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EEG Data Sets Signal Processing Using Wavelet Transforms

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Abstract. Sensing is fundamental to all measurements, and its quality depends on many factors such as size, material used, etc. Physiological sensors measure core body temperature, ambulatory blood pressure, blood oxygen etc. Sensitive medical equipment EEG (Electroencephalography) measures electricity levels over areas of the human brain scalp. Data acquisition and processing of these voltages and signals involves lot of processing time. It is possible to expand the signal in a series of wavelets. Then we can join the advantages of the wavelet transform with the atomic decomposition of signal. Wavelet analysis provides a timescale description of any finite energy signal. Essentially, it is a successive decomposition of the signal in different scales. At each step, the corresponding details are separated, providing useful information for detecting and characterizing short time phenomena or abrupt changes of energy. This paper studies wavelet transforms for EEG data processing

Keywords- Sensor, EEG, Neurological Disorder, Wavelets

I. INTRODUCTION

Human brain is a knot of 100 billion neurons and support cells. Our brain cells pulses and vibrates like everything in this Universe. The brain pulse is measured like sound in cycles per second or Hertz. Electrical activity of the brain is called Brainwave pattern, because of its cyclic, "wave-like" nature. It is a combination of millions of neurons sending signals at a time. They are detected using sensitive medical equipment EEG (Electroencephalography) measuring electricity levels over areas of the scalp [1]. Neurons are electrically active cells responsible for brain's functions. A neuron is basically an on/off switch. Either in a resting state (off) or it is shooting an electrical impulse down a wire (on). Has a cell body, a long little wire (the "wire" is called an axon), and at the very end it has a little part that shoots out a chemical. This chemical goes across a gap (synapse) where it triggers another neuron to send a message. There are a lot of these neurons sending messages down a wire (axon). Billions of neurons "spit out" chemicals that trigger other neurons. Different neurons use different types of chemicals. These chemicals are called "transmitters" and are given names like epinephrine, norepinephrine, or dopamine. Neurotransmitter activates a receptor in the dendrite or body of the neuron. Neurotransmitter, when combined with the receptor, typically causes an electrical current within the dendrite or body. Neurons create action potentials (APs). APs are discrete electrical signals that travel down axons and cause the release of chemical neurotransmitters at the synapse-area of near contact between two neurons [10].

Billions of axons are generating a small amount of electrical charge. Communication between brain cells is a bio-chemical event across tiny spaces called *synapses* [2]. Our thoughts, feelings, actions, memories & imaginations are the result of what happens in our synapses [4].

Every neuron receiving synaptic inputs can be thought of as a dipole with a specific orientation and polarity. A dipole corresponding to a single neuron is not detectable with EEG. Thousands of neurons with similar orientation receive similar synaptic inputs, the dipoles sum together to yield sizable voltage signals at the scalp. Different wave patterns are shown in fig. [1] below.

Fig. [1] First Recordings of Brain Activity

II. DATA PROCESSING USING EEG BRAIN MAPPING

Our brain cells pulses and vibrates like everything in this Universe. The brain pulse is measured like sound in cycles per second or Hertz. During an EEG test, electrodes (flat metal discs) are placed over head. The electrodes pick up the electrical signals from brain and send them to an EEG machine.

The electrodes only pick up electrical activity from brain; they don't give out electrical signals. This means that electrodes don't affect brain and they don't cause any pain. The EEG machine records the electrical signals from brain. They look like wavy lines. These wavy lines represent brainwave patterns. The EEG test can only show your brainwave patterns at the time the test is carried out. At different times, brainwave patterns may be different as shown in the fig. 2 below.

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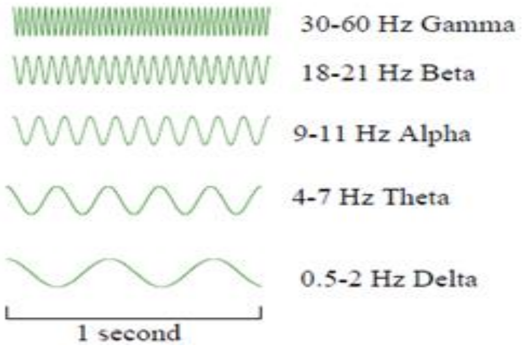

Fig, 2 Brain-Wave Patterns

An EEG test only gives information about the electrical activity in brain. It doesn't show if there's any damage or physical abnormalities in brain. EEG is used in the evaluation of brain disorders. Most commonly it is used to show the type and location of the activity in the brain. With discovery of brainwaves came the discovery that electrical activity in the brain will change depending on what the person is thinking. For instance, the brainwaves of a sleeping person are vastly different than the brainwaves of someone wide awake.

A typical adult human EEG signal is about 10µV to 100 µV in amplitude when measured from the scalp and is about 10–20 mV when measured from subdural electrodes. Since an EEG voltage signal represents a difference between the voltages at two electrodes, the display of the EEG for the reading encephalographer may be set up in several ways. The EEG signal is small compared to the amplitude of common artifacts (muscle, mains power frequency radiation) [3]. Clean signals are dependent on low scalp/electrode impedance, differential amplifiers, and filtering. The EEG is typically recorded by an "instrumentation" amplifier which uses a third "common" electrode to remove noise. EEG reflects activities of neural cells appearing on the surface of scalp [1].

