Analyzing and Processing EEG-based Multichannel Signals Acquired during Sleeping

P. Vergallo, A. Lay-Ekuakille, N.I. Giannocaro
Department of Innovation Engineering, University of Salento, 73100 Lecce, Italy

A.Trabacca, R. Della Porta, M. De Rinaldis
Scientific Institute I.R.C.C.S. "E. Medea"– "La Nostra Famiglia" - Neurorehabilitation Unit 1 (Developmental Neurology and Functional Rehabilitation) - Brindisi Research Centre. Brindisi , Italy

Abstract— **Processing of signals acquired from sensor systems needs accurate algorithms to extract information of interest concerning the problem under study. In this work Empirical Mode Decomposition method is used on EEG signals obtained during polysomnography examination, when electromyographic (EMG) signals are acquired too. EMD method decomposes a signal into components named Intrinsic Mode Functions (IMF) which can exhibit important time-frequency information related to signals under observation. Since EEG signals are obtained from multiple electrodes, the problem is addressed to processing of signals acquired from multiple channels according to sensor array techniques. The objective of this work is to define an automatic method to detect transient event, changes of sleep stage in EEG signals which can allow an evaluation of the state of the patient. In this first step we analyze and process EEG signals through EMD method to remove EMG contributes. The obtained results are encouraging in the definition of a future multivariate approach to quantify brain activity by evaluating correlation of the IMFs calculated for each channel.**

Keywords-component; Biomedical measurements, signal processing, sleep EEG, Empirical Mode Decomposition.

I. INTRODUCTION

The analysis of different physiological signals as electroencephalographic (EEG) ones can point out features related to state of patient. In particular, the recording during the sleep is useful to discriminate sleep or vigilance stages, transient events or abnormalities. So the development of advanced techniques to process these signals are of great interest. In the clinical approach the study of the sleep consists in the recording of a set of physiological signals during an examination called polysomnography. In this examination, EEG signals, electrooculogram (EOG) signals, and electromyographic (EMG) signals are acquired in order to define the state of the patient under observation. EEG signals reflect the electrical brain activity measured through 19 electrodes placed on the scalp according to the international 10-20 system. EOG signals measure the ocular activity with electrodes placed on the circumference of the eyes orbit, and EMG signal represents the muscular activity recorded by one electrode placed on the chin. The standard method is based on the construction of hypnograms which provide information about the macrostructure or architecture of sleep, sleep stages and cycles [1]. The definition of the hypnograms needs to evaluate variations in EEG, EOG, EMG signals. So hypnograms and statistic data obtained by expert medic allow to associate for each epoch a label indicative of the state of the patient in order to make a clinical decision. Sometimes the interpretation of the signals may be complicated due to artifacts or noise present in the signals. Thus, advanced techniques can be of help in the diagnosis in order to extract features of interest or to study different indices which allow a major evaluation [2]. Since the EEG signal is an important indicator with specific features concerning the physiological state of the patient, its information must be preserved because it could be contaminated by EMG artifacts. Thus, we apply EMD method to remove in EEG signals EMG artifacts [3,4]. The choice to use this method is due to intrinsic nature of EEG signals which are nonlinear and nonstationary. Empirical Mode Decomposition decomposes the original signal in a linear combination of intrinsic oscillatory modes, called Intrinsic Mode Functions (IMFs). This decomposition is adaptive and efficient, because it is based on the local characteristic time scales of the data, and so it is very good for nonlinear and non-stationary processes in comparison with standard methods as Fast Fourier Transform (FFT) or Wavelet Transform (WT) which use predefined basis functions as the sum of sinusoids with fixed frequency, phase and amplitude. For this motivation the accuracy of FFT and WT methods depends strongly on data length and their stationarity.

In order to remove EMG artifacts from EEG signals, we apply EMD on each channel of acquisition and we calculate a correlation coefficient for the IMFs related to each channel to determine if EMG artifacts are present in EEG signal or less. The obtained results are encouraging in the definition of an future multivariate approach to explore the sleep process as a function of brain region.

