ELECTROENCEPHALOGRAM ANALYSIS WITH WAVELET TRANSFORM AND NEURAL NETWORK AS A TOOL FOR ACUTE ISCHEMIC STROKE IDENTIFICATION

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Abstract— The prevalence of stroke in Indonesia are 7% based on the health proffesionals statement and 12.1% based on patients' symptoms' history. Early examination using CT scan causes radiation effects and spent high operational cost whilethe prevalence of stroke based on diagnosis or symptoms were higher in the lowest (13.1 ‰) and mid lower (12.6 ‰) quintile of ownership index. This studytried to analyze the signals of EEG automatically based ontraining data sets from normal patients and patients with acute ischemic stroke (AIS) using digital signal processing such as wavelet transform and feedforward type of neural network with Extreme Learning Machine (ELM) algorithm. It was claimed that electroencephalography could help to confirm or detect acute ischemic strokewhich is shown by the presence of the slow wave and the asymmetrical wave of right and left hemisphere. This study uses Delta Alpha Ratio (DAR), Delta Theta Alpha Ratio (DTABR) and Brain Symmetry Index (BSI)'s value as the ELM input feature score which were obtained by Wavelet (Daubechies 4) transformation and Welch's method to identify acute ischemic stroke. In this study, the performance of systemtest accuracy, sensitivity and specificity were above 93%.

Keywords— Electroenchepalogram (EEG), Acute Ischemic Stroke, Wavelet Transform, Extreme Learning Machine (ELM).

I. INTRODUCTION

Stroke is one ofthe major health problems that need special attention. Stroke attack could potentially lead to enormous psycho-social burden and a significant impact on health resources in the development of the national health system[1]–[4]. Therefore, it is necessary to diagnose stroke especially in the early stage condition [5], [6].Neurodegenerative disorders in stroke causes symptoms include: paralysis of the face or limbs, slurred speech and others [7]. The result of Health Research in 2013 were performed on people aged over 15 years, showed that the prevalence of stroke in Indonesia are7% based on the health professionals statement and 12.1% based on patients' symptoms' history. The prevalence of stroke in the group increases with age, the highest are at age ≥75 years (43.1‰) and (67.0‰). [7]

Computed Tomography (CT) scans and Magnetic Resonance Imaging(MRI) iscommonly used examination methods for stroke diagnosis because theycan provide images of the brain as well as blood vessels. MRI images are able to provide an overview of blood vessels more clearly than a CT scan, but it requires more preparation because it is necessary to remove the metal material in and around the patient examination area. Therefore, the CT scan is preferred for early examination or acute conditions. On the other hand, the use of CT scan cause the radiation impact to patients and require high operating costs, while the prevalence of stroke based on diagnosis or symptoms were higher in the lowest (13.1 ‰) and mid lower (12.6 ‰) quintile of ownership index [7].

Kenneth G. Jordan [8]suggested that electroencephalography can help to confirm or detect acute ischemic stroke which is shown by the presence of the slow waves(theta-delta activity) on the electroencephalogram (EEG)spectral and reducedcerebral blood flow. Michael J.A.M. van Putten and Tavy [9]used the Brain Symmetry Index in monitoring the signal from hemispheres in stroke patients using Quantitative electroencephalograph. QEEG has improved detection and localization of pathophysiology of brain ischemia [10]–[12]. Rosmehah Wan Omar Wan, et al [13]used k-Nearest Neighbors (k-NN) classification technique for classifying brain waves in acute ischemic stroke.Huang, Shen and Duong used Support Vector Machine (SVM) for predicting acute ischemic tissue [14]. While Rajini and Bhavani used segmentation and texture features for detection of ischemic stroke[15].

This research study is conducted to analyze EEG signals EEG automatically based on normal patients and patients with acute ischemic stroke using digital signal processing such as wavelet transform and feedforward type of neural network with Extreme Learning Machine (ELM) algorithm.

