

Final Report

PREDICTION OF SEIZURES DURING SLEEP

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1.0 Clinical Need

There is a need to alert individuals who are at high risk for seizure during sleep to an impending epileptic event to decrease the frequency of Sudden Unexpected Death in Epilepsy [1].


2.0 Background

Sixty-five million people around the world have epilepsy. In the United States, 1 in 26 people will develop epilepsy at some point in their life. Epilepsy is a condition characterized by disturbances in the electrical activity in the brain, resulting in a seizure. Symptoms of a seizure can range from a minor space out (absence seizure) to severe convulsions (tonic-clonic seizures). Typically, epilepsy is diagnosed in a person who has had two or more seizures, or had one seizure with a high risk for future episodes. Types of seizures are classified by where they begin in the brain. Focal onset seizures originate in a group of cells

in one side of the brain. Generalized onset seizures originate in groups of cells in both sides of the brain. Types of generalized onset seizures include tonic-clonic (also known as “convulsive”), absence, and atonic. Treatments for epilepsy include seizure medication, devices, surgery, and dietary therapy. These treatments have proven to be effective in many, but not all, epileptic individuals. For 1 in 3 people with epilepsy, there is currently no available treatment that controls their seizures. In rare instances, epilepsy can even lead to death [1].



**EPILEPSY
FOUNDATION**
SUDEP INSTITUTE

SUDEP Action 
Making every epilepsy death count

Figures 1 and 2 - Major epilepsy support organizations:
The Epilepsy Foundation and SUDEP Action are both organizations that support those epilepsy through fundraising, education, service, and research [1][2].

Sudden Unexpected Death in Epilepsy (SUDEP) is believed to be the leading cause of epilepsy-related deaths, affecting 1 in 1000 people with epilepsy. SUDEP is cited as the cause of death in an epileptic person when no other cause of death is found. For this reason, most cases of SUDEP are not diagnosed in individuals until an autopsy is performed. Although the specific causes of SUDEP are relatively unknown, several potential risk factors have been identified. People who experience generalized tonic-clonic seizures are at the highest risk for SUDEP. Other risk factors include, but are not limited to, abrupt changes in medication, excessive drinking, using illegal substances, having epilepsy for more than 15 years, and having seizures during sleep [1].

Although very little is known about the causes of SUDEP, experts in the medical community generally agree that the incidence of SUDEP can be reduced through improved early detection methods and monitoring of patients when they are about to have or are actively suffering from a seizure [3].

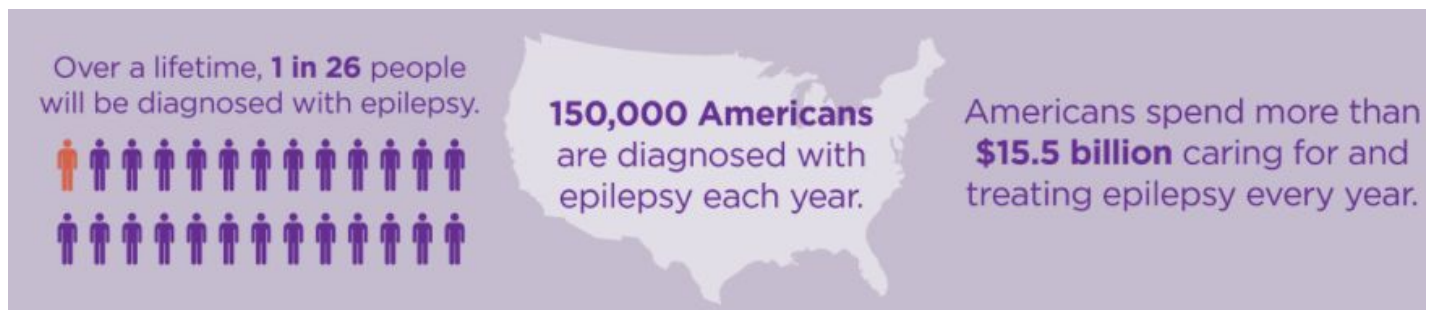


Figure 3: Epilepsy statistics: This graphic presents statistics on the frequency of epilepsy diagnoses as well as the cost of epilepsy care [4].

3.0 Project scope

This project proposes to deliver a safe, comfortable, and easy to use device that can be worn overnight. This updated project scope incorporates the use of heart rate and heart rate variability, which will be fed into a decision tree algorithm to accurately predict an impending seizure, and will alert the user a short time (on the order of minutes) before the seizure begins. The proposed device will be delivered to Dr. David Lardizabal and the BME 401 instructors, including the necessary software for seizure prediction and a user manual for safe operation by the May 2018.

4.0 Overview of chosen solution

Based on Pugh Chart analysis, our device used data from a 2-channel ECG recording to predict seizures. Hydrogel electrodes were used to collect data into an Arduino, which simultaneously transmitted the data directly to computer [5]. Finally, a decision tree algorithm processes the data to determine if the patient is in a pre-ictal state alert them when this occurs.

This design allows data to be recorded safely and comfortably from the patient with inexpensive electrodes that can be disposed of after use. An Arduino is an inexpensive and easy-to-use method of acquiring analog data that can securely transmit the data to a computer. Furthermore, sensing cables and a 2-channel ECG board are made for Arduino that will make it easy to record these signals. The decision tree algorithm works well with the small amount of data that we will have and can be easily implemented on almost any software platform. A diagram of the device structure is presented in Appendix A. A schematic of the circuit is presented below and in Appendix B.

5.0 Design Specifications

Table 1: Design Specifications			
Specification	Unit	Value	Description
Safety	Unitless	Unitless	Device should be safe to wear during sleep. It should minimize sharp edges or cords that can tangle, and should be properly insulated
Comfort	Unitless	Unitless	Device should not prevent the user from sleeping comfortably
Size (area)	cm ²	100 cm ²	Part of the device in contact with the patient should not hinder the patient's ability to sleep and should be large enough to be able to collect the relevant data
Weight	g	250 g	Part of the device in contact with the patient should not hinder the patient's ability to sleep
Operating time	Hours	12 Hours	Device should function throughout the night
Consumer Cost	\$	\$1,000	Device consumer cost is predicted by client to be of similar cost to current AED devices
Production Cost	\$	\$300	Device production cost is estimated to be 1/3 of the consumer cost
Prediction Interval	Min	5 min	Device should be able to alert the patient of impending seizure 5 min prior to onset
Prediction Alert	Unitless	Unitless	Device should acoustically alert the patient when an impending seizure is predicted
Sensitivity	%	99%	Device should accurately predict an impending seizure within a certain percentage
Security	%	100%	Data collected will only be accessible to the user and to emergency services
Time to Completion	Months	-	A prototype must be completed by May 2018.
User Satisfaction	Unitless	4/5	Overall user satisfaction (based on the results of the survey) will be assessed and should indicate that the device was easy to use.

Table 1 - Design Specifications: This is an updated table of the design specifications that was presented in the validation and verification report. Since then, the specification of transmission was removed. Because the device is completely wired, this specification was no longer relevant. The user satisfaction specification was also added to allow quantifiable measurement of how easy the device is to use.

6.0 Validation and Verification Plan

The validation and verification plan proposed is broken down according to each design specification. Specifications that were not testable were verified by inspection at the end of the project.

Because we had a very limited set of data from real patients, we prepared computer simulations of ECGs from patients both at baseline and during a seizure [6]. The characteristics of the ECGs were determined using information from the literature. We simulated 100 ECGs for 12-25 minutes each that had randomized heart rate, heart rate variability, durations, and seizure start times. Features of the various regions of the seizure simulations are presented in Table 2. While this did not perfectly simulate a typical human ECG, it allowed us to test if our algorithm could identify the differences between baseline, pre-ictal, and ictal based on changes in heart rate and heart rate variability, and predict the seizure ahead of time.

Table 2: Simulation Characteristics		
Measurement	Duration (s)	Heart Rate (bpm)
Baseline 1	600-1200	60 - 100
Preictal	60 - 240	90 - 120
Seizure	60-120	120 - 200
Baseline 2	36 - 120	60 -100

Table 2 - Parameters for Simulations: Simulations were constructed using the four regions described in this table. They each had a variable duration and were comprised of randomized heartbeats with a heart rate that varied according to the values listed.

The data was processed by being divided into overlapping 5-second windows. For each window, the mean heart rate and heart rate variability were computed. A sample view of a simulation and the corresponding computed heart rate and heart rate variability can be seen in Appendix C.

After this processing was complete, the data was then used to train and test the model. Ten iterations of machine learning and prediction were performed. With each iteration, 50 of 100 simulated seizures were randomly selected and used to train a new binary classification tree in MATLAB, allowing 500 unique tests to be performed. A sample view of a classification tree constructed using simulated data can be seen in Appendix D. The remaining 50 simulations were used to test the model. For each testing window, the mean heart rate and heart rate variability were computed and were used to make a classification of baseline, pre-ictal, or ictal. The classifications were compressed such that three consecutive classifications of either a -1 or 1 were required for the user to receive an alert.

In order to test a human ECG, an Arduino setup was used. A sample view of ECG data collected using the Arduino is presented in Appendix E. However, because this device could not be tested on a person having a real seizure, the Arduino was not sufficient simulation for our device to prove its accuracy.

The data obtained from our client was used for additional testing after the model was trained. A sample view of data collected from our client with the heart rate and heart rate variability computed using the same method as described for the simulations can be seen in Appendix F. A zoom view of this data on baseline and pre-ictal/ictal regions can be seen in Appendices G and H respectively. Of the 24 sets of data provided, a sample classification tree that was generated using 12 randomly selected files can be seen in Appendix I.

A user feedback form was used to further validate the device. The survey was taken by students at Washington University in St. Louis who were asked to test the device and evaluate its ease of use and describe how comfortable it felt to wear the electrodes. The results of the survey are presented in Appendix K.(I

6.1 Testable Specifications

6.1.1 Operating time:

The prototype for this device required a computer and an Arduino that remain operational overnight. Because the computer was running a power-intensive prediction algorithm, it was likely to require connection to a power source overnight. This was tested by examining the power consumption of the device over the course of 8 hours using a 15 inch MacBook Pro with a 2.2GHz Intel Core i7 processor to see if it was possible for the device to remain disconnected overnight. Because the Arduino was wired to the computer, it had a consistent power supply so long as the computer was operational.

6.1.2 Prediction interval:

The prediction interval was defined as the time between the first pre-ictal alert and the start of the seizure (as documented upon the simulation's construction). As described previously in Section 6.0, testing was done with 10 iterations of 50 simulations each, allowing for 500 total prediction intervals to be identified.

6.1.3 Sensitivity:

The sensitivity of the device for a given seizure is defined using the following equation.

$$Sensitivity = \frac{True\ Positives}{True\ Positives + False\ Negatives}$$

The classifications for each window were compared to the true labels given to each window (as documented upon the simulation's construction). Each window was assigned to one of four categories according to the table presented in Appendix J and the sensitivity was computed. As described previously in Section 6.0, testing was done with 10 iterations of 50 simulations each, allowing for 500 total prediction intervals to be identified.

6.1.4 Size and Weight:

We measured the dimensions of the electrode pads in contact with the patient using a ruler and identified the mass of the electrode pads in addition to the wires connecting them to the Arduino using a scale. Because this device is intended for use during sleep, the only concerns with respect to size and weight are those that are in contact with the patient.

6.2 Non - Testable Specifications

6.2.1 Prediction Alert:

The device should be able to alert the patient to an impending seizure when it is predicted. This will be tested by inspection to determine if this function is operational.

6.2.2 Safety:

The safety of the device was determined by inspection to ensure that the device had minimal sharp edges and cords that can entangle the user. Wires were properly insulated to avoid any possible electrical shock. The inspection was completed assuming proper use as per instruction by the user manual (regular electrode replacement, only being used during sleep, etc.).

6.2.3 Comfort:

The safety of the device was determined by inspection. The device should have minimal sharp edges, cords that can tangle and insulated wires so that the patient is able to sleep comfortably.

6.2.4 Production and Consumer Costs:

The total cost of the prototype and estimated additional costs for the user were tabulated to determine if the production and consumer costs exceed \$300 and \$1000 respectively.

