The Preliminary Study of EEG and ECG for Epileptic Seizure Prediction based on Hilbert Huang Transform

Worawich Phornsiricharoenphant[1], Songpol Ongwattanakul[2], Yodchanan Wongsawat[3]
Department of Biomedical Engineering
Mahidol University
Nakornpathom, Thailand
[1]worawich.ph@gmail.com, [2]songpol.omg@mahidol.ac.th, [3]yodchanan.won@mahidol.ac.th

***Abstract*—Epilepsy is a chronic brain disorder. The patient are suffer from the unpredictable seizure. The conventional method for studies the characteristic of epileptic seizure is measuring the Electroencephalogram (EEG). On the other side, there are some studies reported about the relation between heart rate from Electrocardiogram (ECG) and epileptic seizure. This paper is a preliminary study about EEG and ECG based epileptic seizure prediction. The feature extraction method is based on the Hilbert Huang Transform (HHT) and we try to indicate some phenomena of EEG and ECG before the seizure onset. We extract the mean instantaneous frequency from EEG and R-R interval from ECG. The result shows the mean instantaneous frequency in mode one of intrinsic mode function was significantly dropped down simultaneously with R-R interval variation before seizure onset, the prior time is around 130 second. So, we can conclude that there is a possibility to use these two feature as a indicator for early prediction.**

Keywords*—*Epilepsy; EEG; ECG; Hilbert Huang Transform

I. Introduction

For human, any dysfunctions that happen to the brain are significantly affect their daily life. An Epilepsy is one of the brain dysfunctions that effect around 50 million people worldwide. According to the definition of International League Against Epilepsy (ILAE) "An epileptic seizure is a transient occurrence of signs and/or symptoms due to abnormal excessive or synchronous neuronal activity in the brain. Epilepsy is a disorder of the brain characterized by an enduring predisposition to generate epileptic seizure, and by the neurobiologic, cognitive, psychological, and social consequences of this condition. The definition of epilepsy requires the occurrence of at least one epileptic seizure." [1]. The patient were at risk of injury or death and also other people around them from an accident due to the unconsciousness during epileptic seizure.

The conventional method that supports the physician to observes the characteristic of epileptic seizure and diagnosis precisely is Electroencephalogram (EEG). Since there is significantly difference between normal EEG and epileptic EEG. So, It can be distinguish into normal for normal EEG, Pre-ictal or interictal for period before seizure onset and ictal for period during seizure. There were several studies use EEG for automate seizure onset detection based on many different method. A Linear prediction error, component analysis and fast fourier transform had been applied to extract feature from EEG combined with the classifier such as thresholding, support vector machine and decision tree classifier respectively [2][3][4]. However, another biological signal like Electrocardiogram (ECG) can reveal some characteristic that maybe helpful for indicate the seizure onset. Zijimas et al. reported about the heart rate variation before the seizure. They found that most of patient heart rate increase more than 10 beats per minute and a small number of patient was decrease more than 10 beats per minute before seizure onset [5]. So, the EEG and ECG based method for epileptic seizure detection had been studied. The feature extraction technique for EEG such as Fast fourier transform, a frequency based method, and heart rate viability analysis had been proposed by Greene et al. which classify the seizure by linear discriminant analysis [6]. Another study use Gabor function to extract feature from both EEG and ECG and classify the seizure by probabilistic neural network (PNN) [7]. There is no study about early prediction utilizing the feature from both EEG and ECG simultaneously. With this reason lead us to do this preliminary work.

This paper proposes the feature extraction method for EEG and ECG based on Hilbert Huang transform first derived in [8] and evaluate the possibility for using both EEG and ECG for early prediction. We consider the feature such as R-R interval and instantaneous frequency from ECG and EEG signal respectively at the time before the seizure onset and try to define some phenomena. The Hilbert Huang transform and feature extraction method was describe in section II. Our result and phenomena are present in section III. The discussion about the algorithm and result are describe in section VI and also the conclusion in section V.

II. Method

In this paper feature extraction technique was based on Hilbert Huang Transform. The Hilbert Huang Transform is consist of two main part that is Empirical mode decomposition and Hilbert transform. We use empirical mode decomposition for detecting the R-peak of ECG signal and for EEG we decompose it by EMD and use the Hilbert transform to find the instantaneous frequency.

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A. Empirical Mode Decomposition (EMD)

The Empirical mode decomposition is a method that decompose the input signal into subcomponent call intrinsic mode function (IMF). Each IMF is represent different pattern of oscillation that contain in the input signal, the first IMF contain highest oscillation component and the last IMF contain lowest oscillation component or we call it is residue. The IMF stopping criteria was determined by a Cauchy type of convergence test. It has been defined as (1)

$$SD_k = \frac{\sum_{t=0}^{T} |h_{k-1}(t) - h_k(t)|^2}{\sum_{t=0}^{T} h_{k-1}^2} \tag{1}$$

Where $h_k(t)$ is successive sifting result and k denote the k th IMF. The test requires the normalized squared difference between two successive sifting operation to be small than the predetermine value. We initially set this value small as must as we can, while the sifting process still functioning. From experiment the proper value is 0.3.

