Non-Invasive, Inductive Electrodes for Application in Brain Computer Interfaces

Colin Ecsedy, Justin Marriott, and Andrew Parker

Biological Engineering

Introduction

Brain-Computer Interfaces (BCI) have proved to be a major factor in facilitating motor recovery, recovery of hearing and vision loss, and other debilitating conditions and diseases (Nicolas-Alonso, 2012). This is accomplished by measuring neurological signals and interpreting that information into a desired action. The most common method of sensing neurological activity for BCI is by either surface or implanted electrodes that are either prone to unreliability or are dangerously invasive (Alpert, 2008). Part of this unreliability is based on the low specificity of the electrode method, requiring many pairs of electrodes to accurately detect signals in a particular area. By utilizing information from other, more difficult to read areas of the nervous system, such as the spinal cord, a greater level of specificity can be achieved.

Objective and Specifications

This design will be a non-invasive alternative to traditional electrodes that has the capability to record neural signals in these more difficult to read areas reliably and accurately.

The sensor will:

- Be non-invasive
- Not cause harm from chronic use
- Record as distinct of signals as a surface electrode
- Easily identify signals based on muscle movement
- Provide consistent and precise data

Methods

Taking the results from the resonant frequency section of the prerequisite tests a coil measuring 1" in diameter was produced using 40 AWG magnet wire, wrapped 598 times around a 3-D printed scaffold with a 1mF, 10V capacitor connected to one end of the coil. Due to the shielding tests window flashing was placed on top of the coil scaffold. As the resolution on the Arduino during the data collection was found to be insufficient LabView was used while connected to a Tektronix TDS 310 Digital Oscilloscope.

To filter out any noise or other outside interferences that are above 50Hz three unity gain active filters were placed in series after the signal being acquired was increased by nearly 5,000,000x using two INA118p operational amplifiers placed in series as shown in the schematic of Figure 5 were placed between the coil and the data acquisition device.

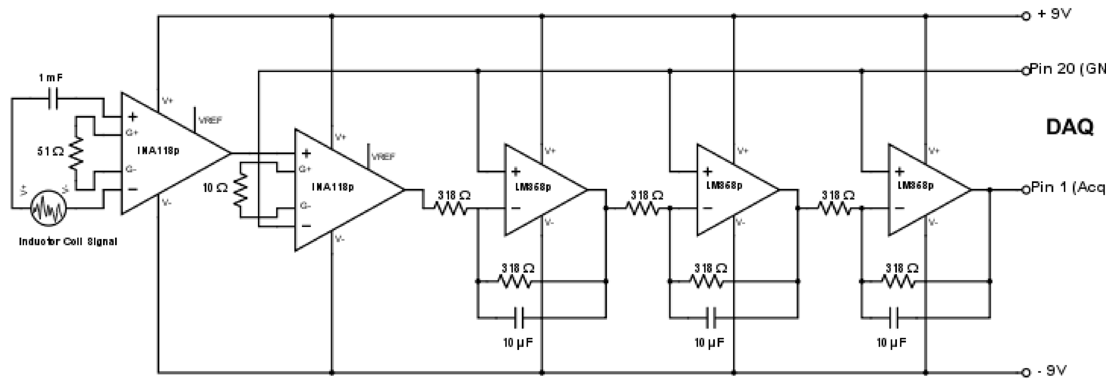

Figure 5. The schematic used to amplify and filter the signal acquired from the volunteer.

The coil was placed at the C4 location on the scalp to while to volunteer was asked to lift their left in a continuous fashion. The coil was then placed at the F_{pz} location on the forehead to measure alpha waves.

