

HUMAN MOTOR CORTEX DETECTION USING WAVELET THRESH-OLD ALGORITHM AND fNIRS TECHNOLOGY

TÌM HIỂU HOẠT ĐỘNG CỦA NÃO NGƯỜI SỬ DỤNG THUẬT TOÁN NGƯỠNG WAVELET VÀ CÔNG NGHỆ fNIRS

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ABSTRACT

The functional Near-Infrared Spectroscopy (fNIRS) technology has been a noninvasive technique and it has also contracted researchers in studying the brain activity of human in recent years. Human brain research is an essential task for scientists and doctors more understanding about brain activity for diagnosis. In this article, the experiments of lifting her/him left hand up and down were performed to measure the concentration of Oxygenated – Hemoglobin (Oxy-Hb) of the human brain by fNIRS, in which the obtained Oxy-Hb signals measured from the brain have the relationship of human movements. The Oxy-Hb signals were pre-processed using a Savitzky-Golay filter to reduce noise and artifacts and to smooth the fNIRS data. Therefore, a wavelet decomposition algorithm was employed to divide the data into the different components (details – d and approximations – a) for determination of features. Moreover, the components were classified by the mean threshold to determine the motor control area of the human brain, in which the classification of the Oxy-Hb signals may allow to determine the right/left hand lifting. Experimental results were worked out with different subjects to detect the motor area at brain hemisphere related to the right/left hand.

Keywords: Savitzky–Golay filter; Wavelet decomposition; fNIRS signal; Motor control area; Mean threshold.

TÓM TẮT

Kỹ thuật phổ cận hồng ngoại chức năng là một kỹ thuật không xâm lấn đã được sử dụng để nghiên cứu những hoạt động của não người. Nghiên cứu hoạt động của não là một việc làm cần thiết để giúp các nhà khoa học hiểu hơn về bộ não của con người. Trong bài báo này, thí nghiệm nâng tay trái lên xuống được thực hiện để đo nồng độ Oxygenated – Hemoglobin (Oxy-Hb) trên não người sử dụng kỹ thuật fNIRS. Dữ liệu nồng độ Oxy-Hb được tiền xử lý sử dụng bộ lọc Savitzky-Golay để giảm nhiễu. Từ đó, một thuật toán phân rã wavelet được sử dụng để chia dữ liệu thành nhiều thành phần khác nhau (chi tiết – d và xấp xỉ - a). Tiếp theo đó, thành phần xấp xỉ - a sẽ được phân loại với một ngưỡng được lựa chọn để tìm ra khu vực điều khiển vận động trên não người. Kết quả thí nghiệm được thực hiện với nhiều đối tượng khác nhau để chỉ ra khu vực điều khiển vận động trên bán cầu não trái.

Từ khóa: Bộ lọc Savitzky-Golay; phân rã dùng Wavelet; tín hiệu fNIRS; khu vực điều khiển vận động; ngưỡng trung bình

1. INTRODUCTION

The human brain is a complex structure with hundred billions of neurons distributed on the brain map with different areas for many activities. This problem has actually been a challenge for scientists and researchers to explore it by relating to body activities in recent decades. In order to study the brain activity, several modern technologies such as EEG, fMRI and fNIRS [1-5] have been applied, in which the fNIRS technology, which is non-invasive, is used to collect brain data [6]. In addition, the fNIRS allows measuring the continuous changes of Oxygen - Hemoglobin (Oxy-Hb) and Deoxygen – Hemoglobin (Deoxy-Hb) in the human brain.

Signals obtained from human body often have many noise and artifacts. Therefore, the Savitzky-Golay filter is one of filters allows smoothing the signals [7-8]. A Savitzky-Golay filter is applied in this research to process the unknown problems of brain signals.

Wavelet decomposition algorithm, which is often used to analyze signals or images, is employed to process fNIRS data in this research [9-12]. In experiments, the fNIRS data obtained from human brain often include many uncertain characters such as noise, artifact and interference. Therefore, the wavelet decomposition algorithm allows reducing the uncertain characters in the fNIRS data for more exactly detecting the motor cortex areas.

Signal thresholding selection is one of algorithms is often used to classify complex

signals in human body [13]. In this study, a mean threshold algorithm is proposed to classify fNIRS signals. The threshold is often selected to be able to extract characteristics of the wavelet signals for determining the motor control area of the human brain.