The EMD sifting process of signal $x(t)$ can be briefly describe as follow:

a) *Step 1:* Identify all maxima and minima point of input signal : $g(t) = x(t)$

b) *Step 2:* Connect all maxima and minima point with cubic spline interpolation to get upper and lower envelope.

c) *Step 3:* Calculate the mean envelope:

$$m(t) = \frac{(g_{up}(t) + g_{down}(t))}{2}$$

d) *Step 4:* Subtract the mean envelope from input signal:

$$h(t) = g(t) - m(t)$$

e) *Step 5:* Determine whether $h(t)$ is IMF or not. If does not pass the criteria for IMF repeat step 1 to 4 again by using $h(t)$ as a new input: $h(t) = g(t)$

f) *Step 6:* After get an IMF $c = h(t)$ Subtract IMF from input signal $g(t)$: $r(t) = g(t) - c(t)$

g) *Step 7:* Use $r(t)$ as a new input signal: $r(t) = g(t)$ and repeat step 1 to 6 again until $r(t)$ is a residue so the sifting process will be done.

After sifting process we get a series of IMF and one residue. The number of IMF will directly relate to the IMF stoppage criteria in sifting process. We will discuss about the IMF stoppage criteria later in section 4.

B. Hilbert trancform

After we get a series of IMF, the next step is finding the instantaneous frequency. In order to find the instantaneous frequency we take the Hilbert transform of each IMF. So, the Hilbert transformation $H[x(t)] = y(t)$ where $x(t)$ is k th IMF is define as (2).

$$y(t) = \frac{1}{\pi} p.v. \int_{-\infty}^{\infty} \frac{x(\tau)}{(t-\tau)} du \tag{2}$$

where $p.v.$ indicate the principle value of the singular integral. With Hilbert transform the analytic signal can define as (3).

$$z(t) = x(t) + iy(t) = a(t)e^{i\theta t} \tag{3}$$

So the instantaneous amplitude and phase is

$$a(t) = \sqrt{x^2 + y^2}, \text{ and } \theta(t) = \arctan\left(\frac{y}{x}\right)$$

Now we already know the instantaneous phase then we can find the instantaneous frequency by find the rate of change of the phase defined in (4).

$$\omega(t) = \frac{d\theta(t)}{d(t)} \tag{4}$$

C. ECG and EEG feature extraction

In this paper we use the sample data from CHB-MIT Scalp EEG Database that is available online via physionet website. The signals were sampled at 256 samples per second with 16-bit resolution. We select only sample that record both EEG and ECG simultaneously. So, we get only one subject that have three seizure event. Our selected files contain twenty three EEG channel record with the international 10-20 system of EEG electrode placement and one ECG signal.

We use only the EMD to extract the feature from ECG signal. First, the rectangular window with 256 sample length overlap 50% had been add to ECG signal. After windowing we taking the EMD, the result come out with a series of IMF. In order to detect the R-peak we consider only second and third IMF. This two IMF are clearly represent some oscillation that can be use to indicate the R-peak see Fig 1. We rectified and sum this two mode of IMF to change it into a pulse of heart beat see in Fig 2. The peak of pulse indicate the R-peak. So, the next step is finding the peak location of each pulse and calculate the R-R interval from the different between two adjacent peak. Finally, the R-R interval plot has been generated for visualization.

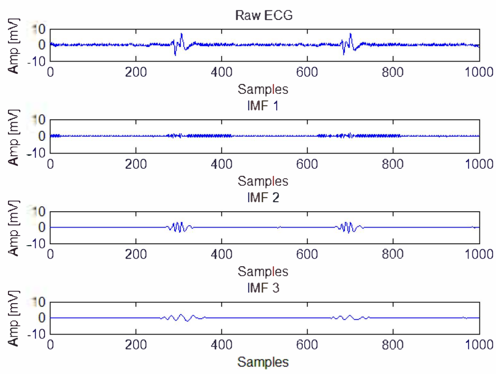

Fig 1. Raw ECG and first three mode of IMF

For EEG signal, we windowing the signal with hamming window with 256 length of sample and 50% overlap. After windowing the EMD had been applied. We consider only the first three IMF, because the first three IMF are already represent all of the human EEG frequency in alpha and beta band. For the IMF lower than that it will consider as movement artifact and has been cut out. The Hilbert transform had been taken to each mode of IMF to calculate the instantaneous frequency. We also calculate the mean of instantaneous frequency. The time frequency plot and mean time frequency plot had been generated for visualization.

III. Result

In this paper we have 3 events of seizure that record the EEG and ECG signal simultaneously. Fig. 2 shows the result of EMD based R-peak detection. The red circle indicate the R-peak that we got from our algorithm. It represent acceptable result and range of accuracy for R-peak detection.

