Investigation of the Effect of Video Game Play on Cognitive Behaviour using Adaptive Noise Cancellation and Wavelet Transform

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Abstract
This work shows the effect on cognitive performance while playing action video game based on the beta waves variation. The Present work initially shows the Signal to Noise Ratio (SNR) improvement by using an adaptive noise cancellation technique for suppressing the noise, here is to eliminate the ECG artifact from noisy EEG signal and then the wavelet analysis of EEG signals is done to study the brain activity. EEG signal is acquired experimentally from the subject by using the 10-20 system of electrode placement. In first stage the adaptive noise cancellation technique is implemented with the help of an adaptive filter to remove the artifact and hence to improve the signal to noise ratio (SNR). The adaptive algorithm used for the filter is the LMS which is a FIR based digital filter. A synthetic signal is also simulated to give a concept of the effect of the proposed active noise cancellation method to remove the noise or artifact. Synthetic signal analysis shows the suitability of the adaptive noise cancellation technique which is a de-noising tool, and here the de-noised signal is the error signal. Then in second stage, the de-noised signal is processed and the Wavelet Transform is used to provide the information of the β-activity. EEG signals from the frontal and parietal lobes are recorded and the effect is analyzed as the frontal and parietal lobe is associated with reasoning, planning, problem solving and orientation, recognition and perception of stimuli respectively. However, the presence of artifacts like electrocardiogram(ECG) in the EEG signal is a major problem in the study of brain activity. Though it is needed to record cerebral signals, it also records the signals that are not of cerebral origin called artifacts. Artifact removal from EEG signals is essential for better analysis and diagnosis. The EEG signal acquired from a patient is generally noisy and non-stationary by nature. So an adaptive noise cancellation technique is used to remove the artifact and hence the signal to noise ratio of the acquired EEG signal is improved. The EEG signal alone, is acquired from the subject and is used as the reference signal in the ANC noise cancellation technique to get the de-noise EEG signal. Then the de-noised signal is processed and the Wavelet Transform (WT) is used to provide the information of the β-activity. Experiments reveal that the proposed ANC method of noise or artifact removal along with the Wavelet Transform can be used to provide a clear information of the β-activity during the action video game play. The increase in the Beta activity in the eleventh hour of game play than the game play of the first hour indicates increase in cognition due to training in action video game play.

Keywords: Artifacts, Adaptive Filter, Wavelet Transform, ANC, ECG, EEG

1. Introduction
The electroencephalogram (EEG) signals are used in neuroscience to correlate the brain activity. In research studies the effects on cognitive performance while playing action video games is investigated. To examine the brain dynamics during the play of action video game the EEG can be used. The EEG frequency range is classified into several frequency components as delta rhythm (0-4Hz), theta rhythm (4-8Hz), alpha rhythm (8-12Hz), beta rhythm (12-30Hz), and gamma rhythm (above 30Hz). The theta and alpha reflect the information processing involving attention and working memory retention, whereas the beta and gamma reflect the processing of the contents of experience. While all frequencies work in concert, individual frequencies can be associated with...
specific cognitive processes\(^4\). The focus of this paper is to investigate the dynamic brain activity in the frontal lobe and parietal lobe, during continuous video game play\(^5\). An EEG signal is the brain electric activities recorded by placing electrodes on the scalp. The EEG analysis technique is used to detect the brain functions and also can be used to detect the brain abnormalities. The unwanted cerebral signals called artifacts, obscure the EEG signal while recording. The presence of artifacts in the EEG may reduce its clinical usefulness. So the suppression of these artifacts is very essential for the processing of the EEG signals\(^6\). The Electrocardiogram (ECG) signals are the most commonly artifacts in EEG signals. The ECG artifacts affect the EEG signals. The conventional filtering techniques cannot be applied to minimize ECG artifacts from the noisy EEG signals. Hence, adaptive noise-cancelling schemes can be applied effectively in these situations\(^7\). The presence of artifacts in EEG may reduce the clinical usefulness of the EEG signals and the analysis may be difficult so in the first stage of the proposed technique, this work focuses on removing ECG artifacts present in the EEG signal. The present work is implemented by using an adaptive filtering (ANC) technique for removing the noise from the EEG and hence for the improvement of the signal to noise ratio (SNR\(^8\)). The ANC technique is designed with the help of a LMS adaptive filter. The LMS filter is based on the Finite Impulse Response\(^9\). Then in second stage the wavelet transform is used on the de-noised EEG signal to give information about the β-activity of the brain signal\(^10\).

