THE MULTIRESOLUTION WAVELET ANALYSIS OF THE BRAIN SIGNALS OF EPILEPSY PATIENTS

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Abstract – Wavelet transform is a new topic in signal processing. Its development and application remains an active and important area of research. In addition, the brain is the most vital organ of human. Trying to understand the brain means that trying to understand oneself. Thus, humans have tried to analyse and obtained some information about brain. However, its diseases are very hard to detect. This paper presents a tutorial introduction of the multiresolution wavelet analysis theory, implementation and interpretation of the wavelet transform about epilepsy disease. The paper concentrates on the application of the multiresolution wavelet transform to taking data from volunteers' electroencephalography (EEG) data. The method of Multiresolution wavelet analysis (MRWA) serves as a link between the discrete and continuous theory. Because of that, in that paper, that EEG data will be examined by using Multiresolution Wavelet analysis and it will be summarized how to defect the disease by using signal processing.

Keywords—*Wavelet, Multiresolution Wavelet Analysis, EEG, Epilepsy*

1. INTRODUCTION

THE brain, which is the centre of all our senses, thoughts, feelings, is a very soft piece of meat that has been settled in a hard skull. Besides its simple appearance, it is the most complex structure in the universe. It receives signals from the body's sensor such as kidney, lung, heart, and outputs data to the muscle then they realize the motions. The other mammal brains have the identical structure as human brains, but it is smaller in relation to body size than human brains.

The human brain acts as a communication system that is comprised of neurons. Neuron is a tiny nerve cell that is worked as transceiver by electrical signals from sensory cells that is called sensory neurons, over long distances within the body.

The importance of the human brain is that:

1. It regulates internal processes, which are most often involuntary such as heartbeat, dilation of pupil, involuntary contraction of muscles, and voluntary contraction of muscle as in smooth muscle contraction such as in the process of peristaltic movement [1].

2. It acts as an important part of the body system that enable cognitive processes like remembering, thinking etc. How the brain works is an important thing to understand because we are humans in possession of a brain.

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3. It provides coordination of bodily activities so that there is a balance between the actual physiological responses and the anticipated physiological responses. For example, voluntary movement although voluntary, you do not take too steps at a time while working neither do you jerk. The action is a step by step forward sequential of backward sequential movement except you jerk or jump. Even if you are not currently thinking about working, you still have a part of your brain that coordinates orientation of the body in space (parietal cortex, cerebellum).

1.1. Main Parts of Brain

The cerebrum, cerebellum, and brainstem composed the brain.

Cerebrum is the colossal piece of the brain. It contains right and left hemispheres. It achieves the important activities such as touching, hearing, interpreting, emotions, and well checking of functions [2].

Cerebellum is the last part that came to exist in the process of the evolution. It takes the data from Cerebrum and it coordinates muscular contraction, physical balance [2].

Brainstem as shown in the Figure 1. acts as a transhipment centre conjoining the cerebrum and cerebellum to the spinal cord. Breathing, warmth of body, sleep-wake cycle are completed successfully [2].

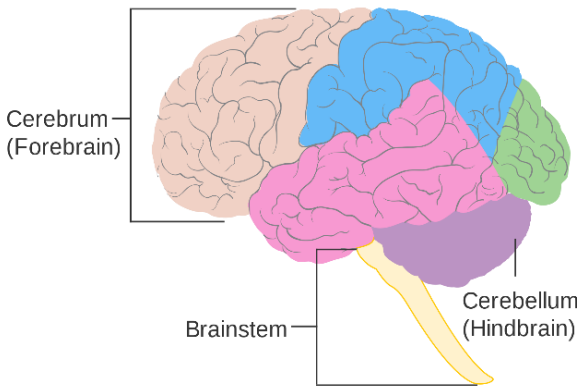

Fig.1. Main Parts of a Brain [10]

The Cerebrum is split in half: the right and left hemispheres. Latin name of fiber bunch is corpus callosum. It sends the messages and information from side to side. Each hemisphere checks and rules the converse part of the body. If a Paralysis occurs on the left part of the brain, your right part such as arm, leg etc. may be crippled [2].