II. IMPORTANCE OF AN ACCURATE EEG SIGNAL ANALYSIS

In Polysomnography examination, signals from EEG, EOG and EMD are acquired together. The EEG signal is a very important complex signal to determinate the brain state of the patient and allows to discriminate walking, sleeping, and seizure [2,5,6]. Researches are focused to quantify the information in it by performing time and frequency analysis.

In particular in polysomnography the study of EEG signals allows to classify the sleep stage, to detect abnormal events, prediction of epileptic seizures and to monitor brain injury. Fig.1 shows the international system 10-20 of placement of the electrodes used.

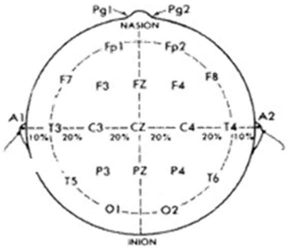

Fig.1. International system 10/20

The standard positions are identified by a letter and a number. The letters are: F = frontal; T = temporal; C = central; P = parietal; O=occipital; A = ear (reference point). The even numbers are related to the right hemisphere, the odd to the left. Z indicates the center line. A_1 and A_2 are at the lobes of the ears and they are used as a reference. The standard mounting is 19 electrodes-based.

There are three connection types: unipolar, bipolar, and referred to the average. We consider bipolar connection where the voltage differences between pairs of electrodes is taken into account. This allows a more precise localization of the activity areas. One of the major limitations in the electroencephalography technique, that may adversely affect the diagnostic and prognostic value of the instrumental examination itself, is the presence of electrical artifacts on EEG. The artifact in electroencephalography is defined as any potential source not recognized in the normal brain EEG changes, which distorts the brain bioelectrical activity, and they can be due to noise generated from the equipment specification, electromagnetic interference coming from external field of recording, or by physiological electric potentials of cerebral origin, e.g. physiological artifacts from eye and eyelid movement, from cardiovascular activity, from muscle activity [7]. The artifacts can compete with the electric potential of cerebral source and so they can blur important information. To ensure the reproducibility and reliability of signal, it is important to consider both the technical variables (e.g. the choice of the positions of the electrodes on the scalp, the characteristics and parameters observed during the recordings) and physiological (e.g. conditions of the subject during recording). The knowledge of the multiplicity of causes and morphological aspects of the artifacts can allow the eventual elimination of the same, when possible.

Dataset analysed in this work was obtained during polysomnography examination in Scientific Institute I.R.C.C.S. “E. Medea” in Brindisi, and it contains 16 EEG channel signals and one EMG signal acquired by an electrode placed on the chin of the patient.

III. Empirical Mode Decomposition

Empirical Mode Decomposition (EMD) is a method developed by Huang et al [3] for the time-frequency analysis of nonlinear and non-stationary signals. EMD method separates the time-series into intrinsic oscillations called intrinsic mode functions (IMF) by using local temporal and structural characteristics of the data. The crucial point in EMD method is the computation of the local mean of the original signal based on the calculation of the local extrema [8]. Thus, the original signal is modeled as a linear combination of these IMFs. For a signal $x(t)$, EMD method calculate a set of N IMFs, which represent the high frequency part of the signal, and a residue signals corresponding to the low frequency part of the signal.

Thus, for an arbitrary signal $x(t)$, EMD method is implemented in the following way [9]:

- Identify all extrema (maxima and minima) of $x(t)$;
- Generate the upper and lower envelope ($e_{min}(t)$, $e_{max}(t)$) by interpolation of the maxima and minima points with a cubic spline;
- Compute the mean as $m_1(t) = (e_{min}(t)+e_{max}(t))/2$;
- Extract the first component $h_1(t) = x(t)-m_1(t)$;

$h_1(t)$ to be considered an IMF should be symmetric and to have all the maximum points positive and the ones of minimum negative. So the described process is iterated more times to obtain an IMF, by considering $h_1(t)$ the new signal on which the aforementioned process is applied.