2. Underlying Theory

The proposed method of signal processing is implemented in two stages. The SNR of the EEG signal acquired from the subject is improved by implementing the ANC technique in first stage. In this ANC technique an adaptive FIR based LMS filter is used. The ECG signal acquired alone from the subject is used as the reference signal for the adaptive filter. In the next stage, feature is extracted from the filtered EEG signal. Feature extraction is done with the implementation of the wavelet transform\(^11\).

2.1 Adaptive Noise Cancellation

The signal to noise ratio of the desired EEG signal can be improved by suppressing the artifact. This noise suppression can be possible by the implementation of the Adaptive noise cancellation (ANC) technique. The ANC technique is used to enhance the SNR of the acquired EEG signal. For the ANC to be implemented digital filters are used, FIR filters are mostly used as compare to IIR filters. In this present work, a finite impulse response filter (FIR) is used. The schematic diagram of an adaptive noise cancellation (ANC) scheme is shown below in Figure 1. This scheme makes use of an reference input signal \(G_n\). This input signal \(G_n\) is filtered by an adaptive filter and then subtracted from a primary noisy input signal \(X[n]\). The primary input signal \(X[n]\) is noisy in nature as it containing both the signal and the noise, \(x[n] + G_n\). The noise is eliminated due to the subtraction between the noisy primary signal and the reference signal. This way the noise cancellation is done. An appropriate adaptive process is followed to control the Filtering and subtraction. Adjustment is accomplished through an adaptive algorithm that responds to an error signal dependent, among other things, on the filter’s output.

![Figure 1. Schematic of the ANC Scheme.](image)

2.2 Wavelet Transform

Wavelet transformation is one of the most popular of the time-frequency-transformations. In wavelet transformation a function is represented by wavelets. For physiological signal analysis like EEG analysis the frequency domain analysis is very useful. The EEG signals are dynamic, sometimes transient and mostly non-stationary in nature. So for its better practical analysis, we need to know their frequency components as well as times at which they occur. So, their time-domain analysis also needed. The wavelet transform of a signal \(f(t)\) at the scale \(a\) and position \(b\) is computed by correlating \(f(t)\) with a wavelet atom:

\[
W_f(a, b) = \int_{-\infty}^{\infty} f(t) \frac{1}{\sqrt{a}} \psi^* \left( \frac{t-b}{a} \right) dt = < f(t), \psi_{a,b} >
\]
2.3 Wavelet Packets

In high frequency region the frequency resolution is very poor in case of wavelet transform. This is the one of the major drawback of the Wavelet Transform. In wavelet packet by using the tow-scale relations repeatedly each octave frequency band of wavelet spectrum is further subdivided into finer frequency band. In wavelet packet the function can be obtained by:

\[
\Psi_{j+1}^{2j-1}(t) = \sqrt{2} \sum_{k=-\infty}^{\infty} h(k) \Psi_{j}^{j}(2t - k)
\]

\[
\Psi_{j+1}^{2j}(t) = \sqrt{2} \sum_{k=-\infty}^{\infty} g(k) \Psi_{j}^{j}(2t - k)
\]

The first wavelet \(\Psi(t)\) is the mother wavelet function. Then the \(h(k)\) and \(g(k)\) are the quadrature mirror filters which is associated with the mother wavelet function and scaling function. The relations between the \(j\) level and the \(j+1\) level which is recursive are:

\[
f_{j+1}^{2j-1}(t) = \sum_{k=-\infty}^{\infty} h(k)f_{j}^{j}(2t - k)
\]

\[
f_{j+1}^{2j}(t) = \sum_{k=-\infty}^{\infty} g(k)f_{j}^{j}(2t - k)
\]

And at the position \(k\) of \(j\) level the wavelet coefficients \(c_{j}^{k}\) can be obtain from:

\[
c_{j}^{k} = \int_{-\infty}^{\infty} f(t)\Psi_{j}^{j}(t)dt
\]

3. Validation of Proposed Algorithm on Synthetic Signal for Achieving Adaptive Noise Cancellation

In this section the ANC is used on synthetic signal for removing the artifact and the performance of the proposed method is evaluated. The technique is to use the ECG signal as a reference signal for the adaptive filter, used for adaptive noise cancellation (ANC) of the noisy EEG signal (EEG signal mixed with ECG artifact). In line with that, a synthetic signal that is the EEG signal mixed with the ECG artifact is generated and as given below:

\[X(n) = x[n] + G_{n}\]

The synthetic signal is the combination of the desired signal \(x(n)\) and the ECG artifact \(G_{n}\). The signals \(X(n), G_{n}\) and \(x(n)\) are shown in Fig.2(a)–(c), respectively.

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![Figure 2](a) Synthetic signal to check the suitability of the proposed technique; (a) Generated synthetic signal (b) Reference ECG artifact (c) Desired signal.