6.2.5 Security:

Potential sources of data leakage or security breaches were inspected to ensure the device keeps patient health information secure.

6.2.6 Time of Completion:

The prototype must be completed by May 2018.

6.2.7 User Satisfaction

A google form was used to assess user satisfaction with this prototype. The survey was taken by students at Washington University in St. Louis who had minimal experience with MATLAB and Arduino. Because the device could not be tested on its intended audience the value of the device with respect to seizure prediction was not evaluated. This form examined the safety, comfort, user interface, and ease of use of this device.

7.0 Assessment of final product

7.1 Testable Specifications

7.1.1 Operating time results

After 2.5 hours the computer had roughly 20% power remaining. Based on this power consumption, it is recommended that the computer be connected to a power source throughout the night.

7.1.2 Prediction interval

A histogram of the prediction interval for each seizure is presented in Figure 4. The mean prediction interval was 99 seconds, which was below the target specification of 5 minutes.

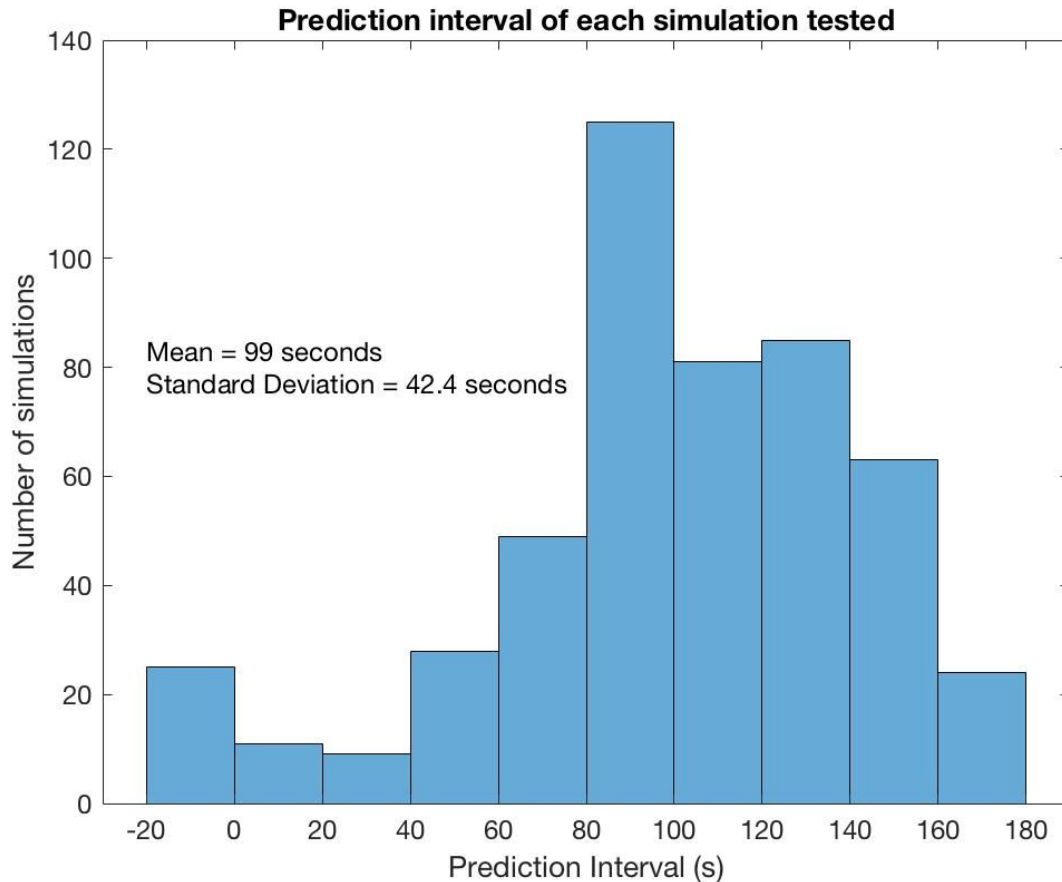


Figure 4 - Prediction Interval Histogram: This histogram presents the results of 500 simulations being tested using 10 different classification trees. The prediction interval was defined as the time between the first pre-ictal alert and the start of the seizure (as documented upon the simulation's construction). The mean and standard deviation are shown.

7.1.3 Sensitivity

A histogram of the sensitivity for each seizure is reported in Figure 5. The mean prediction interval was 79%, which was below the target specification of 99%.

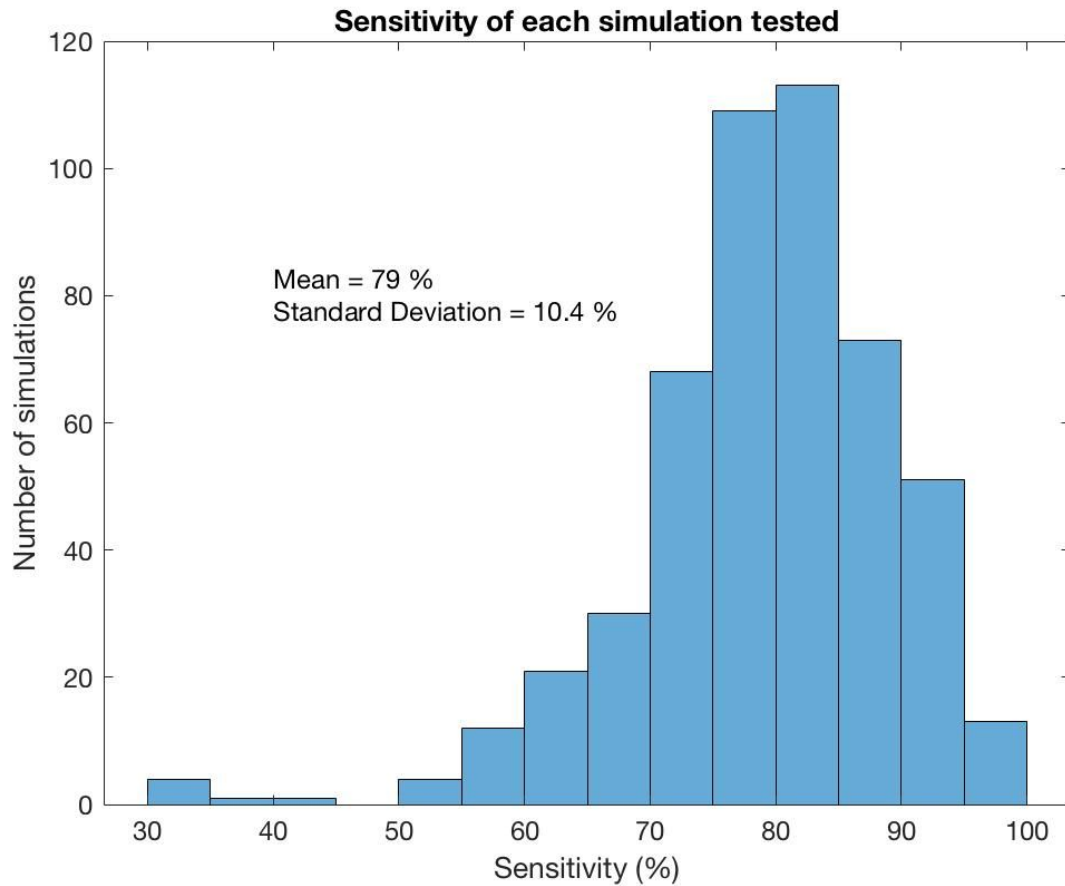


Figure 5 - Sensitivity Histogram: This histogram presents the results of 500 simulations being tested using 10 different classification trees. The sensitivity was defined according to the equation presented in Section 6.1.3. The mean and standard deviation are shown.

7.1.4 Size and weight

The size and weight measurements are reported in Table 3.

Table 3: Size and Weight Table	
Measurement	Value
Area	31.39 cm ²
Volume	3.86 cm ³
Mass	25.15 g

Table 3 - Size and Weight Measurements: This table presents the size and weight of the pieces of this device that are in contact with the patient. The area and volume were measured using the electrode pads and the mass was measured using the electrode pads and the electrode wires.

7.2 Non-testable specifications

7.2.1 Prediction Alert

If three consecutive classifications are made in the -1 or 1 categories, the software will alert the user with a message box and sound that there is a seizure impending or occurring.

7.2.2 Safety

In its current iteration, the only pieces that come in contact with the patient are the hydrogel electrodes. The AD8232 Single Lead Heart Rate Monitor [7] includes protective measures to keep the user safe in the event of an equipment failure. These electrodes contain no sharp edges and are safe to wear overnight. The arduino and heart rate monitor do contain some sharp edges that the user should be aware of during setup, but this is of minimal risk during use. The primary risk to the patient are the electrode wires that could tangle during sleep. For a complete safety analysis, refer to the DesignSafe in Appendix M.

7.2.3 Comfort

The device has been inspected and the two primary sources of discomfort are the hydrogel electrodes and the electrode wires. The hydrogel electrodes are small and should not cause much discomfort if changed regularly (once/day). The wires could tangle during sleep and should be changed to a wireless type in the next iteration of this device.

7.2.4 Production and Consumer Cost

Table 4 outlines the components that contributed to the cost of the prototype presented in this report as well as additional costs the user must bear in order to use this device.

Table 4: Production and Consumer Cost		
Type of Cost	Item	Cost
Production Cost	Sensor Cable - Electrode Pads (3 connector)	\$4.95 [8]
	SparkFun Single Lead Heart Rate Monitor	\$19.95 [9]
	Arduino Uno Microcontroller	\$34.90 [10]
	Total	\$59.80
Consumer Cost	Adhesive Hydrogel Electrodes*	\$186.15 [11]
	MATLAB Home License	\$149.00 [12]
	Total	\$394.95

Table 4 - Production and Consumer Costs: This table presents the components that contribute to the cost of producing the prototype as well as additional costs the user must bear in order to use this device.

* This is the annual cost of adhesive hydrogel electrodes was calculated assuming that it would be replaced daily

7.2.5 Security

This device does not currently store any user data for more than a few seconds, all connections are wired, and no internet connectivity is required. As a result, there is no security risk for the patient's health information.

7.2.6 Time of Completion

Though future directions have been suggested, a complete prototype of the device has been completed by the end of May 2018.

7.2.7 User Satisfaction

The results of the user satisfaction survey are presented in Appendix K.

7.3 Summary of Verification and Validation Results

A summary of the results described in sections 7.1 and 7.2 is presented in Table 5.

Table 5: Summary of Verification and Validation Results		
Specification	Target	Result
Operating Time	12+ hours	12+ hours when connected to a power source
Prediction Interval	5 minutes (300 seconds)	99 Seconds
Sensitivity	99%	79%
Size	100 cm ²	31.39 cm ²
Weight	250 g	25.15 g
Prediction Alert	Presence of alert upon -1 classification	Presence of alert upon -1 classification
Safety	See DesignSafe	
Comfort	See DesignSafe	
Production Cost	\$300	\$59.80
Consumer Cost	\$1000	\$394.95
Security	Patient health data is secure	Patient health data is secure
Time of Completion	May 2018	May 2018
Overall User Satisfaction	4.5	4.5

Table 5 - Summary of Verification and Validation Results: This table presents the components that contribute to the cost of producing the prototype as well as additional costs the user must bear in order to use this device.

7.4 Limitations

The largest limitation for this project is that the algorithm was trained using simulated data due to the limited availability of real patient data. Machine learning algorithms rely on having large amounts of training data. Dr. Lardizabal was only able to obtain data from 24 seizures. Though this was valuable in determining the proof of concept for this project, it was insufficient for high specificity prediction. This is crucial because it affects the sensitivity and prediction interval when used on patients.

The use of simulated ECG data as a substitute for patient data came with its own set of restrictions. One major barrier was the complexity with which these simulations could be varied. These simulations only varied in heart rate and heart rate variability. Further research on ECG patterns in the pre-ictal stage could reveal other features of the waveform that can be utilized to improve the predictive accuracy. Additionally, because the simulations had a fixed range of durations for the pre-ictal stage, the prediction interval was limited to this region.

