Signal Comparison of Developed EEG Device and Emotiv Insight Based on Brainwave Characteristics Analysis

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Abstract. The usage of wireless system and dry electrode on electroencephalography (EEG) device becomes widely demanding, particularly in commercial purposes. While the wireless system is needed for lesser cable interference and practical function for mobility, the dry electrode is very important for signal consistency in longer period of brainwave acquisition. Previously, a wireless EEG device was developed in our laboratory; however, the evaluation of the acquired brainwave is needed for further usage and development. This research aimed to compare the signal acquired by the developed EEG device using Emotiv Insight device as a benchmark, which is already an established wireless and dry electrode-based EEG on the market. The brainwave acquisitions were conducted on the subject while resting with eyes closed. AF3 and AF4 of frontal lobe channels were used as the electrode placements. The results were then characterized using frequency band analysis, SNR comparison, and general signal inspection. The result showed that the signal patterns on both devices were visually similar. A minor difference on the amplitude scale can be adjusted by normalization method. The result of alpha band calculation, which is normally detected in resting activity, found similar on both devices. Furthermore, the SNR result from developed device was considered fairly close to the benchmarking device. This study showed that developed EEG device was considered comparable to Emotiv Insight in detecting alpha band extracted from resting frontal lobe, as well as in the brainwave filtering process and accuracy.

1. Introduction
Electroencephalography or EEG is a really important tool to detect and diagnose various brain diseases and abnormalities. Supported by its reliability, fast and practical operation, it has long been known as a gold standard in neurological assessment [1]. Apart from those advantages, it comes with several drawbacks. The electrode wire is a challenge on the acquisition process since an electromagnetic induction could be yielded by the cable hassle. The wire is also sensitive to a small static charge [2]. On the use of wet electrode, drying gel or liquid could be another source of variability and limit the length of simultaneously recording time [3]. On the other hand, various developments on wireless system and dry electrode on medical technology becomes widely demanding, particularly in commercial purposes [4,5]. While the wireless system is needed for lesser
cable interference [2] and practical mobility, dry electrode is important for signal consistency in long period of brainwave acquisition [3].

Various products of wireless EEG are available on the market. Most products are non-clinical and used for personal evaluation. Compared to the clinical EEG, those products are much cheaper and easier to operate. Previously, a wireless EEG device was also developed in our laboratory [6]; the device is shown by Figure 1. This device is equipped with dry-active electrodes as the sensor. The active part of the electrode was built from male pins of pin header which is commonly used as a circuit connector and easily found. The pins were horizontally attached to the circle-shaped PCB with 2 cm in diameter. Several modules related to signal preprocessing were also developed; those are the preamplifier, active filter, and driven-right leg (DRL) modules. The performance of those modules was already evaluated using signal generator; the results are presented on [6]. However, the measurement using the real EEG signal is needed for further evaluation.

![Figure 1. The developed EEG device](image)

This study aimed to compare the signal acquired by the device to Emotiv Insight as a benchmark. Emotiv Insight is already an established wireless EEG device on the market which, similarly, use dry electrode as the sensor. This product has five EEG channels, which are AF3, AF4, T7, T8, and Pz. In this study, the brainwave acquired from channels AF3 and AF4 at the frontal lobe were compared and analyzed.

2. Material and Methods
The brainwave acquisition was conducted on healthy subjects while on a resting state and eyes closed condition. The acquisition environment was arranged to be in a quiet condition to avoid the influence of undesired audio stimulation, which may affect the EEG signal of the resting state. Each acquisition process was conducted in 5 minutes duration. The channels AF3 and AF4, which were used as the channel montage, are roughly located at the upper forehead. These channels are known as two of several EEG channels which represent left and right prefrontal cortex, respectively [7,8]. The eyes-closed on resting state condition was chosen instead of eyes-opened since it is found to have higher cortical activation on prefrontal cortex [9]. Therefore, eyes-closed condition is assumed to result on more significant difference on the signal from both devices compared to eyes-opened.

