Classifying the EEG Signal through Stimulus of Motor Movement Using New Type of Wavelet

Endro Yulianto*, Adhi Susanto*, Thomas Sri Widodo*, Samekto Wibowo**
*Department of Electronical Engineering and Information Technology, Engineering Faculty, Gadjah Mada University, Yogyakarta, Indonesia
**Medical Faculty, Gadjah Mada University, Yogyakarta, Indonesia

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ABSTRACT

Brain Computer Interface (BCI) refers to a system designed to translate the brain signal in controlling a computer application. The most widely used brain signal is electroencephalograph (EEG) for using the non-invasive method, and having a quite good resolution and relatively affordable equipments. This research purposively is to obtain the characteristics of EEG signals using the motor movement of "turn right" and "turn left" that is by moving the simulation of steering wheel. The characteristic of signal obtained is subsequently used as a reference to create a new type of wavelet for classification. The signal processing, including a 4 – 20 Hz bandpass filter, signal segmentation in 1 to 2 seconds after stimuli and signal correlation, is used to obtain the characteristic of EEG signal; namely *Event–Related Synchronization/Desynchronization* (ERS/ERD). The result of test data classification to two new types of wavelet shows that each volunteer has a higher correlation value towards the new type of wavelet that has been designed with various wavelet scales for each individuals.

Corresponding Author:

Endro Yulianto
Department of Electronical Engineering and Information Technology, Engineering Faculty, Gadjah Mada University
Yogyakarta, Indonesia
Email: endro_yulianto@yahoo.com

1. INTRODUCTION

BCI is a system that enables someone to be capable of controlling a computer application by using a bioelectrical signal coming from the brain, commonly called electroencephalograph (EEG). The BCI system is designed to improve the independence and quality of life and to decrease a social cost of an individual suffering from the nerve disorder such as stroke and amyotrophic lateral sclerosis (ALS) [4].

EEG comes to be the most widely used bioelectricity in the application of BCI system since it has been taken through the *non-invasive* method; that is by locating the electrodes onto the surface of the head skin without any surgery for the brain commonly called as *invasive* method. Other reasons are related to the simplicity of using EEG and, compared to other equipments such as Magnetoencephalograph (MEG), Functional Magnetic Resonance Imaging (fMRI) or near-infrared signal (NIRS), the equipment for obtaining the EEG data is relatively affordable [3].

The system of BCI can be used in several applications such as by moving the wheelchair, robot arm, *word speller* and many others in which each application requires an accurate type of EEG signal. Hence, a process of signal processing is deemed to be essential to obtain a specific characteristic of EEG signal that, in turn, could be applied in that application accurately. This is due to that the EEG signal obtained from measurement is still mixed with noise and artefact. The emergence of noise and artefact in the EEG signal is mainly determined by other bioelectricity such as electrooculogram (EOG), electrocardiogram (EKG), electromiogram (EMG) and, most importantly, activity of signal background from the brain itself [1].

One of EEG signal types that can be applied in BCI is *Event–Related Synchronization/Desynchronization* (ERS/ERD) that might be emerged for the existence of the motor movement. ERS/ERD is characterized by the existence of the significant increase and decrease of amplitude compared to that of EEG signal when someone is in the resting phase. In this case, amplitude of ERS is higher than that of the signal during the resting phase and amplitude of ERD is smaller than that of the signal during the resting phase [2].

Several researches have been conducted to obtain the characteristics of EEG signal related to the motor movement. Deepa et al. (2011) [5] have conducted a research using the EGG data from 118 electrodes using the stimulus of motor movements, that are through the movements of right hand, left hand and right leg. The signal processing to calculate the energy from the EEG signal is conducted using Gaussian Smoothened Fast Hartley Transform (GS-FHT) after the processing using the filter of *chebyshev* 5 – 15 Hz in obtaining the range of beta frequency of EEG signal related to the motor movement. Furthermore, signal classification uses IB1 (Instance-Based) and AD Tree (Alternating Decision Tree) with an input in the form of energy obtained from GS-FHT.

Huang et al. 2011 [7] conducted a research using a brain signal to control the computer cursor. In this research, it is found that when performing a movement or desire to do a movement of right hand and left hand, ERD will dominantly appear in the motor areas of the brain; namely the left motor area and the right motor area, which are oppositely located. The movement of ERS can additionally be found in the opposite motor areas of the brain. Hence, the movement of the right hand and the left hand in which ERD and ERS occur in the opposite motor areas can be used to perform four movements through the two-dimensional controlling cursors; those are the left hand of ERD for turning left, left hand of ERS for moving up; right hand of ERD for turning right and right hand of ERS for moving down. In this research, 16 points of electrode (CZA, C3A, CZ, C1, C3, C5, CZP, C3P, PZ, P3, C4A, C2, C4, C6, C4P, P4) are placed in the right and left area of *motor cortex* using the filter band pass of 9 - 32 Hz. To select and classify the characteristics of ERS/ERD, the method of *genetic algorithm* (GA) based on *mahalanobis linear distance* (MLD) and *decision tree classifier* (DTC) is used by using an adaptive model.