Due to the project's time frame, motion artifacts, which are heavily present in real patient data, were unable to be added to our simulations. These differences may have affected the ability for this prototype to achieve the sensitivity and prediction interval as specified when being tested on users.

Other major limitations stemmed from our construction of our prototype. Our prototype contains several wires, which can pose dangers such as entanglement during sleep and possible shocking. Therefore, we believe that in its current state our prototype is limited in the safety and comfort provided to the user. Furthermore, it is required for our prototype to be connected to a power source in order to operate throughout the night. Finally, our algorithm was compiled using Arduino and MATLAB which may require additional costs to download.

8.0 Future Directions

The current machine learning algorithm can be trained using real patient data and simulated ECG signals to predict an impending seizure. The first iteration of this prototype is evidence that there is value to this type of project, but there are several improvements that can be made to improve the accuracy. Due to the limited amount of patient data gathered, future researchers should look into gathering ECG data from patients with epilepsy to train the machine learning algorithm. This will significantly improve the sensitivity of this model.

Improvements made to the simulations could also improve the accuracy of the device. Current simulations only vary in heart rate while having other variables constant. The more accurate these simulations can mimic real-patient data such as adding motion artifacts and looking into the variability in amplitudes could potentially improve our prediction accuracy. Lastly, future researchers should look into making the prediction tree user specific to each user instead of using the same classification tree for every user. This would require the device to continuously collect data and update its own model. The device can learn as it is being used so that it becomes more attuned to the particular user.

The current prototype uses an Arduino that collects physiological data sends ECG data to the computer. One major improvement that can be made to our prototype is to make the device wireless. The elimination of wires will reduce the risk of possible safety hazard as well as make sleeping more comfortable. In addition, a padded enclosure around the microcontroller will make it more durable and reduce the risk of the device being damaged. Other improvements could include converting the software to a mobile phone app which would eliminate the need of a computer as well as compiling the matlab code into an executable file. These changes could lower costs for the user and make the device easier to use.

9.0 Updated Design Schedule

An updated design schedule is presented in Appendix L.

10.0 Team responsibilities

The team responsibilities are presented in Table 6 below.

Table 6: Team Responsibilities			
Responsibility	Nikhil Patel	Jack Lin	Josh Olick-Gibson
Written Reports	x	x	x
Preliminary Presentation	x		
Website		x	
Progress Presentation		x	
Verification and Validation Presentation			x
Final Presentation	x	x	x
Machine Learning Algorithm	x		
Data Processing	x		
ECG Simulations		x	
Arduino Circuit/Software			x
Software Flow Diagrams			x
Weekly Reports		x	
User Manual			x

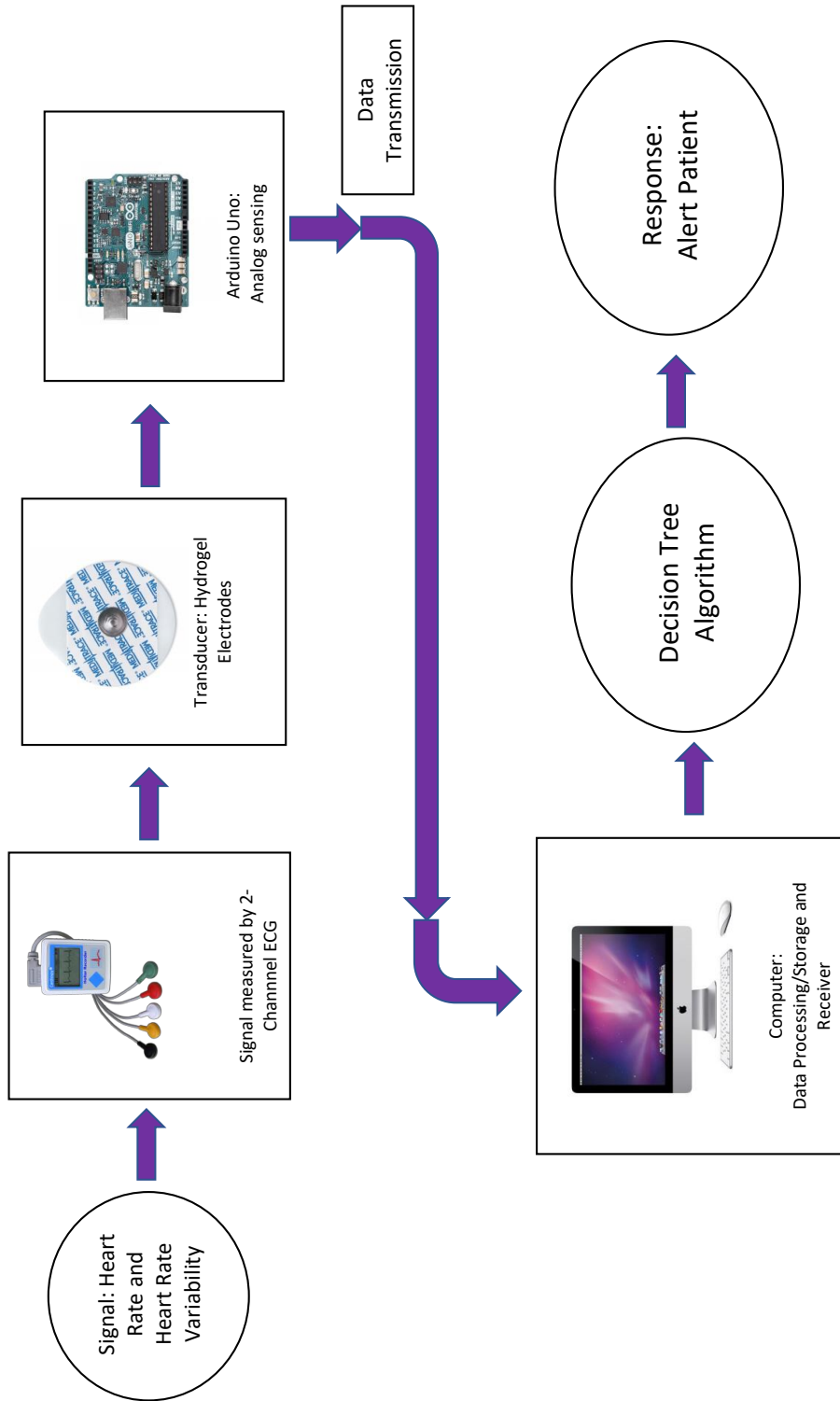
Table 6 - Team responsibilities: This table presents the responsibilities of each team member throughout the duration of this project.

11.0 DesignSafe

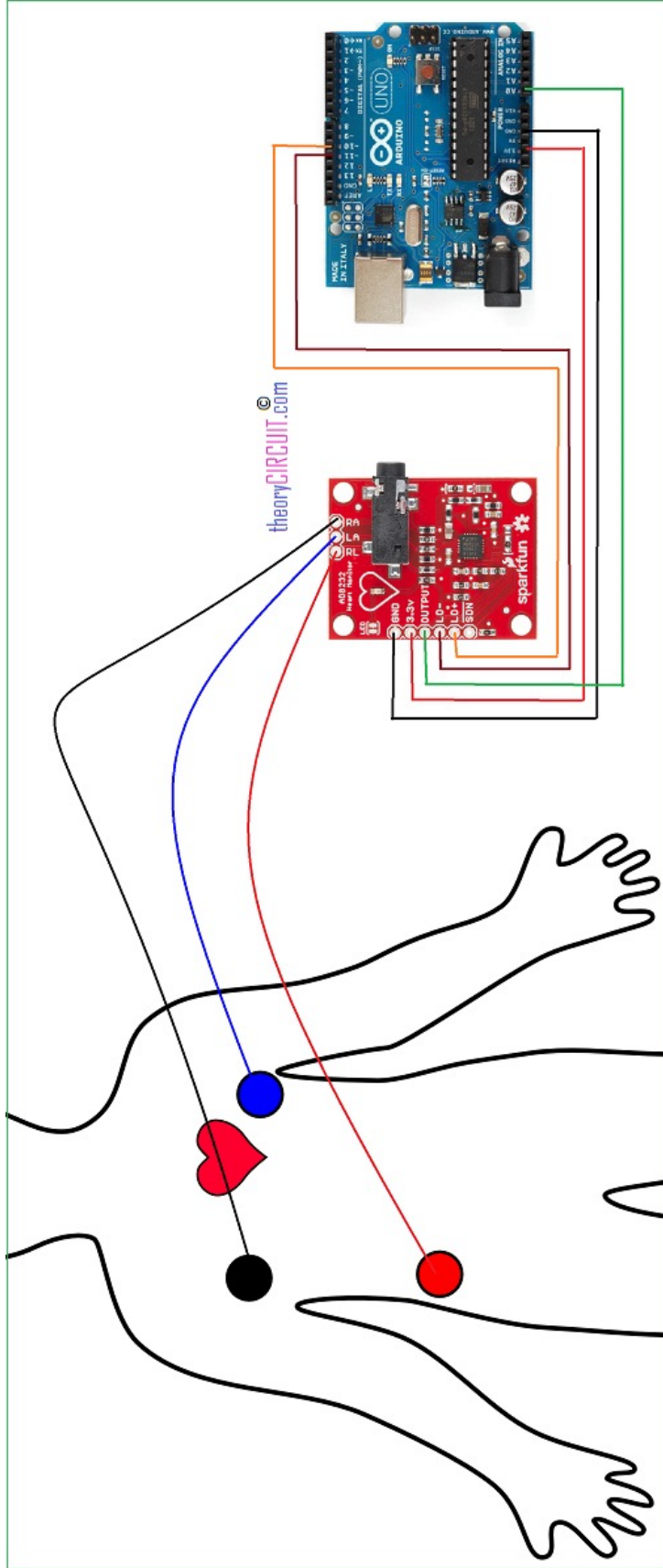
The DesignSafe for this project is presented in Appendix M.