1.2. Lobes of the Brain

The cerebral hemispheres has four lobes that are frontal lobe, temporal lobe, parietal lobe, and occipital lobe. Each lobes has

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different actions but the crucial point is that each lobes does not plough a lonely furrow. They have complicated relations [2].
Frontal Lobe: The tasks of judgement, planning, sexual impulses, behaviour, problem solving, and organizing the motor skills belong to the frontal lobe [3].
Parietal Lobe: It is responsible for sensory information that is collected in various parts of the body. Functions such as information processing, spatial orientation, speech, visual perception recognition, reading and writing are the tasks of the Parietal Lobe.
Occipital Lobe: It interprets the visual stimulation. Damaged occipital lobe may cause visual disturbances and hallucinations.
Temporal Lobe: Its functions are about understanding language, memory, hearing, sequencing and organization [2].

1.3. Brain Waves

The best explanation to understand the brain waves is that they are the models of electrical activities that occur inside the head. Brain waves are very important to all situations of brain functioning: behaviours, thoughts and emotions. SI Unit of Brain wave frequencies are Hertz (H). It means cycles per second. There are four ranges of brainwaves.
Gamma Brainwaves (38-42 Hz): Gamma brainwaves are the most vigorous waves in the spectrum. They have the fast brainwave frequency with a small amplitude.
Beta Brainwaves (14-30 Hz): They are characteristic of a linked mind, which is extremely alert and quite-focused. Beta function is fast-connect and activity. In addition, it is tendency to control the waking state of consciousness [4]. They are generally detected in the frontal lobes and it is seen on both sides of the brain.
Beta brainwaves are linked when the brain is awaken or processing functions such as solving hard problems, criticise of conditions or making a speech that aims to teach [4].
Alpha Brainwaves (9-13 Hz): Beta Brainwaves are faster than the Alpha Brainwaves. They show a relaxed awareness in the consciousness. Alpha is detected in the front part of the head. Alpha brainwaves are about relaxation like making meditation, imagination and intuitive thinking as convalescence from edgy thoughts [4].
Theta Brainwaves (4-8 Hz): They can indicate drowsiness, and the first phase of sleep or somnolence. Theta activities are commonly seen on children up to thirteen mostly in their sleep. They are about accessing subconscious information, half-awake half-asleep state, and attenuation in body rhythms, such as heart rate and breathing [4].
Delta Brainwaves (Below 4 Hz): They can explain deep sleep or thinking. They are in tendency to be the slowest waves with the highest amplitude [4].
Brain diseases can be in different forms. In addition, these diseases can be reasons of some disorders in different part of body such as paralysis, epilepsy. This paper will focus on that part of subject. The disease will be diagnosed more easily by analysing and comparing the data, which were taken from patient and healthy people.
Epilepsy is a brain disease caused by the deterioration of the standard activity of the brain because of abnormal electrical activity that occurs temporarily in the nerve cells. Epilepsy could be a conclusion of a medical injury or brain damage or other reasons. Some seizures that are dependent on tumour or bleeding in brain could be treated by surgery. In some cases, seizures can be treated by some medicines, in other cases are called refractory epilepsy. Also for some patients, vagus nerve stimulator (VNS) that is like cardiac pacemaker, inserted to patient by surgery. This device could decrease the number of seizures [5].

2. MULTIRESOLUTION WAVELET ANLAYSIS

The time-frequency resolution problems are originated by the Heisenberg uncertainty principle. A fixed time-frequency resolution is used to resolve for the STFT. A signal, which is at different frequencies with different resolutions, is analysed by Multiresolution Analysis (MRA). Multiresolution time-frequency plane is showed the change in resolution schematically in Figure 2 [6].

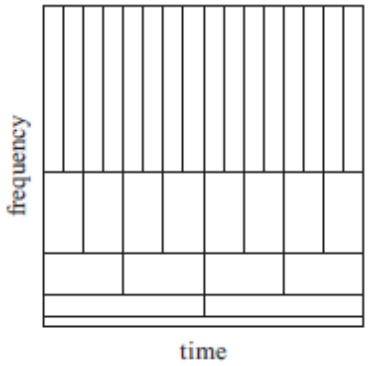

Fig.2. Multiresolution time-frequency plane [6].

