A step towards multi-level human interface devices: a system that responds to EEG/SEMG triggers

John G. Heng*

N3.2-01-24, School of Mechanical and Aerospace Engineering,
Nanyang Technological University,
Nanyang Avenue, 639798, Singapore
Fax: +65 67924062
E-mail: mkhheng@ntu.edu.sg
*Corresponding author

Subhasis Banerji

N3-01a-01, Robotics Research Centre,
School of Mechanical and Aerospace Engineering,
Nanyang Technological University,
Nanyang Avenue, 639798, Singapore
Fax: +65 67924062
E-mail: bane0002@ntu.edu.sg

Abstract: This project forms the basis of our wider project scope which is to develop a multi-level interface device, which can increase the levels of interaction at the human machine interface (HMI).

This paper describes the work done so far to establish a viable, practical, low equipment and low computation cost system which is responsive to electroencephalogram-surface electromyogram (EEG-SEMG) triggers. The system consists of the user required to perform tasks for our system to achieve four states of switching. The system then uses this as a trigger in order to help the user operate everyday equipment. It is intended that the device can be worn or carried around easily, whether the person is able-bodied or disabled.

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

Keywords: human machine interface; HMI; human computer interface; electroencephalogram; EEG; surface electromyogram; SEMG; mind control; LabView; biomechatronics; biomedical robotics; multi-level interface; disabled; mental tasks.

Reference to this paper should be made as follows: Heng, J.G. and Banerji, S. (2010) ‘A step towards multi-level human interface devices: a system that responds to EEG/SEMG triggers’, *Int. J. Biomechatronics and Biomedical Robotics*, Vol. 1, No. 2, pp.93–98.

Biographical notes: John Heng is an Assistant Professor at Nanyang Technological University, School of Mechanical and Aerospace Engineering, Division of Mechatronics and Design, Singapore. He received his PhD in Design, Manufacture and Engineering Management from Strathclyde University, Glasgow, UK in September 1995. He is a member of the Institution of Mechanical Engineers (IMechE), Institution of Engineering and Technology (IET) and is a Chartered Engineer registered with the UK Engineering Council since 1996. His current research interests lie in rehabilitation engineering and assistive technologies. In particular, active accelerated rehabilitation in stroke patients, extending to multi-level haptic interface devices for enhanced man-machine interaction. His teaching responsibilities currently include subjects on mechanical and mechatronics system design and analysis.

Subhasis Banerji is a Research Associate at the Robotics Research Centre, School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore. After graduating in Production Engineering in 1987, he has worked in industry for 18 years, specialising in the design of robotics and mechatronics application in the foods, beverages and pharmaceutical industries in India. In the past few years, he has spent his energies studying natural functional recovery in human beings which led to completing his MSc in Biomedical Engineering in Singapore. His current research interests include brain plasticity, study of biosignals, and application of robotics technologies to accelerated functional recovery from stroke.

Copyright © 2010 Inderscience Enterprises Ltd.

1 Introduction

In a constantly fast paced world of ever-increasing complexity, the demands on individuals, operators and machines are nearing a saturation point (e.g., fighter pilots, professional computer gamers, etc…).

There is a strong need to re-assess how we as humans interact with technology. Man's interaction with nature has always been multi-sensory and multi-level, born out of man's nature to be a multi-tasker. We find more and more people associating intimately with technology for day to day activities.

As part of a wider effort to develop a multi-level haptic device so as to increase the levels of interaction at the man-machine interface, we currently define four levels of HMI interaction.

Level 1 being the direct physical input, e.g., keyboard, mouse, joystick, etc.

Level 2 the secondary input, e.g., head tracking, and eye tracking.

Level 3 is the neuro and muscle input, e.g., EEG, SEMG.

Level 4 involves involuntary biosignal input, e.g., heart rate, respiratory rate, etc.

This work focuses on the Level 3 interface of EEG-SEMG input.

Many research institutions around the world are engaged in the research of establishing EEG controlled devices mainly by brain computer interface (BCI) (Obermaier et al., 2003; Culpepper and Keller, 2003; Kronegg et al., 2007; Bianchi et al., 2007). 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 Obermaier et al. (2003) uses the signal trigger of the left and right brain activity (Pfurtscheller et al., 1997, 2000), funnelling 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 a mental activity of the brain can be obtained reliably from convenient sites of the brain, the ability of mind control 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 (Kronegg et al., 2007).

This paper describes the EEG-SEMG experiments currently being carried out at Nanyang Technology University, Robotics Research Centre to develop a practical, low equipment cost, reliable EEG-SEMG (mind controlled) device for disabled persons and able people working in challenging environments.