Mizuno et al. 2010 [8], while measuring EEG, conducted a research using four orders: order for relax or resting, order for multiplication of 2 digits, order for writing letter and order for turning around three-dimensional crossbar. The electrode of EEG is placed into the points C3, C4, P3, P4, O1 and O2 with the 10-20 system. The extraction of EEG characteristic is done using *maximum entropy method* (MEM) and investigation is performed towards the signal of EEG in the range of frequency of *alpha* and *beta*. The range of *alpha* and *beta* afterwards is redivided into several ranges of frequency in order to obtain the most accurate features. The range of frequency of alpha 8-12 Hz is then divided into 3: alpha1 8 Hz, alpha2 9-10 Hz and alpha3 11-12 Hz, while for *beta* (13-30 Hz) is divided into 2: beta1 13-19 Hz and beta2 20-30 Hz. All signals in those frequency ranges are used as the characteristic or feature. For clustering data, Learning Vector Quantization (LVQ) is used then.

Yulianto et al. 2012, [10] conducted a research towards the signal of EEG taken from the electrodes placed in C3, C4, P3 and P4 using the 10-20 international system supported by a stimulus that is by moving the simulation of steering wheel “turn right” and “turn left”. The data segmentation within 1 second before reaching 2 seconds after stimulus is done to make the signal processing merely focused on EEG with the motor movement. Several band pass filters; namely 4 – 8 Hz, 4 – 13 Hz, 4 – 20 Hz, 8 – 13 Hz, 8 –20 Hz and 13 – 20 Hz are used to accurately obtain the characteristics of EEG signal related to the motor movement. Correlation towards all data of EEG that have been segmented is conducted using Hamming Window that shifted to obtain the characteristic of EEG signal through the movement of “turn right” and “turn left”. The characteristic of EEG signal obtained from the result of signal correlation is used to select the form of mother wavelet appropriate for the process of classification, which was conducted using the method of correlation using the mother wavelets; namely Daubechies8, Daubechies9, Daubechies10, Symlet6 and Symlet8.

Yulianto et al. 2012 [11] similarly conducted a research with the equal data but with different method in signal processing. The segmentation of the EEG signal was conducted in the data of 1 second until 2 seconds after the stimulus in the form of the movement of simulation of steering wheel “turn right” and “turn left” given. The filter bandpass 4 – 20 Hz was conducted to remove the unnecessary noise and signals. Furthermore, the correlation towards all data of EEG that has been segmented was conducted using Hamming Window shifting with the overlap of 10 data. Afterward, the correlated signals were classified into one matrix group for EEG signals with the movements of “turn right” and “turn left”. Eigen value decomposition is used to find out the signal with the highest Eigen value of each group subsequently used as the characteristics of EEG signal for the movement of ‘turn right” and “turn left”. Classification is done using the method of correlation using the mother wavelet, which, in this case, is Mexican Hat.

This research is purposively to make a new type of wavelet - besides the other types of mother wavelets that previously exist. This is based on the characteristic of signal obtained from the signal processing. The new type of the wavelet is used for the classification of EEG signals for the movements of “turn right” and “turn left”. The method of signal processing conducted in this research refers to the equal method conducted in our previous research (Yulianto et al. 2012 [10]). However, the classification is conducted without using the available mother wavelet, but using the wavelet that is created based on the characteristic of the signals obtained from the process of signal processing.

2. FUNDAMENTAL

This part discussed about the fundamental theories supporting the research.

2.1. BCI System

BCI refers to a system that is able to interpret the brain signal to control or communicate with the world outside. There are two methods developed in this system: *Synchronized* and *Self-paced*. The first type is the initial version of BCI in which the users only can do controlling and communicating using the outside devices in the period that has been determined by the system. In the second type, *Self-paced*, the users can do controlling and communicating anytime. In the system of BCI, the type of *Self-paced* consists of two conditions: *Intentional-Control* (IC) and *No-Control* (NC). IC refers to a condition in which the BCI system is in an active condition to do the control or communication with the outside devices; while NC refers to a condition in which the system is in inactive one [6].