Prerequisite Tests and Results

Resonant Frequency of Neurons

- A wide range of coils were created to determine the best dimensions for the final design.
- Using equations 1 and 2 several coils were created at different resonant frequencies, with or without capacitors.
- Results showed that the coil with the capacitor was able to reach power transfer in the hertz range instead of the Mhertz range, with power transfer at 2-5% (Figure 1a).

$$rf = \frac{1}{2\pi\sqrt{LC}} \quad (1)$$

$$L = \frac{4}{5}\frac{r^2N^2}{6r+9l+10d} \quad (2)$$

Shielding

- As power transfer is low shielding is needed to block outside noise.
- Different materials based on Geetha et. al.'s "EMI shielding: Methods and Materials" were used as shielding.
- Data found that window flashing was the best at shielding without interfering with the signal being acquired (Figure 1).

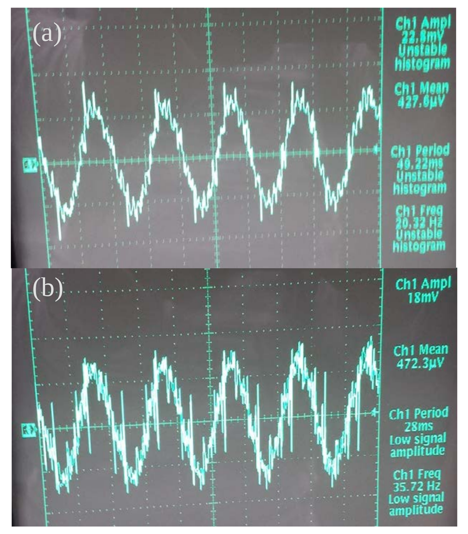

Figure 1. The coil with capacitor when using flashing (a) and without flashing (b).

Data Acquisition

- Arduino and NI LabView compared for data acquisition.
- Between the two, data collected from a waveform generator were compared.
- Arduino's 10 bit resolution and slow sampling rate make measurement difficult. Data collected using the diagram in Figure 2 in LabView was capable of higher sampling rate and resolution.

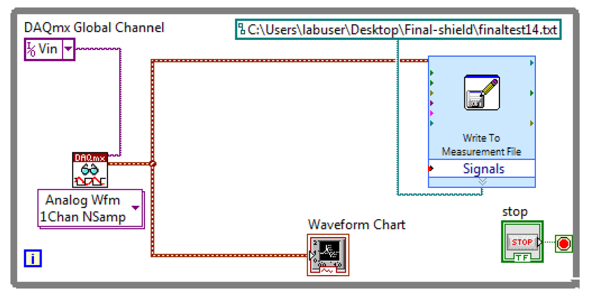

Figure 2. LabView block diagram.

Filtration

- Noise attenuation above electric mains (60 Hz).
- Multiple low-pass filters as seen in Figure 3 were connected in series to test how much multiple filters would decrease the signal acquired.
- Effective noise reduction was reached at 3 filters (Figure 4).

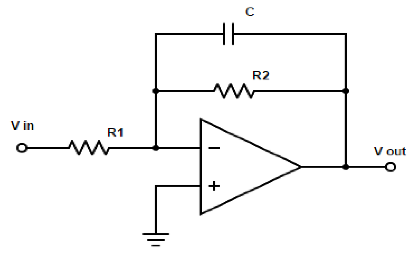

Figure 3. Active low-pass filter (Nilsson, 2005).

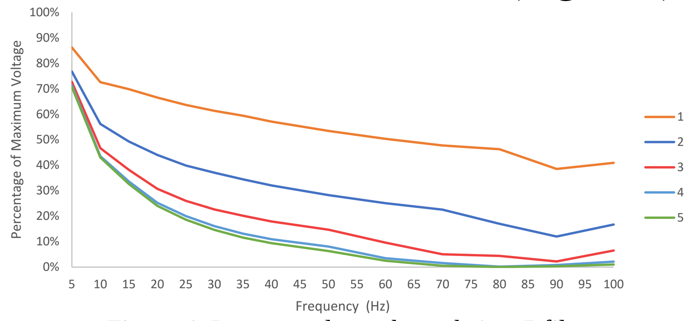

Figure 4. Percent voltage through 1 to 5 filters.