II. LITERATURE REVIEW

A. Electroencephalogram (EEG)

Electroencephalogram (EEG) is a bioelectric signals coming from the electrical activity in the cortex or the surface of the scalp, caused by physiological activity of the brain [16]. Continuous EEG (CEEG) is the most sensitive neuro diagnostic method for detecting acute ischemic stroke[8]. In patients with cerebral ischemic injury or ischemic stroke, EEG correlated with cerebral blood flow (CBF) level. CBF In normal people are 50 to 70 $mL \cdot 100g^{-1} \cdot min^{-1}$ and EEG

also showed normal pattern (alfa and beta wave), whereas CBF in patients with ischemic stroke declines to 25 to 30 $mL \cdot 100g^{-1} \cdot min^{-1}$ and EEG recordings also showed a slow waves (delta and theta wave) as well as the asymmetry wave of right and left hemisphere.

EEG signal in **Error! Reference source not found.**was recordedfroma 68 yearold woman with acute stroke on the left hemisphere in a sleep stage. The EEG signal spectra showed a striking asymmetry of the waves and the suppression of all frequency from all over the left hemisphere. These phenomena are marked with arrows and labels.

B. Brain Symmetry Index (BSI)

Brain Symmetry Index (BSI) is used to measure the degree of symmetry of left and right brain activities. The symmetrylevel value is measuredbased on the average absolute difference of the power spectral densityfromthe right and the lefthemisphere in the frequency range of 1 to 25 Hz. TheBSIthat is used to look for abnormalities in patients with stroke is defined as the following Equation: [18]

$$\mathrm{BSI}(t) = \frac{1}{M}\sum_{j=1}^{M}\left\|\sum_{i=1}^{N}\frac{R_{ij}(t)-L_{ij}(t)}{R_{ij}(t)+L_{ij}(t)}\right\| \quad (1)$$

With M : The number of Fourier coeffisient,
N : The number of channel pairs,
$R_{ij}(t)$: EEG signal onthe right hemisphere,
$L_{ij}(t)$: EEG signal onthe left hemisphere

Fig. 1shows the waveform asymmetry between the left and right hemisphere during clamping of the right carotid. The slow-wave appear on the right hemisphere due to clamping. Brain Symmetry Index (BSI) is one way to determine the presence of ischemic brain to assess the symmetry of right and left brain waves. BSI value starts from 0 which shows perfectly symmetrical on all channels, and 1 for the highest value to indicate a very asymmetrical wave. [9]

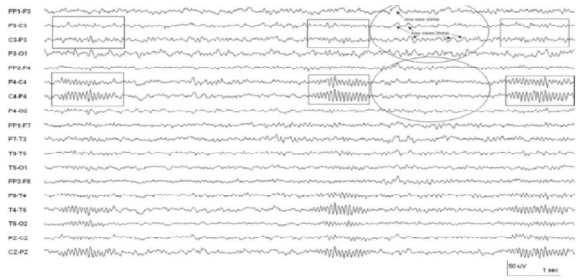


Fig. 1Slow wave and asymmetry wave in stroke patient's EEG [17]

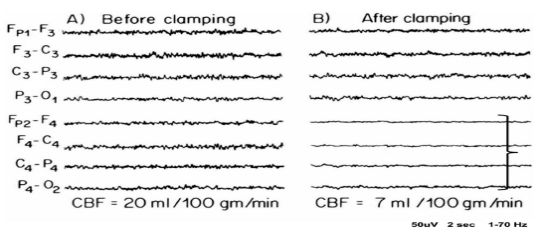


Fig. 1a) normal EEG before clamping, b) EEG during clamping of the right carotid [8]

C. Extreme Learning Machine(ELM)

Extreme Learning Machine (ELM) is a type of feedforward neural network with a single hidden layer. ELM utilize Moore Penrose pseudo inverse theory that using the inverse matrix in the learning process. [19]