List of Appendices

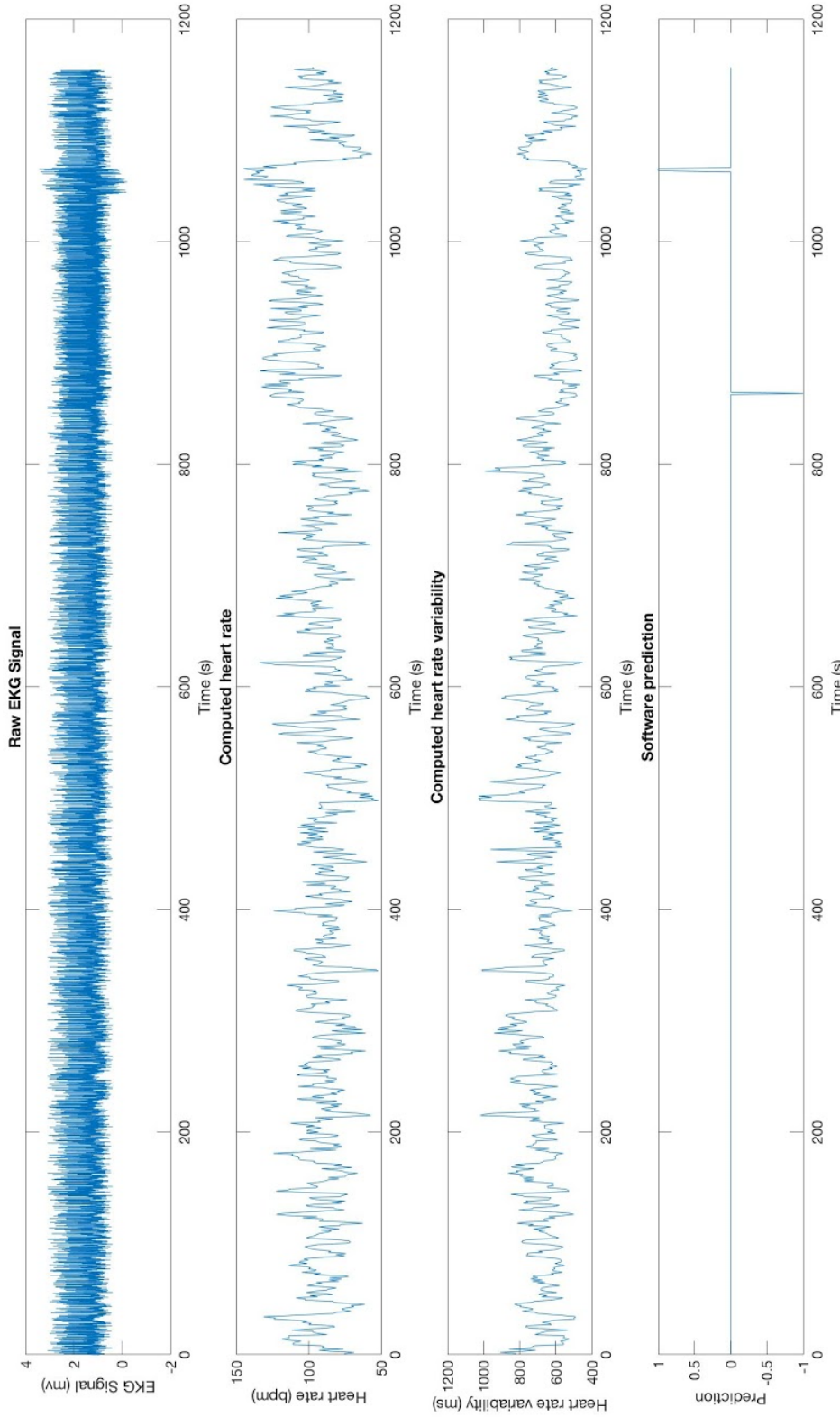
- A. Diagram of device structure
- B. Schematic of the Arduino circuit
- C. Sample view of simulations with heart rate and heart rate variability computations
- D. Sample classification tree generated from simulated data
- E. ECG Data collected using Arduino
- F. Sample view of client data with heart rate and heart rate variability computations (Total)
- G. Sample view of client data with heart rate and heart rate variability computations (Baseline)
- H. Sample view of client data with heart rate and heart rate variability computations (Seizure)
- I. Sample classification tree generated from patient data
- J. Table of sensitivity categories
- K. Results of user satisfaction survey
- L. Updated design schedule
- M. DesignSafe
- N. Code file descriptions
- O. Software flow diagram: predictSeizures.m
- P. Software flow diagram: prepToPredict.m
- Q. Software flow diagram: processSimData.m and processEDFData.m



Appendix A: This diagram shows the process by which ECG data is collected from the patient using Arduino, processed using a decision tree machine learning algorithm, and used to emit a response if necessary to alert the patient to an impending seizure.

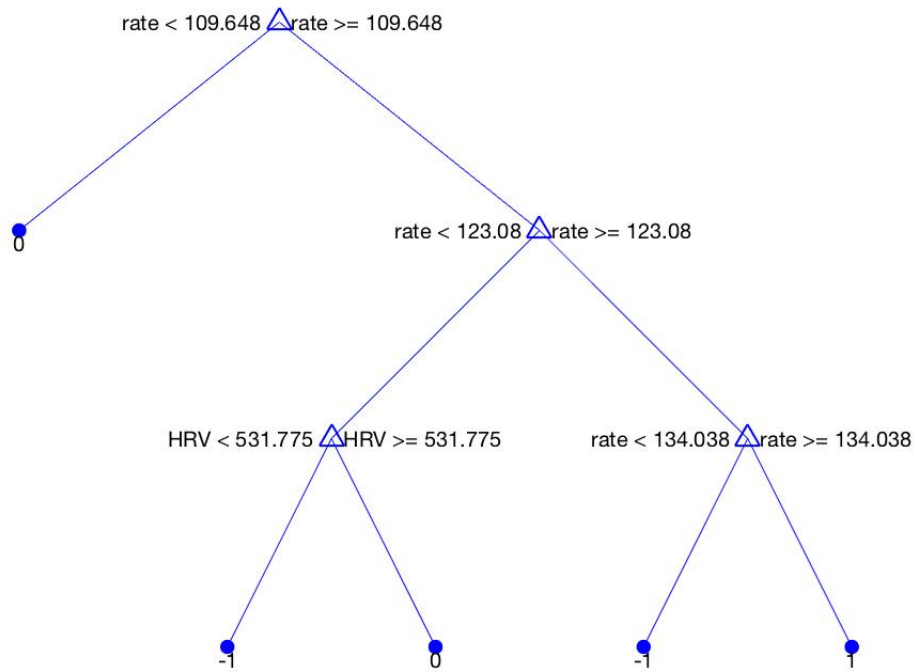


Appendix B: This schematic shows the proper way to connect the AD8232 heart rate sensor chip to the Arduino and how to properly place the electrodes on the body. Given the equipment used for this prototype, the electrodes combine to a single tip that can be plugged directly into the chip rather than each being connected independently [7].

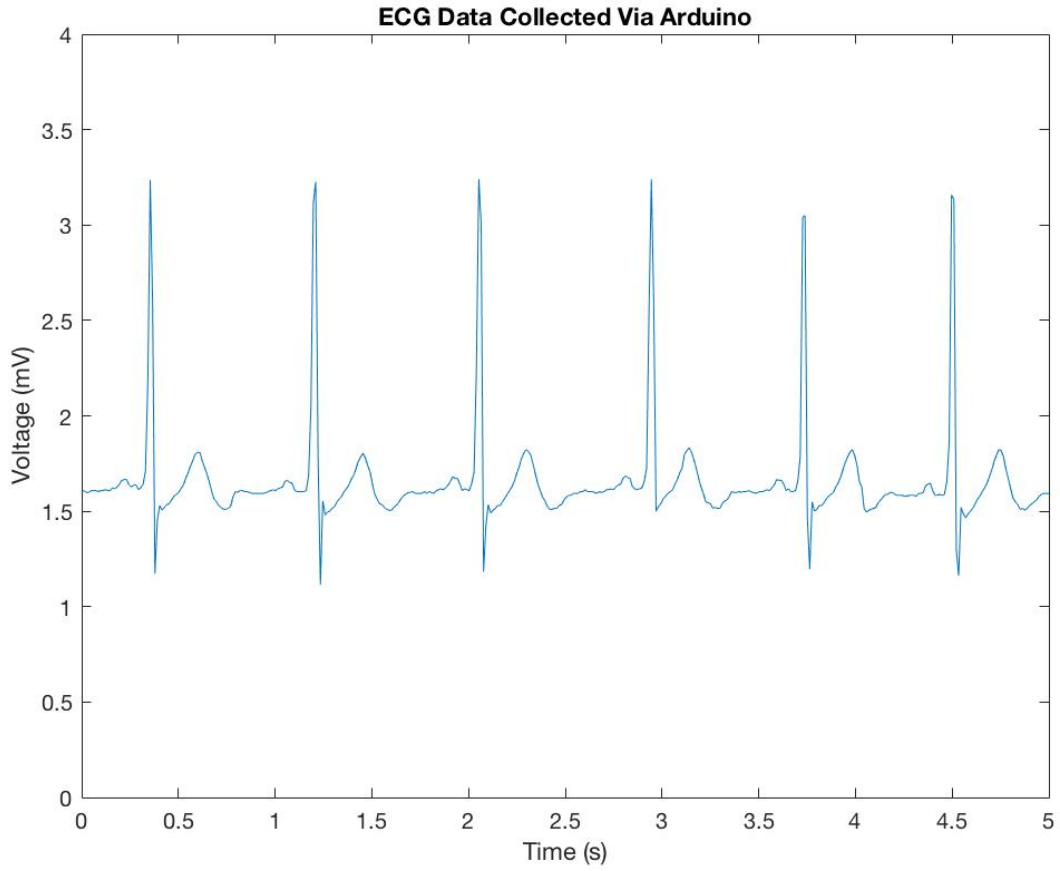


Appendix C: A sample simulation of ECG data generated using a MATLAB simulator. The data contains four regions: baseline, pre-ictal, ictal, and another baseline. The top panel shows the raw data. The second panel shows the heart rate computed as a sliding 5-second window. The third panel shows the alerts that would be made to the user when this model was tested using a trained decision tree classifier.

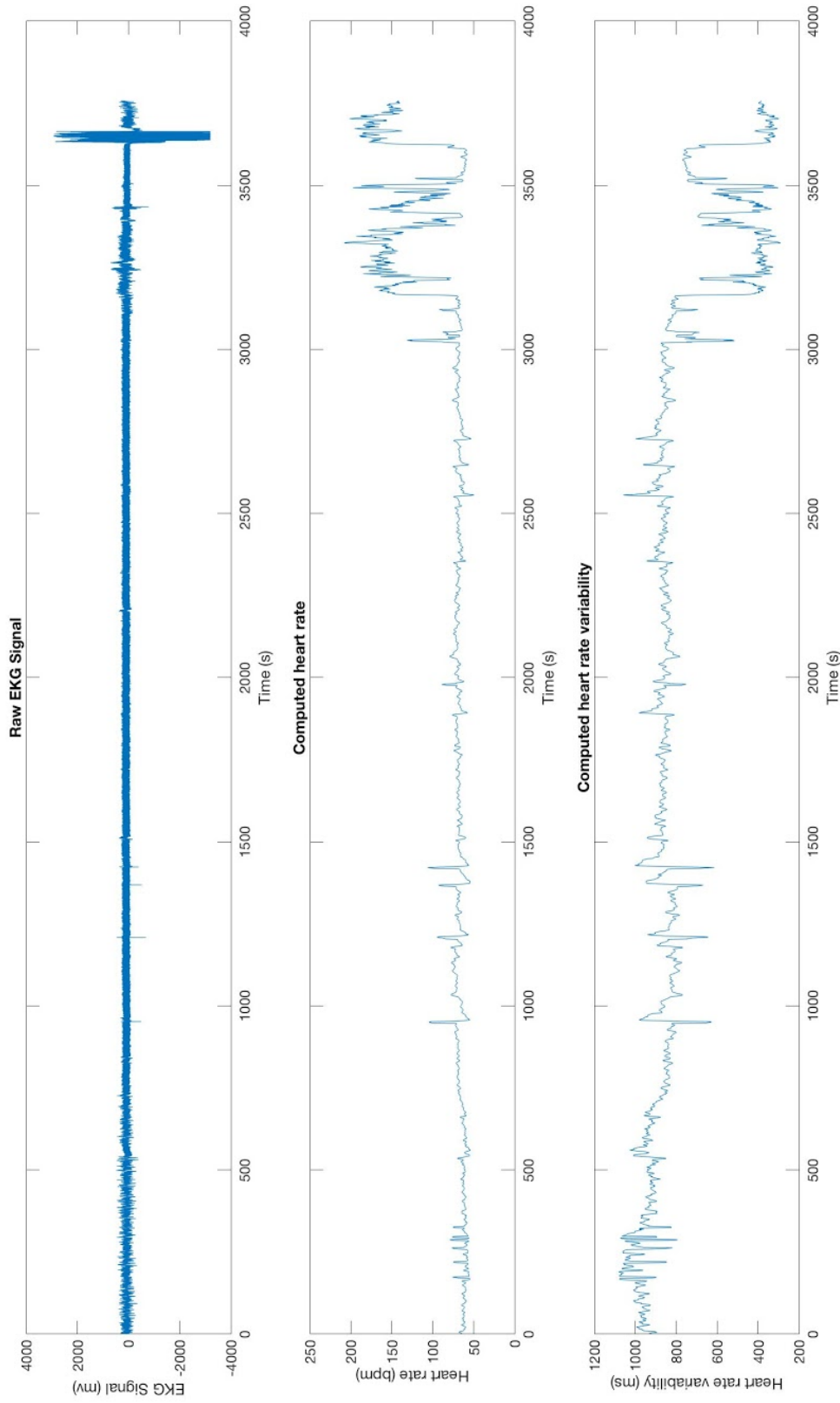
Appendix D: Sample classification tree generated from simulated data



