EEG (Mind controlled) system with four trigger states in a multi-level haptic devices for disabled persons

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ABSTRACT

This paper describes the work that has been carried out so far to establish viable, practical, low equipment and low computation cost system of a wider Electroencephalogram-Surface Electromyogram (EEG-SEMG) based control system for disabled users. The system consists of the user required to perform mental tasks for our system to achieve 4 states of switching which is picked up through the EEG sensors. The system will then use this as a trigger in order to help the disabled user operate everyday equipment (e.g. electrical appliances, operate wheel chair, or personal computer). The system is designed to be compact and low cost as it is intended that the system can be worn on the patient or carried around in the wheelchair.

The setup of the equipment, the process of the experiments, the types of mental tasks that the user will be required to perform, signal processing and corresponding trigger output commands that are generated will be described.

General Terms

Design, Experimentation

Keywords

Human-computer interaction, brain-computer interface, bio-signals, mind control.

1. INTRODUCTION

Many research institutions around the world are engaged in the research of establishing EEG controlled haptic devices mainly by EEG systems or Brain Computer Interface (BCI) [1] [2] [3] [4]. There have been various levels of success using each reading scheme. Each has its own signal processing strategy and experimental setup. The virtual keyboard created by [1] uses the signal trigger of the left and right brain activity [5] [6], funneling down to the final letter. Signals of this method gathered are transient and the rate of letters generated is between 0.67 to 1.02 letters/min. If signal correspond to a mental activity of the brain can be obtained reliably from convenient sites on the scalp, the ability of mind control activity can be improved considerably. The current number of mental tasks that can be captured to improve the information-transfer rate (ITR) is determined to be around four and increasing the number of mental tasks to improve the ITR leads to small gains [3].

This paper describes the EEG experiments currently being conducted at Nanyang Technology University, Robotics Research Centre to develop a practical, low equipment cost, reliable EEG-SEMG multi level haptic device for disable persons.

2. EEG-SEMG EQUIPMENT SETUP

2.1 System Structure

In order to establish that reliable EEG signals were being captured from the test subjects, the EEG equipment initially used was the Mindset 24R, shown in figure 1. Through the supplied Mindmeld software, it was able to capture the EEG data from our test subjects. However operating external devices in real time was not possible using the manufacturer's software. Data from Mindmeld could only be exported to text or excel files and then read by NI LabVIEW to drive or operate external devices through NI-6259 Multi I/O unit.

Figure 1: Equipments and materials used in the experiment

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Mindset 24R was also very expensive and did not provide a practical low cost solution for reliable everyday EEG-SEMG use for disabled users. What was required was to build our own low cost EEG capture devices with the required low noise amplifier gain and robust filters that could measure and capture the EEG signals in the µV range, amplify them to the mV range which could than be captured by NI-6259 multi I/O unit. The signal would then be processed using LabVIEW with the appropriate signal processing strategies and output the corresponding triggers to NI-6259 where it could then be used to drive a variety of everyday devices. Once the signal could be captured on the NI platform, a variety of embedded and standalone devices, such as NI CompactRIO, could be deployed.

The proposed low cost interface used to 'replace' Mindset 24R is shown in figure 2.

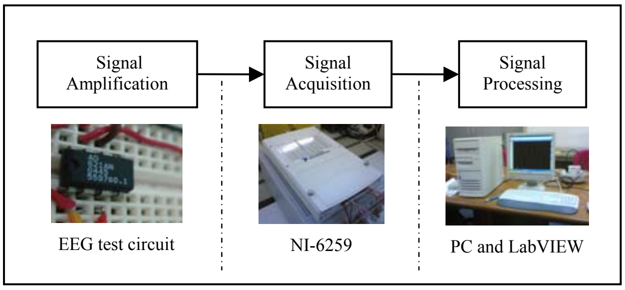

Figure 2: system structure of EEG-SEMG setup

The proposed amplification circuit, shown in figure 3, deployed a low cost instrumentation amplifier to augment the collected EEG signal in differential mode. Gain of such amplifiers was programmable to give flexibility in detecting EEG and SEMG signal. From previous experiment it was found that SEMG signal could be decently recorded by using an amplifier of at least 20dB gain. However EEG required higher gain amplification with superior S/N ratio to be properly recorded.