A single hidden layer type of feedforward neural network with L hidden nodes and activation function g(x) be modeled mathematically by the following Equation:

$$\sum_{i=1}^{L}\beta_i G(a_i, b_i, x_j) = t_j, \quad j = 1, \dots, N \quad (2)$$

where$a_i$is theinput weightvector connecting theinput nodes and the *i*thhidden node. β_i is the weight vectorconnecting the *i*thhiddennodeand the output node.While,$b_i$is the threshold orimpact factor of the *i*thhidden node. [19]

$$\sum_{i=1}^{L}\beta_i G(a_i, b_i, x_j) = t_j, \quad j = 1, \dots, N \text{is equivalent to} H\beta = T$$

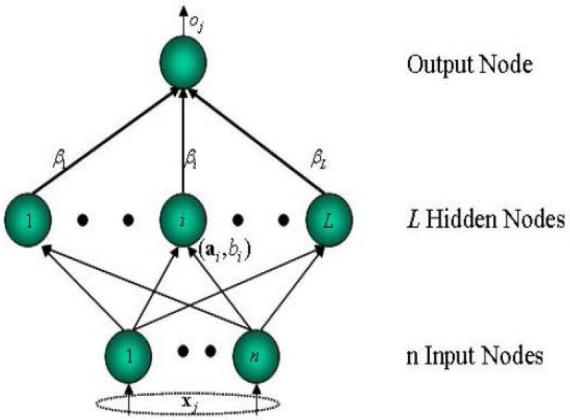


Fig. 3feedforward neural network architecture (ELM) (http://www.ntu.edu.sg)

where :

$$H(a_1, \dots, a_L, b_1, \dots, b_L, x_1, \dots, x_n) = \begin{bmatrix} G(a_1, b_1, x_1) & \dots & G(a_L, b_L, x_1) \\ \vdots & \dots & \vdots \\ G(a_1, b_1, x_N) & \dots & G(a_L, b_L, x_N) \end{bmatrix}_{N\times L} \quad (3)$$

and

$$\beta = \begin{bmatrix} \beta_1^T \\ \vdots \\ \beta_L^T \end{bmatrix}_{L\times m} \text{and} T = \begin{bmatrix} t_1^T \\ \vdots \\ t_L^T \end{bmatrix}_{N\times m} \quad (4)$$

ELM is used to minimize the training errorwithMoore Penrose Pseudo Inverse theory, so to obtain the output vector β based on equation (3) and (4) is multiplying the inverse matrix$H$ (H^{+}). [19]

$$\beta = H^{+}T \quad (5)$$

ELM parameters such asinput weight (a_i)andhidden node biases (b_i)selected at random, so that the ELM has a fast learning and able to produce high accuracy.

III. PATIENT ANDMETHOD

This research study was conducted and approved by the Ethics Committees of the National Brain Center Hospital (RS PON), Jakarta.The EEG signals were obtained by EEG machine from Biologic Netlink System and XltekEEG 32U, Natus using sampling frequency of 256 Hz and 512 Hz and saved intoEuropean Data Format (.edf).There were 32 subjects both of 16 normal patients and 16 patients with acute ischemic stroke, which were confirmed by CT-scan. Normal patients are patients who not experiencing a stroke during EEG recording, while patients with acute ischemic stroke are patients who suffered a stroke due to blockage in the blood vessels of the brain within <72 hours after stroke attack. EEG recording were done for about 30 minutes with 32 channel electrode.