2.2. **Wavelet Transformation**

There are two types of wavelet transformation frequently used in the signal processing: *Discrete wavelet transforms* (DWT) and *Continuous wavelet transforms* (CWT). DWT is used to perform decomposition of signal to be the signal in the high frequency group called “*detail*” signal and the low frequency group called “approximation”. Meanwhile CWT runs based on the principle of signal correlation to mother wavelet. The result of CWT is a number of coefficients of wavelet C that are the function of scale and position. The multiplication of each coefficient with certain scaled and shifting wavelet will result in the wavelet element for the original signal. CWT is defined as an integral of signal multiplied with the function of the scaled and shifting wavelet ψ (scale, position, time):

$$C(skala, posisi) = \int_{-\infty}^{\infty} f(t)\Psi(skala, posisi, t)dt \quad (1)$$

$$CWT_x^{\psi}(\tau, s) = \Psi_x^{\psi}(\tau, s) = \frac{1}{\sqrt{|s|}} \int x(t)\psi^*\left(\frac{t-\tau}{s}\right) dt \quad (2)$$

In the equation of (1) and (2), τ refers to shifting, *s* as scale, $\psi(t)$ as the function of transformation or commonly called *mother wavelet*. Meanwhile, the term of translation or shifting is related to the location of *window* that continually shifts along the signals that will be transformed.

3. RESEARCH METHOD

The data in this research were taken from the points of electrode C3, C4, P3 and P4 (Central and Parietal) from the brain using the unipolar technique of “10-20 System” using the instrument of *Biosignal Measurement Instrument K&H Type KL-710* with sampling frequency at 200 Hz. This instrument is a data acquisition tool consisting of software and hardware for acquisition and analysis of biological signal data. Several experiments of measurement that can be done in this instruments may include Electroencephalograph, Electrooculograph, Electromyograph, Electrocardiograph, hearth beat and heart sound, blood pressure, respiration, and pulmonary Function.

In order to obtain the EEG signal with the motor movement in the form of movement of “turn right” and “turn left”, the volunteers are required to move simulation of the steering wheel to the right and to the left based on the direction on monitor. The computer monitor placed approximately four meters in front of the volunteers will show the direction in the form of arrow directing to the right and left direction. Of 22 volunteers participated in this research, it is found that the data of EEG signal for “turn right” and “turn left” from each of the volunteers is 25 data.

Those EEG data are then filtered using the bandpass filter 4 – 20 Hz in order to remove the discarded signal disturbances such as bioelectrical signal from the muscle, bioelectricity from the movement of eyeball and signal background appearing during the process of obtaining data. To make the extraction of the characteristics of EEG signals can be focused on the signal merely related to the motor movement; data segmentation within 1 second before reaching 2 seconds is done once the stimulus appears on the monitor.

This is due to the response of EEG signal towards the motor movement occurred in a very short time before and more or less 1 second after the emergence of stimulus [9].

The segmented signal for each movement of “turn right” and “turn left” of each volunteer is grouped to obtain the group of 25 data for “turn right” and 25 data for “turn left”. To obtain the characteristic of EEG signal with the motor movement of “turn right” and “turn left”, correlation towards the group of 25 data was performed. The first data was correlated to the second data up to the 25th data. *Windowing* in the form of *Hammnig window* along 200 data was performed to each signal from the 25th data with the overlap of 10 data for each window shifting. Furthermore, the 2nd data was correlated to the third data until the 25th data as well as until the 24th correlated to the 25th data. Correlation coefficient is obtained by seeking the ratio of Eigen value, which is a ratio of the first Eigen value and the second Eigen value from the matrix of signal covariance in the window pair. At this point, the highest ratio of Eigen value indicates that the signal has a high correlation value.

The potential of the brain as a result of a mechanical movement is characterized by the increase and decrease of signal amplitude in a significant manner [2]. Hence, the maximum and minimum points in each of the correlated signal groups are sought in which the points subsequently are shifted into one point. The groups of signal with the maximum and minimum peak points that have been combined are averaged to obtain one averaged signal with maximum peak and one average signal with minimum peak from 22 volunteers. The averaged signal is used as a characteristic of motor movement of “turn right” and “turn left” [10].

Finally, one characteristic of EEG signal will be obtained for the movement of “turn right” and “turn left” with the maximum and minimum peak in the electrodes C3, C4, P3 and P4 here as the averaged result of the signal characteristics from 22 volunteers. To obtain one feature as a reference in creating a new type of wavelet, correlation is done in each of signal pair from each electrode. The signal pair with the lowest correlation coefficient will become a reference to create a new type of wavelet. The lowest coefficient of the signal pair indicates that the characteristics of signal “turn right” and “turn left” in the electrodes has the most different form. The table below shows the coefficient correlation in each signal pair “turn right” and “turn left” for each position of electrodes C3, C4, P3 and P4 for EEG signal with the motor movement:

Table 1. Correlation coefficient of signal characteristic in each pair of electrode

3	**PEAK MAX**	593
	PEAK MIN	540
C4	**PEAK MAX**	372
	PEAK MIN	551
P3	**PEAK MAX**	371
	PEAK MIN	385
P4	**PEAK MAX**	371
	PEAK MIN	243

Table 1 clearly shows that the signal in the electrode P4 with the minimum peak point has the lowest correlation coefficient. Hence, the characteristic of the signal is used as a reference in creating a new type of wavelet “turn right” and “turn left”.