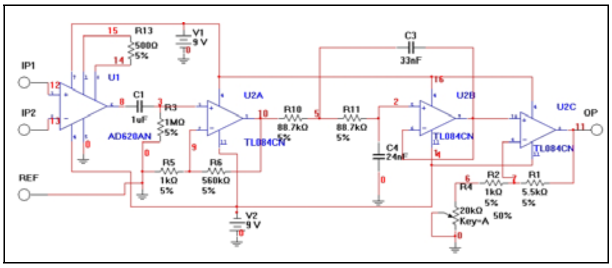

Figure 3: Proposed design of the amplification circuit

2.2 The Electrodes

To ensure good reading of EEG signal, our experiment setup used commercially available electro cap with standard 10-20 electrodes placement. The electro cap was excessive and inconvenient for daily application as it might cause dizziness after long usage. It also required long setup process with the application of electro gel. In addition, application of gel required slight skin abrasion which might put the user into the risk of infected by the blood-born pathogens [7].

Our research team intended to explore possibility of using more reliable and gel-free electrodes as proved possible by [8]. Reduction of the number of electrodes was also possible by eliminating recording channels which were redundant. Minimum number of electrodes would decrease the required installation time and further enhance the comfortability of the device.

3. EXPERIMENTS

3.1 Experiment Setup and Method

The experiments were done on several university students whose ages were between 19-23 years old. EEG signal collection was conducted using mindset 24R. Sampling rate of the recording device was set to 256 Hz. The electrodes were placed on the scalp of the test subject based on the international 10-20 standard. On each electrode, skin impedance was measured to ensure that it was below 10kΩ. Application of electrode gel is necessary to reduce the skin impedance. High skin resistance level could cause collection of excessive noise from the environment. Linked-ear referential montage was selected and ground electrode on the scalp was introduced to minimize the 50Hz artifacts originated from the power line [9].

Recording was conducted in an air conditioned room with minimal distraction. The test subject was asked to sit on an armed chair with adjustable height, as shown in figure 4. Prior briefing was given to test subjects before execution of each mental or physical task. The test subject performed assigned tasks alternately with relax state as the base line.

Figure 4: Pilot experiment setup on the test subject using Mindset 24R

The mental tasks included arithmetic calculation, movement imaginary, emotional thought by visualizing respective events, visualizing a two dimensional object and listening to songs. Meanwhile physical tasks observed were hand and finger movement, eyes closure, eyes squeezing, biting and brow movement.

During mental arithmetic test, the observer verbalized arbitrary numbers to be added by the test subject. The added numbers were categorized into two or three digits addition. At the end of one recording, the test subject was then asked to reveal the sum. In addition to that, the test subject was also given a task to generate random numbers to be added by himself for specific duration.

Movement and moving imaginary were done with the effort of minimizing transfer of movement to the head. This was to prevent excessive noise and artifacts during recording. The test subject was queued to perform the same particular task, followed by resting, repetitively in one recording session.

The same recording procedure was applied in the listening songs task. The songs were played repetitively with specific time of silence between each play. However in eye opening and closing task, adjustable lighting was introduced to the experiment. The test subject did the same eye opening and closing in both bright and dark environment. Dark environment was simulated by wrapping towel around the test subject's eyes while maintaining convenient space for eye lids movement.

3.2 Signal Processing

There were a lot of robust EEG signal analysis methods, such as Wavelet Packet [10] and Fractal Time Series [11]. However this project focused on establishing an interface between human and machine by implementing simple and basic signal processing strategy.

For offline analysis, the collected EEG signals were saved in local computer hard drive and converted into tabbed text files after the experiment. These files were then read by NI LabVIEW for further signal processing and analysis. Specifically signal points were extracted from the file and reconstructed into a waveform with pre-specified sampling rate. Upon successful construction, offline signal analysis was conducted. Initially Spectral power density was carried out as a preliminary observation tool on the reconstructed signal. This tool was available as one of the Express Virtual Instruments (VIs) in NI LabVIEW 8.0. By using this function, specific frequency band of the signal that was affected by the experiment could be extracted.

