Analog Spike Processing for Brain-Machine Interfaces

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Project Overview

Brain Machine Interfaces (BMIs) are implanted chips that help computers parse electric signals in the brain. BMIs have the potential to give paralyzed patients control of robotic limbs, increasing independence and quality of life for the US's 18k new Spinal Cord Injury patients and 185k new amputees each year.

A heated area of current BMI research is in improving the power and compute efficiency of brain signal decoding chips. Canonical chips use digital binning algorithms to extract bucketed spike counts from analog voltage data, and cutting-edge research recently introduced chips that compute the Fourier transform to enable later reconstruction of the original waveform.

The characteristics of analog computers make them uniquely suited for shallow, real-time, fuzzy computations like the kind required for brain signal analysis. Current implants are too slow and power hungry for unmonitored 24/7 use. This project aims to build analog circuits that improve the power efficiency of existing digital algorithms, bringing us closer to clinically feasible implants.

This project has progressed along the need-finding and problem definition steps of the design thinking process and needs funding for the first cycle of prototyping. The project is based on academic literature and is an example of "learning [academia] by doing [research]." This project could not be imagined without Nueva's Design Thinking and eXperimental Research (XRT) education and the support of the I-Lab and Joey Kovacevich Social Innovation Fellowship.

Innovation: Why Analog Computers and Brain Machine Interfaces?

Brain Machine Interfaces (implanted chips) are more clinically feasible than Brain Computer Interfaces (surface electrodes) because implanted electrodes can pick up more precise signals and are more robust for everyday living. BCIs also have less restrictive space and power constraints, as they are large and often have wired connections. Analog computers have seen a resurgence in general machine learning applications and have been explored in BCI contexts, but have not been applied to brain-machine interfaces.

Analog computers are particularly applicable to the implanted "feature extractor" component of a brain-machine interface (as opposed to the "decoder" which can be a smartphone): the feature extractor must be immutable, robust, and power efficient. Analog computers have a unique set of pros and cons that make them extremely well suited for this application:

Advantage	**Relevance**	**Disadvantage**	**Irrelevance**
Extremely efficient for fuzzy computation.	Brain signal analysis requires efficient calculation of small continuous values.	Computations are not precise. Can't compute discrete values.	The implanted chip does not need to perform discrete computations.
Suited to shallow computation. More operations are noisy.	Modern DL models are prohibitively deep for analog computers, but BMI analysis computations are shallow.	Not reprogrammable, poor for general computing uses (eg. personal computer)	After a circuit is developed, it need not be changed. Current implanted ASICs are also static: this problem is non-unique.
Suited to one-off, online computation. Computations are not repeatable.	The implanted chip need not repeat computations or store state over time. Data is sent off-device in real-time.		

Project Timeline

By June 20	Purchase Materials
By August 12	Build an analog DFT, test with the Caltech MICS lab

After initial data collection and testing, we may proceed with further iteration, implementation in circuit board form, or publication as applicable.

Cost Breakdown

for a prototype on the order of kHz and V.

$300	Multi-channel data acquisition board
$100	Prototyping (Breadboards, jumper cables, heat shrink, mounting hardware, tape, etc)
$100	Chips (ADCs, clocks, amplifiers, etc)
$50	Misc. Components (LEDs, resistors, etc)
$100	Arduino + Shields + Other drive electronics

Total: $650