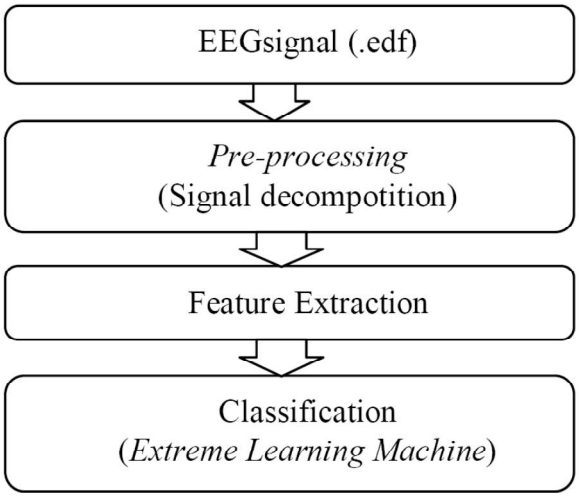


Fig. 2 Flow diagram of methodology

EEG signal data in European Data Format (.edf)will be converted into ASCII data using Matlab script (edfread) from Brett Shoelson [20], then is filtered into 4-sub wave based on frequency ranges(alpha, beta, theta and delta) using signaltransformation. The results ofsignal transformation are used to extract the features which are required as input of feedforward neural network with Extreme Learning Machine (ELM) algorithm to differentiate normal patients with acute ischemic stroke patients.

In this study, the features required as input to the feedforward neural network with ELM algorithm are: (1) Delta/Alpha Ratio (DAR),

(2)(Delta+Theta)/(Alpha+Beta) Ratio (DTABR) and (3)Brain Symmetry Index (BSI). These features are defined as the following:

$$DAR = \frac{\text{Relative Power Ratio Delta}}{\text{Relative Power Ratio Alpha}} \quad (6)$$

$$DTABR = \frac{\text{Relative Power Ratio Delta+Theta}}{\text{Relative Power Ratio Alpha+Beta}} \quad (7)$$

BSI values were calculated using Equation (1).

The flow diagram of this method is shown inFig. 2. Power spectral density is the most common feature use in analyzing EEG signal. Spectral power for each electrode is performed using DWT (Discrete Wavelet Transform) to decompose EEG signal into 4-sub wave (alpha, beta delta and theta) in measuring the delta/alpha ratio (DAR) and (delta+theta)/(alpha+beta) ratio (DTABR).

A signal$x$ must be passed in two DWTfiltration, the high pass filter (g) and low pass filter (h) so that the frequency of the signal can be analyzed. The analysis of the frequency component was done by using the result of resolution (k) after the signal passes through those filtrations. The analysis of different frequencies by using different resolutions is called multi-resolution analysis[21].

The Discrete Wavelet transform of data sequence $x(k)$with multi resolution analysis is defined as:[22]

$$a_{(k)}(l) = x(k) * \varphi_{k,l}(n)$$
$$d_{(k)}(l) = x(k) * \psi_{k,l}(n) \quad (8)$$

where$a_{(k)}(l)$and$d_{(k)}(l)$are approximation coefficient and detail coefficientat resolution of $k$with$n$is time sequence, $\varphi_{k,l}$ and $\psi_{k,l}$ are defined as following Equation:

$$\varphi_{k,l} = 2^{\frac{k}{2}} h_k(n - 2kl)$$
$$\psi_{k,l} = 2^{\frac{k}{2}} g_k(n - 2kl) \quad (9)$$

MATLAB provides several multi resolution Wavelet analysis functions: [C,L] = wavedec(*x*,*N*,'wname')returns the wavelet decomposition of the signal *x* at level *N*, using type of Wavelet family'wname'. This study use Daubechies 4 (Fig.3) as a type of Wavelet families and the decomposition level of DWT can be seen at **Error! Reference source not found.**.

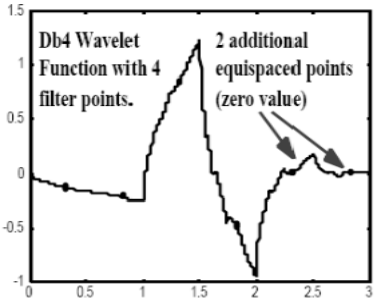


Fig.3 Daubechies level 4 [23]

The type selection of Wavelet familiesis the important thing in the Wavelet transformation. Daubechies level4th (db4) has the orthogonal shapeso approximates the EEG signal and has the smallest error value in the EEG signal processing compared to other types of mother wavelet.[23]

Each sub wave decomposition then be calculated the total power or energy as well as the Relative Power Ratio (RPR) to get the value of DAR and DTABRfeatures.