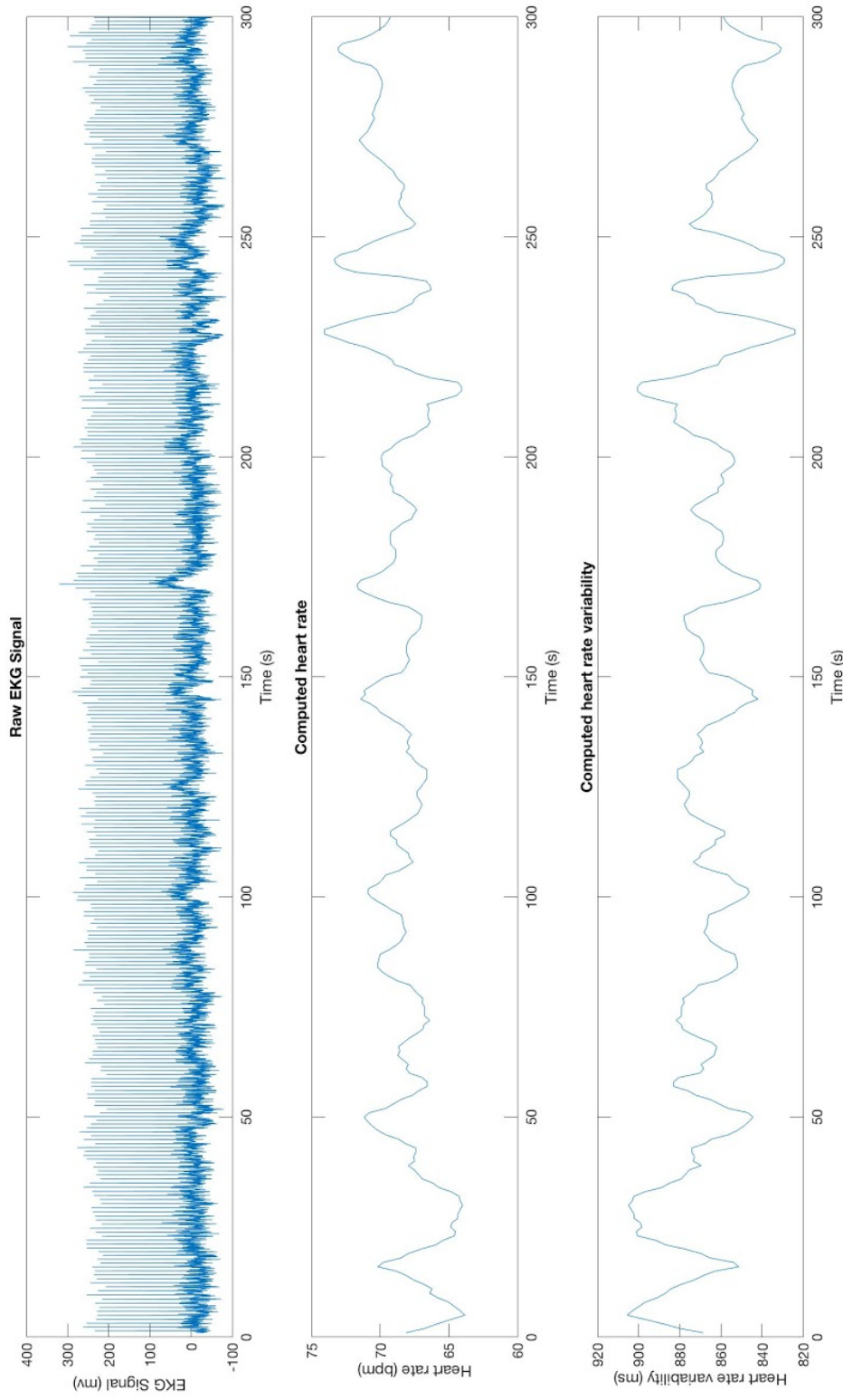
Appendix D: A sample view of a classification tree constructed using 50 randomly selected seizure simulations. 0 indicates a baseline classification, -1 indicates a pre-ictal classification, and 1 indicates an ictal classification. “Rate” refers to the heart rate and “HRV” refers to the heart rate variability.



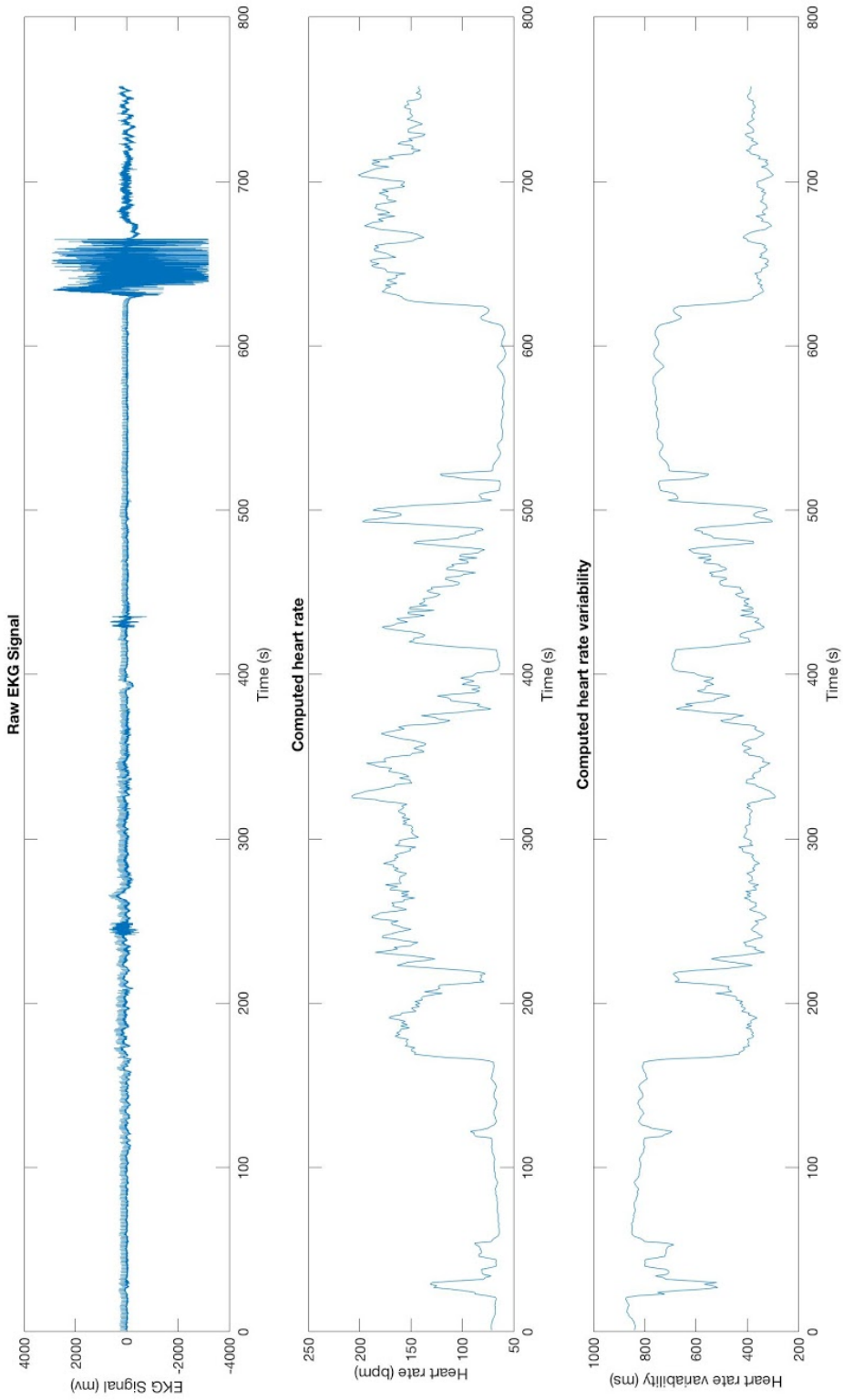
Appendix E: A sample collection of ECG data from the Arduino during baseline. This data was plotted in real time using MATLAB and was subsequently processed for classification using a decision tree model.



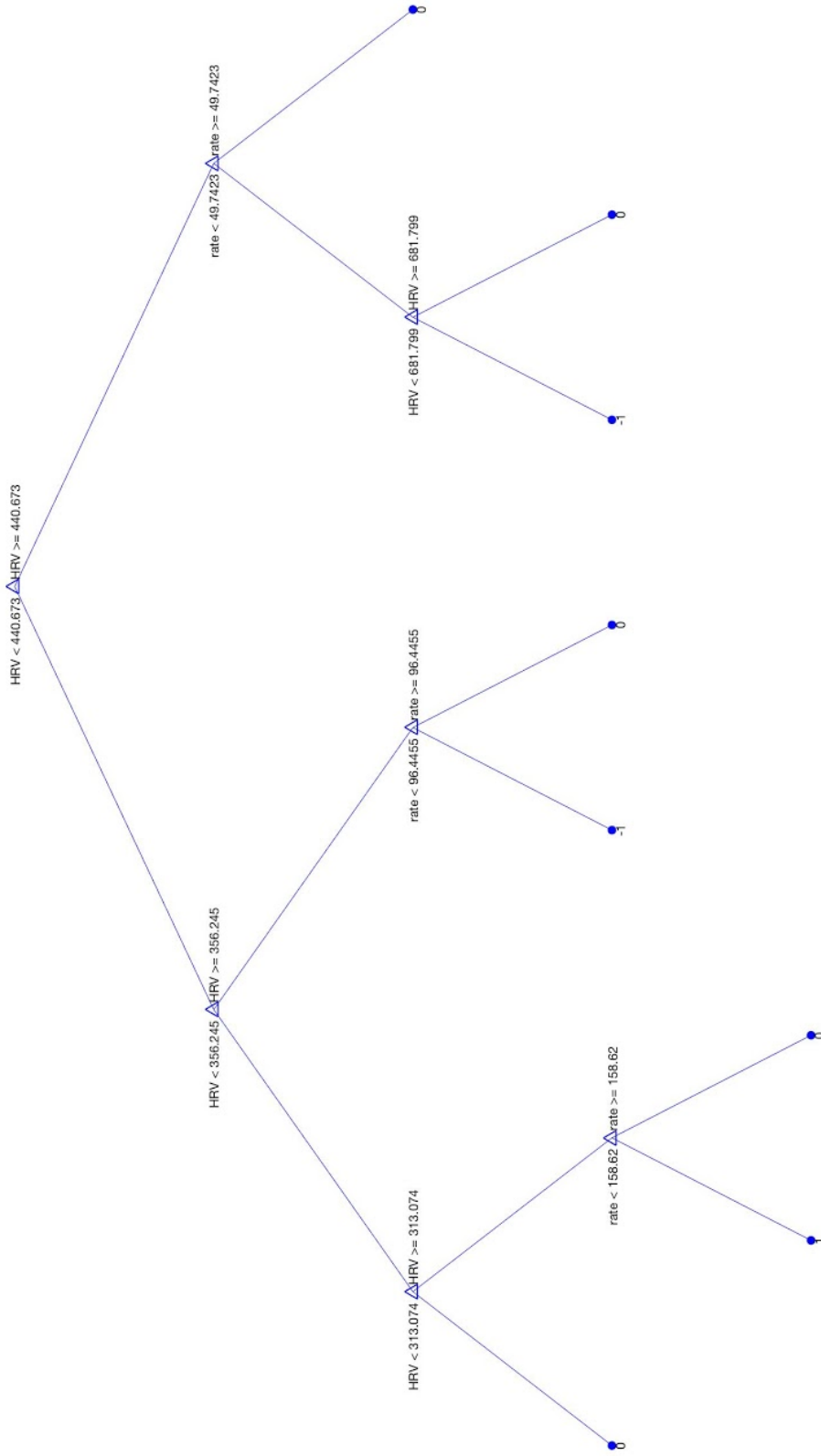
Appendix F: A sample view of patient ECG data provided by our client. The top panel shows the raw data. The second panel shows the heart rate computed as a sliding 5-second window. The third panel shows the heart rate computed as a sliding 5-second window. The region of large amplitude on the raw signal shows where the seizure occurred. This region and the region several minutes prior show increased heart rate and decreased heart rate variability.



Appendix G (Baseline): A close-up view of the data presented in Appendix F highlighting a region of baseline data. The top panel shows the raw data. The second panel shows the heart rate computed as a sliding 5-second window. The third panel shows the heart rate variability computed as a sliding 5-second window.



