputs:

Alarm Time: 7:00 AM
Time Buffer: 30 minutes

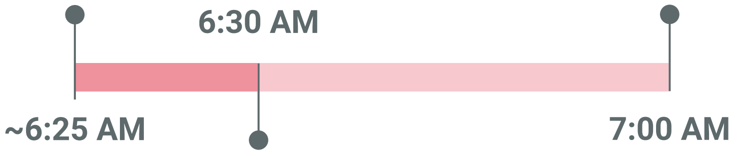
System:

Wake Window: [6:30 AM 7:00 AM]
Wake Time: TBD by Chesto

If no consecutive light sleep stages are detected within the wake window, alarm will ring at 7:00 AM.

Sleep Stage Monitoring

Chesto Alarm monitors current sleep stages throughout the night. Alarm logic starts about five minutes before the start of the wake window, and looks for light sleep stages.

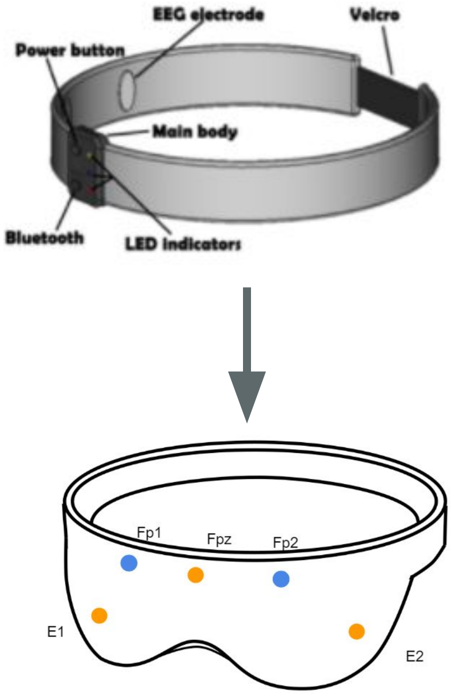


Wake Window

Chesto Alarm will ring sometime between 6:30 AM and 7:00 AM.

Design Change System-Level Design (Overview)

- Addition of EOGs
  - For better REM and Wake accuracy
- Headband -> eye mask
  - Design of eye mask
- Self-annotated sleep stages
  - AASM (American Academy of Sleep Medicine) manual



Design Change System-Level Design (Overview) (cont.)

- Removed machine learning
  - Simple algorithm instead
- Utilize resource on mobile for processing
  - Alarm logic

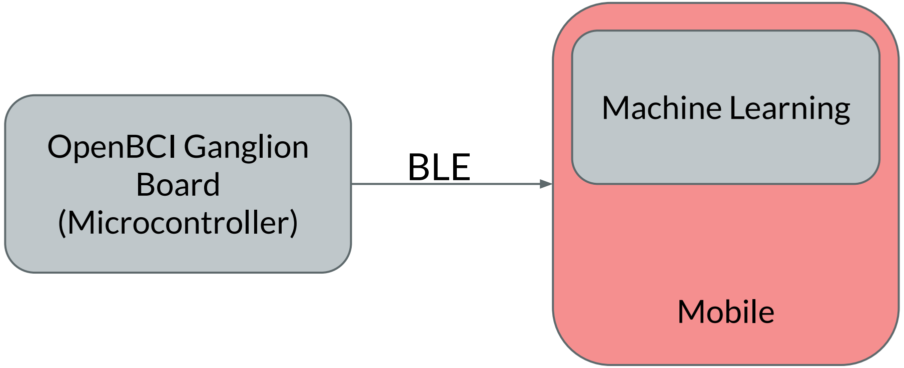


Figure 1: Explored Design

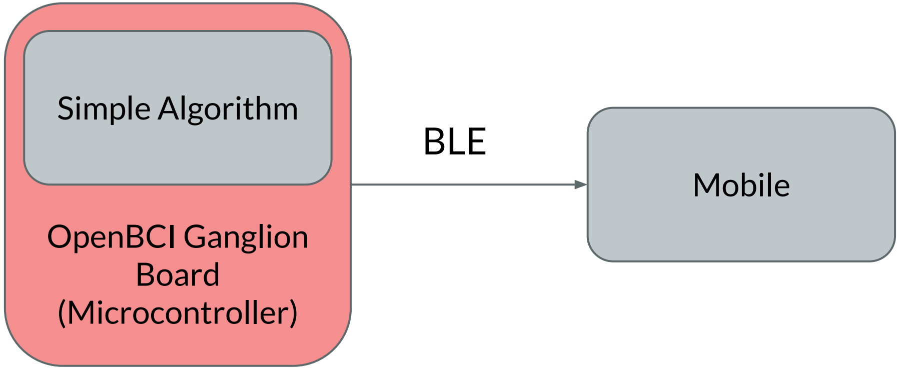
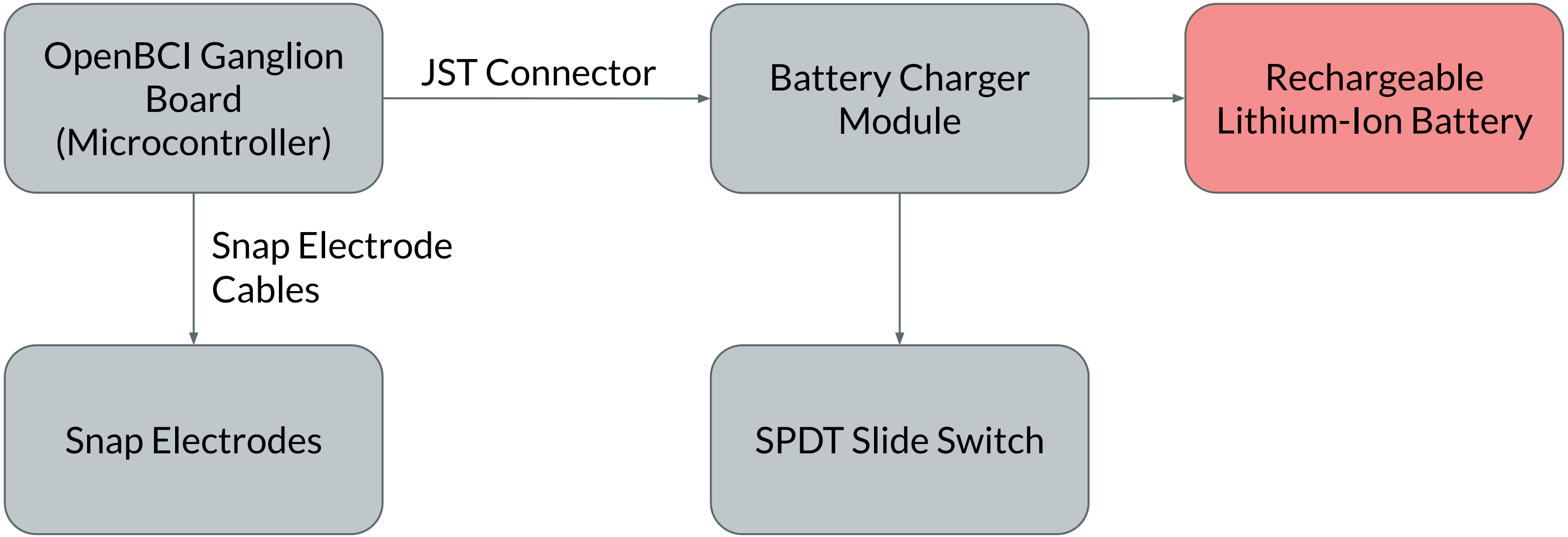