After k times, $h_{1k}(t)=c_1$ is define as IMF, and this is the faster oscillation mode present in the data. It is separated from the data as reported in Eq.(1):

$$r_1(t) = x(t) - c_1(t) \tag{1}$$

Since in general the residue r_1 still contains oscillations of period more long, it is treated as the new signal and the previous steps are applied on $r_1(t)$, until the residue becomes a function without a point of maximum and minimum. At the end of the decomposition process, the EMD method expresses the signal $x(t)$ as the sum of a finite number of IMFs and a final residual:

$$x(t) = \sum_{j=1}^{n} c_j + r_n \tag{2}$$

We apply EMD method to each channel EEG signal and channel EMG signal. We evaluate the obtained IMFs components by the computation of the correlation coefficients to point out coherent activities in EEG and EMG signals. The correlation coefficients are defined in the matrix R in the following way:

$$R = \frac{C(i,j)}{\sqrt{C(i,i)C(i,j)}} = \begin{bmatrix} \rho_{i,i} & \rho_{i,j} \\ \rho_{j,i} & \rho_{j,j} \end{bmatrix} \tag{3}$$

where, the index i is relative to IMFs of a single EEG channel signal, and the index j is referred to IMFs of the EMG channel signal. $C(i,j)$ is the covariance matrix between the $IMF(i)$ and

IMF(j), and so the coefficients in the matrix ρ are the correlation coefficients of the analyzed IMFs.