In fact, the identification of the motor control area of the human brain is a big challenge for scientists to understand the activity of human brain. In this paper, fNIRS data after pre-processing will be analyzed using wavelet decomposition. In addition, a threshold will be chosen to extract characteristics of wavelet signals to determine the area of the motor cortex. Four subjects (two males and two females) with the average of 21 years old are invited to attend experiments for data measurements. Experimental results obtained will be estimated for finding the motor area.

2. MATERIALS AND METHODS

2.1. Detection Framework

The detection framework as described in Fig.1 consists of four main procedures: (1) fNIRS data acquisition; (2) data pre-processing; (3) data analysis and (4) feature determination by using mean threshold.

Firstly, this study is designed to measure changes in the state of hemoglobin in the human brain using the near-infrared rays by using FOIRE 3000 fNIRS machine (Shimadzu Corporation, Japan). It allows monitoring continuously changes of oxygenated hemoglobin (Oxy-Hb) and deoxygenated hemoglobin (Deoxy-Hb) separately in a non-invasive way.

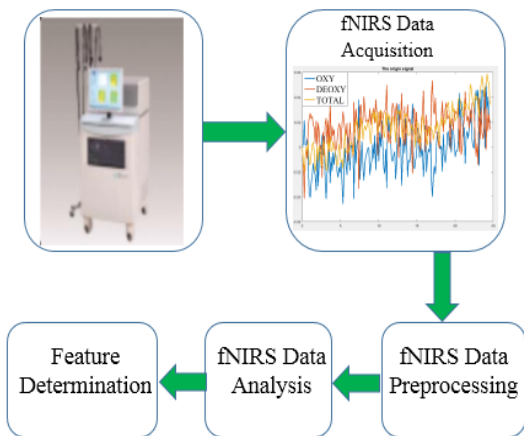


Figure 1. Flowchart of determination framework

Secondly, raw signals were processed using Savitzky–Golay filters and wavelet decomposition algorithms. After being processed, the decomposed data are analyzed to show approximate features of active brain areas. Finally, mean threshold algorithms were applied to determine the significant features of brain areas.

2.2 fNIRS Data Acquisition

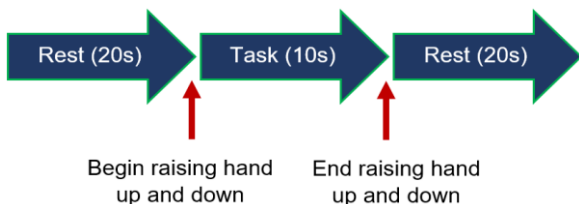


Figure 2. Experimental protocol for fNIRS data acquisition

Four subjects (two males and two females, 21 average years old, 56kg average weight) participated into this study. The subjects were informed the consent agreement after reading and understanding of the experiment protocol and the fNIRS technique as shown in Fig.2. The subjects' activities of raising their hand up and down were used as the motor activity.



Figure 3. A matrix set up at the right brain side to obtain 24 fNIRS channels

Data acquisitions of the motor control task were done according to a timeline set up as shown in Fig.2. At the beginning of the data acquisition process, the subject was relaxed in 20 seconds (*Rest times*). After that, during next ten seconds (*Task times*), each of four subjects moves his left hand up and down; this was repeated five times. The task and the time set can be changed for this data acquisition procedure. In addition to the data acquisition, a 4x4 matrix set up at the left brain corresponding to channels, as shown in Fig.3, for observing oxy-Hb concentration.

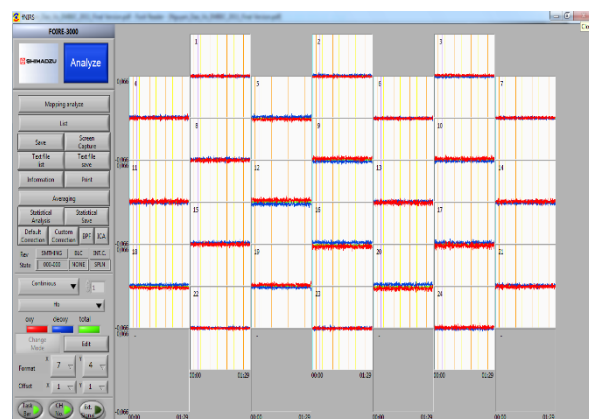


Figure 4. The Oxy-Hb (red), Deoxy-Hb (blue) and Total-Hb (green) signals when measurement with FOIRE-3000 machine