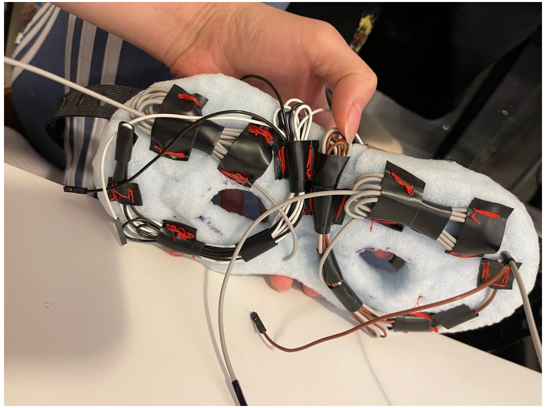
Figure 2: Final Design

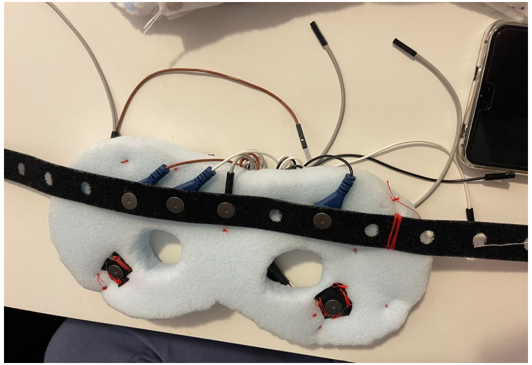
Construction & Progress **Hardware**



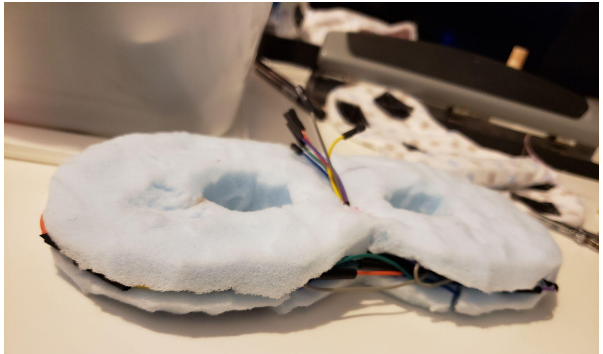
Construction & Progress Hardware/Appearance

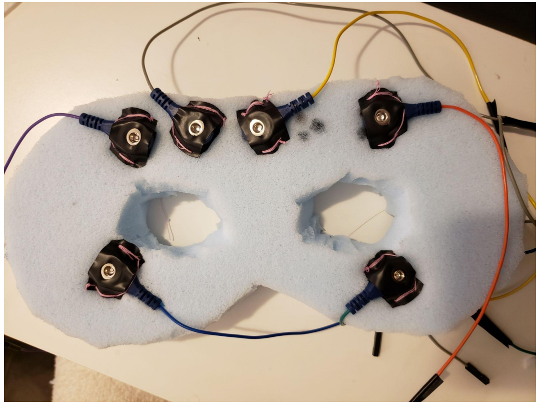
Before:





After:





Appearance Construction & Progress

Before:

After:

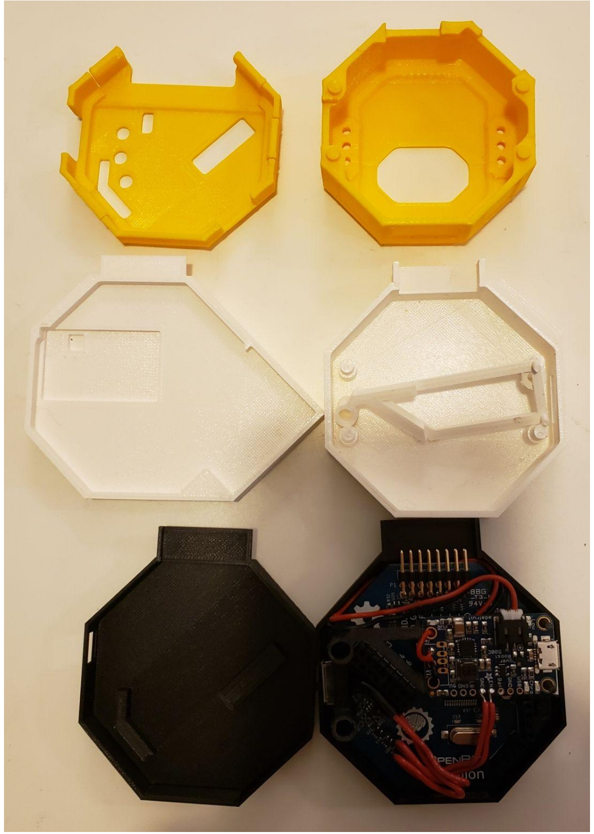
Appearance Construction & Progress

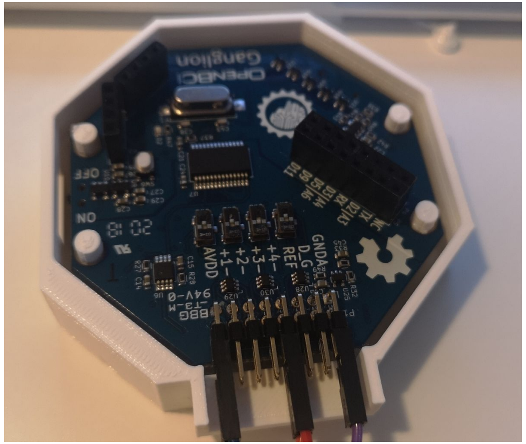
Before:

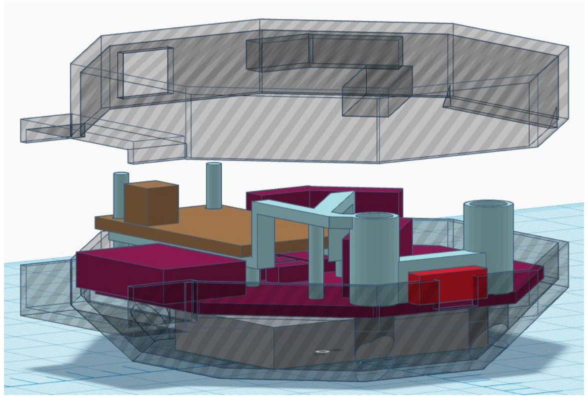
After:

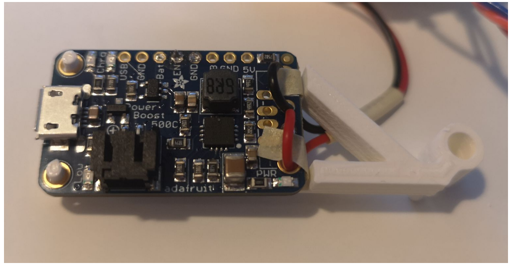
Construction & Progress

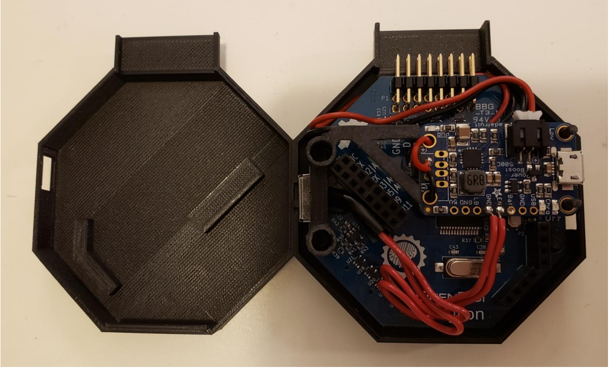
3D Printed Enclosure





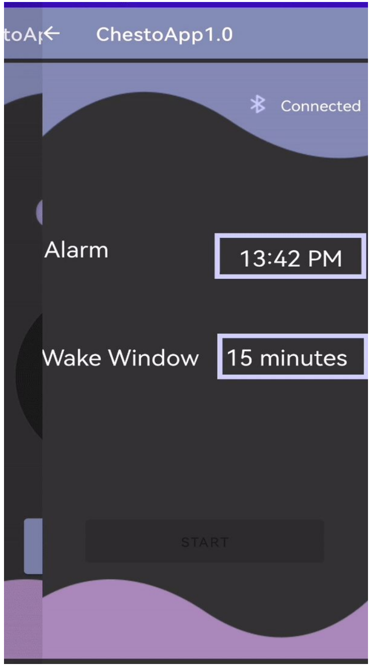




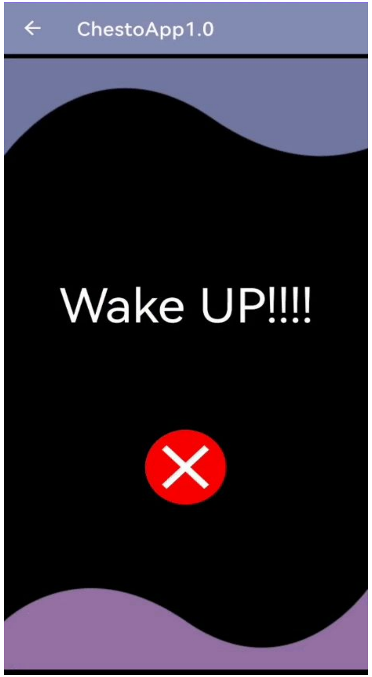


Construction & Progress Software (Mobile Application)