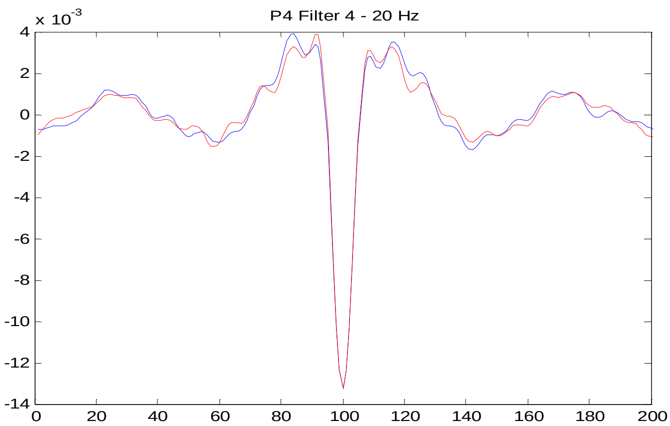

Figure 1. The characteristic pair of P4 with the minimum peak point (right=blue, left=red) [10]

4. RESULT AND ANALYSIS

As previously presented in Section 3 the characteristics of the signal used as a reference to make a new type of wavelet “turn right” and “turn left” are the pair of signal characteristics of electrode P4 with the minimum peak.

To make a signal that has a similar form with the signal characteristic of “turn right” and “turn left”, *curve fitting* is used. *Curve fitting* is used to find out a mathematical model, which is suitable with the signal data “turn right” and “turn left” here by finding certain coefficient to make the function suitable as maximally as possible. Below are two new types of wavelet called “Coka1” and “Coka2”:

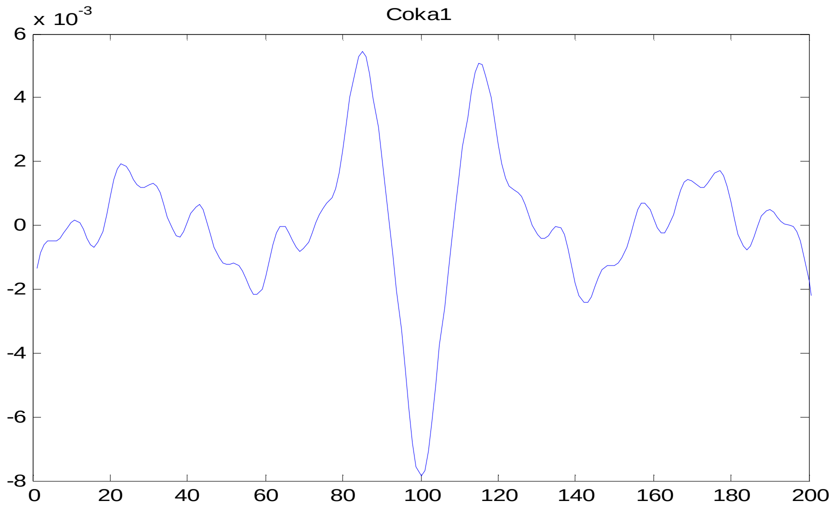

Figure 2. Wavelet “coka1”

The formula of wavelet *“coka1”* is presented as follow:

```
out2 = 1:201;

       a1 =    0.002373;
       b1 =      0.1321;
       c1 =       4.028;
       a2 =    0.001238;
       b2 =      0.2885;
       c2 =       1.016;
       a3 =  5.603e-005;
       b3 =    0.005108;
       c3 =       17.73;
       a4 =   -0.002088;
       b4 =      0.1816;
       c4 =       2.162;
       a5 =    0.001678;
       b5 =      0.2344;
       c5 =       6.378;
       a6 =   0.0004725;
       b6 =      0.6037;
       c6 =      0.8369;

out1 = a1.*sin(b1*out2+c1) + a2.*sin(b2*out2+c2) + a3.*sin(b3*out2+c3) +
       a4.*sin(b4*out2+c4) + a5.*sin(b5*out2+c5) + a6.*sin(b6*out2+c6);
```