Results

The coil (Figure 6) By design is non-invasive and can Even be worn over the clothes and on top of hair. Chronic exposure to low frequency magnetic fields is dangerous but this is mitigated as long as the coil does not transmit signals and only receives them.

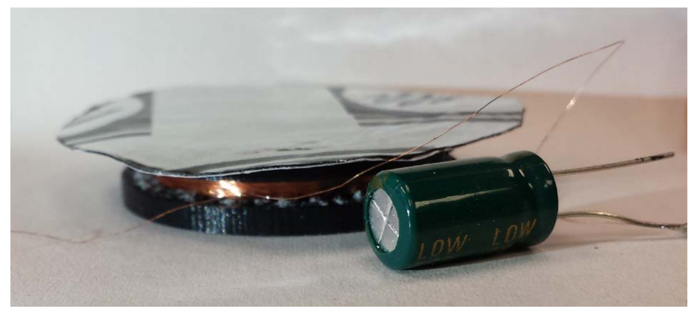

Figure 6. Final coil design with capacitor and shielding.

Motor tests done with the coil on a volunteer showed a difference in activity when the volunteer was at rest opposed to when engaged in motor activity as seen in Figure 7.

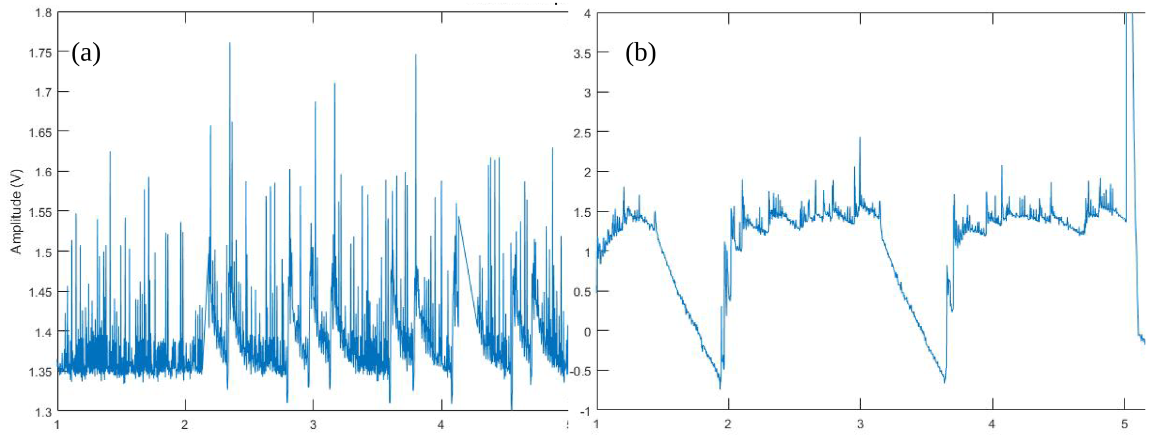

Figure 7. Waveform data of motor tests at rest (a) and during motor activity (b) with the valleys in chart (b) correlating with muscle movement.

During motor rest there was a consistent pattern of activity, however, during motor activity there was a distinct set of valleys and peaks that correlated with the actions of the volunteer. Further tests conducted to analyze if this pattern was due to the presence of artifacts from movement of the coil or from neural activity showed in Figure 8 that the movement of the coil was not sufficient to generate such a signal.