The transmitter and receiver probes with a set of the holder are mounted on the left and right hemispheres of each subject for collecting signals of oxy-Hb, deoxy-Hb and total-Hb are obtained. Oxy-Hb, Deoxy-Hb and Total-Hb signals as shown in Fig.4 were obtained from measurements using the formula available implemented in the fNIRS system. An Oxy-Hb signal may be calculated based on the commutation of absorbance into the hemoglobin (Hb). This formula to calculate oxy-Hb is expressed as follows:

$$\begin{aligned} \text{Oxy - Hb} = & (-1.4887) * \text{Asb}[780\text{nm}] \\ & + 0.5970 * \text{Asb}[805\text{nm}] \\ & + 1.4847 * \text{Asb}[830\text{nm}] \end{aligned} \quad (1)$$

When using this formula, the wavelength correction is automatically applied to each laser when calculating the amount of hemoglobin.

2.3 fNIRS Signal Pre-processing

In order to reduce noise, artifacts (measure, environment and machine effect) and the unknown frequency problem of brain signals, the Savitzky-Golay method is applied [7-8]. The fNIRS output signals x_i to be smoother, are describes as follows:

$$x[k] = \frac{\sum_{i=-n}^n A_i x[k+i]}{\sum_{i=-n}^n A_i} \quad (2)$$

in which A_i is a matrix of integers and n , $k = 0, 1, 2, \dots$

where the A_i matrix designed for this issue is implemented as the following matrix:

$$A_i = i^j = \begin{vmatrix} x_{-n_L}^0 & x_{-n_L}^1 & \dots & x_{-n_L}^M \\ \dots & \dots & \dots & \dots \\ x_0^0 & x_0^1 & \dots & x_0^M \\ \dots & \dots & \dots & \dots \\ x_{n_R}^0 & x_{n_R}^1 & \dots & x_{n_R}^M \end{vmatrix} \quad (3)$$

in which $j = 0, 1, 2, \dots, M$.

After being smoother via the Savitzky-Golay filter, signals will be analyzed by using the Wavelet decomposition algorithm.

Discrete wavelet transformation W employed to calculate its coefficients is presented as follows:

$$x[n] = \sum_{k=0}^{N-1} x[n-1, k].y[2v-k] \quad (4)$$

in which, $y[2v-k]$ is the filter.

In the wavelet decomposition (WD) algorithm, one can decompose the signal into a coarse approximation and detail information [14-15]. In particular, the discrete signal $x[n]$ is passed through both a half band low-pass filter $h[n]$ and a half band high-pass filter $g[n]$ and then both signals were down sampled by a factor of 2. The low pass signal is again successively filtered by $h[n]$ and $g[n]$ and sub sampled by a factor of 2 to obtain the next level approximation and detail coefficients. Therefore, the signal can be sampled by 2 to produce half the number of point. The formulas can mathematically be expressed as follows:

$$d_i[k] = \sum_{k=0}^{N-1} x[n].g[2k-n] \quad (5)$$

$$a_i[k] = \sum_{k=0}^{N-1} x[n].h[2k-n] \quad (6)$$

in which d_i and a_i are called the detail and approximate coefficients of the wavelet decomposition n .

The fNIRS signal is reconstructed by inverting the decomposition step using upsampling and filtering and expressed as follows:

$$\tilde{x}[n] = a_i[k] + \sum_{j=0}^i d_j[k] \quad (7)$$

where $\tilde{x}[n]$ is the fNIRS signal after applying wavelet reconstruction.

The method of decomposition and reconstruction filters by down sampling of 2 is shown in Fig.5. When the fNIRS signal is decomposed, each of down sampling will produce a half-band filter.

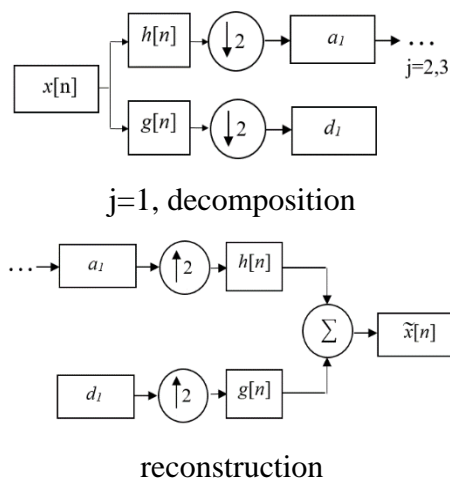


Figure 5. Wavelet decomposition and Wavelet reconstruction algorithms with band filters divided by 2

2.4 Mother Wavelet Algorithm

In order to choose a mother wavelet family for fNIRS signal processing, two methods used to solve this problem are investigation the shape of wavelet decomposition detail and the difference of signal energy. The first method is done by comparing the fNIRS detail shape after wavelet decomposition of a subject with other subjects. An experiment was performed 5 times with the same measurement on the same subjects for analysis. Three wavelet families are chosen to perform this one including: Daubechies (db10), Bior (bior5.5) and Symlets (sym7).