2 EEG-SEMG equipment setup

2.1 System structure

In order to establish that reliable EEG signals were being captured on the test subjects, the EEG equipment initially used was the Mindset 24R, in which 19 channels were used for experiments. However, operating external devices in real time was not possible using the manufacturer's software. Data 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.

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 required 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 are available such as NI CompactRIO could be deployed. The proposed low cost interface used to 'replace' Mindset 24R is shown in Figure 1.

Figure 1 System structure of EEG-SEMG setup

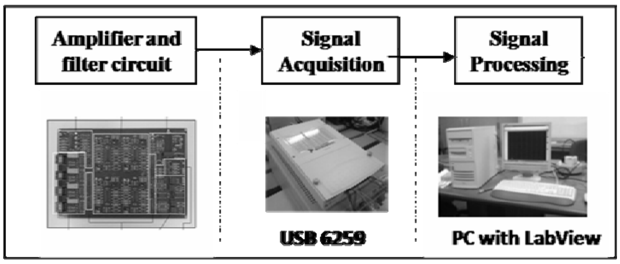
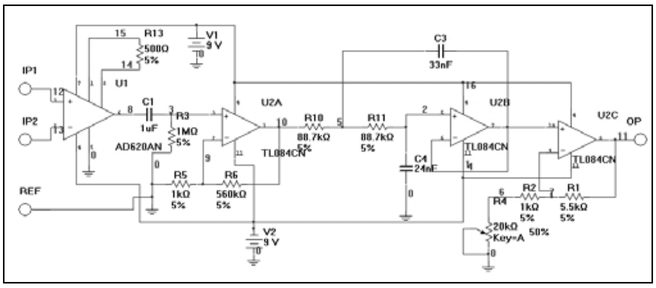


Figure 2 Design of the amplification circuit



Our amplification circuit, shown in Figure 2, 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 20 dB gain. However, EEG required higher gain amplification with superior S/N ratio to be properly recorded.

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 expensive 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 at risk of infection by the blood-born pathogens (Ferree et al., 2001). Our research team intended to explore the possibility of using a more reliable and gel-free electrode design (Taheri et al., 1994). Reduction of the number of electrodes was also possible.

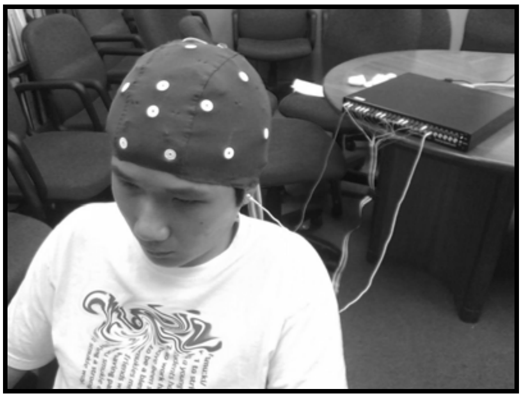
3 Experiments

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 electrodes skin impedance was measured to ensure that it was below 10 kΩ. High skin resistance level caused collection of excessive noise from the environment. Application of electrode gel is necessary to reduce the skin impedance. Linked-ear referential montage was selected and ground electrode on the scalp was introduced to minimise the 50 Hz artefacts originated from the power line (Murali and Kulish, 2006).

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 3. Prior briefing was given to test subjects before execution of each mental or physical task. The test subject performed assigned tasks alternatively with relax state as the base line.

Figure 3 Pilot experiment setup on the test subject using mindset 24R



The mental tasks included arithmetic calculation, movement imagery, emotional thought by visualising respective events, visualising 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 verbalised arbitrary numbers to be added by the test subject. At the end of one recording, the test subject was then asked to reveal the sum. The added numbers were categorised into two or three digits addition. The test subject was also given a task to generate arbitrary number to be added by himself for specific duration.

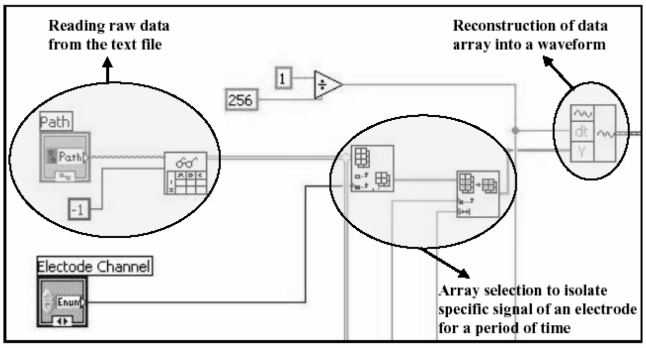
Imaginary movement was done with the idea of minimising transfer of actual movement to the head. This is to prevent excessive noise artefacts during recording. The test subject was queued to perform the same particular task, followed by resting, repetitively in one recording session. In eye opening and closing task, adjustable lighting was introduced to the experiment. The test subject did the same eye opening and closing on 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 (Graimann et al., 2004) and fractal time series (Kulish et al., 2006). However, this project focuses on establishing an interface between human and machine by implementing simple and basic signal processing strategy.