According to Figure 2. it is assumed that low frequencies took place for the whole continuation period of the signal, and high frequencies appear from time to time small explosion. The wavelet analysis calculates the correlation between that signal and a wavelet function ψ (*t*). The resemblance between them is calculated separately in different time period. Thus, this representation ψ (*t*) is called mother wavelet [6].
Different frequency resolutions can be obtained.by making different scaling. Scaling and translating parameters can be established from wavelet and scaling function [7].

$$\phi_{j,k}(t) = 2^{\frac{j}{2}}\phi(2^j t - k) \quad (1)$$

$$\psi_{j,k}(t) = 2^{\frac{j}{2}}\psi(2^j t - k) \quad (2)$$

where j is the dilation parameter, and k is the position parameter. In application, whole data is wanted to see with desired resolution. Thus, the subspaces are defined [7].

$$V_j = Span\left\{\phi_{j,k}(t)\right\} \quad (3)$$

$$W_j = Span\left\{\psi_{j,k}(t)\right\} \quad (4)$$

Some necessities for multiresolution analysis are written below [7];
1. There is an orthogonal feature between the scaling function and its integer translates.

2. The subspaces at low scales are nested within spanned at higher scales.
3. The only common function for all V_j is $f(x) = 0$.
4. Representing function is optional.
For Haar scaling function

$$\phi(t) = \frac{1}{\sqrt{2}}\phi_{1,0}(t) + \frac{1}{\sqrt{2}}\phi_{1,1}(t) \quad (5)$$

Extend the notation of $\phi_{j,k}(t)$, we have

$$\phi(t) = \frac{1}{\sqrt{2}}(\sqrt{2}\phi(2t)) + \frac{1}{\sqrt{2}}(\sqrt{2}\phi(2t-1)) \quad (6)$$

That equation is called multiresolution analysis equation

$$\phi(t) = \sum_n h_\phi[n]\sqrt{2}\phi(2t-n) \quad (7)$$

$h_\phi[n] = \{\frac{1}{\sqrt{2}}, -\frac{1}{\sqrt{2}}\}$ is distinct for Haar scaling functions. Equation (7) means that $\phi(2t)$ is higher frequency function than the $\phi(t)$. It could be designed for discrete low pass filter $h_\phi[n]$ to have $\phi(t)$ [7].
Relation for the wavelet functions is that;

$$\psi(t) = \sum_n h_\psi[n]\sqrt{2}\psi(2t-n) \quad (8)$$

For Haar wavelets, $h_\psi[n] = \{\frac{1}{\sqrt{2}}, -\frac{1}{\sqrt{2}}\}$. Those two filters are connected with

$$h_\psi[n] = (-1)^n h_\phi[1-n] \quad (9)$$

A diagram that is Figure 3. shows the relationship between the sets and the functions [7].

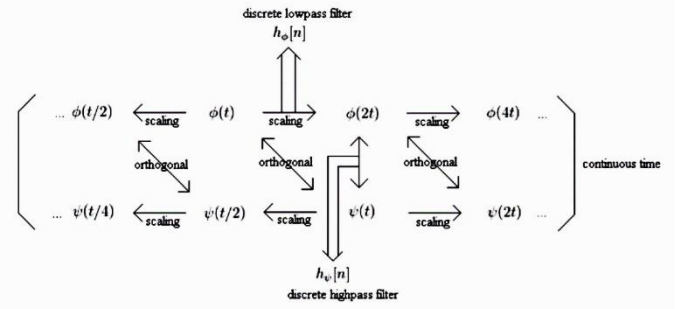

Fig.3. The relationship between scaling and wavelet functions [7].

We union infinite wavelet sets, the sets are equal to the $L^2(R)$, set^2. This is requirement 4. In mathematical words, it is

$$L^2(R) = V_0 \oplus W_0 \oplus W_1 \cdots \quad (10)$$

Thus, any function in $L^2(R)$ could be resolved, by benefitting from the scaling and wavelet functions. Similarity of that concept is like cross-section of a cabbage. When cabbage is cut in the middle, and looked, layers of leaves could be seen. Then if the one layer is taken from them, remaining part is will be cabbage but not the original one. This is the analogy of the scaling function at different scales with different supports but with similar shape [7].