BSI feature values obtained using matlab toolbox "pxx = pwelch (x)" based on Welch method is then calculated with Equation 1 to obtain estimates of the

signal power at various frequencies. Pxx (results Welch method) of the input signal (x) is found by dividing the signal into segments overlap. In this study, one segment contains the data for 20 seconds. BSI value of each segment Welch method results then averaged to be used as input feature on artificial neural networks ELM along with the value of DAR and DTABRfeatures.

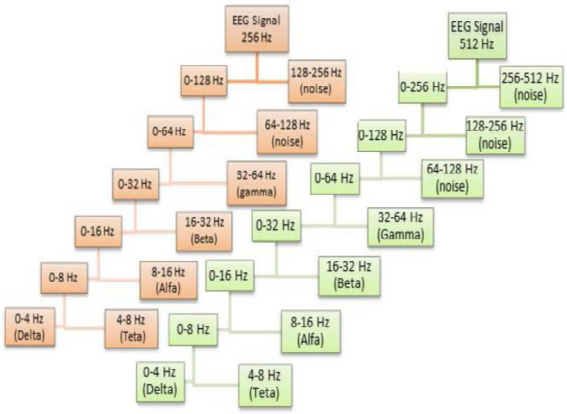


Fig. 6 Signal decomposition using DWT level 6&7

IV. RESULT AND DISCUSSION

The Relative Power Ratio (RPR) as a result of signal decomposition were calculated using DWT. These ratios compared the different frequencies spectrum of the EEG signals, as RPR alpha, RPR beta, RPR delta and RPR theta between normal patients and patients with ischemic stroke patients as shown in**Error! Reference source not found.**.

Based on **Error! Reference source not found.**, it can be seen that there is a difference between the patients' RPR with acute ischemic stroke patients and normal parient's RPR. The delta RPR in patients with acute ischemic stroke tend to be higher than in normal patients, while the RPR alpha and RPR beta tend to be lower.

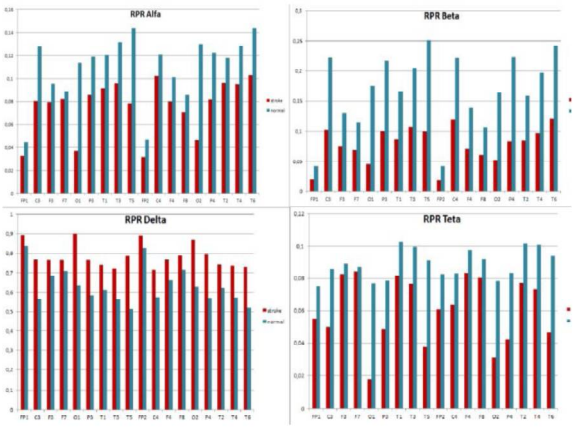


Fig. 7 Comparison of patients' RPR

Features DAR and DTABR are obtained based on the calculation of grades of each sub-waves. DAR and DTABRFeaturesare required to know the ratio of the appearance of slow wave (delta and theta) and fast wave (alpha and beta), while the BSI feature is used to determine the symmetryof brain waves between the left and right hemisphere.The average value of feature between patients with acute ischemic stroke and normal patients are shown in **Error! Reference source not found.**.

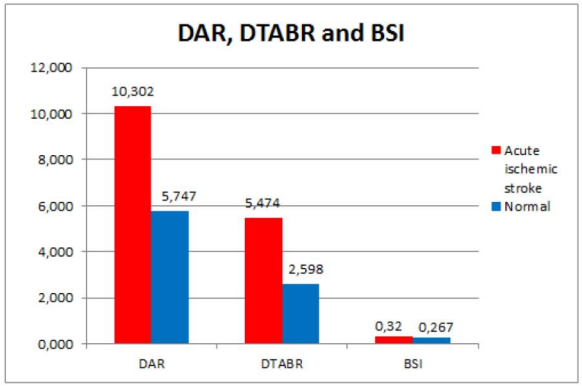


Fig. 8 The average value of feature between patients with acute ischemic stroke and normal patients

Results of testingdataperformed by a ELMtraining algorithm using sigmoid activation functionbased on input data in the form of featuers' value DAR, DTABR and BSI as shown in
Table **1**.

