Prediction of Cardiac Arrest Recovery by Analysis of the EEG and ECG

Jonah Bois[1], Jessica Feltovich[1], Jake Malobicky[1], Katie McFarland[1], Yasmine Sleiman[1]

Mentors: Dr. Stephen Helms-Tillery[1], Dr. Leonidas Iasemidis[1,2]

[1]School of Biological and Health Systems Engineering, Arizona State University

[2]Department of Translational Neuroscience, Neurology and Neurosurgery, Barrow Neurological Institute, Phoenix, AZ

Background

Post-anoxic coma after resuscitation from cardiac arrest is due to the occurred temporary lack of oxygen to the brain. Only 20% to 30% of all patients survive after the first 24 hours of being in the coma state [1]. The outcomes of this condition range from full neurological recovery to different degrees of neurological disability quantified by the Cerebral Performance Category (CPC) scale [2]. A CPC score of 1 would mean that the patient had full recovery of all neurological function, while a score of 5 would mean death. Accurate prognosis of a patient's neurological recovery is vital for helping physicians in determining future treatment plans and resource allocations.

Mission Statement

We strive to provide accurate prognosis for post-cardiac arrest patients to receive a better life-sustaining treatment.

Project Planning

Gantt Chart: Tracks weekly progression of iNeuroCardia's project.

Design Inputs

Customer Need	Metric	Ideal Value
Accurate Prognosis	CPC Ranking	1-5 (Complete CPC Range)
Algorithm Training	True Positive Rate (TPR)	> 80%
Risk of Harm	False Positive Rate (FPR)	< 5%
Output Replicability	Physician Feedback (1-5 Rating)	5/5
Algorithm Efficiency	Time to Produce Output	Real-Time
Compatibility	Ability to connect with ICU devices/wearables	At least 4 devices simultaneously
User Friendliness	End-User Training Time	< 1 Hour
Reasonable Cost	Licensure	$18,000 - $24,000

House of Quality: Ranks our product along with 5 other benchmarks based on their application to each need and metric.

Manufacturing Design

License	1-Year Individual	1-Year Site (4 EEG Machines)	1-Year Site (10 EEG Machines)
Price	~$10,000	~$18,000	~$24,000

Device Concept and Design

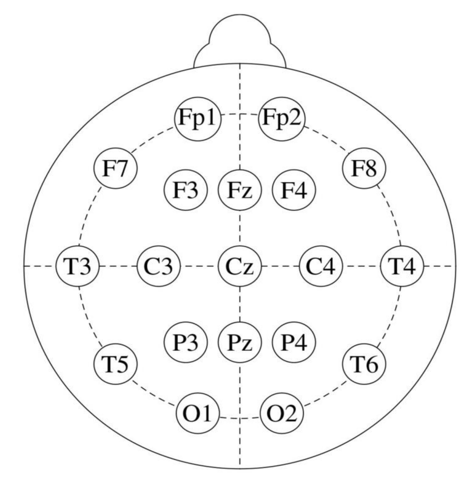

Figure 1: A standard 10-20, 19 channel scalp EEG montage. Adapted from *Vázquez et al. Frontiers in Systems Neuroscience (2021)*

