Development of multithread acquisition system for high quality EEG signal measurement

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Abstract. This work was concerned on development of the EEG acquisition and EEG signal processing by adding active electrodes and implementing multithread techniques. By using active electrodes, mounting them on the scalp surface would be easier to capture low signals of less than 1µV. The active electrodes were used to reduce noise when transfer signals from the electrode to the acquisition systems which equipped 20 gain. The verification was performed by comparing the active and passive electrodes using NETECH MiniSIM EEG Simulator 330. The advantage of this research was to reduce time delay for EEG signal computation on 32 channels. The acquisition system was based on Raspberry Pi and ADS1299 with multithread signal treatment. Signal filtering was performed into different threads and put all the EEG features into the database. A PC was used to process signal calculation such as processing FFT, signal feature extractions, and signal analysis. These calculations were divided into several functionally independent computations. The signals of each channel were calculated into different threads. The results of this work showed the effectiveness of the multithreaded method for processing large amounts of data (32 channels of 24 bits EEG signal) with low noise levels on the active electrodes.

1. Introduction

Electroencephalography (EEG) is a non-invasive method to measure the electrical activity of the brain[1]. The Electrodes are placing on the scalp using conductive gel for maintain good contact between scalp and electrodes. The brain signal amplitude typically is about 10 to 100 µV with classified into 5 frequency band, namely delta (1-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta (13-30 Hz)[2].

On the previous research had been developed 8 channels custom EEG Acquisition board using ADS1299 and Arduino Uno, next to 16 channels custom EEG Acquisition board using ADS1299 and Arduino Due with OpenBCI Processing GUI then develop 32 Channels Custom EEG Acquisition Board with MSP432P401R[3, 4]. The latest of EEG data acquisition was to develop 32 Channels Custom EEG Acquisition board with Raspberry Pi using passive electrodes. There were many attempts to add active electrodes for data acquisition of EEG signals and implementing multithread techniques[5-7]. Which is on the previous develop using single thread processing with passive electrode.
Multi-threading is a technique in computer programming that aims to make processes run in parallel (simultaneously). With this technique, it is possible to make a program do multiple jobs at one time. This technique has advantages and disadvantages, it depends on the case.

The purposes of this study were to develop for better and faster EEG data acquisition based on active electrodes and multithreading techniques. The main advantages of using this technique is that it can make faster because it is done in parallel, while the disadvantage is that this technique requires a very large cost and more resources in contrast with a single-threading. The use of active electrodes and multithreading techniques would be beneficial to determining Ischaemic stroke identification based on FFT, Wavelet and RPR calculations.

2. Methods

2.1. Hardware design

The EEG hardware was modified from the previous 32 EEG channel [2]. The wet electrodes were replaced with dry electrodes using op-amp amplification. The EEG signals were captured by the electrodes and transmitted to the acquisition system via biomedical cables. In the transmission, it is possible that there is interference while being recorded. However, when the system use active electrodes, it may reduce noises while transferring signal into acquisition system due to pre-amplification in the electrodes.

![Active Electrode Circuit Diagram](image)

**Figure 1.** Active electrode circuit diagram

The active electrode was designed using low noise op-amp OPA378 which was suitable for the use of biomedical signals processing. Figure 1 describes the design of a noninverting amplifier with a low pass filter based on $R_3$ and $C_2$[8]. The EEG signal was captured by this active electrode with amplification of 21 times according to Equation (1):

$$Gain = \frac{R_4}{R_3} + 1$$  

(1)
Figure 2 shows the active electrode design connected to the scalp as a dry electrode which can be placed on scalp without applying EEG gel. The advantage of this design is that it reduces the preparation for installation to the user.

![Figure 2. Active electrode board design: (a) top view, (b) bottom view.](image)

The EEG hardware data acquisition was based on 4 ADS1299 to get 32 channels and Raspberry Pi for controlling and assessing EEG signals. The display and other processing were done in a personal computer using MATLAB.

2.2. Acquisition and Signal Processing System

On the EEG processing to decoding neuronal activity generally involves multiple channels and multiple signal features, this will increase computational demand and can affect to make long delays and low update rates. In contrast, faster computational can increase the number of processing steps per second and increase the performance of the EEG processing system. To solve this problem, need some method to run EEG processing separately. This system is developed using a multithread process on the acquisition and extracts the feature to process the EEG signal separately. All of the controlling process, filtering, FFT, and RPR calculation were done in Raspberry Pi using Python.

The multithread process on this acquisition system can be described in Figure 3:
The Read Channels thread is a thread for monitoring data ready and acquisition EEG signal from devices, the thread checks the validity of EEG signals (status and channels) if the signal valid the EEG acquisition signal will send to signal filtering thread and save the signals as filtered signals. The result of this acquisition system can export to European Data Format (EDF) file and display as Graphics.

A signal filtering thread is a thread to filtering the EEG signal from noise and remove the artefacts. The filtering using a Butterworth band-pass filter with fifth-order and frequency range 0.5 Hz to 45 Hz. Each bands was filtered using Butterworth band-pass with fifth-order according the EEG bands. The result of this thread sends to the FFT thread and RPR calculation threads.