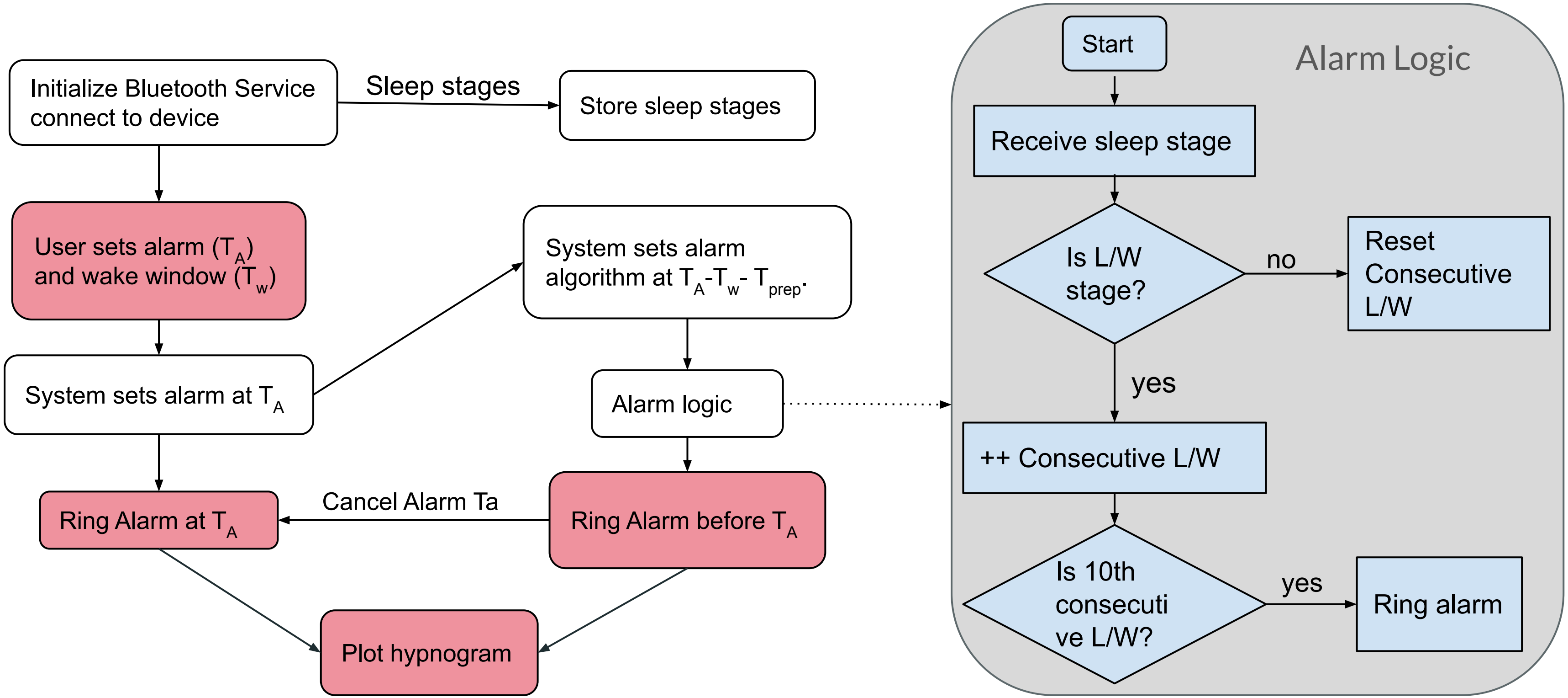
- Bluetooth auto connection
- User sets alarm
- User sets wake window
- Start alarm



- Ring Alarm
- View sleep statistics after waking up



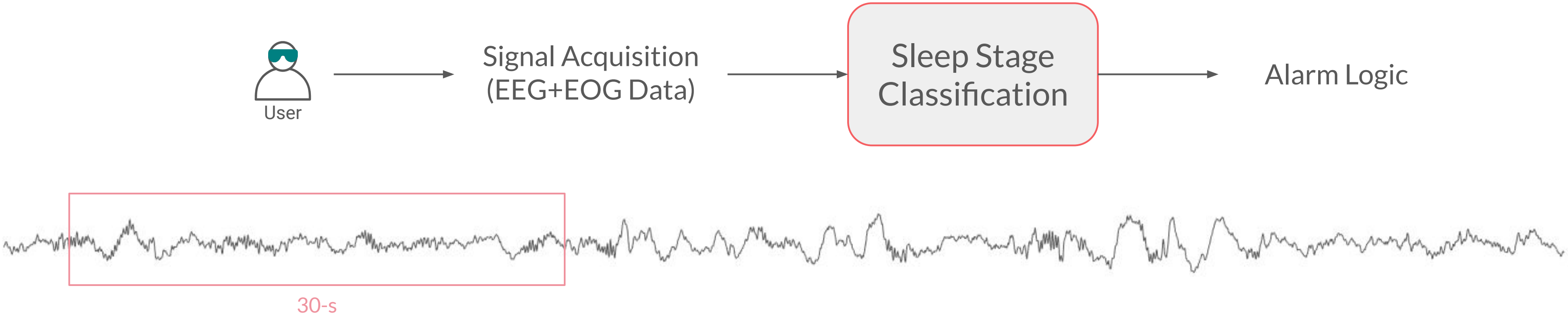
Construction & Progress Software (App Structure)



T_A = time of user set alarm T_W = start of wake window

T_{prep} = time of 10 consecutive L/W stages = 10 * 30 seconds = 5 minutes

Design Outline Sleep Stage Classification



- Frontal EEG (brain waves) and horizontal EOG (eye movement) data collected
- Data analyzed in 30-s segments
- Characteristics of each 30-s segment used to classify sleep stages

Design Change

Sleep Stage Classification (Manual Annotations)

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Before implementing sleep stage classification…

- First needed sleep data and sleep stages corresponding to the sleep data

Sleep stages are typically manually annotated by sleep experts

- Looking at collected polysomnography (PSG) data
- Data in 30 second segments, under American Academy of Sleep Medicine (AASM) [4] guidelines

BUT…

Chesto Alarm is a novel device with specific electrode placements

- Needed to collect sleep data using our own device
- Needed to annotate sleep stages of our collected sleep data

Initial plan:

- We assumed we would be able to receive sleep annotations from a sleep expert
    - *Problem*: We were under budget and time constraints

Altered plan:

- Annotate our own sleep data

Design Outline

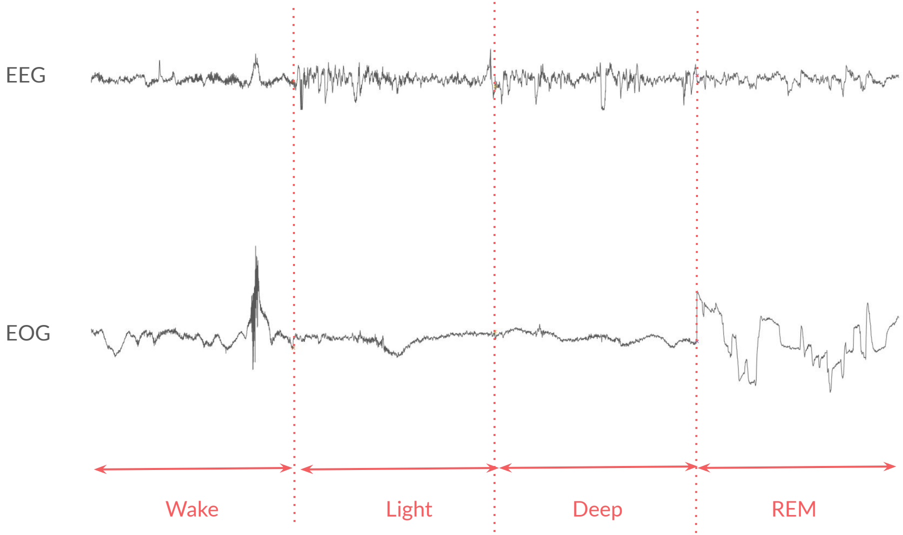
Sleep Stage Classification (Manual Annotations)

- Annotated collected sleep data following AASM guidelines [4]
- Agreement among sleep experts in sleep staging is less than 90% [5]
    - Ours are bound to be much more off!!!

Frequency bands and features used for Sleep Stage Classification

Bands	Frequencies (Hz)	Features for Sleep Stage Classification
δ	0 - 4	Slow Wave Sleep (SWS) 0.5-2Hz in DEEP sleep stage
θ	4 - 8	Low-Amplitude, Mixed Frequency (LAMF) 4-7Hz in LIGHT sleep stages
α	8 - 13	Alpha rhythm in WAKE sleep stage
β	13 - 22	
γ	>35	

Sample EEG and EOG Data with corresponding Sleep Stages (Data taken from sleep-edf)



Design Change Sleep Stage Classification

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<u>PoC Prototype</u>

- Classified stages:
  Wake, Sleep
- Two frontal EEG channels
- **Deep learning**

<u>Beta Prototype</u>

- Classified stages:
  Wake, Light, Deep, REM
- Two frontal EEG and two horizontal EOG channels
- **Simple algorithm**
  - Using EOG values to differentiate Wake and REM from Deep and Light, then
  - Using EEG values to differentiate the rest

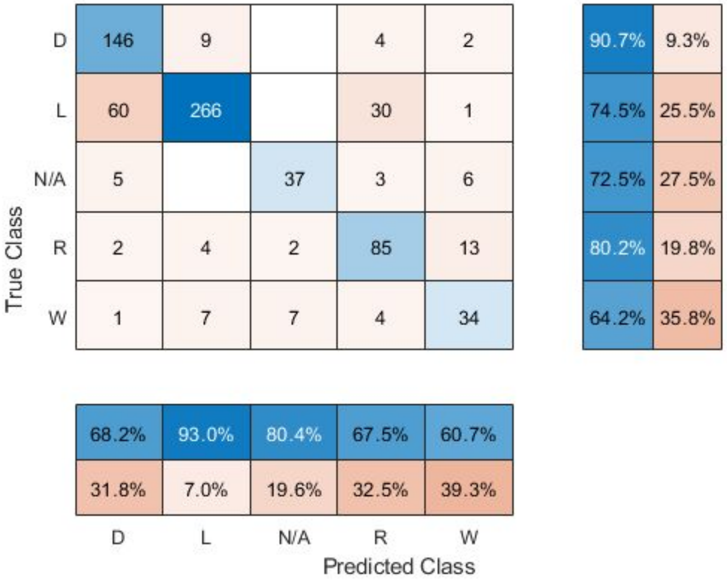
Design change implemented due to lack of room on board used for beta prototype

Future prototypes will likely utilize deep learning methods.

Design Changes

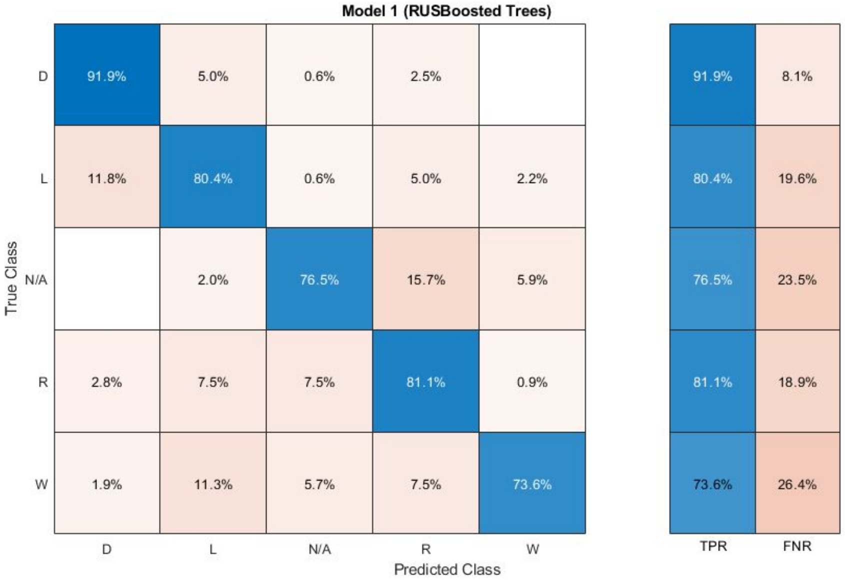
Sleep Stage Classification (Accuracy)