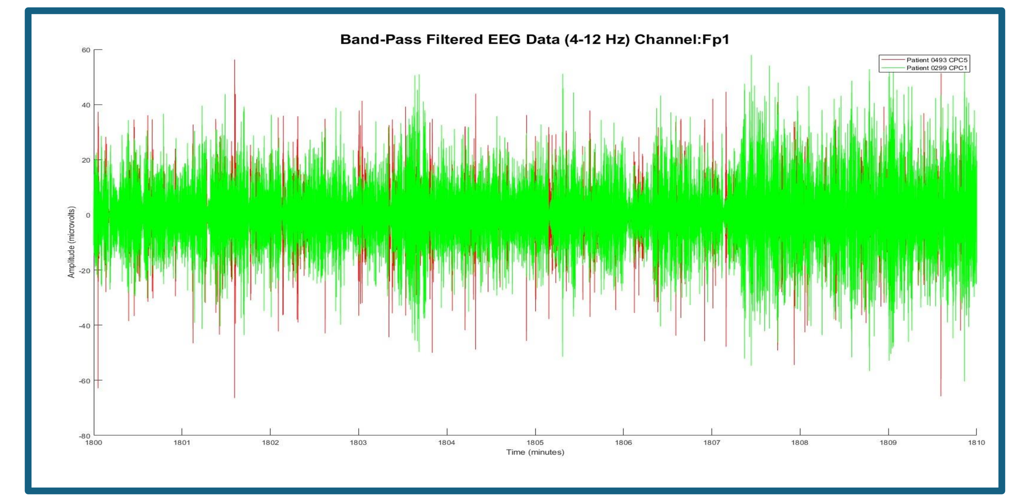

Figure 2: 10-minute segment of high pass and comb filtered EEG signal, which is then band-pass filtered from 4-12 Hz.

We will develop a software module for analysis of the EEG and ECG signals from cardiac arrest (CA) patients using linear (Fourier-based and autoregressive model-based) and nonlinear (entropy) measures of dynamics over hours following CA. The performance of the thus derived features for categorizing CA patients in agreement with the CPC scale will be assessed by Linear Discriminant Analysis (LDA), a common machine learning technique for data classification and dimensionality reduction [3]. A LDA classifier cross-validated with k=5-folds will classify between a good and poor outcome from post-anoxic coma using our extracted features from the linear and nonlinear methods of analysis. K-fold cross-validation randomly splits the data into *k* subgroups, using one of the *k* subgroups as test data, with each subgroup being used once as the test set over *k* iterations. A k-fold cross-validated model produces *k* sensitivity and specificity results, which are then averaged to estimate the device's overall performance.

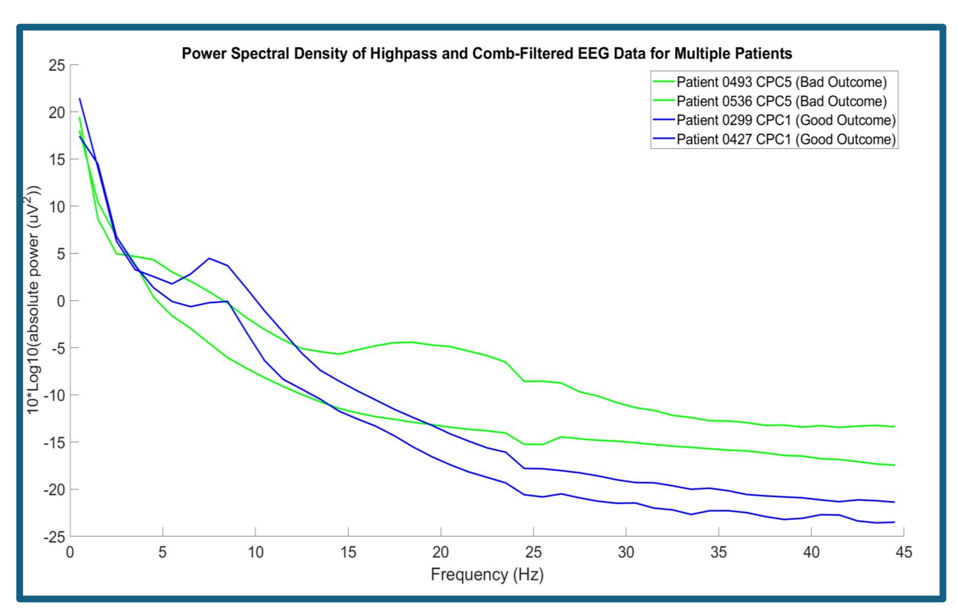

Figure 3: Average power spectral density from 10 second windows of entire EEG signal from channel Fp1 for 4 patients: 2 "good outcomes" and 2 "bad outcomes".