Table 1the results of the test data

Pasient	Doctor's Diagnosis	Software's Result
24E	Acute ischemic stroke	Acute ischemic stroke
26I	Normal	Normal
27T	Acute ischemic stroke	Acute ischemic stroke
28D	Normal	Normal
29S	Normal	Normal
30T	Normal	Normal
31A	Acute ischemic stroke	Acute ischemic stroke
32G	Acute ischemic stroke	Acute ischemic stroke
1L	Acute ischemic stroke	Acute ischemic stroke
2N	Acute ischemic stroke	Acute ischemic stroke
3T	Acute ischemic stroke	Normal
4N	Acute ischemic stroke	Acute ischemic stroke
11E	Normal	Normal
12S	Normal	Normal
14Y	Normal	Normal
15S	Normal	Normal
5S	Acute ischemic stroke	Acute ischemic stroke
6H	Acute ischemic stroke	Acute ischemic stroke
7S	Acute ischemic stroke	Acute ischemic stroke
9B	Acute ischemic stroke	Acute ischemic stroke
16S	Normal	Normal
17J	Normal	Normal
18D	Normal	Normal
19S	Normal	Normal
10L	Acute ischemic stroke	Acute ischemic stroke
13H	Acute ischemic stroke	Acute ischemic stroke
23M	Acute ischemic stroke	Acute ischemic stroke
24E	Acute ischemic stroke	Acute ischemic stroke
20S	Normal	Normal
21I	Normal	Normal
22S	Normal	Acute ischemic stroke
25S	Normal	Normal

Thus, the average values of accuracy, sensitivity and specificity of the software/system are:

$$\overline{accuracy} = \frac{32-2}{32} = 93{,}75\%$$
$$\overline{sensitivity} = \frac{15}{15+1} = 93{,}75\%$$
$$\overline{specificity} = \frac{15}{15+1} = 93{,}75\%$$

Graphical User Interface (GUI) of the programdisplays the identification process of the acute ischemic stroke schemeas on the **Error! Reference source not found.**. The GUI also displays patient, date of recording EEG (Electroenchephalogram) and sample frequency.

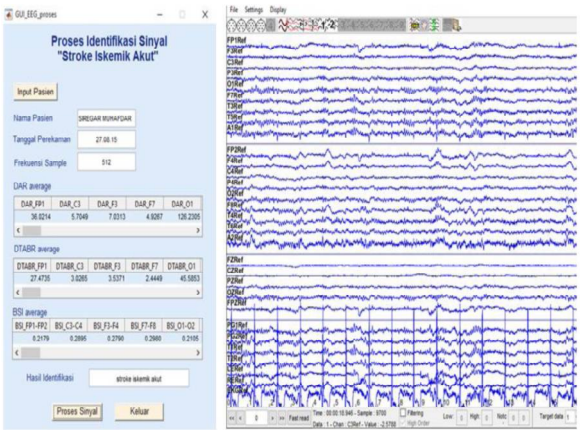


Fig. 9 Graphical User Interface of the developed software

EEG signal data of patients who were identified are displayed in waveforms on each channel electrodes as on **Error! Reference source not found.**. Furthermore, the EEG signal data will be processed to obtain the features' value of DAR, DTABR and BSI then are displayed in the program display process signals in **Error! Reference source not found.**. The feature's value are used to identify whether the patients' EEG is a normal's EEG or acute ischemic stroke's EEG.

CONCLUSION

Wavelet transformation followed by a feedforward neural network with Extreme Learning Machine (ELM)algorithm can be used to distinguish normal's EEG signals and acute ischemic stroke's EEG signals. Wavelet transformation's type for feature extraction is Discrete Wavelet Transform (DWT) with Daubechies Wavelet level 4 (DB4) as a mother wavelet and Brain Symmetry Index using Welch method. In this study, the performance of system test accuracy, sensitivity and specificity were above 93%.

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