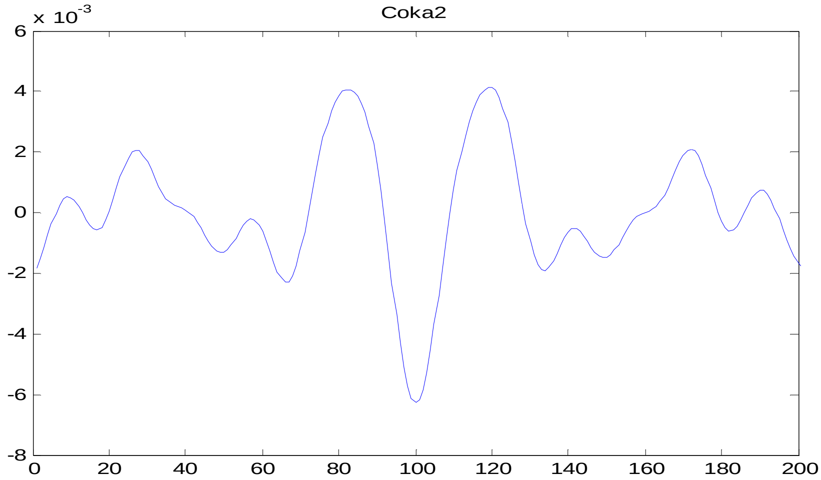

Figure 3. Wavelet *"coka2"*

The formula of wavelet *"coka2'* is presented as follow

```
out2 = 1:201;
       a1 =   1.23e-005;
       b1 =      0.7355;
       c1 =      -1.464;
       a2 =   -0.001992;
       b2 =      0.1769;
       c2 =       2.624;
       a3 =     -0.0015;
       b3 =      0.2246;
       c3 =       4.227;
       a4 =   0.0005516;
       b4 =      0.3833;
       c4 =      -8.286;
       a5 =   -0.002263;
       b5 =      0.1305;
       c5 =       7.317;

out1 = a1.*sin(b1*out2+c1) + a2.*sin(b2*out2+c2) + a3.*sin(b3*out2+c3) +
        a4.*sin(b4*out2+c4) + a5.*sin(b5*out2+c5);
```

The testing of new type of wavelet towards the data of EEG "turn right" and "turn left" is performed to a group of test data that has already been prepared. The test data also includes the data used in the process of data processing. However, the length of the data segmentation is different; that are in 3 seconds before reaching 3 seconds after the stimulus given. The accuracy in this testing is determined by calculating the number of signals with the highest correlation coefficient; namely at the maximum peak and minimum peak in the range of data 1 second to 2 seconds after the stimulus given.

In the following table, *"Right"* refers to the correlation result of new wavelet towards the "turn right" data and *"Left"* refers to the correlation result of new wavelet towards the "turn left" data. "*Peak Max*" is the highest correlation with the maximum peak; "*Peak Min*" is the highest correlation with minimum peak; and "*Peak Max + Min*" is the highest correlation in a signal with maximum or minimum peak – merely selecting one of them. *Diff* refers to the result of reducing the correlation number between the "turn right" data and "turn left" data in the similar wavelet. *Diff* with the highest positive value (+) indicates that the wavelet is more accurate to be used in the "turn right" data; while *Diff* with the highest negative value (-) indicates that the wavelet is suitable to be used in the "turn left" data.

The table below presents the result of correlation of the EEG data "turn right" and "turn left" at the electrode P4 both from 22 volunteers simultaneously and 3 volunteers separately with wavelet "coka1" and "coka2" in the scale of 1:200. The numbers presented in the table are the maximum and minimum values (in %) from the result of correlation from scale 1 to 200 for each type of wavelet.

