Design and Implementation of a Portable EEG-based Brain-Computer Interface as a Pilot Study: Monitoring Tourette's Syndrome Patient's Brain Waves with Music of Bach

可攜式腦波儀之設計、實作與腦機介面先導研究--腦波偵測暨分析妥瑞症與巴赫音樂

Major Category: System
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Abstract

Electroencephalography (EEG) has been employed for engineers, neuroscientists and roboticists to detect brain related activity during attention, mental meditation, or motor function. EEG has been used as well in the recent research and clinical setting for diagnosis of brain related disorders.

Noninvasive electroencephalogram (EEG)-based brain-computer interfaces (BCI) are characterized as a technique to record and measure brain activities and thus various brain signals can be monitored and decoded. Evolving BCI systems based on EEG have been developed which enables scientists to go for research frontiers of signal sensing, biomedical engineering, and neurotechnology since the past decades.

This project is aimed at improving and optimizing design and implementation for an innovative low-cost portable EEG-based BCI instrument. As for improving optimization and enhancing stability, the circuit breadboard was designed into a PCB layout circuit. The PCB board accordingly can be stacked on top of the Raspberry Pi 3 so it becomes a portable BCI device based on EEG.

Tourette's Syndrome (TS) is currently considered a neurodevelopmental genetic disorder. Recent research findings address the effect of musical activity for TS patients. Observed musical activities include musical performance, mental imagery of musical performance and listening to music.

Previous research conclusions on music and the brain were heavily drawn from self-reported questionnaires done by Tourette Syndrome patients. Thus, the study attempts to further conduct an experimental design investigating noninvasive EEG-based BCI, which monitors brain wave signals derived from Tourette's Syndrome patients with any music effects of Bach. The experiment results explore to be aligned with the rising research theme of digital signal processing and EEG data analysis in recent years. The recorded brain waves seem to demonstrate the experiment results that Minor scales likely tend to have a soothing and slowing effect on the TS listener and Major scales are much bolder and cheery. Fast-paced tunes would lead to result in more energetic and less relaxed. Slow-paced tunes would result the opposite. The preliminary experiment results may illustrate that Bach classical music compared with mild pop music leads to more relaxation for TS patients.

Keywords:
EEG (electroencephalography), BCI (Brain-Computer Interfaces), Music of Bach, Tourette's Syndrome

1. Introduction

This project is aimed at improving and optimizing design and implementation for an innovative low-cost portable noninvasive EEG-based BCI instrument.

As the result to improve optimization and enhance the stability of the prototype-based instrument, the circuit breadboard was further designed and turned into a PCB layout circuit. The PCB board accordingly can be stacked on top of the Raspberry Pi 3 and it becomes a safe, convenient, portable BCI device based on EEG.

Tourette's Syndrome (TS) is currently considered a neurodevelopmental genetic disorder. TS is defined as a neuropsychiatric disorder characterized by multiple motor tics and at least one vocal tic [4]. Recent research findings address the effects of musical activity for TS patients. Self-reported musical activities include musical performance, mental imagery of musical performance, and listening to music [1].

Previous research conclusions on music and the brain were heavily drawn from self-reported questionnaires done by Tourette Syndrome patients. The study thus attempts to conduct an experimental design investigating noninvasive EEG-based BCI which monitors brain wave signals derived from Tourette's Syndrome patient with any music effects of Bach. The experiment results explore to be aligned with the rising research theme of signal processing and EEG data analysis. The recorded brain waves in the experiment seem to illustrate the following results:

1) Minor scales tend to have a soothing and slowing effect on the TS listener which results in more relaxed brain waves and major scales are much bolder and cheery, resulting in more concentrated brain waves.

2) Fast-paced tunes would lead to result in more energetic brain activity and less relaxed; Slow-paced tunes would result the opposite.

We will continue to proceed innovative low-cost portable EEG-based BCI instruments. As expected, a completed Guidebook [2] of design solutions and prototyping paradigms of EEG-based BCI will be introduced in early 2023 authored by a European research team in Electrical Engineering.