The overall stages of this study are shown by Figure 2. Both developed and Emotiv Insight devices yield a similar data format, so the treatments to the acquired raw data from both devices were also similar. Since offset data values were generated by both devices, the data normalization was needed before signal processing was performed on the data. The normalization was conducted by removing the baseline value, which was found in all recorded data from both devices. The removal was done by subtracting the baseline value from the recorded data, resulting in a zero-offset data. The normalized EEG data was then analyzed and the results from both devices were compared to evaluate the performance of the developed device.

In this study, three analyses were performed to evaluate the acquired signal from both devices. Those analyses are explained as follows.
2.1. General signal inspection
EEG signal is known to be non-stationary, non-correlated and highly dynamics. Visually, it is acquired as a non-linear, random, and non-rhythmic time series data [10,11]. Those characteristics are represented on the directly acquired EEG signal regardless of the employed device and recording system. An inspection was considered important to perform on the pattern and trend of the time series signal, as it represents the characteristics. To evaluate those characteristics, a general visual inspection was conducted on the raw signal acquired from both devices.

2.2. Signal-to-noise ratio (SNR) calculation
SNR is understood as the measure of signal level compared to the level of background noise of a time series. It represents the system capability on identifying the desired signal from noise. Particularly for EEG, it is required to have a high SNR as possible since the noise is in the same voltage range as the desired signal [13].

In this study, SNR was calculated by dividing the signal variance by the noise variance, as outlined by [14]. The signal and noise variances were defined using bandpass filters at certain bandwidth of frequencies. This study used 0.5 Hz to 35 Hz of frequency bandwidth to compute the signal variance, while out-of-band frequencies were entirely included on the calculation of noise variance. The corresponding SNR was calculated using equation (1).

\[
SNR = \frac{\sigma_{signal}^2}{\sigma_{noise}^2}
\]  

(1)

2.3. Frequency band analysis
Further process on the normalized signal was performed to obtain the clean EEG signal. Bandpass filtering procedure was conducted to the signal on the range of 0.5 Hz to 35 Hz. This resulted in the EEG signal only without blinks (mostly below 0.5 Hz) and unwanted noise, such as the AC frequency which is appeared on 50 Hz or 60 Hz.

To evaluate the device ability on receiving the EEG signal on resting state and closed-eye condition, the frequency band analysis was conducted. Welch’s method was employed to obtain the power spectral density or PSD. It is one of various non-parametric methods to estimate the spectral density based on periodogram calculation and Fast Fourier Transform or FFT. Technically, it divides signal into overlapping segments before the calculation of periodogram [15].

To obtain the frequency band, Welch’s method was applied to signals from each device. This process then yielded the power spectral density or PSD data of every calculated frequency. Since the closed-eye resting state condition is assumed to less appear on delta and higher beta, which is detected on deep sleep and active cognition respectively, the PSD data was cut into the frequency ranges of theta (4-8 Hz), alpha (8-15 Hz), and lower beta (15-20 Hz). The frequency bands from each device were then analyzed.
3. Results and Discussion
Several requirements on the acquisition condition are needed in every recording session; generally those are clean scalp, correct ground usage, clean electrodes, correct referential electrode, low impedance condition, and an electronical or digital filter to reduce the AC frequency (50 Hz or 60 Hz depend on country). Other condition, such as patient or participant activity while recording session also affects the data since a small movement would generate muscle-based signal known as artifacts. This signal usually has significantly higher amplitudes compared to EEG signal. A comprehensive detail of the requirements is orderly presented by [12]. Once the requirements are satisfied, the acquired raw signal should be recognizable as an EEG signal and presenting the previously stated characteristics.