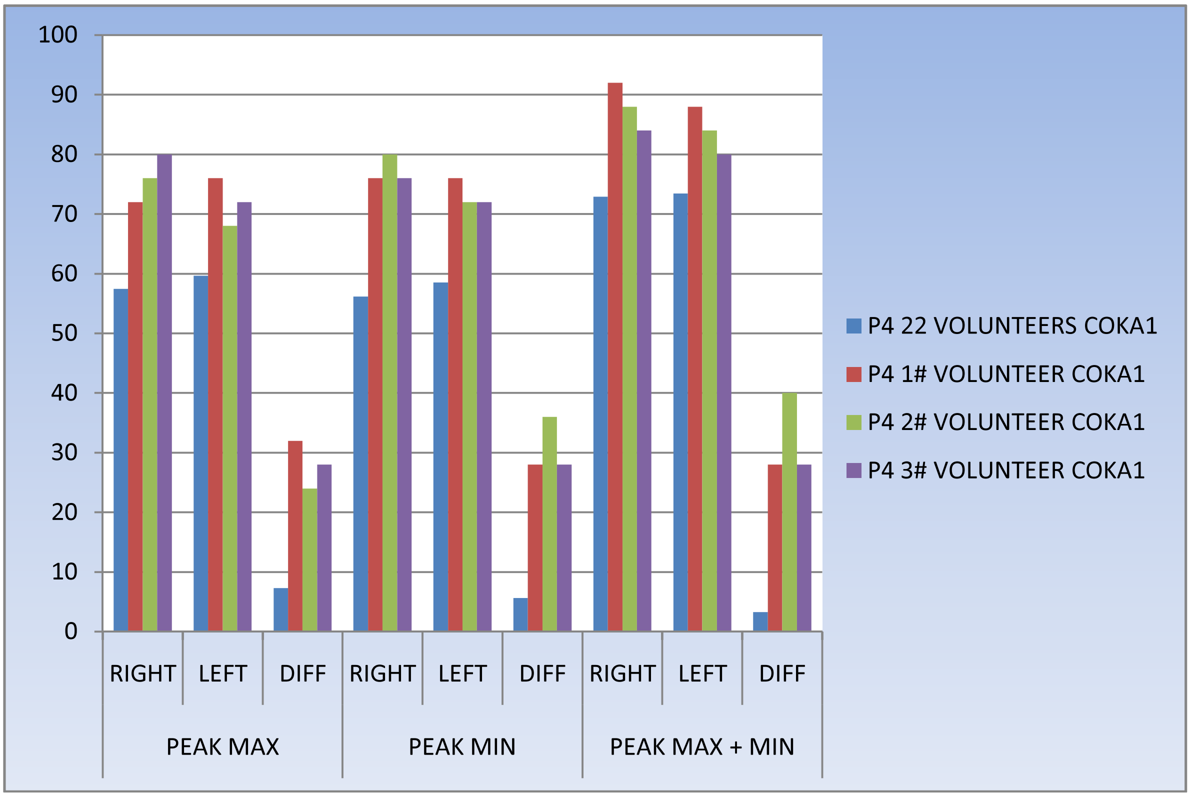

Figure 4. The Result of Correlation of EEG data in the Electrode P4 with a maximum value towards Wavelet *"coka1"*

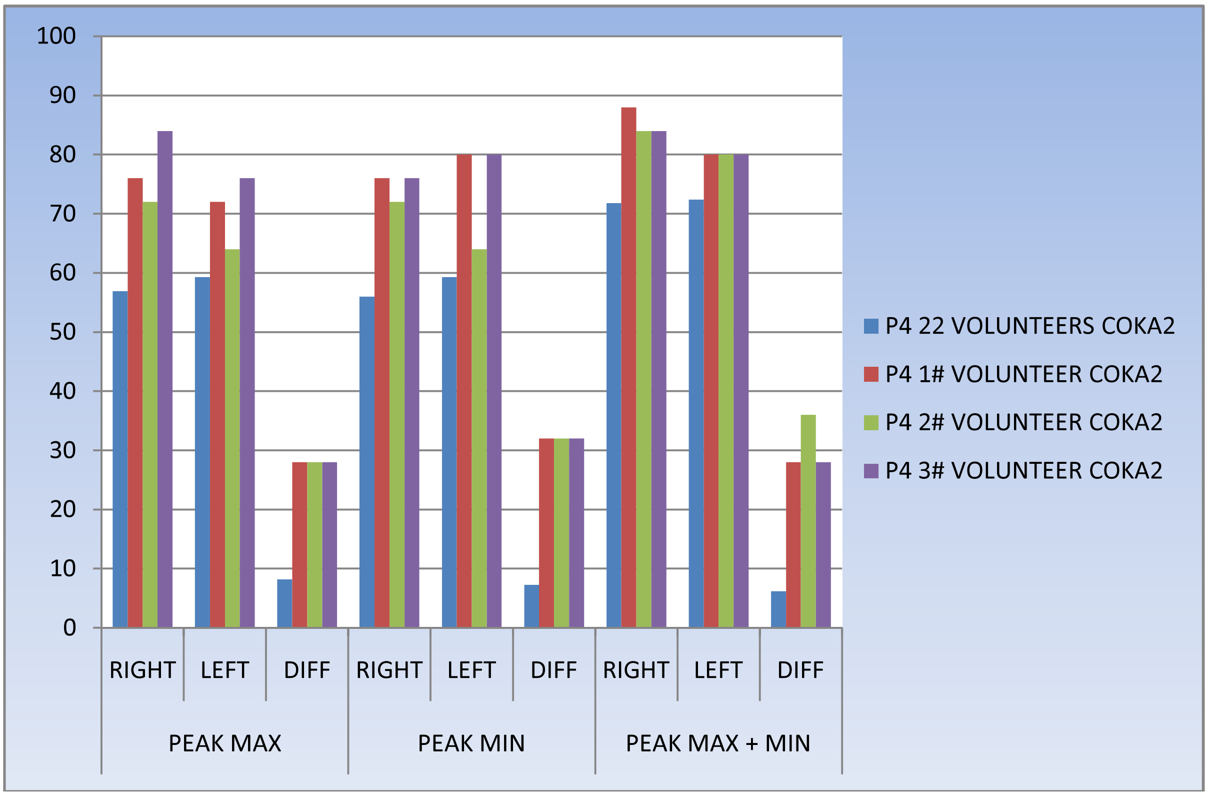

Figure 5. The Result of Correlation of EEG data in the Electrode P4 with a maximum value towards Wavelet *"coka2"*