Besides, the difference in energy of the fNIRS signal before and after the wavelet analysis was compared. The method is worked out by calculating the difference between the original signal energy and the restoration signal one after the wavelet analysis. The original signal energy and the restoration signal one are calculated as follows:

$$P_o = \sqrt{\frac{\sum_{j=1}^L x^2[n]}{L}} \quad (8)$$

and

$$P_w = \sqrt{\frac{\sum_{j=1}^L x^2[k]}{L}} \quad (9)$$

in which

L is the length of $x[n]$.

P_o is the original signal energy.

P_w is the restoration signal energy.

The different energy between two signal energies is calculated using the following formula:

$$Pe = Po - Pw \quad (10)$$

After computing the energy error between the original signal and the restoration signal energy, the minimum value of Pe indicates that the energy of the restoration signal is the same to that of the original signal. Therefore, the restoration signal is reliable. Based on the Pe value and the shape of wavelet coefficients, one mother wavelet may be chosen for fNIRS signal processing.

2.5 Data Analysis and Feature Determination

After the analysis using the wavelet decomposition algorithm, the approximate signal (a_3) is processed by using a mean threshold algorithm [1, 13]. In this project, the mean threshold algorithm was utilized to determine the motor control area in the human brain. In particular, the average value M is calculated to produce the approximate (a_3) using the following equation:

$$M = \frac{\sum_{n=1}^L a_3}{L} \quad (11)$$

where a_3 is the approximate value of wavelet the decomposition with fNIRS data and L denotes the number of samples.

In addition, the standard deviation SD in case of brain active signal can be calculated as follows:

$$SD = \frac{\sqrt{\sum_{n=1}^L (a_3 - M)^2}}{L} \quad (12)$$

A mean threshold algorithm using Eq. (12) and Eq. (13) is built to determine the motor control area to other areas as follows:

$$THR = M - z * SD \quad (13)$$

where z is the coefficient of the standard deviation.

This paper shows the detection of motor control area based on the change of amplitude of fNIRS data. Therefore, the threshold determined based on fNIRS data in the motor active case plays an important role. After calculating the threshold for each channel data, the threshold was compared with others channel to indicate the motor control area of the human brain.

3. RESULTS AND DISCUSSION

Firstly, the fNIRS data were passed a filter using the Savitzky – Golay method. In this case, $n = 21$ and $M = 9$ was chosen to smooth fNIRS signals using Equation (2). An original data (blue) and the smoothed data (red) were shown in Fig.6.

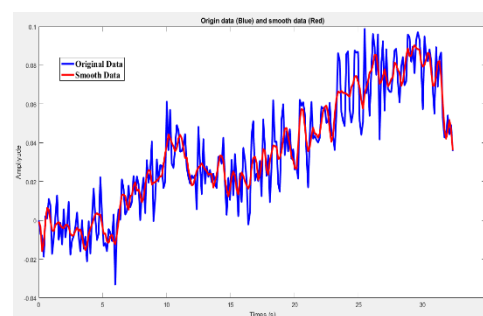


Figure 6. Original signal and the smoothed signal using Savitzky–Golay filters

Secondly, fNIRS data were smoothed with Savitzky – Golay filter was analyzed using wavelet decomposition. The mother wavelet family was chosen by comparing the shape of wavelet coefficients of the

Daubechies (db10), Bior (bior5.5) and Symlets (sym7). The waveform of wavelet coefficients was plot as Fig.7. According to this result, the signal waveform after analysis is most stable when the Bior wavelet family (bior5.5) is used. The shape of signal when used others wavelet is the less stable waveform.

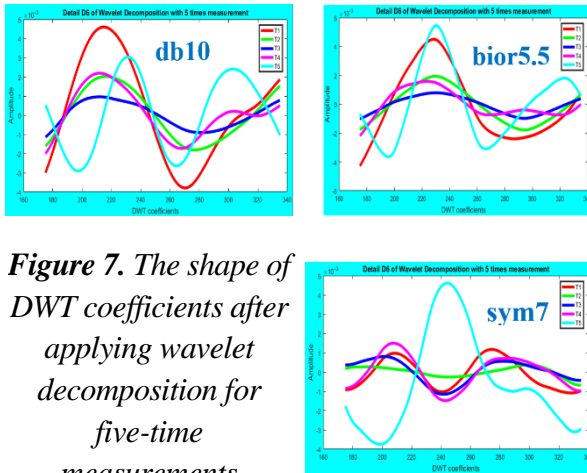


Figure 7. The shape of DWT coefficients after applying wavelet decomposition for five-time measurements

When using three wavelet families as above, the different energy (Pe) of the signal before and after analyzing is calculated as in Table 2.