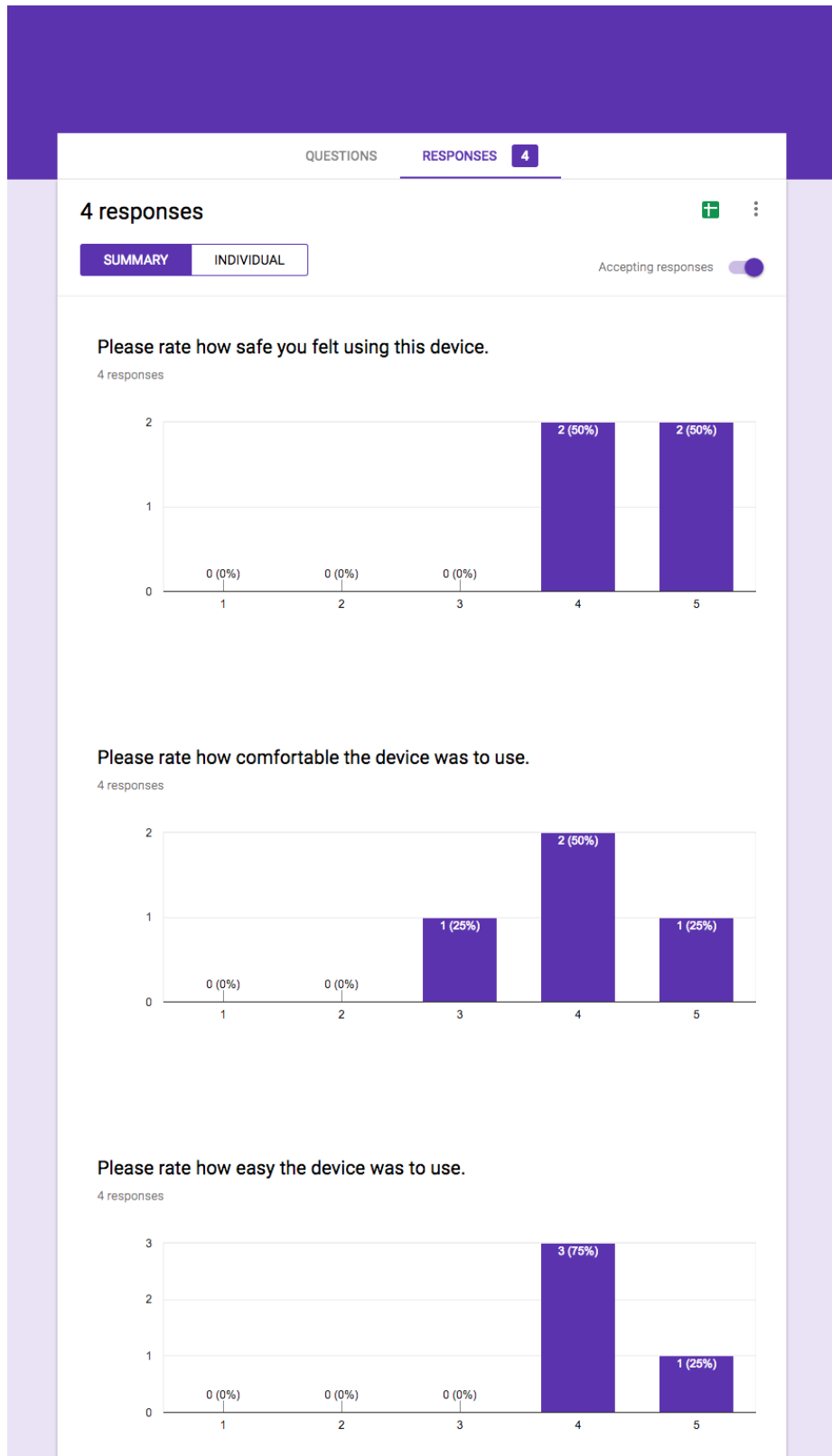
Appendix H (Seizure): A close-up view of the data presented in Appendix F highlighting a region of seizure data. The top panel shows the raw data. The second panel shows the heart rate computed as a sliding 5-second window. The third panel shows the heart rate computed as a sliding 5-second window.



Appendix I: A sample view of a classification tree constructed using 12 randomly selected sets of patient data. 0 indicates a baseline classification, -1 indicates a pre-ictal classification, and 1 indicates an ictal classification. “Rate” refers to the heart rate and “HRV” refers to the heart rate variability.

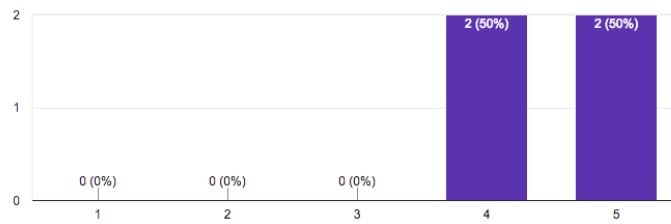
Appendix J: Definitions for Sensitivity Computations		
Label	Alert	Category
-1	-1	True Positive
1	1	True Positive
0	0	True Negative
-1	0	False Positive
1	0	False Positive
1	-1	False Positive
0	-1	False Negative
0	1	False Negative
-1	1	False Negative

Appendix J: This table presents the combinations of true labels and alerts that were used to assign each sample to a category. “Alert” refers to whether the device would alert the patient to an impending seizure (-1) an active seizure (1) or not send an any alert as a result of baseline classifications.



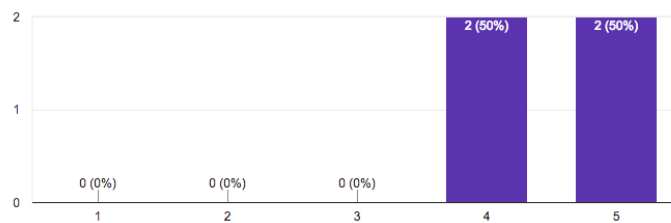
Please rate your opinion of the cost of the device.

4 responses



Please rate your overall satisfaction with the product.

4 responses



Additional Comments: Please let us know how this product can be improved with respect to any of the questions asked above, or in other ways that may not have been asked about.

4 responses

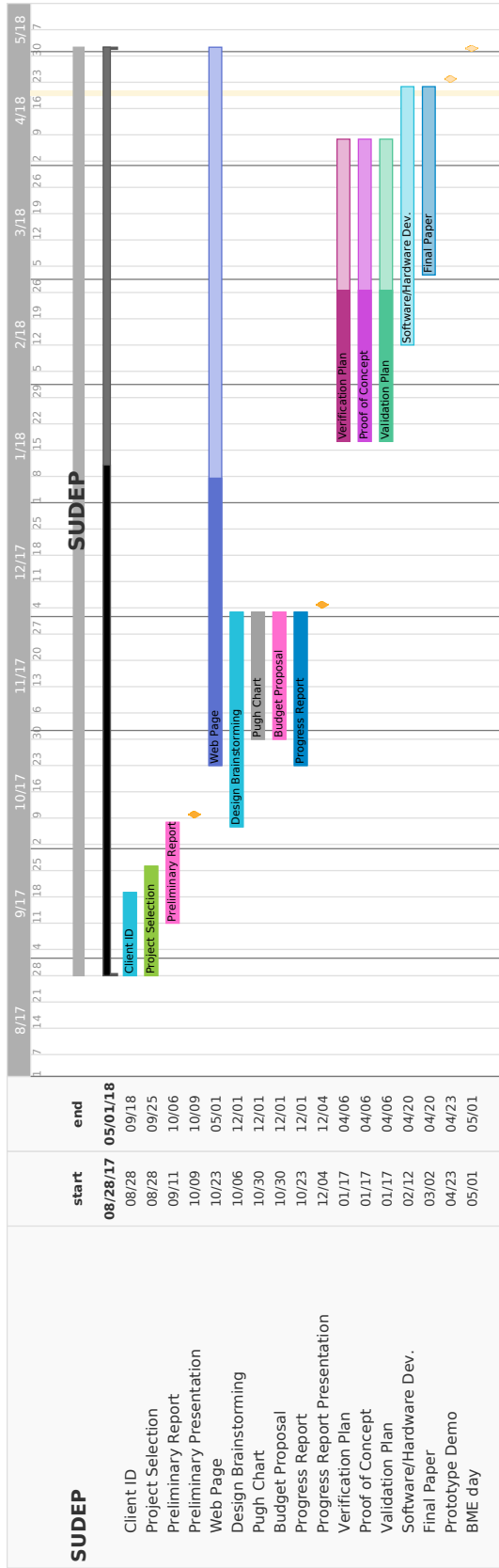
Less wires. Less initial setup steps

It could be more comfortable

Interesting project! I am curious to see this used on someone having a seizure!

The wires are kind of annoying, but it was cool to see it tell me my heart rate

Appendix K: This is a presentation of the results of the user satisfaction survey. The survey was taken by students at Washington University in St. Louis who were asked to test the device and evaluate its ease of used and describe how comfortable it felt to wear the electrodes.



Appendix L: Updated design schedule

		Arduino						Electrodes	
Item	Algorithm	Patient						Patient	
User	Patient	Send the collected ECG signals to a computer						Collect ECG signals from the patient	
Task	Use program on ECG Signal								
Hazard	Breach of Patient Data	Wire Entanglement	Injury from sharp edges	Possible burns	Cardiac pacemaker interference	Possible Shock and Sparking	Electrical Overload	Skin Irritation	
Cause / Failure Mode	Unauthorized use	Movement in sleep	Corners of device may be sharp	Exposure to electrical currents	Electrical Interference from Electrodes	Uninsulated wiring	A voltage of greater than 12V is applied.	Allergic reactions from electrodes and the reuse of old electrodes	
Severity	Minimal	Slight	Slight	Slight	Slight	Minimal	Minimal	Slight	
Exposure	None	Remote	Remote	None	None	None	None	Remote	
Probability	Negligible	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	
Risk Level	Low	Low	Low	Low	Low	Low	Low	Low	
Method of Risk Reduction / Mitigation	Only use program on Authorized Device	Reduce the number of stray wiring	Pad any possible sharp edges	Insulate all exposed wiring and ensure AD8232 chip has protective measures	Consult a physician before using the device	Insulate all exposed wiring and ensure AD8232 chip has protective measures	Do not apply a voltage greater than 12V	Replace electrodes after every use and do not use the same electrodes for more than 12 hours	
Severity	Minimal	Slight	Minimal	Minimal	Slight	Minimal	Minimal	Minimal	
Exposure	None	None	None	None	None	None	None	Remote	
Probability	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	
Risk Level	Low	Low	Low	Low	Low	Low	Low	Low	
Person Responsible	Nikhil Patel	Josh Olick-Gibson	Josh Olick-Gibson	Josh Olick-Gibson	Nikhil Patel	Nikhil Patel	Jack Lin	Jack Lin	
Date	20-April-18								