Direct visual inspection was also performed on the collected signals. Offline analysis in NI LabVIEW allowed separation of the observed signal into different band of frequency, i.e. Delta (1-4Hz), Theta (4-8Hz), Alpha (8-13Hz), Beta (13-30Hz) and Gamma (30-40Hz). The signal separation was achieved through implementing Filter Express VI, readily available in LabVIEW. Filter was specified as a third order Butterworth bandpass filter with low and high cutoff frequency dependant on the desired wave band, e.g. Alpha band had low cutoff frequency of 8Hz and high cutoff frequency of 13Hz. To enhance the visual analysis, signal squaring and averaging was applied on the filtered signal. However there was no standard VI to achieve such function in NI LabVIEW 8.0. Hence a simple squaring and averaging sub VI was created. The block diagram of the squaring and averaging sub VI for offline analysis was displayed in figure 5.

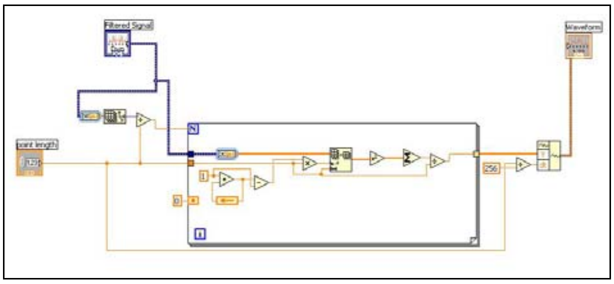

Figure 5: Sub VI for signal squaring and averaging in offline analysis

In addition, online signal acquisition and processing was possible in LabVIEW. Firstly, signal was acquired using DAQ Assistant VI that pulled the analog signal data from NI I/O hardware. Once the signal was acquired, filtering and further statistical analysis on the signal could be implemented. There were some modifications from offline signal processing. In online processing, Collector and Statistics VI were used instead of the user-defined squaring and averaging sub VI. Figure 6 shows the proposed real-time signal acquisition and processing block diagram for eyes close/open detection.

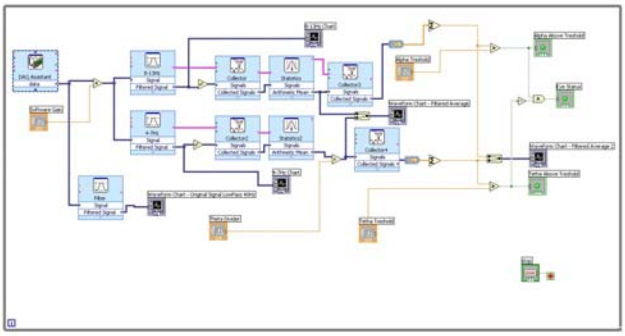

Figure 6: Online signal acquisition and processing block diagram for detection of eye close/open in LabVIEW

4. RESULTS

From the experiment, significant change was detected in the alpha band activity due to eye opening and closing task. Specifically the collected signal, after squaring and averaging every 16 points, displayed significant reduction in magnitude when the person opened his eyes in environment with normal brightness. This unique feature of alpha wave was detected from several electrodes at position Fp1, Fp2, F3, F4, O1 and O2 on the scalp, shown in figure 7.

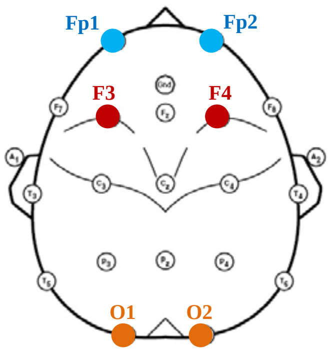

Figure 7: electrode position where change in alpha wave was detected when the test subject open and close eyes

Experiment of eye opening and closing was also conducted on the same test subject with towel covering his eyes. This was done to prevent the test subject's eyes from receiving any light during the experiment. There was no significant change in alpha wave activity detected. This suggested that the detected signal was not artifacts originating from muscle contraction. In fact many researches had been conducted to study the correlation between eye closure and EEG alpha wave activity [12] [13] and the possibility of using such signal as a trigger for brain-computer interaction [14][15][16]. Figure 8 displays the processed Alpha signal collected from electrode Fp1.