From these energy errors, one can see that they are as small as the restoration signal. Thus, according to the stability of waveform and the energy errors of signals when restoring, the Bior wavelet family (Bior 5.5) produces the best results.

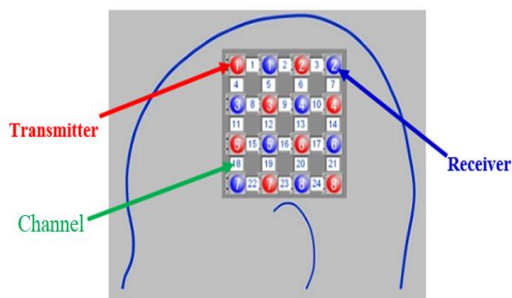


Figure 8. Schematic of the measured matrix including transmitter (red), receiver (blue) and channels at the left brain

In this study, the decomposition wavelet transform algorithm with the “Bior5.5” function is a mother wavelet. By try to do with another experiment, the best wavelet decomposition levels obtained in three levels. So, the signal was decomposed into three levels to determine coefficients from d1 to d3 and a3. When fNIRS data were decomposition to achieve wavelet coefficients in three levels, the shape of coefficients was stabilized.

With the arrangement of eight pairs of the transceiver and receiver on left hemisphere as shown in Fig.8, one collected all 24 channels. In order to find motor area of the human brain, all of channels were analyzed using the wavelet decomposition algorithm in Eq.(5) and Eq.(6). After analyzing 24 channels of signals, the approximation coefficients (a_3) are obtained and analyzed by using the wavelet decomposition with “bior5.5” as shown in Fig.9.

The shape of the approximation – a_3 was drawn to detect features of the motor control area with all of the channels. However, channels 5, 9 and 16 only show the same shapes as shown in figures. 10, 11, 12 and 13, while other channels had the different shapes compared with the channels 5, 9 and 16.

Table 1. Thresholds of four subjects were calculated

Channel No.	Signal thresholds			
	Sub - 1	Sub - 2	Sub - 3	Sub - 4
1	0.0422	0.0200	-0.0251	0.0076
2	0.0438	-0.0089	-0.0404	-0.0008
3	0.0674	-0.1369	-0.0035	0.0107
4	0.0657	-0.0307	-0.0025	0.0134

5	0.0844	0.0378	0.0335	0.0490
6	0.0687	0.0122	0.0124	0.0268
7	0.0549	-0.0287	0.0318	-0.0006
8	0.0320	0.0076	-0.0135	-0.0210
9	0.0742	0.0520	0.0347	0.0462
10	0.0324	0.0293	0.0022	0.0020
11	0.0450	0.0112	0.0175	0.0157
12	0.0350	0.0123	0.0089	0.0106
13	0.0164	0.0088	0.0092	-0.0076
14	0.0322	0.0157	0.0052	0.0160

15	0.0337	0.0163	0.0083	0.0215
16	0.0501	0.0435	0.0455	0.0404
17	0.0461	-0.0078	-0.0109	0.0322
18	0.0116	0.0133	0.0109	0.0181
19	0.0479	0.0382	0.0222	0.0289
20	0.0414	0.0291	0.0055	0.0188
21	0.0510	0.0151	0.0307	0.0258
22	0.0295	0.0356	0.0017	0.0204
23	0.0380	0.0329	0.0123	0.0068
24	0.0498	0.0229	0.0030	0.0296

Table 2: The energy errors of the original signal and the reconstruction signal after wavelet analysis.