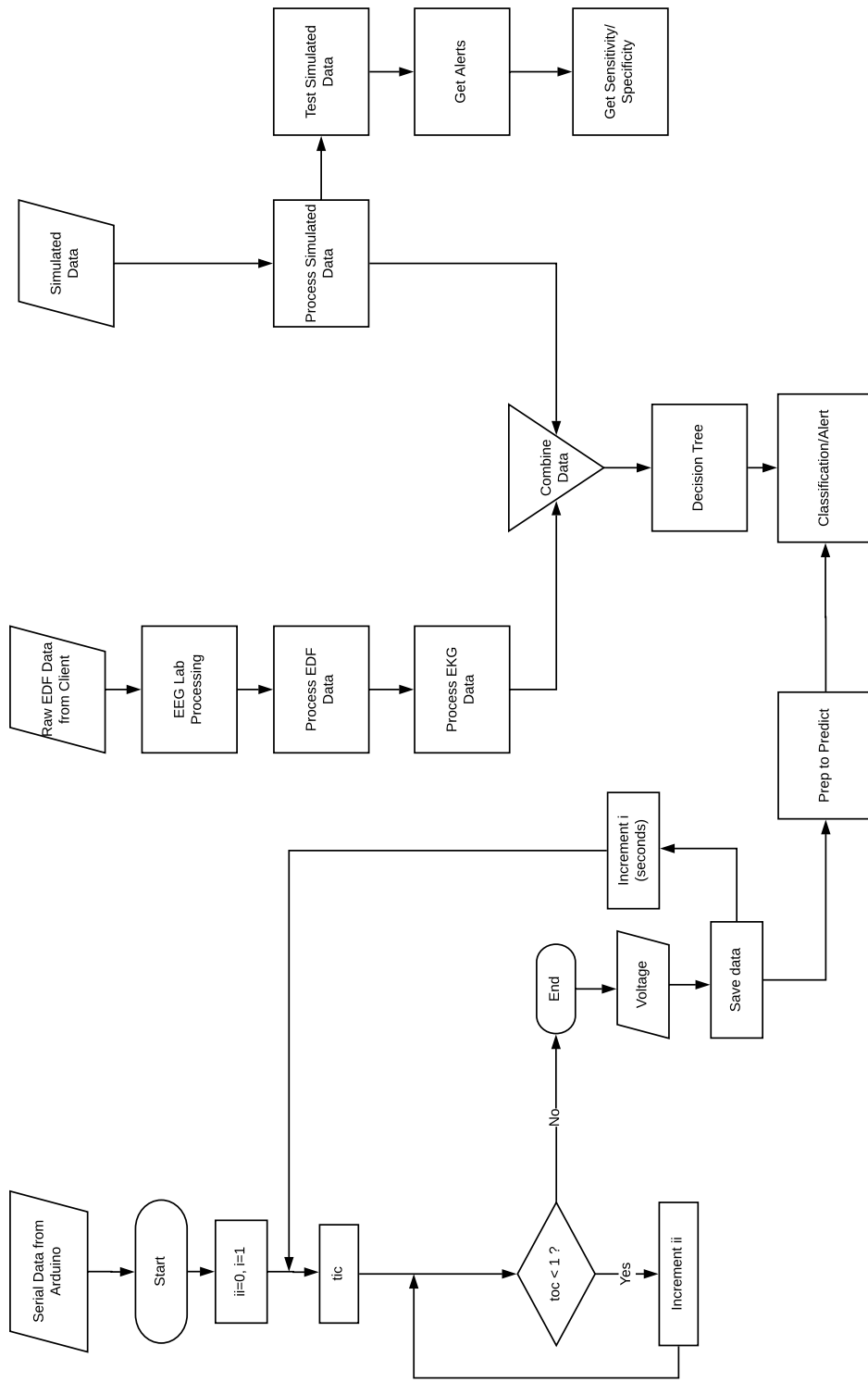
Appendix M: DesignSafe analysis with legend

Severity	Exposure	Probability
Catastrophic	Frequent	Probable
Serious	Occasional	Possible
Slight	Remote	Unlikely
Minimal	None	Negligible

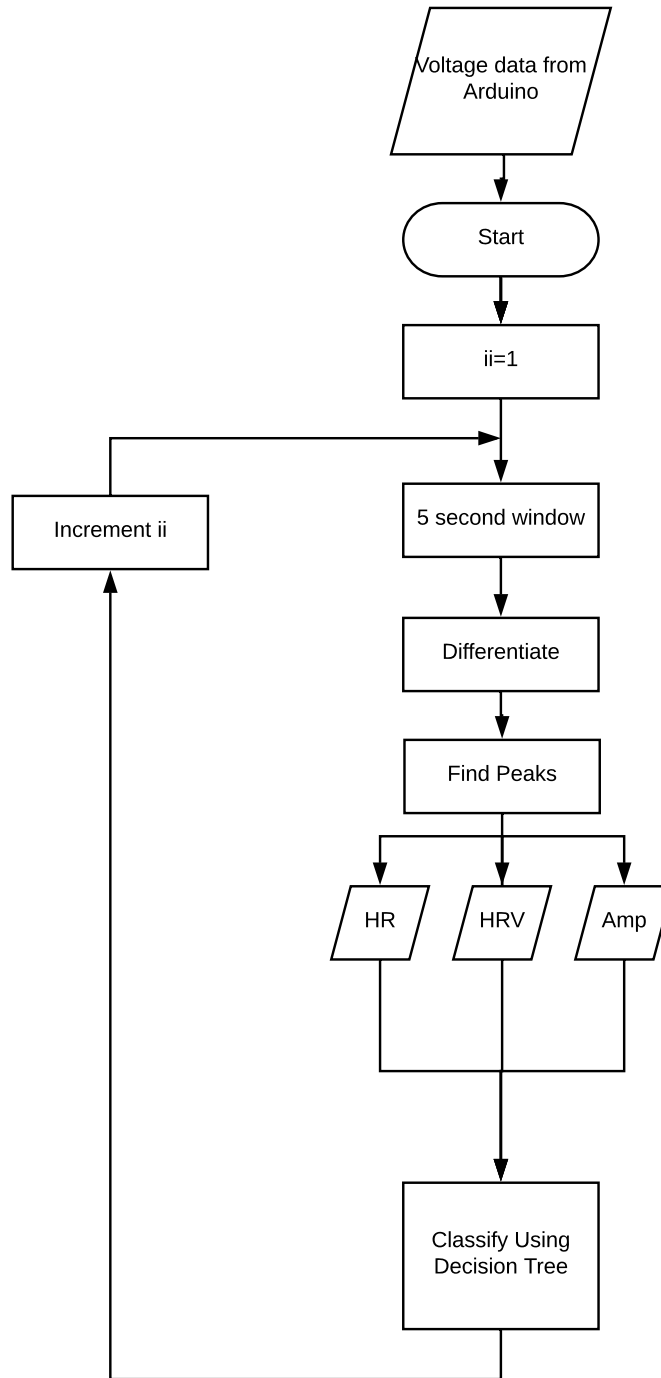
- I. Data Processing (Code provided to the user)
 - a. predictSeizures.m
 - This is the file that the users will run to get the program started. It constructs the classification tree, launches the arduino script, begins data collection and makes one classification each second, alerting the user if a seizure is impending or active based on these classifications
 - b. combineData.m
 - Takes in a list of processed data files (such as the output of processSimData or processEDFData) and combines it into one continuous table that can then be used to construct a decision tree
 - c. decisionTree.m
 - Takes in one large table of data that has been processed (the table consists of samples of 5-second data with mean heart rate and heart rate variability values) and uses the fitctree MATLAB function to construct and return a binary classification tree
 - d. prepToPredict.m
 - Processes a single sample of data (5 seconds long) from the data being collected via the Arduino and processes it into a form that can be predicted upon by the classification tree by computing the heart rate and heart rate variability
 - e. processEKGData.m
 - Computes the heart rate and heart rate variability for all (overlapping) 5-second windows in the dataset and saves it into a table format that can be used to construct or test on a classification tree
 - f. processSimData.m
 - Processes each simulation file in the directory provided using processEKGData.m. This uses the “mark” files that annotate the start and stop times of the pre-ictal and ictal phases of the simulation to generate labels
 - g. processEDFData.m
 - Processes each data file in the directory provided using processEKGData.m. This uses the seizure start and stop times provided by Dr. Lardizabal that annotate ictal phases and labels the pre-ictal phase as the 5 minutes prior to seizure onset. The input to this function is the data that is output from the EEGLab software downloaded from Mathworks that processed the EDF files and converts them into a format readable by MATLAB [12].
- II. Testing (Code used for generating figures/data presented in this report)
 - a. testSimData.m
 - Generates a classification tree using 50 randomly selected simulations of the 100 available and tests the remaining 50 on this tree. The prediction interval and sensitivity are computed (the latter using getSensSpec) after the classifications are processed into alerts (using getAlerts).
 - This process is done 10 times (creating 10 different classification trees in the process)
 - The data is plotted in a histogram format
 - b. testClientData.m
 - Generates a classification tree using 12 randomly selected data sets of the 24 available and tests the remaining 12 on this tree. The prediction

- interval and sensitivity are computed (the latter using `getSensSpec`) after the classifications are processed into alerts (using `getAlerts`).
 - This process is done 10 times (creating 10 different classification trees in the process)
 - The data is plotted in a histogram format
 - c. `generatePlots.m`
 - Used to generate the plots of raw data, heart rate, heart rate variability, and alerts over time for an ECG simulation as presented in the appendix
 - d. `generatePlotsClient.m`
 - Used to generate the plots of raw data, heart rate, heart rate variability, over time for a patient ECG provided by our client as presented in the appendix
 - e. `getAlerts.m`
 - Compresses the set of classifications passed into it such that an alert at any given time point occurs if the classification at that time point and the two prior are all 1s or -1s
 - f. `getSensSpec.m`
 - Uses the set of classifications and true labels passed into it to determine the sensitivity and specificity of the given simulation
- III. Simulation Generation (Code used to generate ECG simulations)
 - a. `P_wav.m`
 - Generates a simulated P wave using inputs of time, p wave amplitude, duration and heart rate. This is accomplished by using the Fourier series equation.
 - b. `U_wav.m`
 - Generates a simulated U wave using inputs of time, U wave amplitude, duration and heart rate. This is accomplished by using the Fourier series equation.
 - c. `Q_wav.m`
 - Generates a simulated Q wave using inputs of time, Q wave amplitude, duration and heart rate. This is accomplished by using the Fourier series equation.
 - d. `T_wav.m`
 - Generates a simulated T wave using inputs of time, T wave amplitude, duration and heart rate. This is accomplished by using the Fourier series equation.
 - e. `Qrs_wav.m`
 - Generates a simulated QRS wave using inputs of time, QRS wave amplitude, duration and heart rate. This is accomplished by using the fourier series equation.
 - f. `S_wav.m`
 - Generates a simulated S wave using inputs of time, S wave amplitude, duration and heart rate. This is accomplished by using the Fourier series equation.
 - g. `Baseline.m`
 - Simulates a baseline ECG signal given an input of a specified number of beats. Each beat will have a randomly generated heart rate between the range of 60 to 100 beats per sec.
 - h. `Preictal.m`