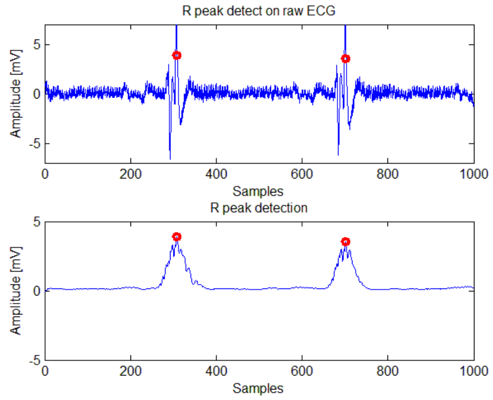

Fig 2. The result of R-peak detection. (Top) Real ECG plot with R-peak marker. (Bottom) The heart beat pulse.

In Fig 3. shows the raw EEG compare with the first three mode of IMF that we got from the EMD sifting process. After calculating the instantaneous frequency, each IMF represent the frequency range around 40 - 60 Hz, 10 - 40 Hz and 5 - 10 Hz for mode 1, 2 and 3 respectively The time frequency plot are shown in Fig 4. With this plot we cannot clearly indicates any phenomena that happen before the seizure onset but if we consider the mean line of time frequency plot it will be more clearly to indicate some phenomena.

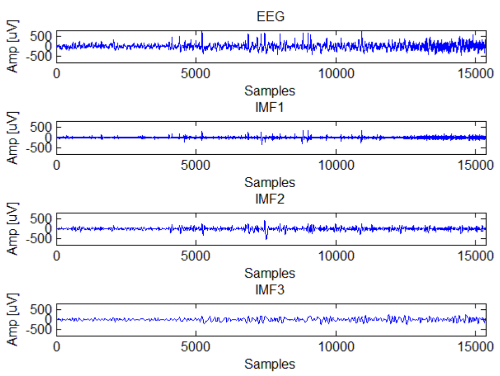

Fig 3. Raw EEG data and first three mode of IMF.

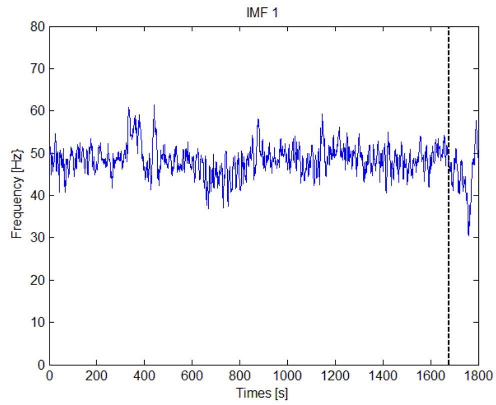

Fig 4. Time frequency plot of first seizure event.

In Fig 5. shows the mean line of time frequency plot of mode 1 and R-R interval plot of first seizure event. A vertical black dash line indicates the seizure onset.

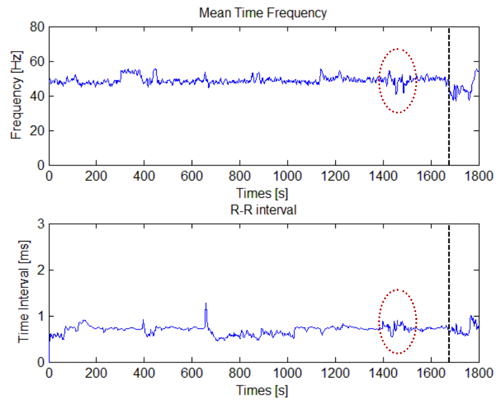

Fig 5. (Top) A time frequency plot overlap with mean line. (Bottom) A R-R interval plot.

The phenomena that we found before the seizure onset in all of seizure events are in the same direction. There is a significantly drop down of frequency simultaneously with the R-R interval variation (shows in red dot circle) and the early detected times that we get are show in Table I. However, we only found this phenomena only on mode 1 of IMF.

Table I. Time prior seizure onset of three seizure event

Seizure event number	Early detected times [second]
1	229
2	20
3	141

IV. Discussion

From our implementation, the HHT based feature extraction algorithm are working well. However, there is a question about the way to choose the IMF criteria. Actually there was two stoppage criteria one is the criteria that we use in this paper. The other one is based on the IMF definition. It checks the number of consecutive sifting, when the number of zero crossing point and extrema point are equal or differ at most by one. Many studies have used EMD are frequently use this second criteria. However, from our experiment we already implement both criteria in our algorithm. The first criteria giving a fast calculating time more than second criteria. Since, we plan to implement this algorithm in real time system, the processing time are the important factor that we must consider. So, the first criteria will be more suitable for the future implementation.

From our result, the phenomena that we found is dropping down of mean time frequency and R-R interval variation. This two phenomena will simultaneously happen. So, there was a possibility to use both EEG and ECG for early prediction of epileptic seizure in the way that we cross checking this two feature along the time. On the other hand, our result did not guarantee for all case of epileptic seizure because of the lower number of sample. So, we will increase the number of sample to confirm this phenomena in the future.

V. CONCLUSION

We have present the HHT based EEG and ECG feature extraction for prediction epileptic seizure. According to the dropping down of EEG frequency in IMF mode 1 simultaneously with R-R interval variation. So, we can conclude that the R-R interval and instantaneous frequency of EEG can be a significant index for early indicate the seizure onset.

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