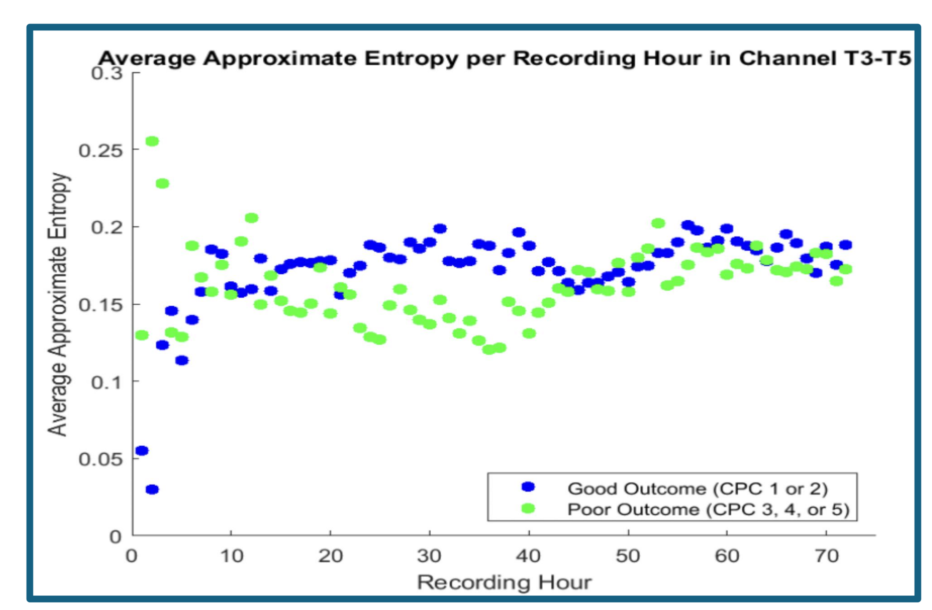

Figure 4: Average approximate entropy values in bipolar channels T3-T5 for patients in two different outcome groups. This was computed over 10 second segments for each hour.

Product Specifications

CPC Score	Outcome
1	Good Neurological Function
5	Death

Key Band Frequencies	Value
Theta	4 – 8 Hz
Alpha	8 – 12 Hz

Variables	Values
Sampling Frequency	500 Hz
Butterworth High Pass Cutoff	0.1 Hz
Comb Filter	25 Hz intervals (until 200 Hz)
Class/Pathway	Class II/510k