3. APPLICATION OF MRWA TO THE BRAIN SIGNALS

First of all the data is taken from health and disease volunteers then they are shown in waveform. After that, that signals are analyzed by making multiresolution wavelet analysis. Finally, their results are compared and discussed. Volunteers' data is taken from reference [8].
Data_b: EEG Data of Healthy Person
Data_d: EEG Data of Seizure-Free Interval
Data_e: EEG Data of During Seizure

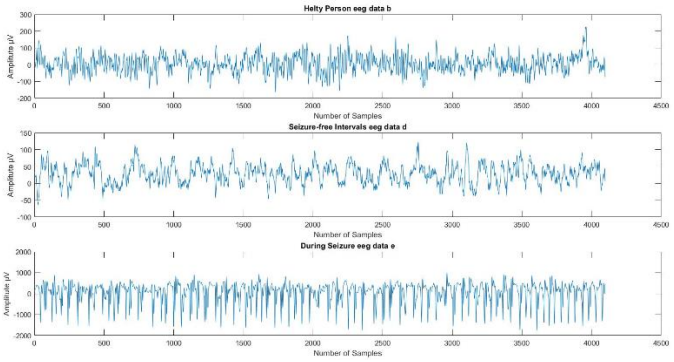

Fig.4. Waveform of Taken Data.

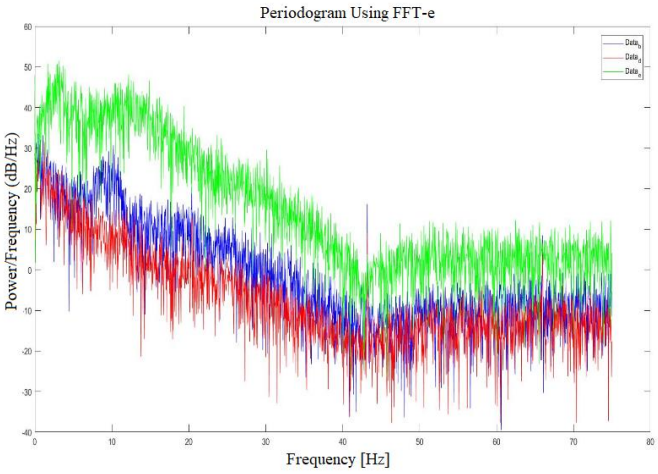

Fig.5. Imbricated Power Spectrum Density Graphs of Taken Data.

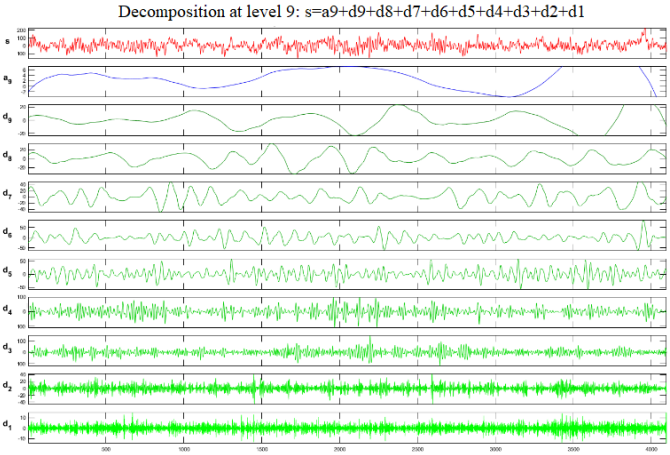

Fig.6. Multiresolution Wavelet Analysis of Data_b (Db-9).

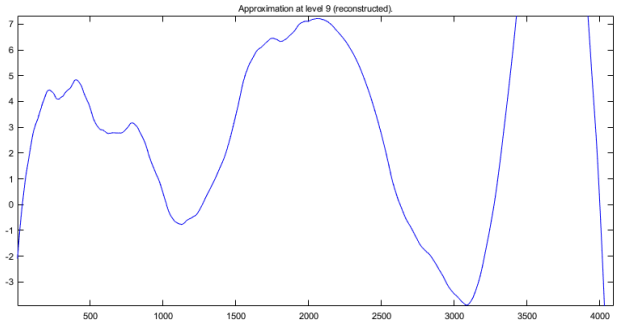

Fig.7. Approximation at level 9 of Data_b (reconstructed).