EEG is a non-stationary signal. FFT cannot describe it fully. Need transforms localized in time and frequency domain. Wavelet transform (WT) solves the above problem. WT has the ability to indicate signal which localized in time or frequency domain. Both the transforms are linear time-frequency representations for which rules of superposition or linearity apply.

Biomedical signals contain critical feature of frequency domain parameters. Time localization is an issue as it needs to study frequency content changes over time. Biological signals are spreaded over wide range of frequency spectrum. It is desirable to use basis functions that have a wider frequency spread as most biological signals do. Wavelet theory provides wideband representation of signals.

TIME DOMAIN

Larger scale factor generates same function compressed in time. Analyzing signal contracted in time, signal features or changes that occur over a smaller time window can be studied. Similarly smaller scale function enables larger time translations or delays in the basic signal.

FREQUENCY DOMAIN

Larger scale factor has the effect of frequency compression as the analysis window in the frequency domain is contracted. Frequency domain scaling effect is to be used for frequency localization.

Degree of resolution available in frequency and time domains is of importance. Small window size in time domain yields poor frequency resolution while offering excellent time resolution and vice-versa (STFT has same time-frequency resolution regardless of frequency translations).

III. EEG SIGNAL PROCESSING USING WAVELET ANALYSIS

The complex character of EEG and its significance in brain research and clinical practice brought early introduction of signal analysis methods to EEG studies. The next subsections briefly describe basic methods for EEG signal processing. Spectral methods of EEG processing can be traced back to the first attempt of Fourier analysis application to EEG in 1932 [Dietsch 1932].

In 19th century, the French mathematician J. Fourier showed that any periodic function can be expressed as an infinite sum of periodic complex exponential functions. Many years after he discovered this remarkable property of functions, his ideas were generalized to first non-periodic functions, and then periodic or non-periodic discrete time signals. It is after this generalization that it became a very suitable tool for computer calculations. In 1965, a new algorithm called Fast Fourier Transform (FFT) was developed and FT became even more popular.

The information provided by the integral, corresponds to all time instances, since the integration is from minus infinity to plus infinity over the time. This is why Fourier transform is not suitable if the signal has time varying frequency, i.e., the signal is non-stationary. This means that the FT tells whether a certain frequency component exists or not. This information is independent of where in time this component appears.

Therefore a linear time frequency representation called Short Fourier Transform (STFT, sometimes called Gabor analysis) was introduced. In STFT, the signal is divided into small segments, where these segments (portions) of the signal can be assumed to be stationary. For this purpose, a window function is chosen. The width of this window must be equal to the segment of the signal where its stationarity is valid.

The most important result of the wavelet transform is the location of the composing wavelets in time. Sharp, time-limited signal parts would be represented by wavelets that are scaled down in duration. As in Fourier analysis, the contribution of the composing wavelets to the signal provides information about the temporal properties of the signal on different time scales.

Linear decomposition of signal in a wavelet basis was a significant improvement over the short time Fourier transform, allowing for orthogonal representation, fast numerical implementations and multiresolution decomposition of signals[6]. WT is being successfully applied e.g. for analysis of time-locked EEG phenomena (evoked potentials), where it's main drawback-sensitivity of the representation to the time shift of analyzed window is not essential. However, neither WT nor STFT provide enough resolution and flexibility in a general case, like description of transients occurring more or less randomly in time.

Based on Heisenberg's uncertainty principle stated above, it is hard to get a good resolution for both time and frequency concurrently. Lower frequencies are better resolved in frequency and higher frequencies are better resolved in time.

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Multiple Rate Analysis (MRA) analyzes the signal at different frequencies with different resolutions [6]. It is designed to give good time resolution at high frequencies and good frequency resolution at low frequencies. This approach makes sense especially when the signal at hand has high frequency components for short durations and low frequency components for long durations. Wavelet analysis is one of MRA techniques as shown in fig. 3 below using Matlab. It is a recent approach, suitable for analyzing signals with rapidly changing spectra. It provides a time-frequency representation without assuming stationary, by using an adaptive window function. The size of the window is inversely proportional to the frequency. Thus we'll have large windows at small frequencies (maximize frequency resolution at such frequencies) and small windows at large frequencies (maximize time resolution at such frequencies) Comparing this to the STFT case, where the time-frequency resolution stays the same Wavelet analysis has obvious advantage.

EEG's are complex signals whose statistical properties depend on both the space and time. Regarding temporal characteristics, EEG signals are chaotic and highly non-stationary. Nevertheless, they can be analytically subdivided into short representative epochs where stationarity hypothesis is accomplished.