Wavelet family	Five times measurement					Average
	T1	T2	T3	T4	T5	
Daubechies (db10)	1.0797	0.3491	0.3466	0.3633	1.1888	0.6655
Bior (bior 5.5)	0.4595	0.1678	0.1204	0.1210	0.4294	0.2596
Symlets (sym7)	0.1852	0.0645	0.0447	0.0527	0.1798	0.1054

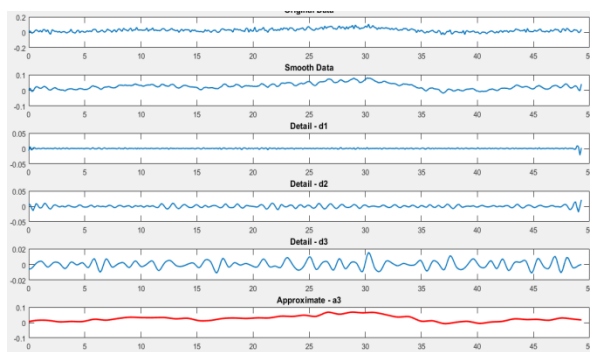


Figure 9. fNIRS data were analyzed using the wavelet decomposition with bior5.5

Moreover, the coefficients were averaged to produce a threshold, called the mean threshold. Based on data obtained from four subjects, one can calculate the threshold using Eq. (13). The results obtained on four subjects are shown in table 1, in which the thresholds

obtained from channels 5, 9 and 16 are higher than that of channels left. According to the concentration of Oxy-Hb levels in the blood, the activity areas of the human brain will have a higher concentration of Oxy-Hb other areas [16-17].

In summary, three channels 5, 9 and 16 are collected with mean thresholds of Oxy-Hb change higher than that of other channels and they also have the same features during motor control task. While other channels show different wave shapes due to noises, artifacts, and interferences from equipment and environment. The concentration of Oxy-Hb in the human brain is increased when the human brain is active.

In addition, the increasing of Oxy-Hb in the human must correspond to each of the brain activity. Therefore, the threshold of fNIRS data was computed to find the cortex areas of human brain which has higher concentration than another area.

4. CONCLUSION

The fNIRS data were collected on four subjects and pre-processed to reduce noise and artifacts. A mean threshold algorithm was proposed to calculate threshold values of approximation coefficients (a_3) obtained from the decomposition wavelet transformation for detection of the motor control area. In particular, the fNIRS data were smoothed using the Savitzky–Golay filter.

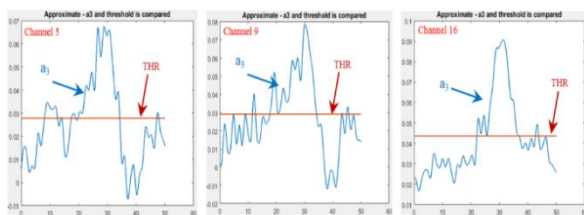


Figure 10. Approximation – a_3 of channels 5, 9 and 16 of the subject-1

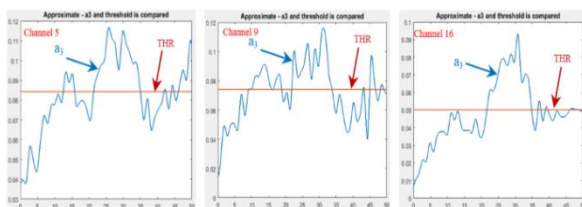


Figure 11. Approximation – a_3 of channels 5, 9 and 16 of subject-2

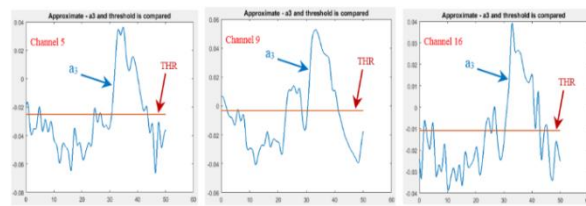


Figure 12. Approximation – a_3 of channels 5, 9 and 16 of subject-3

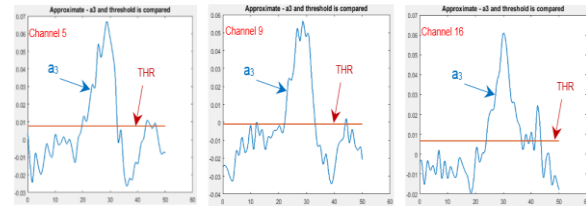


Figure 13. Approximation – a_3 of channels 5, 9 and 16 of the subject 4

Moreover, the wavelet decomposition algorithm was employed to calculate wavelet coefficients such as d and a . From these approximate coefficients a , the mean threshold values of channels 5, 9 and 16 allows us to recognize the motor control area of the human brain. Experimental results showed to illustrate the effectiveness of the proposed mean threshold method combined with the wavelet decomposition transformation for detecting the motor control area. Moreover, this research will be the base of exploring the brain signal in the future.

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