Simple Algorithm



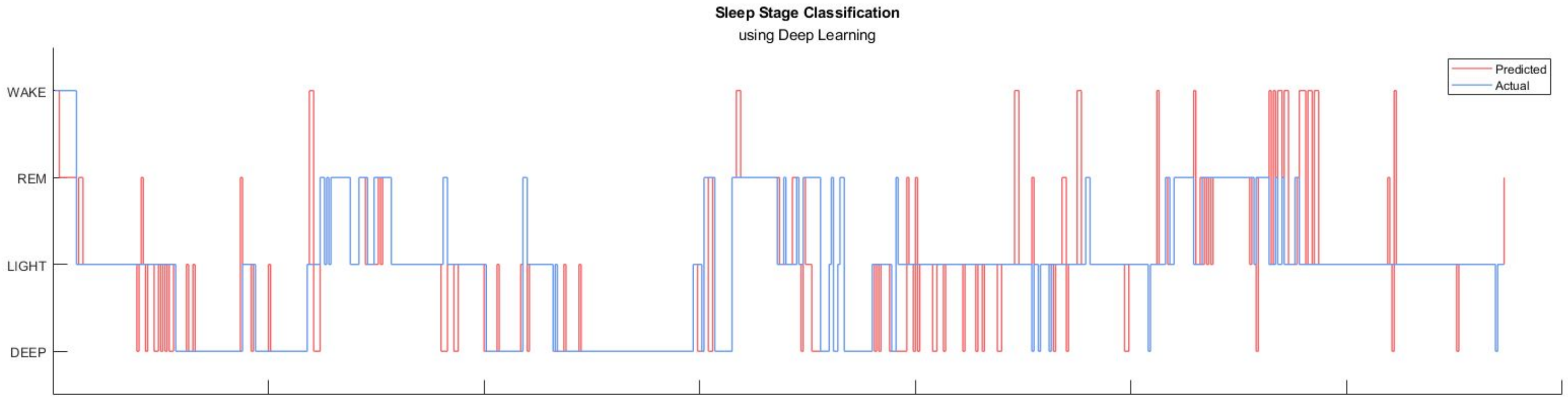
Accuracy ≈ 78%

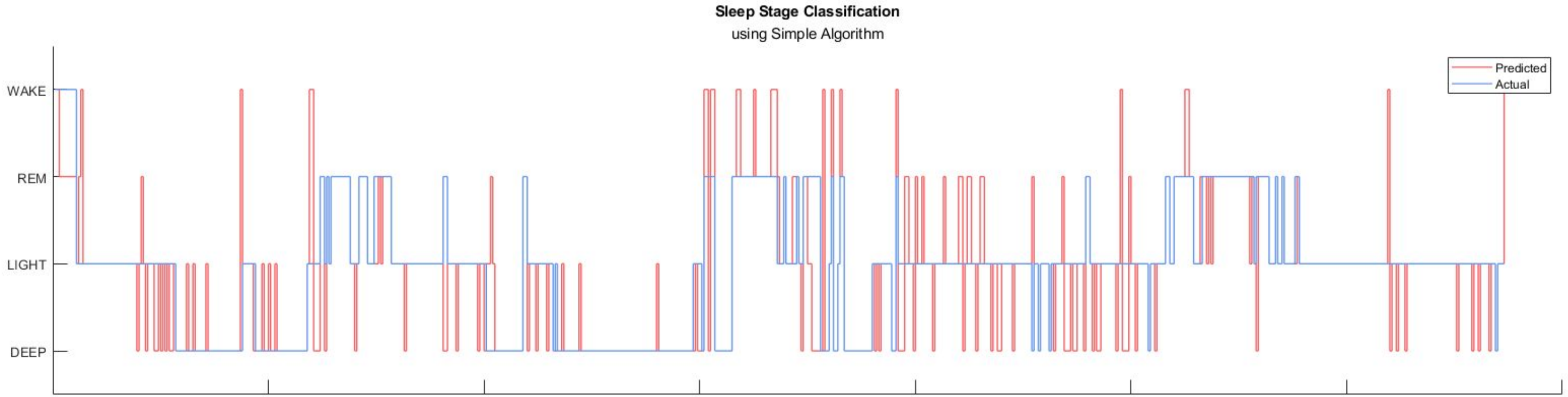
Deep Learning Classifier



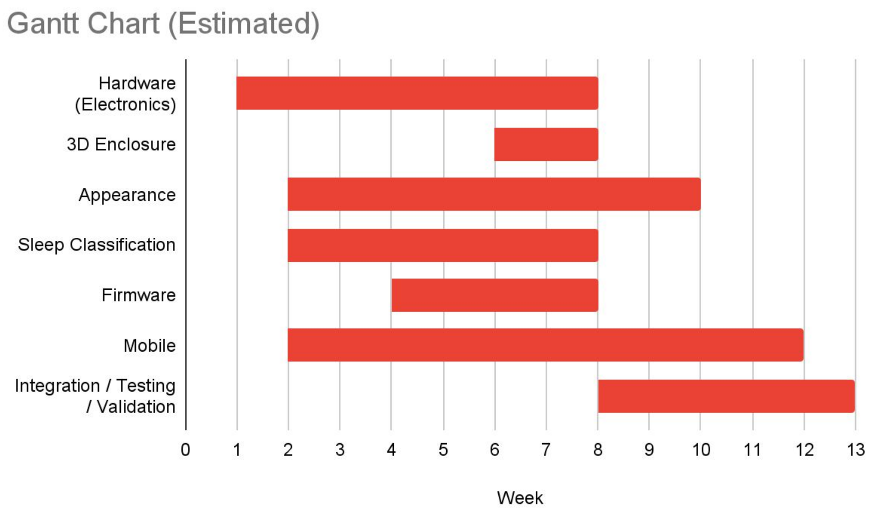
Accuracy ≈ 82%

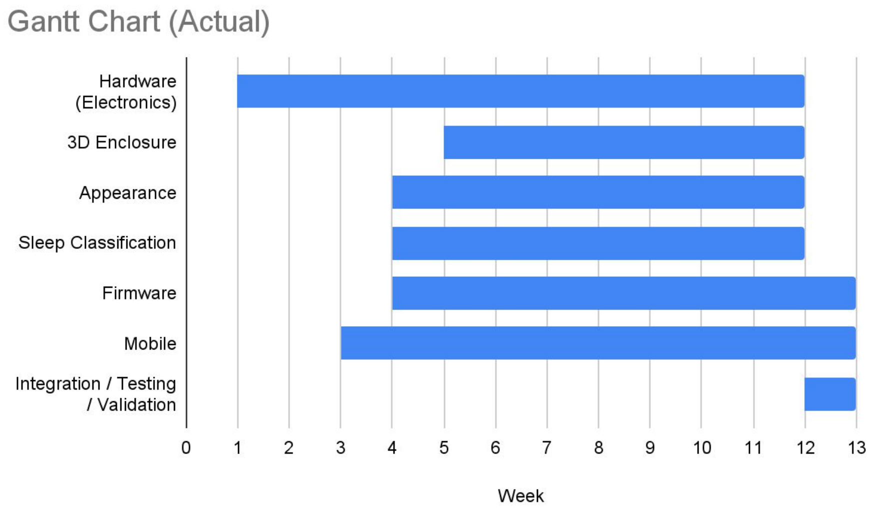
Sample Hypnograms - Overnight Sleep Data





Schedule (Gantt of estimated & actual)





Business Case/Costs

Market

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Global Market for Sleep Technology

- $16.25 billion CAD, based on study in 2020†
- Expected to reach $50.75 billion CAD by 2027 †

Global Market for Sleep Wearables

- $3.39 billion CAD, as of 2020 [1]
    - $1.1 billion CAD in North America
- Expected to reach $5.25 billion CAD by 2026 [2]

Expected Market Share for Chesto Alarm

- First Year
    - 0.0072% in North America
        - Minimum 200 devices
        - Sales revenue of $79,998 CAD
- Later Years
    - 0.02% of global sleep wearable market
        - 2000 annual sales
        - Sales revenue of $0.8 million CAD

Cost & Financing

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PoC (Phase I)	Beta (Phase II)	Market Price
CAD $410	**CAD $1400**	**CAD $399^{99}**

PoC (Phase I) — CAD $410
- Muse 2
- Fabric/Padding

Beta (Phase II) — CAD $1400
- Ganglion Board
- Electrodes/Cables
- Battery
- 3D Printing Material
- Fabric/Padding
- Power Supply

Market Price — CAD $399^{99}

Competition & Price

	Muse S^{TM} (Gen 2) 	Sleep Cycle	Fitbit 	Chesto Alarm^{TM} 
Wearable Device	Headband	No Wearable Device	Wristband	Eye Mask