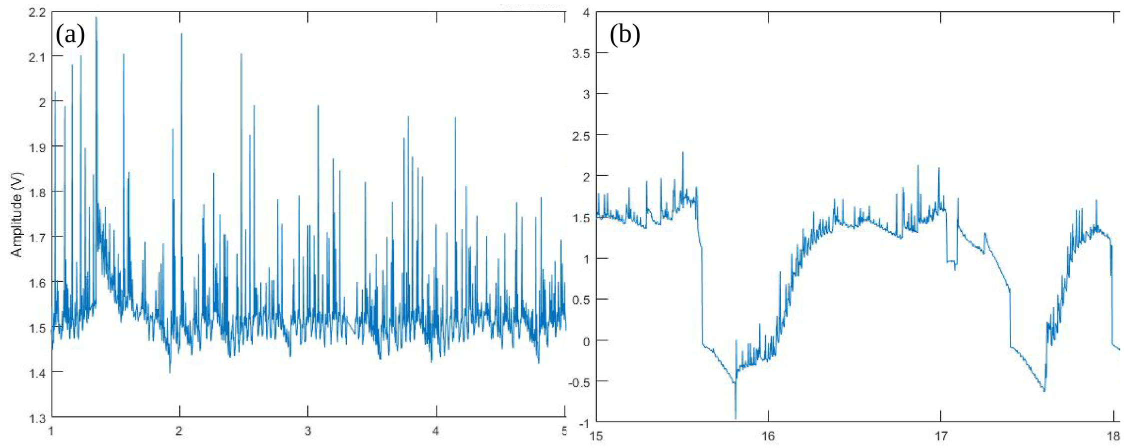

Figure 8. Waveform data of signals acquired when coil is moved by hand (a) and when volunteer resumes motor activity (b).

These results strongly suggest that the signals acquired are due to the movement of the volunteer and not the coil though when the waveform data was analyzed by Fast-Fourier-Transform (FFT) in Figure 9 there was no recognizable relationship to the brain waves usually associated with motor activity (8 – 20 Hz).

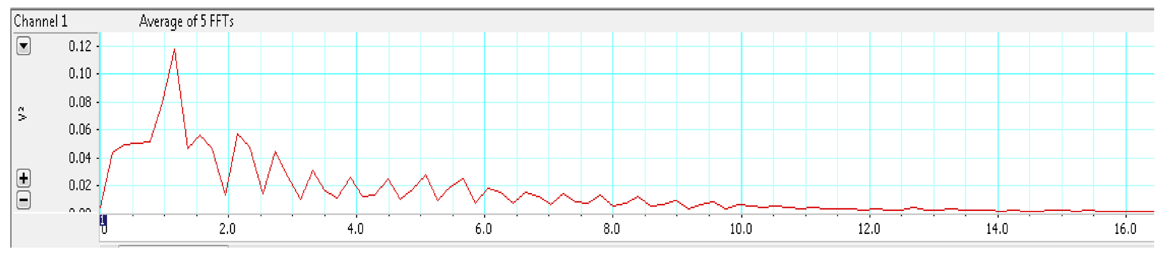

Figure 9. Power spectrum of active motor cortex showing little activity in the 8 -20 Hz region.

Conclusions

Distinct patterns based on muscle movement could be discerned using this new design, however, the results show no distinguishable relationship to specific frequencies of neurological activity. The coil was also unable to provide distinct signals based on muscle movement, or consistent and precise data. Though, with a manufacturing cost of $3.28 per coil compared to an average cost of less than $0.50 per disposable surface electrode the development of a new method of analysis may not be cost effective. If a way to accurately analyze and correlate the activity measured by the coil is not achieved it is unknown whether the signals it records are as accurate and clear as those measured by surface electrodes.

The largest hurdle in the implementation of this design was in the data acquisition system. A more versatile and stable system would allow for more accurate measurements and which in turn would aid in the development of a method of analysis.

Although the benefit of this design is its reusability, safety, and ability to function without direct skin contact, further testing and better data acquisition is necessary.

Future Work

Further work on this project would include making the coil more sensitive to neural activity as well as decreasing it's size so that it may be used to collect signals from the spinal column. Exploration of more economical methods to build or obtain Superconducting Quantum Interference Device (SQUID) or Spin-Exchange Relaxation Free (SERF) sensors to incorporate into the design could enhance signal acquisition. Improvement in the signal resolution of the Arduino data acquisition would make the sensor more versatile. Replacement of the filters with a Butterworth Filter design to attenuate signals more cleanly.

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