![Figure 3](image)

*Figure 3. The sampled signal acquired from both devices*

The signal comparison from both devices and channels is presented by Figure 3. It is shown that the signal from both channels of Emotiv Insight presented several characteristics of EEG signal. As one of characteristics, a non-stationary time series signal should exhibit trends and seasonality [16], which can be described as a periodic fluctuation over the data. It can be seen from the sampled signal of Figure 3 that, although the data points appear to be random, there is periodic fluctuations on the amplitude. These fluctuations and randomness are also observed on the recorded data from both channels of developed device.

Non-rhythmic trend is also a characteristic that should be observed on acquired EEG data. Rhythmic appearance can be concluded as noise and EKG artefacts. In Figure 3, it is shown that a rhythmic trend is not observed on the data. This can be caused by the filtering process which excludes the environmental noise from the data. In addition, the EKG-like rhythm is not observed on the data. This means that the acquired EEG data are considered to be clean from noise and a valid EEG data.

From the visual inspection, the signal from developed device is considered to have general characteristics of EEG signal. However, the amplitude trend is somewhat higher on developed device. It can also be observed from the result of PSD calculation on Figure 4, which shows a much higher spectral density on developed device compared to Emotiv Insight. Nevertheless, the amplitude scale and value is not comparable since different devices could have distinct amplifier circuit.

![Figure 4](image)

*Figure 4. Power Spectral Density (PSD) on 4 -20 Hz*
The distribution of PSD on the resting state is found to be varying across theta, alpha, and lower beta bands. As presented by Figure 4, the alpha rhythm (8-15 Hz) was dominantly detected by both devices compared to theta and lower beta bands. This result is in line with the classical understanding that a state of relaxed wakefulness with closed eyes is strongly associated with alpha rhythm [17]. A recent study also reported that, on a resting state condition, the PSD of alpha frequencies are elicited highest, followed by theta, and beta with the least power [18].

The different of elicited alpha peak was observed between devices, in which it elicited dominantly in around 10 Hz for Emotiv Insight and 12 Hz on developed device. This different is assumed to be caused by a variation in sample condition. Since the frequency is quite close and still in alpha band, this variation is considered to be insignificant. However, the rise on the 18 Hz of lower beta band on developed device raise a question regarding the resting state condition. It is assumed that the sampling procedure on the brainwave acquisition using developed device still need to be improved since the elicited lower beta band might be caused by the comfortability of the recording session using the device.

![Figure 5. Averaged PSD and SNR comparison of both devices](image)

The results of averaged PSD in Figure 5 also show higher alpha than theta frequency on both devices but lower beta is higher on developed devices. This result concludes the qualitative observation of Figure 4 regarding the rising lower beta frequency caused by comfortability. Anomaly is observed on channel AF4 of developed device. Shown by both Figures 4 and 5, the PSD value of this channel is much lower compared to AF3. SNR analysis is considered useful to gain further information regarding this anomaly. According to SNR result, the anomaly on AF4 of developed device might be caused by high composition of noise detected by the channel. In spite of the same EEG device, the low SNR of AF4 (0.32) compared to AF3 (1.54) might be caused by the dry electrode placement. Similar to the PSD analysis, a procedure improvement is expected to gain accuracy on the brainwave detection by the electrode. In addition, the SNR values of AF3 from both devices are considerably close, which means that a good placement of channel when using developed device would show a comparable capability with Emotiv Insight on noise cancelling performance.

4. Conclusion
In summary, this study showed that the developed device is promising to work on detecting the brainwave. The developed dry electrode is considered a good sensor for the EEG. The filter also worked very well on reducing the noise, as well as the preamplifier module on amplifying the acquired brainwave. The choice of using closed-eye resting state condition is considered to be the best choice on comparing the workability among EEG devices, either the established one or the prototype such as the one we built on our laboratory. Further development is needed for more signal precision and better SNR values. In addition, the improvement is needed for the acquisition procedure, in particular, the dry electrode placement and comfortability, which respectively could affect the noise level and, in our case, bias result on resting versus active cognition on brainwave acquisition in frontal area.
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