Sensors	Brain Waves	Microphone, Body Movement	Heart Rate, Body Movement	Brain Waves, Eye Movement
Smart Alarm	No	Yes	Yes	Yes
Price (CAD)	$\$781^{25}$	Free	$\$99\text{~}399^{95}$	$\$399^{99}$
Est. Annual Revenue	$11.5 Million [3]	$12.2 Million [4]	$1.13 Billion [5]	

Ideal Customer & Considerations

Ideal Customers

- Feels drowsiness and want to reduce sleep inertia
- Need to perform tasks soon after waking up
    - Shift workers, pilots, doctors
- Rely on alarms to wake up

Considerations

- Comfort
    - Light, breathable material doesn’t disrupt sleep
    - Machine washable cover
- Higher accuracy
- Eye mask functions to help falling asleep
- Long lasting battery
- Easy to use

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Risk Analysis / Risk Management

Product Safety

- **Risk:** Wireless emissions, electromagnetic radiation (EMF)
- **Mitigation:** Add electromagnetic shielding to electronic enclosure, wires,

- **Risk:** Electrical shock, liquid damage
- **Mitigation:** Proper water-resistant enclosure, electrostatic discharge (ESD) safe

- **Risk:** Harmful to sleep health?
- **Mitigation:** Conduct long-term testing with sleep experts before launching to market, Psychomotor Vigilance Test (PVT)

- **Risk:** Original commercialization plan fails
- **Mitigation:** Transfer technology to medical field, sell to other companies (Muse)

Adherence to Standards

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List of Engineering Standards