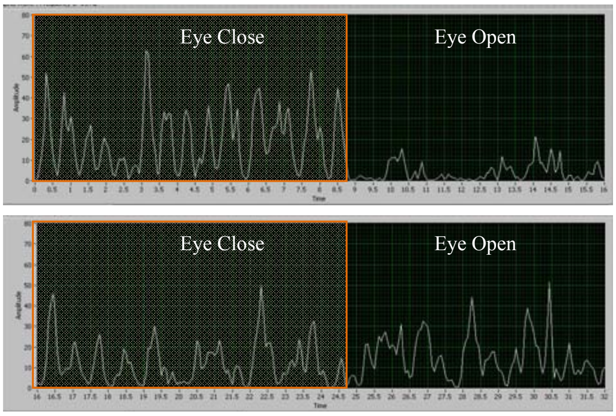

Figure 8: top – processed signal detected at Fp1 in a normal lighting condition; bottom – signal detected at Fp1 in a dark environment

In addition to eyes closure, EEG signal detected on Electrodes O1 and O2 exhibited similar reduction in alpha band when the test subject was doing mental arithmetic calculation with eyes closed. However it was observed that change in O1 was more instantaneous than at O2. Figure 9 displays the alpha band signal, after squaring and averaging, detected on O1 and O2 position when test subject was doing mental arithmetic after relax state.

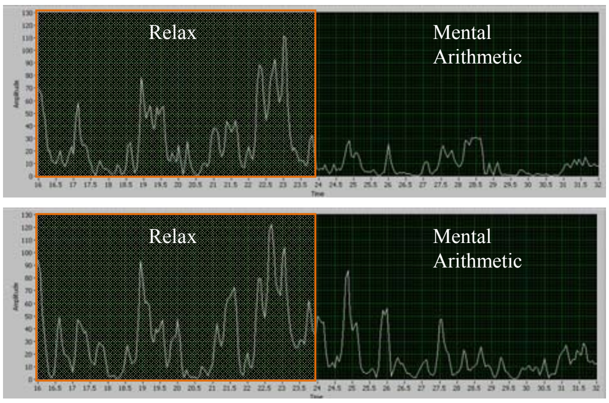

Figure 9: top – processed signal detected at O1; bottom – signal detected at O2

During the experiment some muscle artifacts were also recognized by the EEG recording instrument. Some apparent artifacts were recorded when the person was squeezing his eyes in eyes close and open position as well as blinking. Muscle artifact due to eyes squeezing in eyes open and close condition resulted in excessive signal detected in gamma wave band. It was found that not all of the wave bands were significantly affected by the muscle artifacts. Meanwhile eyes blinking artifact was recognized as a saturated signal in the original signal after the application of 50 Hz low pass filter.

Figure 10 shows artifact signals due to eyes squeezing and blinking detected from electrode channel Fp1.

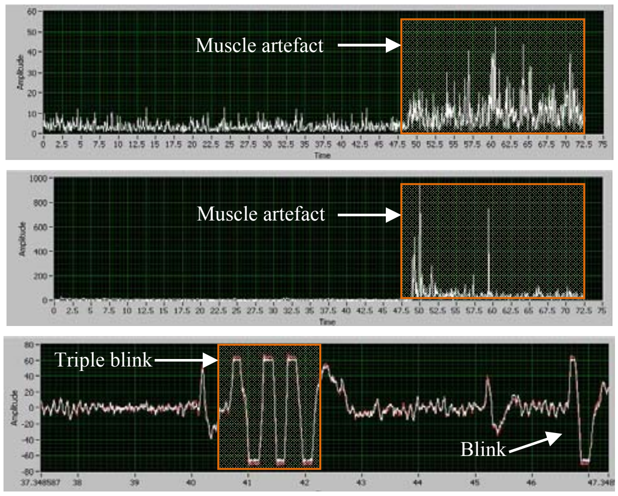

Figure 10: top – gamma wave of eyes squeezing artifact with eyes closed; middle – gamma wave of eyes squeezing artifacts in eyes open condition; bottom – blink and triple blink detected as saturated signal