The collected EEG signals were saved in local computer hard drive and converted into tabbed text files after the experiment. These files was 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. The process of importing recorded EEG data in LabVIEW is elaborated in Figure 4.

Figure 4 Functions to import EEG raw data into LabVIEW



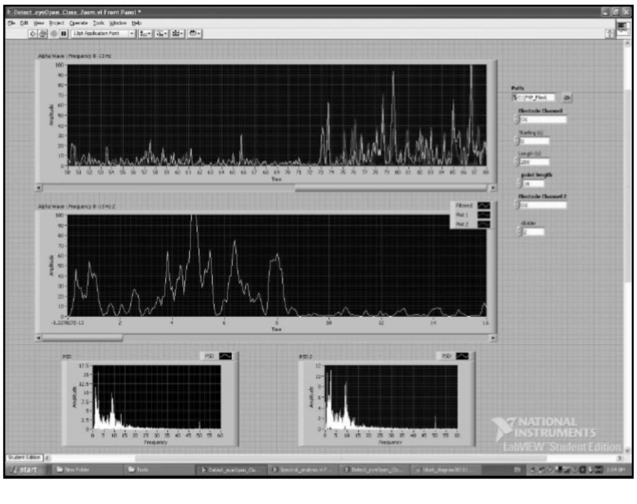
Upon successful waveform reconstruction further processing and analysis could be performed. Initially, Spectral power density analysis was carried out as the preliminary observation tool to determine the effected frequency of the signal. This tool was available as one of the express virtual instruments (VIs) in NI LabVIEW 8.0. There was similar function available in mindmeld 24R for frequency analysis. However, LabVIEW was able to isolate and analyse certain portion of the signals.

Direct visual inspection was also performed on the collected signals. Post-experiment analysis in NI LabVIEW allowed separation of the observed signal into different frequency band, i.e., delta (1–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz) and gamma (30–40 Hz). Filter was specified as the third order Butterworth bandpass filter with low and high cut-off frequency defined based on the desired frequency band.

To further enhance visual analysis of the electroencephalograms, the collected and filtered signal was further processed by using simple signal processing strategies. One of them was signal averaging and squaring. There was no standard sub-VI to achieve such function in LabVIEW 8.0. Hence, a simple squaring and averaging sub-VI was created for the purpose of offline analysis of the experiment result. The squaring and averaging algorithm deploys a for-loop that accepts a filtered EEG signal as input. The number of loops is defined by dividing the point length of the whole input signal with the point length to be averaged. In the loop, the specific signal points are isolated from the overall input signal and squared. The isolated signal points are then averaged by first summing all the signal values, followed by division by the pre-specified signal length.

The final value was then stored as an array point at the end of the loop. At the next loop, another chunk of the signal was processed with the same steps. It was repeated until the last signal point. At the end of the loop, the array of the averaged points was reconstructed back into a signal. Application of averaging and filtering function as well as power spectral density VI is also incorporated in the block diagram. Figure 5 shows the screenshot of the LabVIEW front panel used for visual verification in the experiment.

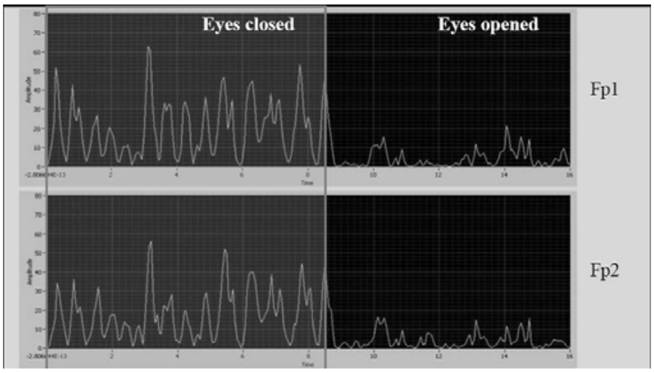
Figure 5 Screenshot of the LabVIEW front panel



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 (Figure 6). This unique feature of alpha wave was detected from several electrodes at position Fp1, Fp2, F3, F4, O1 and O2 on the scalp, as per the 10–20 systems.