2. Methodology and System Design

This is the main flow for the EEG for this project. With three node placements: Fp2, O2 and A1, on the scalp following the 10-20 system, this will be the input for the PCB board which then transfers the analog signals into the ADC, which then inputs them into the Raspberry Pi 3. At last, we use 2 python programs to run the device. The first program saves the signals it records, and the second one loads them out

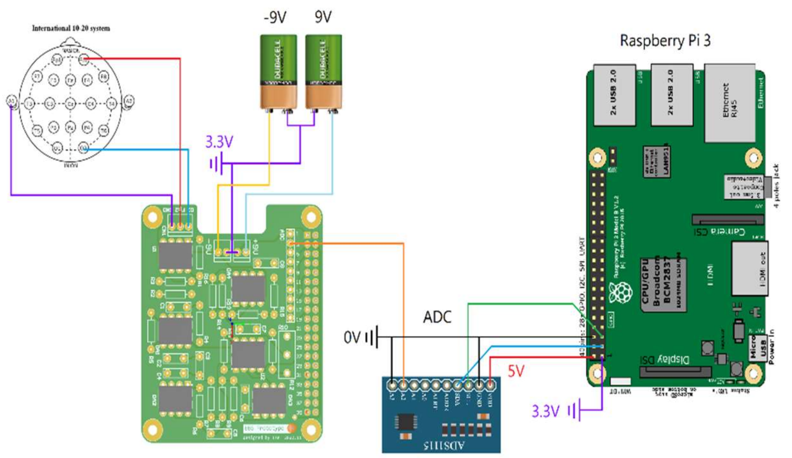

Figure 1:wiring

2.1 Improved and Optimized Design of EEG

This project is referenced and inspired from a GitHub project by Ryan Lopez[3]. The main circuit is composed of 2 amplifiers, 2 notch filters, 1 high pass filter and 1 low pass filter.

Alpha wave signals are weak, ranging from 15-50uV, which is the reason we need two amplifiers in the circuit. The first amplifier takes the inputs from pin 2 and 3 and outputs the difference multiplied by gain 88.2 = 1 + (49.4kOhm)/560R in theoretical value but in the reality it amplified to about 100 times. It is then outputted into the notch filter.

The two notch filters are responsible for the 60Hz power line interference [4]. At first, we tried using one notch filter. It was all normal when we ran it through oscilloscope tests and OrCad simulations. But when we added the ADC and electric caps, the 60Hz was really powerful so we added the second notch filter in. That way, it successfully filtered out the power line interference We also tried different band-stop filters, including the Twin T filter [5].

As we are trying to filter out alpha waves which ranges from 8-12Hz, we need a high pass filter the filter out the lower than 8Hz frequencies. We also need a second order filter[6] for noise reduction, so according to the characteristic of second order filters, we define the cutoff frequency[7]at -6dB roll-off with -40dB/Decade roll-off rate. Cutoff frequency would be at 7.2 Hz according to

$$fc = 1/2\pi RC$$

Similar to the high pass filter mentioned above, the low pass filter has a cutoff frequency at 32.9 Hz. The second to last section of the second notch filter that we mentioned above would be the second amplifier. This amplifier has a gain ranging from 90-460 on top of the first amplifier.

2.2 Designing the PCB Layout for a Portable EEG

After implementing the circuit on the breadboard, we realized that there were still lots of noise and the waves that the circuit was getting was not sable enough. Thus we went ahead and designed the circuit into PCB Layout. We put the circuit into Altium, made our own library of parts and tried to set everything as close to each other so the signals don't get reduced by wiring [8].