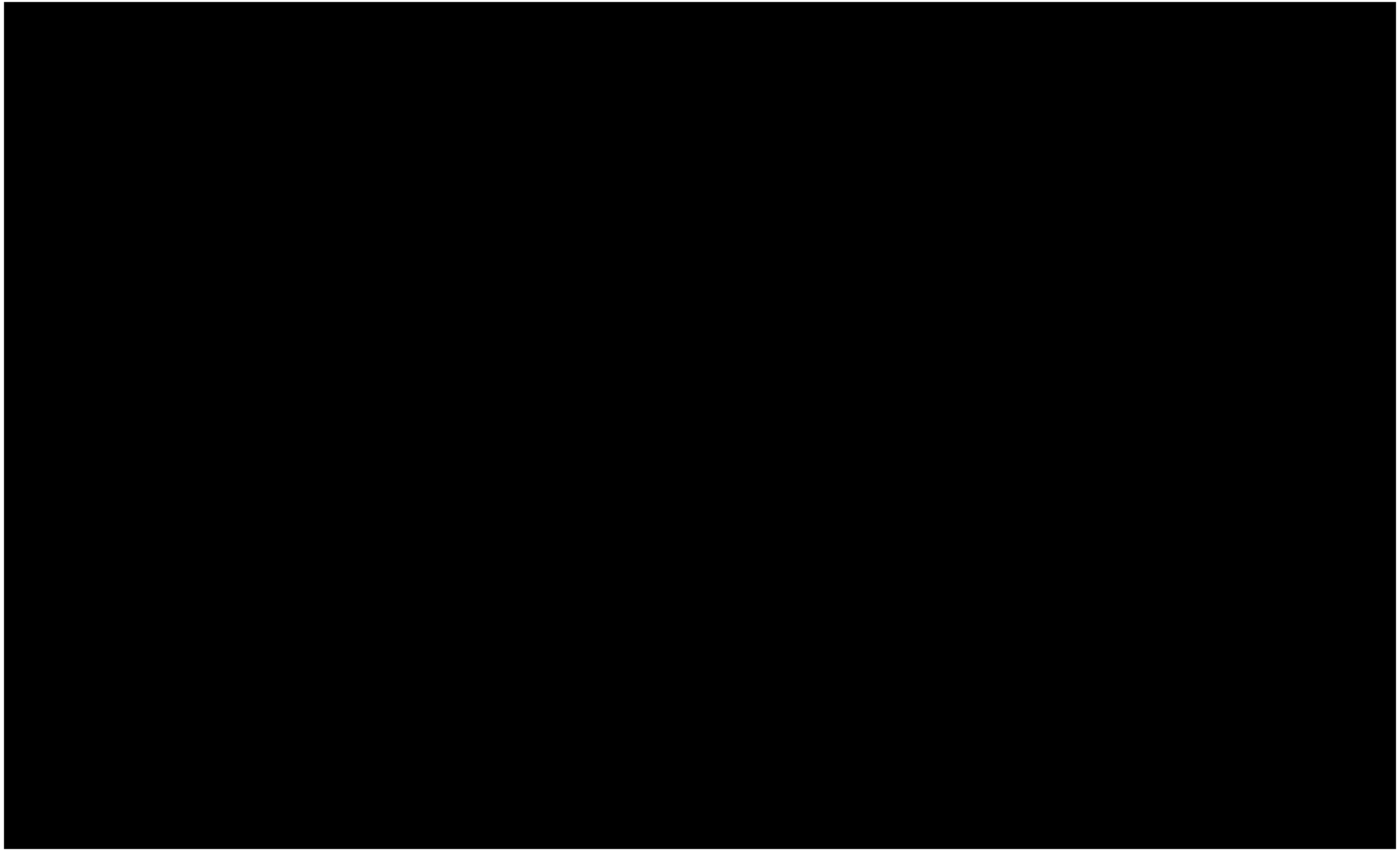
	Engineering Standards with Description
Hardware	***CAN/CSA-C22.2 NO. 60529:05 (R2010)*** - *Degrees of protection provided by enclosures (IP Code)* [11] ***CSA C22.2 No. 0.23-15 (R2020)*** - *General requirements for battery-powered appliances* [12] ***IEEE 1625-2004*** - *IEEE Standard for Rechargeable Batteries for Portable Computing* [13] ***IEC TR 63071:2016*** - *Power supplying scheme for wearable system and equipment* [14] ***IEEE 2010-2012*** - *IEEE Recommended Practice for Neurofeedback Systems* [15] ***IEEE C95.1-2019*** - *IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz* [16]
Bluetooth/BLE	***IEEE 802.15.1*** - *WPAN Task Group 1 (TG1)* [17]
Software	***ISO/IEC 25000:2014*** - *Systems and software Quality Requirements and Evaluation* [18]

Demo

1. Unboxing
2. Setup
3. How to wear
4. Live demo
5. Viewing hypnogram
6. Video
7. Maintenance

Unboxing and Initializing

Functionality Demo



Self-Reflection

Incorporated Feedback

- Long electrode wires
- Use EOG
- Use simple algorithms
- Focus more on comfort

What would we do differently

- Have more in-person meetings
- Break down multi-step tasks into single-step tasks
- Start prototyping earlier on
- Justify assumptions to avoid overlooking important details
- Simplify scope
- Overestimate time required to finish tasks
- Spend less time in meetings
- Explore and try out different methods

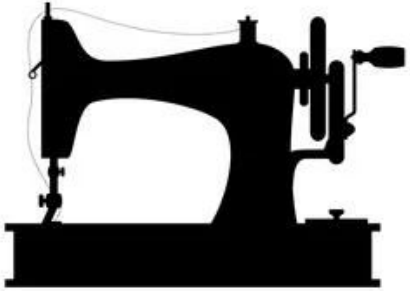
What did the team learn

- How to bring an idea from inception to implementation
- Collaboration with others
- Organizing meetings
- Learned to apply the knowledge and skills to practice

Conclusion

What was learned by team members

Skills	Learned by
Sewing Machine	Maple, Minji, Grace
Sleep Annotations	Maple, Minji, Grace
Android Development	Grace
Machine Learning	Maple, Minji
3D Printing	Maple



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Project Summary

- Background knowledge
  - Sleep stages
  - Sleep inertia
  - Biometric data
- Hardware
  - 3D printed Enclosures
  - Utilizing evaluation board
  - EOG and EEG sensor placements
- Firmware
  - Signal processing on the board
- Software
  - Android application
  - Machine learning
- Appearance
  - Building the eye mask

- Acknowledgements
  - ENSC405W and ENSC440 instructional team
  - Dr.Kent

Future Plans

- Decrease the weight of the eye mask
  - Custom PCB
  - Potentially reduce battery size
    - Dependent on current draw of machine learning on a new microcontroller
    - Optimize battery life
  - Use fabric woven electrodes
- Increase accuracy of sleep staging
  - Sleep experts
  - Predict next sleep stage
  - Improve machine learning algorithm
- Add features for mobile app
  - Cloud implementation
  - Generate reports

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Thank you