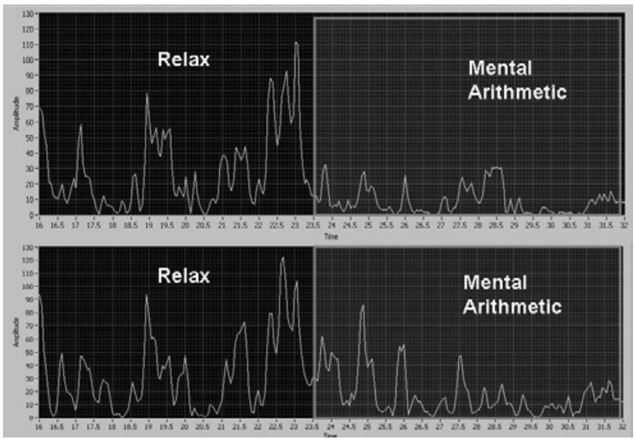
Figure 6 Top – processed signal detected at Fp1 in a normal lighting condition; bottom – signal detected at Fp1 in a dark environment



There was no significant change in alpha wave activity detected. This suggested that the detected signal is not artefacts originating from muscle contraction. In fact, many studies had been conducted to study the correlation between eye closure and EEG alpha wave (Chapman et al., 1970; Barry et al., 2007) and the possibility of using such signal as a trigger for brain computer interaction (Craig et al., 1999; Kirkup et al., 1997; Heasman et al., 2002).

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 with eyes closed. However, it was observed that change in O1 is more precise than at O2. Figure 7 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 7 Top – processed signal detected at O1; bottom – signal detected at O2

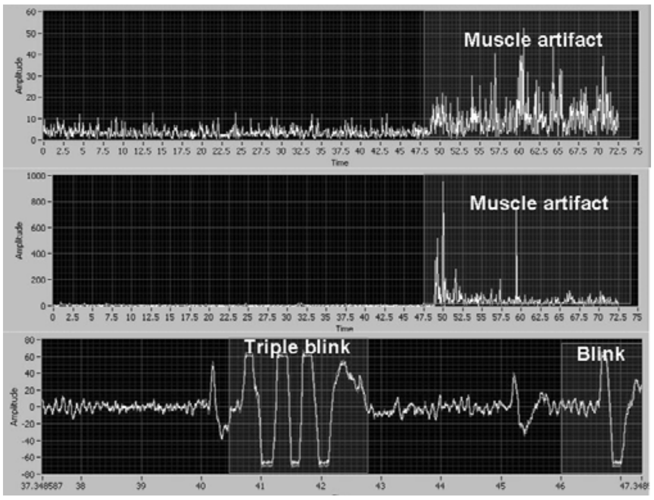


During the experiment some muscle artefacts were also recognised by the recording instrument. Some apparent artefacts were recorded when the person was squeezing his eyes in eyes close and open position as well as blinking. Muscle artefact due to eyes squeezing in eyes open and close condition resulted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

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 recognise difference in alpha wave activity between eye open and close within 10 seconds.

Besides EEG signal, controllable artefacts, such as eye squeezing and triple blinking, can also be used as trigger signal for the application (Figure 8). Application of the artefact signal may extend the ability of the proposed design beyond detecting four mental tasks. Table 1 displays possible combination of EEG signals and controllable artefacts, based on the current state of the project, which can be used as triggers with using two electrodes only.

Figure 8 Top – gamma wave of eyes squeezing artefact with eyes closed; middle – gamma wave of eyes squeezing artefacts in eyes open condition; bottom – blink and triple blink detected as saturated signal



If signals are tapped from two different areas of the head, it is possible to isolate and detect EEG and SEMG signals separately and simultaneously. For example, detecting the alpha band increase at O1, O2 and the SEMG of the brow squeeze can give us two simultaneous switches. The mental arithmetic and the biting signals described above is another combination where the two signals do not interfere with one another. These signals detected at the head can be also combined with muscle SEMG from anywhere in the body. Whereas, the EEG or facial SEMG signal can decide the level or intensity of effort, the SEMG can be the ON/OFF switch for the action, based on previously calibrated thresholds.