FFT process and RPR Calculation run separately in different threads, the FFT calculation was used to check the dominant frequencies of the EEG signal. This threading process the FFT calculation of each 1024 EEG signal each channel and the result is saved as FFT signals. (The FFT calculation was also used for RPR (Relative Power Ratios), DAR (Delta Alpha Ratio), DTABR (Delta + Theta over Alpha Beta Ratio), and BSI (Brain Symmetry Index). These methods were implemented in the thread of RPR Calculation. All of these calculations were used as features extraction in machine learning techniques for determination of acute ischaemic stroke (AIS). The RPR Calculation thread is used to calculate the Relative Power Ratio of each EEG frequency band with all EEG frequency bands (delta, theta, alpha, and beta band). The equation of RPR is described in Equation (2):

$$RPR_i = \frac{PL_i + PR_i}{\sum PL_i + PR_i}$$  \hspace{1cm} (2)

$$DAR = \frac{RPR_i}{RPR_j}$$  \hspace{1cm} (3)

$$DTABR = \frac{RPR_i + RPR_j}{RPR_i + RPR_j}$$  \hspace{1cm} (4)

where $PL_i$, $PR_i$ are the Power Spectral Density (PSD) of each frequency band, $i$ is each frequency band of the EEG signals, the index 1,2,3,4 are for delta, theta, alpha and beta respectively. For the BSI calculation describe in Equation (5):
\[ BSI(t) = \frac{1}{M} \sum_{i=1}^{M} \left| \sum_{j=1}^{N} \frac{R_{ij}(t) - L_{ij}(t)}{R_{ij}(t) + L_{ij}(t)} \right| \]  
\hfill (5)

where \( M \) is the number of Fourier coefficient, \( N \) is the number of channel pairs, \( R_{ij}(t) \) and \( L_{ij}(t) \) are EEG signal for the right and left hemisphere.

The Relative Power Ratio was calculated for each channel and the results of these calculation were saved as RPR data. The RPR function is describe below:

```python
b,a=butter_bandpass(1,4,250,5)  % Delta Band
y=signal.lfilter(b,a,sinyal)
zd=fft(y)
PSd=abs(zd)**2

b,a=butter_bandpass(3,8,250,5)  % Theta Band
y=signal.lfilter(b,a,sinyal)
zt=fft(y)
PSt=abs(zt)**2

b,a=butter_bandpass(7,12,250,5)  % Alpha Band
y=signal.lfilter(b,a,sinyal)
za=fft(y)
PSa=abs(za)**2

b,a=butter_bandpass(13,19,250,5)  % Beta Band
y=signal.lfilter(b,a,sinyal)
zb=fft(y)
PSb=abs(zb)**2

for i in range(chan):
    % RPR for each band
    numd=sum(PSd[i,:])
    numt=sum(PSt[i,:])
    numa=sum(PSa[i,:])
    numb=sum(PSb[i,:])
    denum=numd+numt+numa+numb
    RPRdel = abs(numd/denum)
    RPRthe = abs(numt/denum)
    RPRalf = abs(numa/denum)
    RPRbet = abs(numb/denum)
```

3. Result and Discussion

3.1. Active electrode

The active electrode has been simulated using Multisim with the results shown in Figure 4.
The graph shows that there is no phase change at a frequency of $1 \times 10^3$ Hz so that the electrodes can be used according to the frequency range of the EEG signal.

The system was tested to capture the signal generated by the NETECH MiniSIM EEG Simulator with the results as shown in Figure 5:

![Bode plotter result for active electrode simulation.](image)

**Figure 4.** Bode plotter result for active electrode simulation.

The graph shows that there is no phase change at a frequency of $1 \times 10^3$ Hz so that the electrodes can be used according to the frequency range of the EEG signal.

The system was tested to capture the signal generated by the NETECH MiniSIM EEG Simulator with the results as shown in Figure 5:

![FFT result of passive electrode and active electrode.](image)

**(a)** Passive Electrode

**(b)** Active Electrode

**Figure 5.** The FFT result of (a) passive electrode, (b) active electrode.

The simulator produces a signal of 2 Hz with an amplitude of 2.5 mV. The graph shows that the passive electrode can catch the frequency well, but there is still a disturbance frequency, while the active electrode can catch the frequency well. The graph on the two electrodes shows that there is a frequency disturbance of 50 Hz originating from the voltage source. On the active electrode, the frequency of 50 Hz was caught greater because the active electrode uses a VCC voltage source so that
the Op-Amp can work. The result of TDH calculation is 19.9 for the passive electrode and 38.8 for the active electrode, so that the active electrode can be used for better measurements.

3.2. Multithread processing
Multithread processing result of time process each tread was shown in Figure 6:

![Figure 6](image-url)

**Figure 6.** Time process (a) FFT thread, (b) RPR thread, (c) Filter thread.
Figure 6 shows that the time to process EEG data is linear with the large amount of data being processed, the RPR process takes a long time compared to other processes, this is because the calculation process stages in RPR are more than the other processes. Time required to process EEG signals using Raspberry Pi with multi-thread processing was quite possible to use both for acquisition and signal processing.

4. Conclusion
The design of active electrode successfully obtains high quality EEG signal by reduce noise and faster acquisition as compared to previous results.

Acknowledgement
This study was supported by the Department of Education and Culture of the Republic of Indonesia through DRPM Universitas Indonesia by PDUPT 2020 with contract number NKB-2822/UN2.RST/HKP.05.00/2020.

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