In the simulation analysis, the synthetic signal \(X(n)\) is analogous to the noisy EEG (EEG signal mixed with ECG artifact) signal and \(G_{n}\) is analogous to the ECG signal. In this present simulation study, the filter is designed to extract \(x(n)\) from \(X(n)\) by implementing ANC. The adaptive noise cancellation is achieved by using an adaptive filter. In this work the adaptive filter is a digital FIR filter along with the LMS adaptive algorithm. In the proposed method the signal \(G_{n}\) is used as the reference signal and the input to the adaptive filter. The schematic of the ANC scheme is shown below in Figure 3(a). An adaptive filter is designed and this is implemented with a filter length of 25 and a step size of 0.01. This adaptive filter is used for the purpose of a noise or artifact cancellation. The error signal \(E(n)\) is the de-noised signal in the present work. The corresponding error signal \(E(n)\) after implementation of ANC is shown in Figure 3(b). From the figure the result shows the suitability and the usefulness of the adaptive filter in cancelling the artifact and recovering the desired signal.
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EEG signal is acquired from the subject by using the bipolar electrodes from channels of CZ, PZ and A2 according to the 10-20 international system as shown in the Figure 5.

Figure 5. The 10-20 system of Electrode placement.

During first hour of video game play EEG recording is taken. Then to know the effect of action video game play the subject is instructed and allowed to play the game for 10 hours. The subject is instructed to play the game for 1 hour per day and 1 hour recording is then taken again. During the period of recording the subject is strictly directed to minimize eye blinks and muscle movements to avoid the addition of artifacts. For the purpose of processing analysis both first hour of action video game play and eleventh hour of action video game play recording is taken and in both the case first 30 minutes of game play recording is taken for processing. ANC is implemented on both of these recorded EEG signals for reducing the ECG artifact. The ECG artifact present in the recorded EEG signal is removed by using ANC based on Least mean square algorithm as shown in Figure 6.

For wavelet analysis each 30 minutes of data set is divided into 15 non-overlapping epochs which is of 2 minutes each. Then wavelet transform is used. Seven levels wavelet packet decomposition with ‘db4’ is used for each 2 minutes epoch of EEG signals. Then from the wavelet packet coefficients the spectral energy bands of EEG, corresponding to delta, theta, alpha, beta and gamma are reconstructed.

Figure 6. Noisy EEG signal with ECG artifact and recovered EEG signal after Active Noise Cancellation.
5. Results and Discussion

In the proposed method of EEG signal processing, the Adaptive Noise Cancellation (ANC) is implemented on the noisy EEG signals acquired from the subject. The ECG signal acquired alone from the subject is used as the reference signal for the adaptive digital filter. A Least Mean Square (LMS) adaptive algorithm based Finite Impulse Response (FIR) digital filter having filter length of 25 and step size of 0.05 is designed and implemented. Then wavelet is designed and implementation is carried out to provide the time-frequency information of the EEG signal and hence the β-activity of the brain.

The main objective of this work is to find out the effect on cognitive performance, if action video game is playing by a subject for a longer time. Spontaneous Beta-activity of brain is studied here. Beta-wave of EEG signal is associated with active consciousness, anxious thinking and awareness. So if there is an increase in Beta-wave with the playing of action video game that indicates high level of concentration and attention and hence it indicates an increase in cognition. The increase in Beta-wave can be detected in a time-domain analysis. A time-domain analysis of the increment in Beta-wave is shown in Figure 7 and Figure 8. The variation in Beta-band energy of frontal lobe and parietal lobe from the base line is shown in Figure 7 and Figure 8 respectively. β-waves in both the frontal lobe and parietal lobe is observed. From the result it is noticed that there is a significant difference between first hour and eleventh hour of action video game play.

The above experimental analysis shows the usefulness of ANC for removing the artifact and hence to increase the SNR and also the usefulness of wavelet transform. The wavelet transform gives better time-frequency information. It can be observed that ANC can act as a better de-noising tool and then for the further measurement and analysis the wavelet transform gives more precise information both in time and frequency scale. The proposed method is suitable for the precise measurement where the physiological signal has poor SNR (signal to noise ratio).

6. Conclusion

Experiments reveal that the proposed ANC method of noise or artifact removal along with the wavelet Transform can be used to provide a clear information of the β-activity during the action video game play. The study carried out in this work conclude that the adaptive noise cancellation technique using ECG signal as the reference signal for the adaptive filter improves the SNR of the noisy EEG signal acquired experimentally from the subject. The proposed technique and the methodology of wavelet design and its implementation for feature extraction provide adequate and precise time frequency information in order to analyze the acquired EEG signals from the experimental setup. This gives better information and provides precise information on β-wave and hence the effect on cognitive.
7. References

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