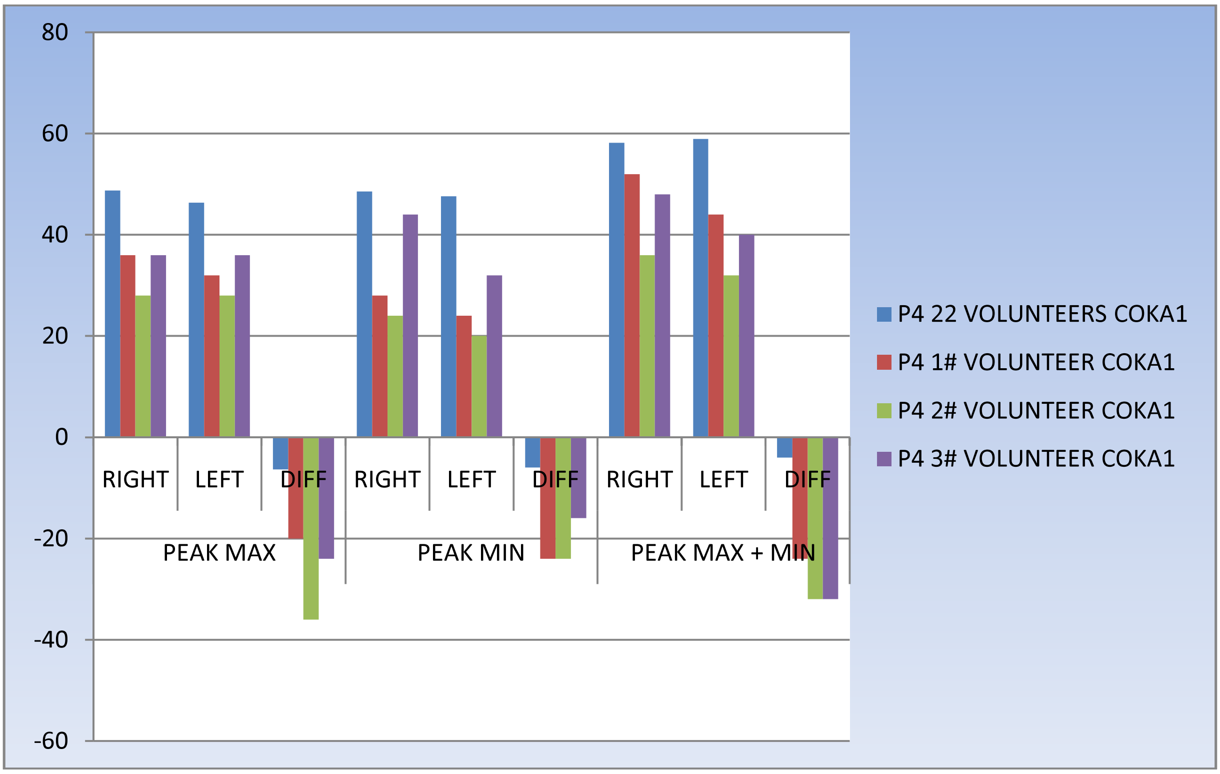

Figure 6. The Result of Correlation of EEG data in the Electrode P4 with a minimum value towards Wavelet *"coka1"*

