REAL-TIME NEURAL SIGNAL FILTERING VIA HODGKIN-HUXLEY SIMULATION MODELS

Peter Leong
Student# 1010892955
peter.leong@mail.utoronto.ca

Karys Littlejohns
Student# XXXX
karys.littlejohns@mail.utoronto.ca

Katherine Shepherd
Student# XXXX
k.shepherd@mail.utoronto.ca

ABSTRACT

—-Total Pages: 2

1 INTRODUCTION

2 MOTIVATION & RELEVANCE

In the field of biomedical engineering, extracting action potential timings from noisy extraceulluar recordings is essential in advancing brain-computer interfaces and neuroscience research. While spike detection itself is a signal processing task, the underlying signal can be described and approximated by the Hodgkin-Huxley (H-H) model. This set of non-linear ordinary differential equations models the ionic conductance changes that generate the action potential waveform. Our challenge is to adapt the H-H waveforms to mimic the noise present in real-life data.

Beyond common EEG readings or microelectrode arrays, neural signal filtering and spike detection is relevant to other closed-loop systems such as epileptic seizure prediction (Addai-Domfe & Daoud, 2024) or adaptive deep brain stimulation for Parkinson's disease (Aljalal et al., 2022). Advancements in filtering are further motivated by the advent of high-density neural probes which generate large data streams requiring efficient, accurate processing solutions (Ye et al., 2024). This project aims to develop a spike detection algorithm based on the H-H model to improve accuracy in low signal-to-noise ratio (SNR) environments.

3 SCOPE & FEASIBILITY

The scope of this project builds upon concepts from ESC103: Engineering Mathematics & Computation and MAT292: Ordinary Differential Equations. The work is divided into three primary phases: (1) generating synthetic neural data by solving the Hodgkin-Huxley equations, (2) processing this data with a digital filter, and (3) developing a spike detection algorithm.

3.1 PROJECT OBJECTIVES

The primary objectives of this project are:

1. **Data Generation:** To implement numerical solvers for the Hodgkin-Huxley (H-H) model to generate realistic synthetic action potential data.
2. **Signal Processing:** To design and apply a digital band-pass filter to isolate the spike waveform from the generated signal and added synthetic noise.
3. **Spike Detection:** To develop an algorithm that detects action potentials using an adaptive threshold, calculated from the estimated noise floor of the processed signal.
4. **Validation:** To qualitatively and quantitatively assess the performance of the detection algorithm on the noisy synthetic data.

3.2 PROJECT MILESTONES & TIMELINE

Although a more detailed outline of our project milestones and timeline can be found in A, several high-level milestones are listed below.

Week 4: Finish implementation of Euler's and Improved Euler's method solvers. Also complete first iteration of noise generation algorithm.

Week 6: Finish implementation of Runge-Kutta method solver(s), and complete first iteration of band-pass filter.

Week 8: Refine band-pass filter, noise generation algorithm, and numerical methods.

Week 10: Discuss and evaluate results in the final report.

Week 11/12: Buffer time in case aforementioned tasks take longer than initially anticipated.

4 Technical Background

Understanding the bioligical model of neuron signals is imperative to acknowledging the abstractions and simplfications made to obtain the H-H equations. In this section, we overview the basics behind action potential in the brain, and biochemical processes that occur to produce these phenomena. Additionally, we outline the handful of key equations we intend to use from the H-H model, and discuss the theory behind the nuermical methods we have chosen.

4.1 The Biological Basis: Ion Channels and Currents

4.1.1 The Cell Membrane and Resting Potential

4.1.2 Voltage-Gated Ion Channels

4.1.3 Sodium-Potassium Pump

4.2 Modeling Neurons as Electrical Circuits

4.2.1 The Parallel Conductance Model

4.2.2 Circuit Analogs: Capacitors, Resistors, and Batteries

4.3 Hodgkin-Huxley Equations

4.3.1 Model Components and Equations

4.3.2 Gating Variables and Activation/Inactivation

4.4 Numerical Methods

4.4.1 Euler's Methods

4.4.2 Runge-Kutta Methods

4.4.3 Comparison of Methods

5 Conclusion

REFERENCES

Gladys Addai-Domfe and Hisham Daoud. Epileptic seizure prediction using spiking neural networks. In *American Epilepsy Society (AES) Annual Meeting*, 12 2024. URL https://www.aesnet.org. Submission ID: 1436. Presentation date: December 7, 2024.

Majid Aljalal, Saeed A. Aldosari, Khalil AlSharabi, Asem M. Abdurraqeeb, and Fahd A. Alturki. Parkinson's disease detection from resting-state EEG signals using common spatial pattern, entropy, and machine learning techniques. *Diagnostics*, 12 (5):1033, 2022. doi: 10.3390/diagnostics12051033.

Z. Ye, A. M. Shelton, J. R. Shaker, J. Boussard, J. Colonell, D. Birman, S. Manavi, S. Chen, C. Windolf, C. Hurwitz, T. Namima, F. Pedraja, S. Weiss, B. Raducanu, T. V. Ness, X. Jia, G. Mastroberardino, L. F. Rossi, M. Carandini, M. Häusser, G. T. Einevoll, G. Laurent, N. B. Sawtell, W. Bair, A. Pasupathy, C. M. Lopez, B. Dutta, L. Paninski, J. H. Siegle, C. Koch, S. R. Olsen, T. D. Harris, and N. A. Steinmetz. Ultra-high density electrodes improve detection, yield, and cell type identification in neuronal recordings. *bioRxiv*, 2024. doi: 10.1101/2023.08.23.554527. Preprint.

A GANTT CHART