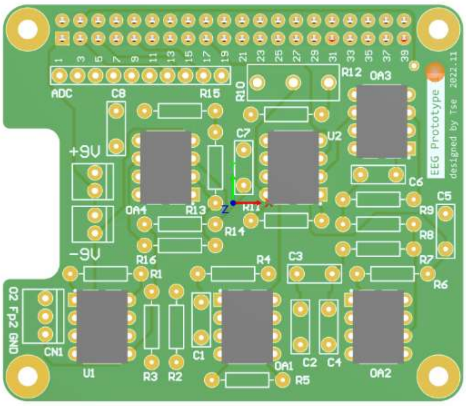

Figure 2: PCB Layout 3D model

2.3 Portable EEG-based BCI Software Design

The software is mainly made of three functions: get_power_spectrum, get_rms_voltage and get_brain_wave[9].

1. get_power_spectrum is the function that allow us to obtain the power spectrum of Fast Fourier transform (FFT) ps[freq]=|FFT(x)|^2[freq]

2. get_rms_voltage is the function that gets the voltage of waves with frequency between freq_min and freq_max. We implemented Parseval's Theorem,

$$\sum_{i=0}^{N-1} x[i]^2 = \frac{1}{N} \sum_{i=-(N-1)}^{N-1} |FFT(x)[i]|^2$$

and resulted in this equation

$$\sqrt{\frac{1}{N}\sum_{i=0}^{N-1} x[i]^2} = \frac{1}{N}\sqrt{\sum_{freqinrange} |FFT(x)[freq]|^2}$$

3. get_brain_wave is the function that cancels out frequency values over freq_max and freq_min, for we only want 8-12 Hz of waves.
4. The save_brain_data main function combines the above and saves signals that are piked up

on the EEG and saves them into a pickle file.
5. The load_brain_data main function then loads the saved pickle files and turns them into comparison graphs.

3. Experimental Results of Music and Tourette Syndrome

For this project, I personally recorded all five music clips on my violin, each for 5 seconds. I then listen to each of the clips for 30 times and document the results [10].

The following are the original music clips that I recorded. There are four pieces for Experimental group, and one pop music piece for Control group.

Experimental Variables with selected music clips from Bach Sonatas and Partitas for Violin Solo:

1. Allegro in A minor, BWV1003
2. Allemanda in D minor, BWV1004
3. Largo in C major, BWV 1005
4. Gigue in E major, BWV 1006.

Control Variable with selected music clip:

River Flows in You, composed by Yiruma in A major

I connect the electrode cups to the pre-Frontal 2 node, which is responsible in a variety of complex behaviors, including planning and focusing; the Occipital 2 node, which is responsible for visual perception, including color, form and motion; and the A1 node, which is contralateral referencing of all EEG electrodes. I press the play button on my computer that plays the music clips and at the same time I press the record button on the EEG device. After pressing both buttons, I stare into the white box in front of me the ensure that I'm only focused on listening to the music coming through the headphones. I repeat this process for 30 times each to capture more data. The results of each recording are then combined into the graphs that will be produced shortly after.[11][12][13]

Take BWV1003 Allegro in A minor for example:

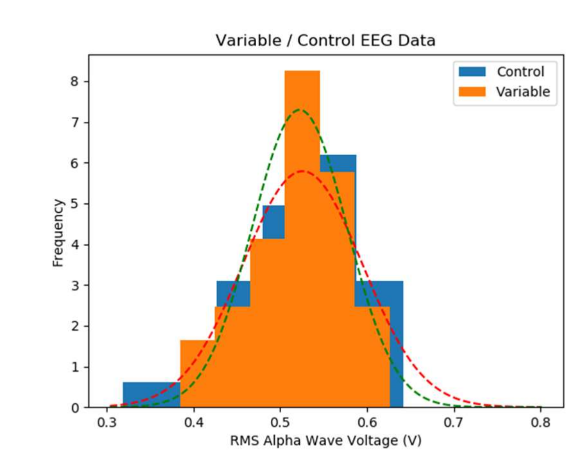

Figure 2: Control and Experimental Variable

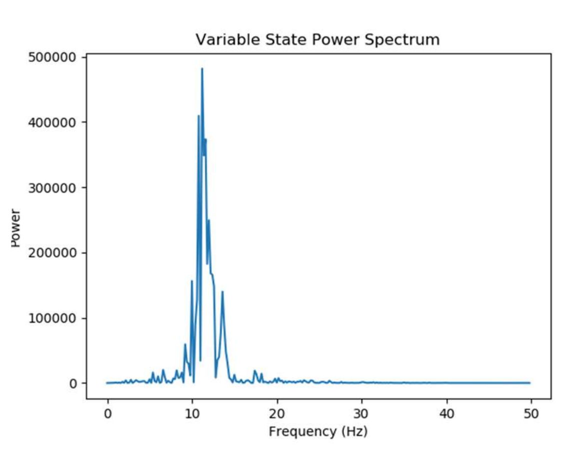

Figure 3:Power spectrum of 1003

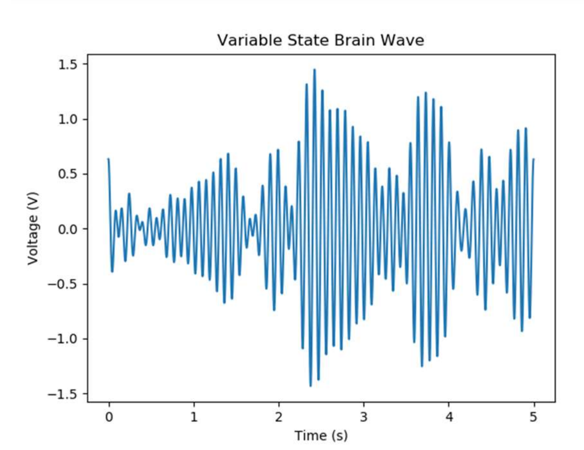

Figure 29:1003 alpha brain wave

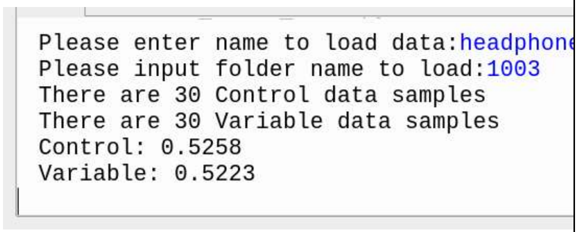

Figure 30:Voltage comparison

The five pieces I've chose are all related to my tics being reduced after playing them or hearing them. The pieces are also divided into two kinds, with the control design being pop and the four pieces for experimental design being classical. Since the EEG has only three nodes and not absolutely stable and that the Alpha waves can be easily interfered, I've decided to only listen to the clips instead of playing them in person. But as tics-reducing can also be related to mental imagery of musical performance, I recorded myself playing the pieces and played them on repeat when conducting the experiment. The results are quite interesting though they were not quite what I expected.

For BWV1003 Allegro in A minor and BWV 1006 Gigue in E major, which are both fast paced, the power spectrum seems much noisier, compared to the other slow-paced pieces, but still has a cleaner spike than the control variable. For BWV1004 Allemanda in D minor and BWV 1005 Largo in C major, which in contrast to the former two, are slow-paced, as a result that the power spectrum spike would be much cleaner, which means the brain waves picked up are more relaxed. These results are what I expected.

As for the voltage acquired, the control variable has voltage of 0.5258V. BWV1003 Allegro in A minor has a voltage of 0.5223V with a 0.66% decrease, BWV 1005 Largo in C major has a voltage of 0.52V with a 1.1% decrease. These two have a lower voltage than the control variable, as lower voltage means more focused and concentrated. BWV1004 Allemanda in D minor has a voltage of 0.5335V with a 1.46% increase, BWV 1006 Gigue in E major has a voltage of 0.5342V with a 1.6% increase. These two classical pieces have a higher voltage than the pop piece, which means that the brain waves recorded are more relaxed.