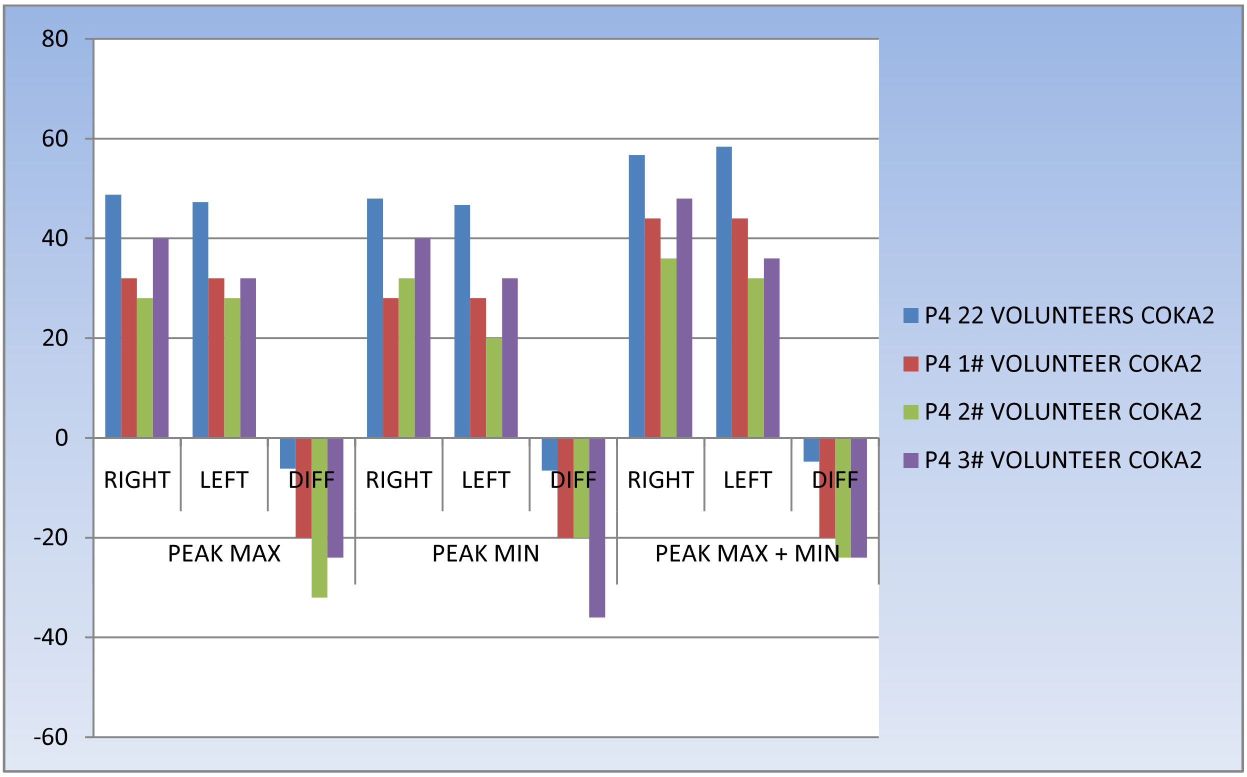

Figure 7. The Result of Correlation of EEG data in the Electrode P4 with a minimum value towards Wavelet *"coka2"*

The figure above shows that the correlation of wavelet "coka1" and "coka2" towards the test data of the EEG signal simultaneously conducted towards 22 volunteers has a lower correlation value compared to the one separately conducted towards 3 volunteers. This then shows that each individual has correlation towards the new type of wavelet with the unequal scales.

5. CONCLUSION

The characteristic of EEG signal with the motor movement appears in the area of the motor cortex of the brain in which in this research the characteristics of signal for the motor movement of "turn right" and "turn left" seem to be different from the electrodes placed in the point P4 (parietal). It can be seen through the correlation value of the signal from the pair of signals "turn right" and "turn left" with the minimum peak that has the lowest correlation value compared to that of the pair of signals from the electrodes C3, C4 and P3.

The result of correlation of EEG data "turn right" and "turn left" towards the new type of wavelet shows that each volunteer has a high correlation value towards the new type of wavelet with the different scales.

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BIOGRAPHIES OF AUTHORS

Born in Banyubiru, 17 July 1976, Diploma of Academy of Electro-medical Engineering of Health Department, Indonesia, 1997, Graduate of Nuclear Engineering of Universitas Gadjah Mada, Yogyakarta, Indonesia, 1999, Master in Institut Teknologi Sepuluh Nopember Surabaya, Indonesia, 2004, From 2007 – present the candidate of Doctor in the Electronics Engineering of Engineering Faculty, Universitas Gadjah Mada, Yogyakarta, Indonesia.

Dr. Adhi Susanto, born in Banjar Indonesia, 1940 obtained M.Sc (1966) and PhD (1988) from University of California Davis. He is a professor at Electronics Engineering Department and Information Technology of Engineering Faculty, Universitas Gadjah Mada, Yogyakarta, Indonesia. The current research field is Electronics Engineering, Image Processing, Signal Processing, Adaptive System, Classification and Pattern Recognition Techniques. He is also a member of IEEE and Planetary Society.

Dr. Thomas Sri Widodo, born in Klaten, Indonesia, 1950. A professor in Electronics and Technology and Information Department, Engineering Faculty, Universitas Gadjah Mada, Yogyakarta, Indonesia. Dipl. Ing. ENSERG, Grenoble, France, 1985, Doctorate d'Etudes Approfondies, Univ. Montpellier 2, France, 1986 Docteur de l'Universite, Univ. Montpellier2, France, 1988. The current research field is system, signal and electronics

Dr. Samekto Wibowo, Medical Faculty University of Gadjah Mada, Yogyakarta, Indonesia, 1969, Master in Universitas Gadjah Mada Yogyakarta in 1975, Doctor from Universitas Gadjah Mada, Yogyakarta, Indonesia in 1998. He is a professor in Neurology of Medical Faculty of Universitas Gadjah Mada, Yogyakarta, Indonesia. The research field is about neurology.