Online signal processing algorithm as described in section 3.2 was also tested using simulated signal taken from existing experiment data. With proper signal threshold value, it was able to recognize difference in alpha wave activity between eye open and close within 10 seconds. Figure 11 displays screenshot of the front panel of the simulation test.

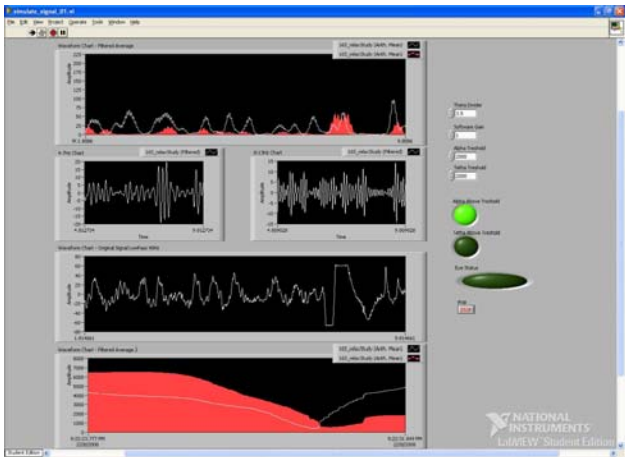

Figure 11: Screenshot of NI LabVIEW front panel for online eye open and close detection simulation

Although there were other experimental tasks (as described in the section 3.1) which had been carried out as part of the research works, the results were still in its preliminary observation and not conclusive yet. More experiments were to be conducted to support the up to date observation of those tasks. Established findings on the other experimental tasks performed would be elaborated on future proceedings.

5. DISCUSSION AND CONCLUSIONS

The conducted experiment has shown some possible trigger signals originated from the brain, specifically from Fp1, Fp2, F3, F4, O1 and O2 electrode position. These signals can be used to establish additional communication channel for Human-Machine Interface (HMI). Given the current detection speed of 0.1 triggers/second, it is possible to develop a robust haptic device, which is able to do 3 - 6 switching functions every one minutes. Moreover the fact, that only simple signal processing is being used, will reduce the manufacturing cost of the system.

In addition to the EEG signals, controllable artifacts, such as eye squeezing and triple blinking, can also be deployed as trigger signal for the application. Application of the artifact signal may extend the capability of the proposed design beyond detecting four mental tasks. Table 1 displays combinations of EEG signals and controllable artifacts, based on the current project state, which can be used as triggers with using two recording electrodes only.

Table 1: Combination of EEG features for possible triggers

Trigger	Electrode Fp1	Electrode O1
0	Eyes open	-
1	Eyes open & squeeze	-
2	Eyes close	-
3	Eyes close	squeeze
4	Eyes close	arithmetic

Previous research has shown that some voluntary muscle artifacts, such as the one observed during eyes squeezing, do not affect the entire band wave, i.e. it is observable only in Gamma band frequency. This will probably help to differentiate the EEG signal from involuntary muscle movement commonly generated by the disabled users, especially those suffered from stroke. A real experiment on such patient is necessary to support the hypothesis.

Further research on other possible trigger signals is crucial to extend the capability of the system. A more systematic approach, through the use of statistical tool, might be beneficial for the future experiment. In addition to that, realization of the amplification circuit and interface need to be completed before more exploration on the application can be done.

6. ACKNOWLEDGMENTS

The authors wish to thank the staff of Robotics Research Centre for the use of their facilities in the conduct of this project. This study is sponsored by AcRF-MOE grant RG22/06.