Thus, based on the experimental results considering the voltage, the sequence from the least to the most effective in relaxing to the brain would be:

1. BWV 1005 Largo in C major (slow)
2. BWV1003 Allegro in A minor(fast)
3. River Flows in You in A major (mild speed)
4. BWV1004 Allemanda in D minor (slow)
5. BWV1006 Gigue in E major (fast)

Although the results aren't exactly what I expected due to the limit of a pilot study, the differences of recorded brain waves does seem to demonstrate that according to the power spectrum spike, minor scales tend to have a soothing and slowing effect on the TS listener which results in more relaxed brain waves and major scales are much bolder and cheery, resulting in more concentrated brain waves. Fast-paced tunes would lead to result in more energetic and less relaxed. Slow-paced tunes would result the opposite.

The results from the experiment also show that otherwise, as for example, BWV 1006 Gigue in E major would be a fast-paced piece, it gave a noisy power spectrum spike, but it was the most effective in relaxing the brain. This may lead to know that only capturing alpha brain waves wouldn't be enough, while different variable errors throughout the experiment could affect the results, which outputs the voltage values with an amount of human and hardware error. Mental imagery of performance might also influence the result.

4. Conclusions

Improvement and Optimization of a Portable EEG-based BCI

The project is aimed at improving and optimizing design and implementation for an innovative low-cost portable noninvasive EEG-based BCI instrument. Along with solutions of improved optimization and enhanced stability of a prototype-based instrument, the circuit breadboard was designed and turned into a PCB layout circuit. The PCB board accordingly can be stacked on top of the Raspberry Pi 3 and it becomes a **safe, convenient, portable** BCI device based on EEG.

Music Effect of Performance Imagery and Music Listening

The study conducted an experimental design investigating noninvasive EEGbased BCI which monitors brain wave signals derived from Tourette's Syndrome patient with any music effects of Bach. Due to the limits of experimental design the research results lead to somewhat music effect of Bach, which are still undefined.

Due to the limit of a pilot study, the differences of recorded brain waves seem to illustrate the following:

1) Minor scales tend to have a soothing and slowing effect on the TS listener which results in more relaxed brain waves and major scales are much bolder and cheery, resulting in more concentrated brain waves.

2) Fast-paced tunes would lead to result in more energetic brain activity and less relaxed; Slow-paced tunes would result the opposite.

The preliminary experiment results may demonstrate that Bach classical music compared with mild pop music leads to more relaxation for TS patients.

Research Limits and Future Studies

The prototype-based portable EEG with the limit--only Alpha brain waves were designed to be detected. We would advance to have Beta brain wave simultaneously investigated for further cross analysis, and test different nodes on the brain as we continue to proceed innovative low-cost portable EEG-based BCI instruments.

The research limit revealed with the experimental design was subject to the issue of experiment reliability. Due to the lack of IRB the Tourette's patient who is the experimental subject happened to be researcher himself. As of future experimental design, application and approval of IRB (Institutional Review Board) for research ethics need to be done accordingly. Thereby, extensive lab experiments or field experiments of noninvasive EEG-based BCI can be legitimately employed. The prospect research collaboration organizations are Prof. Huey-Shyong Wang (M.D.), Neurology, Chung Gung Memorial Hospital (長庚醫院神經內科王煇雄教授團隊)and Taiwan Tourette Family Association. (台灣妥瑞症協會)

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Thoughts

At first I really didn't know what I should do for my project and spent a lot of time trying to think of ideas. I'm really grateful for my adviser, Professor Yi-Wen Liu, who gave me the time and resources that I needed and always encourages me to follow my own pace. Also many thanks to Mr. Ji-Xuan Huang, a master student with the AHG, NTHU, for helping and teaching me the skills I needed throughout the process. I'm really happy that I came up with this project, for I'm really interested in it and want to understand more about myself throughout the process. Of course I learned so much from this project, such as time scheduling, electronic and circuit design, PCB layout and a bunch of python libraries. I hope to take this project to the next level in the future, and I'm thankful for the chance to be able to take part in it.