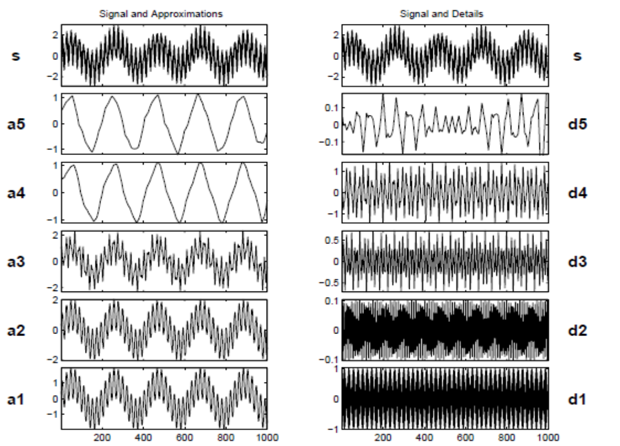

Fig. 3 Multi-level Wavelet Analysis in Matlab

IV. IMPROVEMENTS TO THE TIME FREQUENCY ANALYSIS OF THE EEG SIGNALS USING WAVELET TRANSFORM

Until the introduction of long term monitoring, spontaneous seizure EEG's were obtained only in those lucky situations in which the patient had a seizure during the few minutes of the recording. Normally, interictal EEG's and EEG's without seizure activity were analyzed looking for pathological characteristics such as spikes, paroxysms, low frequency activity, etc. During those interictal EEG's, seizures were activated with photo stimulation, hyperventilation, and other clinical methods. However, provoked seizures do not necessarily have the same behavior as spontaneous ones. In order to overcome this limitation, long term video-EEG monitoring systems were developed. With video-EEG, after days of recording, clinical and electroencephalographic information can be correlated for obtaining an accurate evaluation of the seizures. Seizure starting, duration, post-seizure recovering, classification of the seizure, and different stages are some of the characteristics usually analyzed. However, in the case of tonic clonic seizures, muscle activity provoked by violent movements completely obscures the EEG recordings, limiting the analysis only to the starting and the post-seizure stages. Visual inspection of the EEG and traditional mathematical methods such as Fourier transform are no longer applicable in these cases, owing to the great amount of noise involved. In consequence, brain activity during this kind of seizure has been observed only in special cases, for example in patients treated with a drug that inhibits muscle responses, or by filtering the signal in the frequency range of the muscle activity with standard methods. However, filtering has several disadvantages, because it is impossible to separate brain and muscle activity and, further, it is well known that filtering high frequencies also affects the morphology of the low ones.

A scalp EEG signal is a non-stationary time series that usually presents artifacts due to an electrooculogram, an electromyogram, an electrocardiogram ECG, and others. Artifacts make a mathematical analysis of scalp EEG signals difficult. Sometimes, artifacts are presented for a few seconds, and can be obviated because they obscure only a small portion of the total EEG. In other cases, almost the total signal appears noisy and obscured by them, and very little information about the underlying brain activity can be extracted. When noise is present only in specific frequency bands, a filtering process can be implemented. However, from the point of view of nonlinear dynamics, filtering could be suitable only in some cases depending on the system under study. It is important to emphasize that a poorly designed filtering of the signal can give spurious results ~i.e., filtering frequencies that determine the real dynamics of the signal. Thus in these cases a filtering based on wavelet transform can be implemented in order to obtain a more accurate signal of the process under interest.

Thus in these cases a filtering based on wavelet transform can be implemented in order to obtain a more accurate signal of the process under interest.

In summary, this method allows the elimination of non-desired frequency bands that hide other more interesting or unknown effects. Due to the orthogonality of the wavelet functions employed, we can be assured that only the unwanted and previously selected frequency bands were extracted, without needing to assume that linearity is necessary for making the traditional Fourier-based digital filtering[5].

As it is well known, wavelet analysis provides a *timescale* description of any finite energy signal. Essentially, it is a successive decomposition of the signal in different scales. At each step, the corresponding details are separated, providing useful information for detecting and characterizing short time phenomena or abrupt changes of energy.

V. WAVELET APPLICATIONS

Pattern recognition

a. Biotech: to distinguish the normal from the pathological membranes

b. Biometrics: facial/corneal/fingerprint recognition

Feature extraction

c. Metallurgy: characterization of rough surfaces

Trend detection:

d. Finance: exploring variation of stock prices

Perfect reconstruction

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e. Communications: wireless channel signals
Video compression – JPEG 2000
Sample Applications

- Identifying pure frequencies
- De-noising signals
- Detecting discontinuities and breakdown points
- Detecting self-similarity
- Compressing images

VI. CONCLUSION

Wavelet analysis gives us a powerful tool to confront very diverse problems in applied sciences or pure mathematics. The applications of several methods to the analysis of different type of EEG signals are shown. Methods provide low computational complexity, stable and fast numerical implementations, providing information on the time, resp. time-frequency distribution of signal's energy and straightforward interpretation of coefficients in terms of time-frequency energy content despite all advances due to the development of new techniques and experiments are still very little what is known about EEG behavior and underlying process in the brain.

The fundamental idea how to estimated human state is based on the measuring of dynamic changes of various psychological measures such as EEG, ECG, EMG, etc. by means of medical equipment such as polygraph, and then processing the characteristic (parameterization) of these measured signals to estimate various kinds of human state such as temporal level of mental workload. Naturally, the EEG signal involves the biggest amount of information considering human behavior.

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