7. REFERENCES

[1] B. Obermaier, G. R. Müller, and G. Pfurtscheller. “Virtual keyboard” controlled by spontaneous EEG Activity. IEEE Transactions on neural Systems and Rehabilitation Engineering, Vol. 11, No. 4, December 2003, 422 - 426

[2] Benjamin J. Culpepper and Robert M Keller. Enabling computer decisions based on EEG Input. IEEE Transactions on neural Systems and Rehabilitation Engineering, Vol. 11, No. 4, December 2003, 354 - 360

[3] J Kronegg, G. Chanel, S Voloshynovskiy and T Pun. EEG Based Synchronized Brain-Computer Interfaces: A model for Optimizing the Number of Mental Tasks. IEEE Transactions on neural Systems and Rehabilitation Engineering, Vol. 15, No. 1, March 2007, 50 – 58

[4] L. Bianchi, L. R. Quitadamo, G. Garreffa, G. C. Cardarilli and M. G Marciani. Performance Evaluation and Optimization of Brain Computer Interface Systems in a Copy Spelling Task. IEEE Transs on neural Systems and Rehab Engineering, Vol. 15, No. 2, June 2007, 207-216

[5] G. Pfurtscheller, C. Neuper, C. Guger, W. Harkam, H. Ramoser, A. Schlögl, B. Obermaier, and M. Pregenzer. Current Trends in Graz Brain-Computer-Interface (BCI) Research. IEEE Transactions on Rehabilitation Engineering, Vol. 8, No.2, June 2000, 216-219

[6] G. Pfurtscheller, C. Neuper, D. Flotzinger and M. Pregenzer. EEG-based discrimination between imagination of right and left hand movement. Electroencephalography and clinical Neurophysiology, Vol. 103, 1997, 642-651

[7] T. C. Ferree, P. Luu, Gerald S. Russella, D. M. Tucker. Scalp electrode impedance, infection risk and EEG data quality. Clinical Neurophysiology, Vol. 112, 2001, 536-544

[8] Babak A. Taheri, Robert T. Knight and Rosemary L. Smith. A dry electrode for EEG recording. Electroencephalography *and* clinical Neurophysiology , Vol. 90, 1994, 376-383

[9] S. Murali and V.V. Kulish. Nullification of Electromagnetic Radiation: 50 Hz Artifact during Electroencephalogram Recording. J Med Syst, Vol. 30, 2006, 303-307

[10] Graimann B, Huggins JE, Levine SP, Pfurtscheller G. Toward a direct brain interface based on human subdural recordings and wavelet-packet analysis. IEEE Transactions on Biomedical Engineering, Vol. 51, No. 6, June 2004, 954–962

[11] V.V. Kulish, A. Sourin, O. Sourina. Human electroencephalograms seen as fractal time series: Mathematical analysis and visualization. Computers in Biology and Medicine, Vol. 36, 2006, 291–302

[12] R. M. Chapman, S. A. Shelburne Jr. and H. R. Bragdon. EEG Alpha activity influenced by visual input and not by eye position. Electroencephalography and Clinical Neurophysiology, Vol. 28, 1970, 183-189

[13] R. J. Barry, A. R. Clarke, S. J. Johnstone, C. A. Magee, J. A. Rushby. EEG differences between eyes-closed and eyes-open resting conditions. Clinical Neurophysiology, Vol. 118, 2007, 2765-2773

[14] A. Craig, P. McIsaac, Y. Tran, L. Kirkup, and A. Searle. Alpha wave reactivity following eye closure: a potential method of remote hands free control for disabled. Technology and Disability, Vol10, 1999, 187-194

[15] L. Kirkup, A. Searle, A. Craig, P. McIsaac, P. Moses. EEG-based system for rapid on-off switching without prior learning. Medical and Biological Engineering and Computing, Vol. 35, September 1997, 504-509

[16] J. M. Heasman, T. R. D. Scott, L. Kirkup, R. Y. Flynn, V. A. Vare and C. R. Gschwind. Control of a hand grasp neuroprosthesis using an electroencephalogram-triggered switch: demonstration of improvements in performance using wavepacket analysis. Medical and Biological Engineering and Computing, Vol. 40, 2002, 588-593