Table 1 Combination of EEG signal features for possible triggers

Trigger	*Electrode Fp1*	*Electrode O1*
0	Eyes open	-
1	Eyes open and squeeze	-
2	Eyes close	-
3	Eyes close	Squeeze
4	Eyes close	Arithmetic

5 Conclusions and future work

The conducted experiments have 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. Given the current detection speed of 0.1 trigger/second, it is possible to design a robust and effective device with low manufacturing cost.

Further research on other possible trigger signals can extend the capability of the system. A better statistical tool might be beneficial for future experiments. The research group is working towards hardware development for the realisation of the unified EEG/SEMG interface for real time analysis and trigger generation. The real time interface will then enable use of various EEG/SEMG controlled devices by able bodied people, as well as those with motor and other disabilities.

Acknowledgements

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, Singapore. Our gratitude to William Kangdra for his involvement in this project who has since left the project group.

References

Barry, R.J., Clarke, A.R., Johnstone, S.J., Magee, C.A. and Rushby, J.A. (2007) 'EEG differences between eyes-closed and eyes-open resting conditions', *Clinical Neurophysiology*, Vol. 118, pp.2765–2773.

Bianchi, L., Quitadamo, L.R., Garreffa, G., Cardarilli, G.C. and Marciani, M.G. (2007) 'Performance evaluation and optimization of brain computer interface systems in a copy spelling task', *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, June, Vol. 15, No. 2, pp.207–216.

Chapman, R.M., Shelburne, S.A. Jr. and Bragdon, H.R. (1970) 'EEG alpha activity influenced by visual input and not by eye position', *Electroencephalography and Clinical Neurophysiology*, Vol. 28, pp.183–189.

Craig, A., McIsaac, P., Tran, Y., Kirkup, L. and Searle, A. (1999) 'Alpha wave reactivity following eye closure: a potential method of remote hands free control for disabled', *Technology and Disability*, Vol. 10, pp.187–194.

Culpepper, J. and Keller, R.M. (2003) 'Enabling computer decisions based on EEG input', *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, December, Vol. 11, No. 4, pp.354–360.

Ferree, T.C., Luu, P., Gerald, S.R. and Tucker, D.M. (2001) 'Scalp electrode impedance, infection risk and EEG data quality', *Clinical Neurophysiology*, Vol. 112, pp.536–544.

Graimann, B., Huggins, J.E., Levine, S.P. and Pfurtscheller, G. (2004) 'Toward a direct brain interface based on human subdural recordings and wavelet-packet analysis', *IEEE Transactions on Biomedical Engineering*, June, Vol. 51, No. 6, pp.954–962.

Heasman, J.M., Scott, T.R.D., Kirkup, L., Flynn, R.Y., Vare, V.A. and Gschwind, C.R. (2002) '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, pp.588–593.

Kirkup, L., Searle, A., Craig, A., McIsaac, P. and Moses, P. (1997) 'EEG-based system for rapid on-off switching without prior learning', *Medical and Biological Engineering and Computing*, September, Vol. 35, pp.504–509.

Kronegg, J., Chanel, G., Voloshynovskiy, S. and Pun, T. (2007) 'EEG based synchronized brain-computer interfaces: a model for optimizing the number of mental tasks', *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, March, Vol. 15, No. 1, pp.50–58.

Kulish, V.V., Sourin, A. and Sourina, O. (2006) 'Human electroencephalograms seen as fractal time series: mathematical analysis and visualization', *Computers in Biology and Medicine*, Vol. 36, pp.291–302.

Murali, S. and Kulish, V.V. (2006) 'Nullification of electromagnetic radiation: 50 Hz artifact during electroencephalogram recording', *Journal of Medical Systems*, Vol. 30, pp.303–307.

Obermaier, B., Müller, G.R. and Pfurtscheller, G. (2003) ''Virtual keyboard' controlled by spontaneous EEG activity', *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, December, Vol. 11, No. 4, pp.422–426B.

Pfurtscheller, G., Neuper, C., Flotzinger, D. and Pregenzer, M. (1997) 'EEG-based discrimination between imagination of right and left hand movement', *Electroencephalography and Clinical Neurophysiology*, Vol. 103, pp.642–651.

Pfurtscheller, G., Neuper, C., Guger, C., Harkam, W., Ramoser, H., Schlögl, A., Obermaier, B. and Pregenzer, M. (2000) 'Current trends in Graz brain-computer-interface (BCI) research', *IEEE Transactions on Rehabilitation Engineering*, June, Vol. 8, No. 2, pp.216–219.

Taheri, B.A., Knight, R.T. and Smith, R.L. (1994) 'A dry electrode for EEG recording', *Electroencephalography and Clinical Neurophysiology*, Vol. 90, pp.376–383.