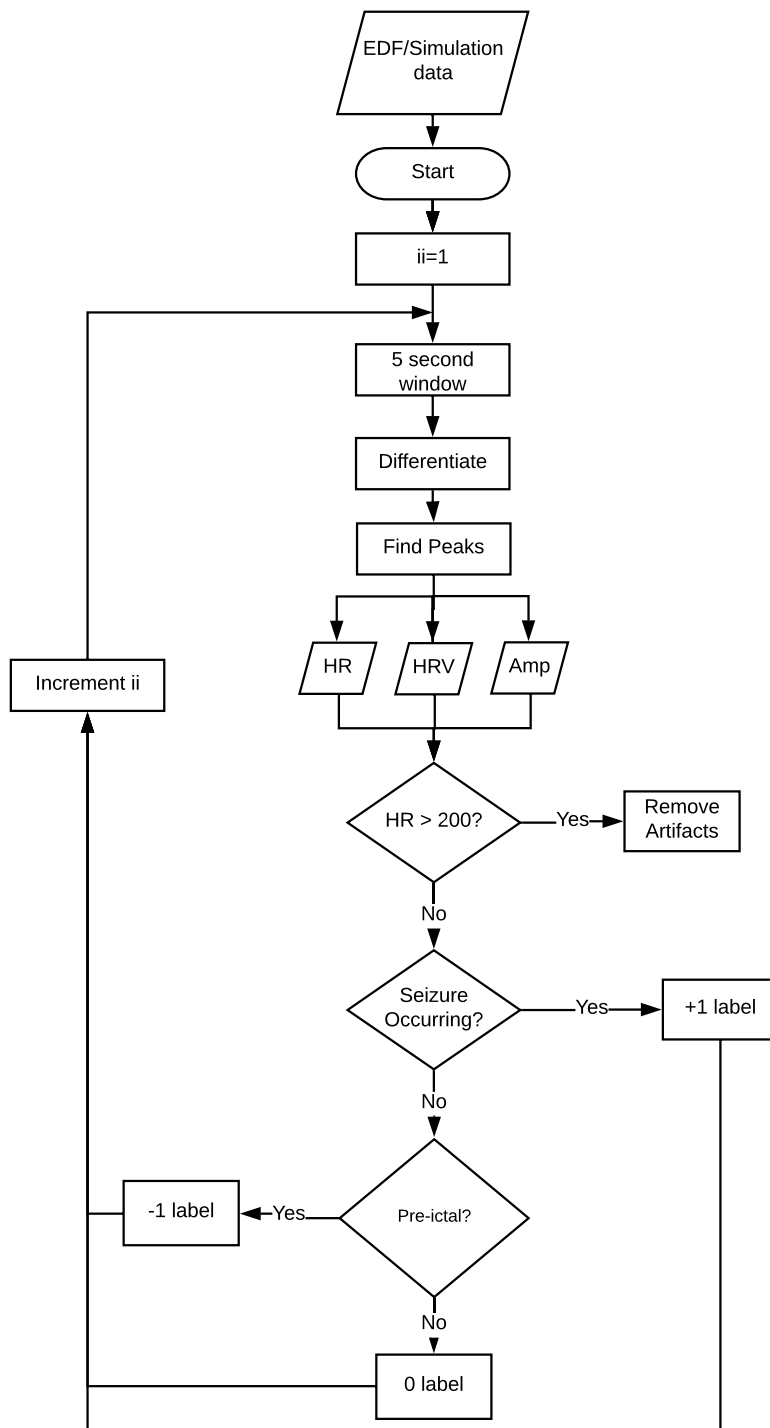
- Simulates a preictal ECG signal given an input of a specified number of beats. Each beat will have a randomly generated heart rate between the range of 90 to 120 beats per sec.
- i. Seizure.m
 - Simulates a seizure ECG signal given an input of a specified number of beats. Each beat will have a randomly generated heart rate between the range of 120 to 200 beats per sec.
- j. Baseline2.m
 - Simulates a second baseline ECG signal given an input of a specified number of beats. Each beat will have a randomly generated heart rate between the range of 60 to 100 beats per sec.
- k. Run100.m
 - Generates 100 files of the full ECG waveform consisted of the baseline, preictal, seizure, and 2nd baseline.



Appendix O: Software flow diagram of predictSeizures.m. This is the file that users will run in MATLAB to collected data using the Arduino, have it processed, and receive alerts to impending/active seizures. Functions from several other files are called in predictSeizures.m and are described in Appendix N.



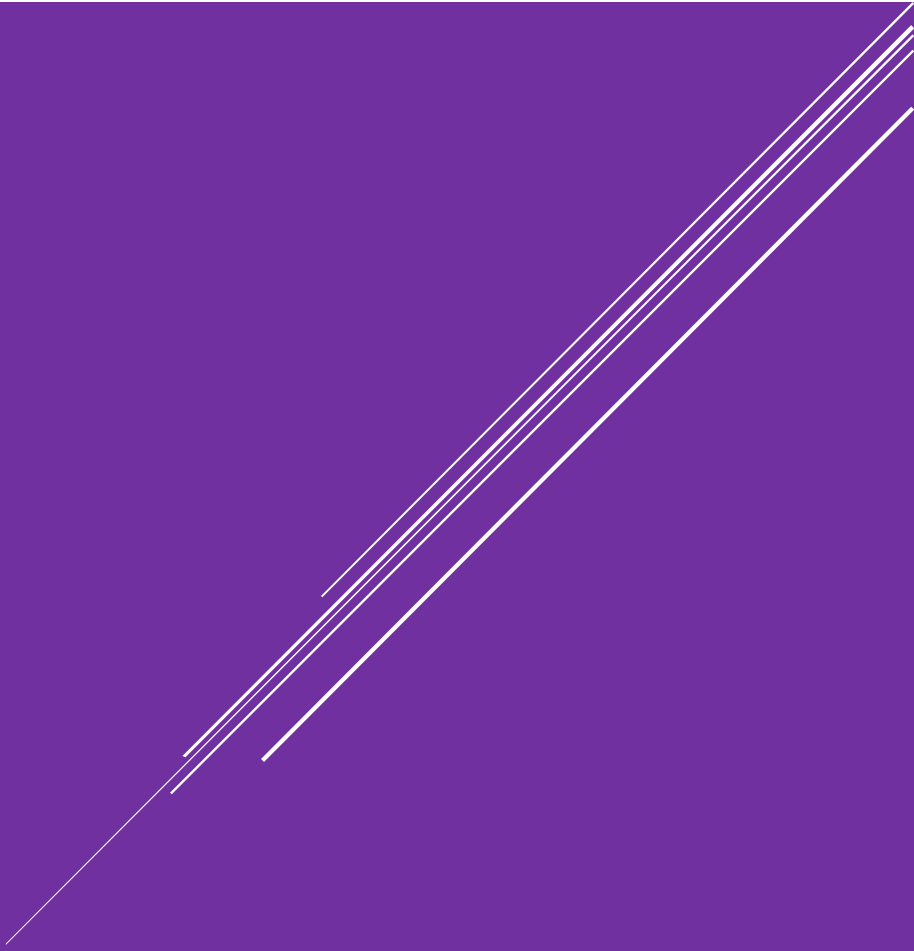
Appendix P: Software flow diagram of prepToPredict.m. This is the file that processes each 5-second window collected via Arduino and computes the heart rate, heart rate variability, and average amplitude of the QRS. The output of prepToPredict.m is classified using a decision tree before the next window is processed.



Appendix Q: Software flow diagram of processSimData.m and processEDFData.m. These files process each 5-second window in the simulation and patient data sets. It computes the heart rate, heart rate variability, and average amplitude of the QRS for each window. Labels for each window are assigned using start and stop times for the pre-ictal and ictal regions provided to the function.

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SEIZURE PREDICTION DEVICE

User Manual

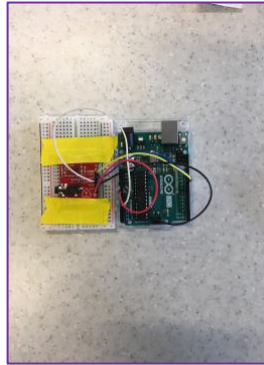
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Components of the Device



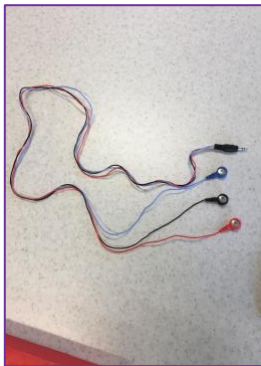
Computer



Arduino



Electrode pad



Electrode wiring



USB cable

Cautionary Notes

- This device is only meant to be worn while the patient is sleeping.
- If you have a cardiac pacemaker, please consult your physician before using this device.
- The computer must remain connected to a power source for the entire duration of use.
- Ensure that the volume on your computer is turned up so that you can hear any alerts that may occur.
- Check the settings on your computer to ensure that your computer will not go to sleep due to inactivity.

Before Use

Step 1: Turn on your computer. Make sure you are connected to the internet and that the computer is connected to a power source.

Step 2: Use the USB cable to connect to the computer as shown in Figure 1:



Figure 1

Step 3: Use the other end of the USB cable to connect to the Arduino as shown in Figure 2:



Figure 2

Step 4: Connect the electrode wiring to the Arduino as shown in Figure 3:

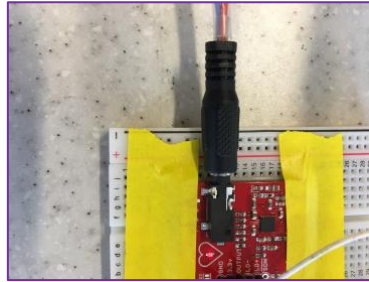


Figure 3

Step 5: Snap the metal portion of the electrode pads into ends of the electrode wiring as shown in Figure 4:

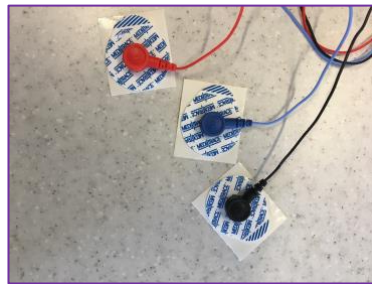


Figure 4

Step 6: Install the latest version of MATLAB. Please visit the following link:
<https://www.mathworks.com>.

Step 7: Install the latest version of Arduino. Please visit the following link:
<https://www.arduino.cc/en/Main/Software>

Step 8: Install the MATLAB Support Package for Arduino Hardware. To do so please visit the following link: <https://www.mathworks.com/matlabcentral/fileexchange/47522-matlab-support-package-for-arduino-hardware>.

Step 9: Remove the white slip from the back of the electrode pads and attach the sticky sides of the electrode pads onto skin according to Figure 5.

- a. Place the red electrode on the right, lower side of the stomach.
- b. Place the black electrode on the right side of the chest.
- c. Place the blue electrode on the left side of the chest.

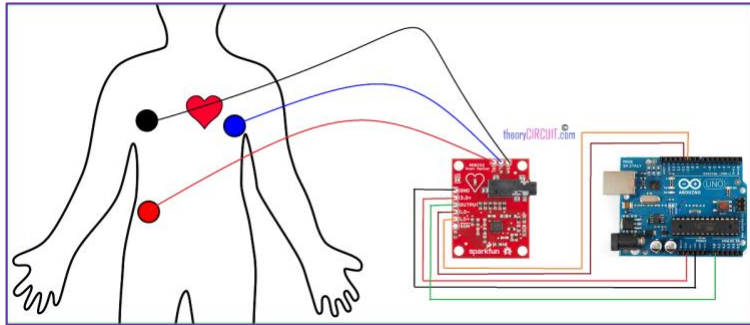


Figure 5

Step 10: Initialize MATLAB.

Step 11: Plug the Arduino into computer with the given USB cable.

Step 12: Download the zip file titled: “Predict Seizures” using the following link:
<http://teamsudep.weebly.com/software-download.html>

Step 13: Within the zip file, open the script titled “predictSeizures.m”.

Step 14: Press the “Run” button, located at the top center of the screen as shown in Figure 6:



Figure 6:
The “run”
button

Step 15: If you receive the following message, click “Add to path” (see Figure 7 below). If not, please disregard this step.

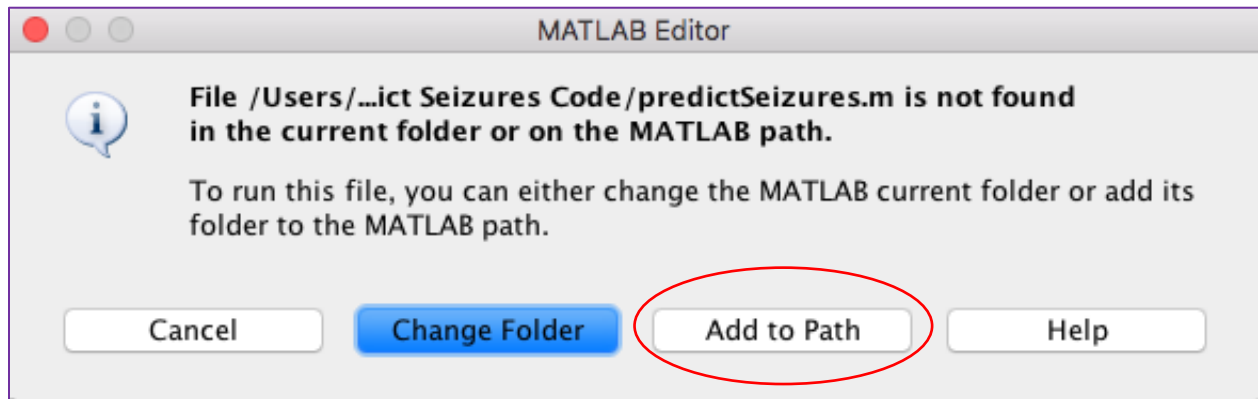


Figure 7

Step 16: Go to sleep.

After Use

Step 1: End the MATLAB script by pressing Ctrl+C (if using a PC) or Command+C (if using a Mac)

Step 2: Remove electrodes from body.

Step 3: Discard the white pad of each of the three electrodes and replace them with new ones.