Product Architecture

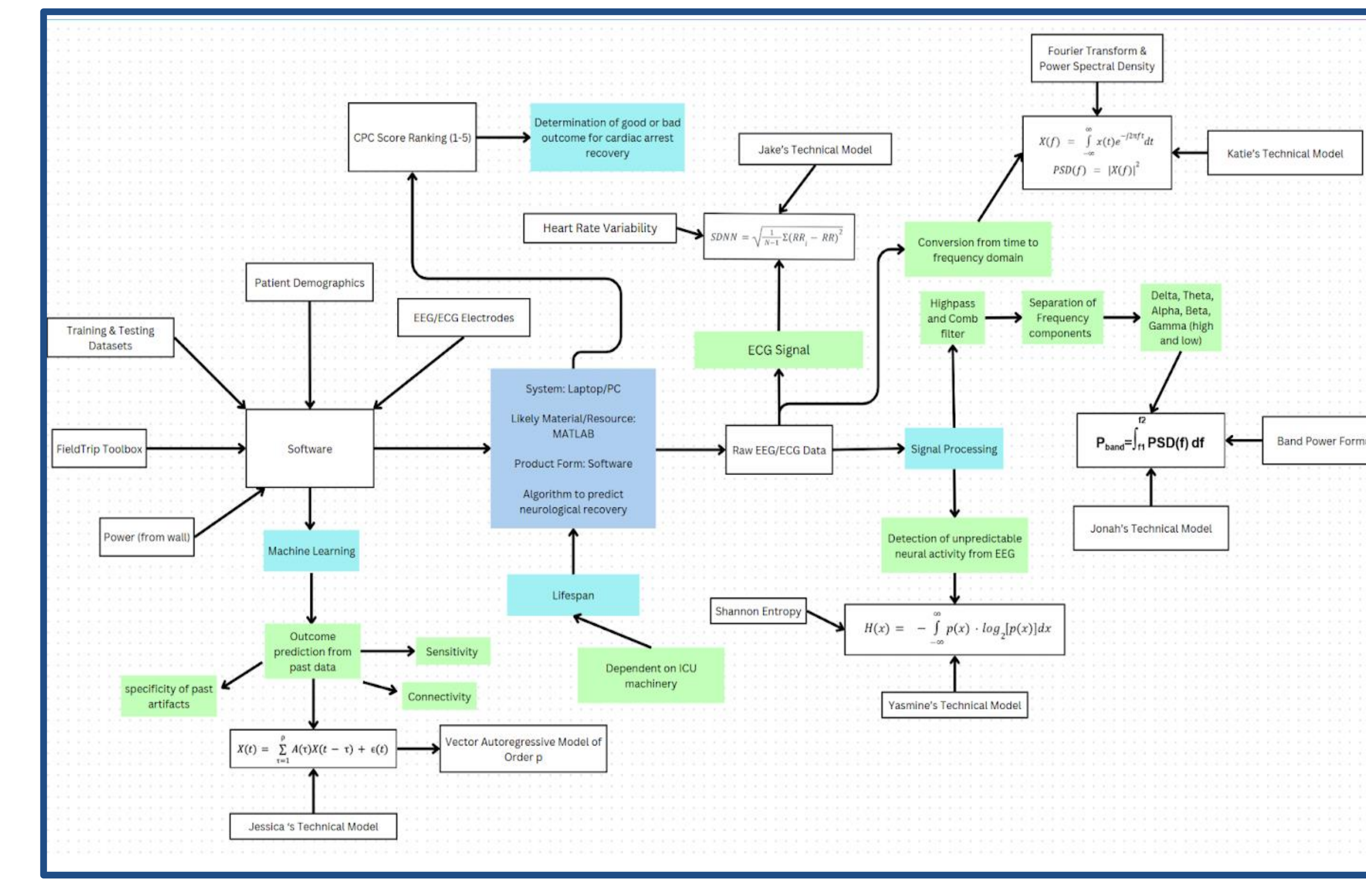

Figure 5: Initial product architecture displaying input and output relationships based on our developed technical models. This shows the process from raw data input, to analysis techniques, and to the results that will be provided by the final product.

Band Power: $P_{band} = \int_{f1}^{f2} PSD(f)\, df$

Shannon Entropy: $H(x) = -\int_{-\infty}^{\infty} p(x) \cdot log_2[p(x)]dx$

Power Spectral Density: $PSD(f) = |X(f)|^2$

Fourier Transform: $X(f) = \int_{-\infty}^{\infty} x(t)e^{-j2\pi ft}dt$

Larger Shannon entropy values correlate well with more disorder in brain activity, indicative of parallel multi-processing and healthy cognitive function [4,5].

Design Status and Future Work

The FFT-based methods of analysis are in the final stage of development (integration with the main code to start producing massive results over time per patient). The autoregressive model-based methods of analysis are in the stage of testing with simulation data. The nonlinear methods of analysis are also in the testing phase. We have just begun exploring the integration of the machine learning part of the design.

Acknowledgements

We would like to thank our collaborators at Barrow Neurological Institute, Dr. Leonidas Iasemidis and Alexander Nicholas, for their guidance and support during this project. Another thank you goes out to our faculty mentor, Dr. Stephen Helms-Tillery, for providing additional input and expertise.

References

Scan here to view the references utilized.