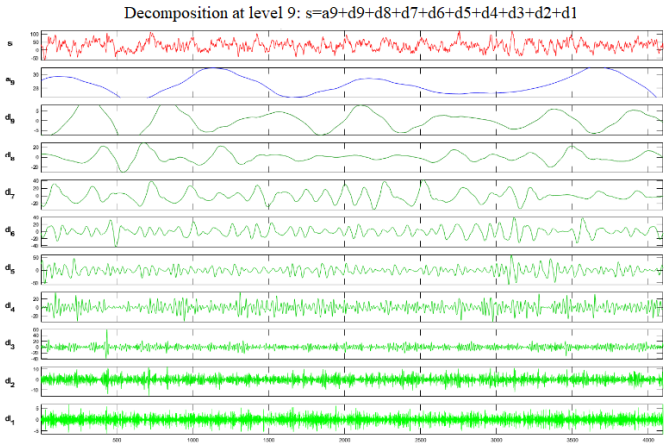

Fig.8. Multiresolution Wavelet Analysis of Data_d (Db-9).

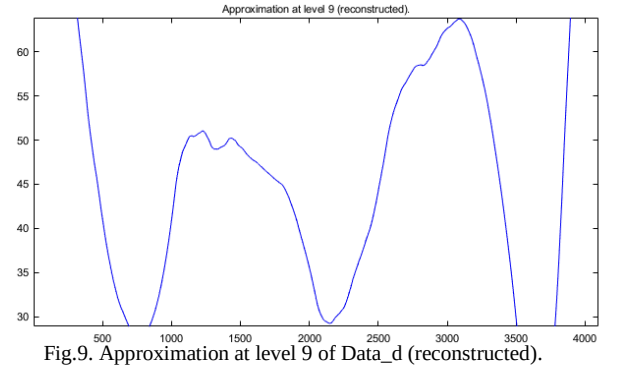

Fig.9. Approximation at level 9 of Data_d (reconstructed).

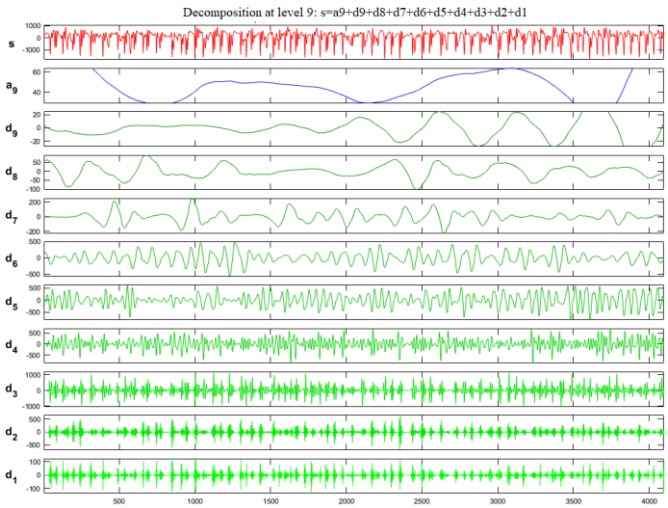

Fig.10. Multiresolution Wavelet Analysis of Data_e (Db-9).

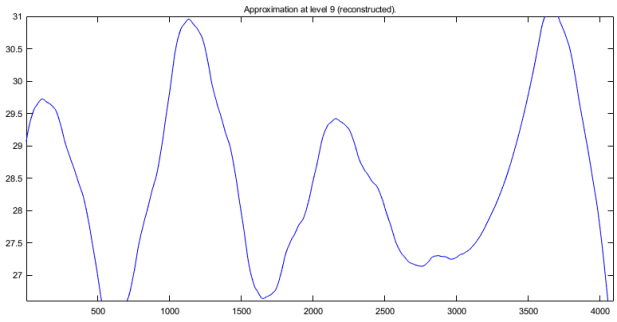

Fig.11. Approximation at level 9 of Data_e (reconstructed).

4. CONCLUSION

Wavelets Analysis is a method that analyse and process the signals that has carry data. It has a strong mathematical background. Wavelets Analysis has increased its popularity independently in the fields that study signal processing mainly such as seismic geology and disease analysis in the medical field. Continuous Wavelet Transform is a good method to analyse the signal, however when it comes to the reconstruction of the signal it might not be that good. Because of that, the given data is analysed by using MRWA is rather than CWT.

In this paper, data was taken from the healthy person's and epilepsy patient's was examined. Epilepsy patient's at the time of seizure data and at the time of normal data were taken. The collection and analysis of these data contains important information for diagnosis. First of all, statistical analyses have been done and then the signals were analysed. The results of the analysis of signals that are belonged to patient and healthy person, show that the constructed and reconstructed graphs help to make determinative interpretation to detect the disease.

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BIOGRAPHIES

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