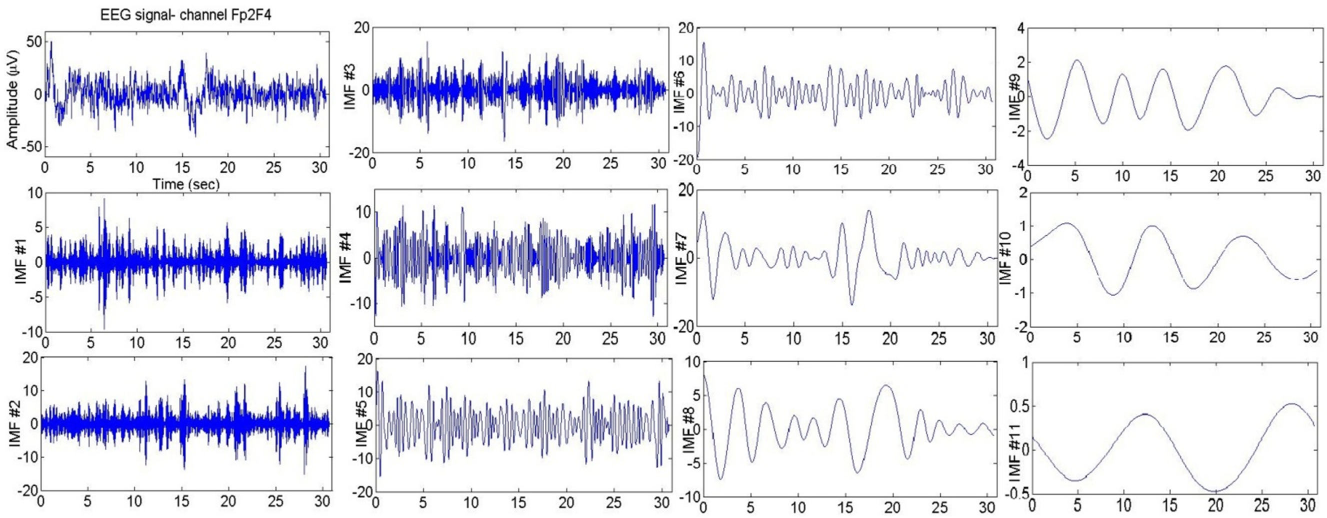

Fig.2. EEG signal and the first 11 calculated components

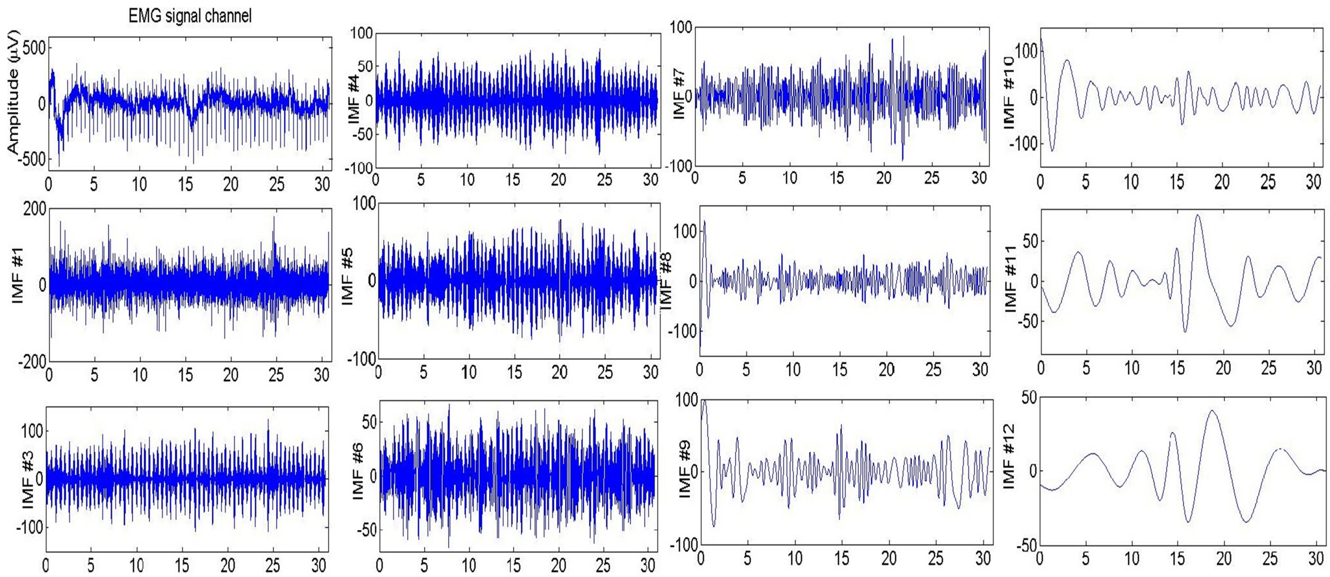

Fig.3. EMG signal and the 1 and 3-12 calculated components

IV. Results

In Fig.2 and Fig.3 the more significant calculated IMFs for an channel EEG signal and relative EMG signal acquired at the same instant are reported respectively. In Table I the calculated correlation coefficients are indicated. The coefficients which are more indicative of the maximum correlation (it is chosen as value ρ>0.4) are marked. So IMF7 of the EEG signal is strongly correlated with IMF11 of EMG signal, and IMF8 of EEG signal is correlated with IMF12 of EMG signal.

TABLE I. Correlation Coefficients

EEG/EMG	IMF1	IMF2	IMF3	IMF4	IMF5	IMF6	IMF7	IMF8	IMF9	IMF10	IMF11	IMF12
IMF1	0,0034	0,014	0,0061	0,0009	-0,0047	-0,0033	-0,016	-0,0153	-0,003	-0,0047	0,0154	0,0063
IMF2	0,0155	0,0045	0,0083	0,0043	0,005	0	-0,005	0,0009	0,0018	-0,0025	-0,0026	0,0003
IMF3	0,0128	0,0017	-0,0169	0,0009	-0,0112	-0,0063	-0,0006	-0,0063	-0,002	0,0049	0,0085	-0,0017
IMF4	-0,0385	0,0082	-0,001	-0,005	-0,0024	0,0003	-0,0047	-0,0032	-0,0038	-0,0025	-0,0065	-0,0065
IMF5	-0,0249	-0,0576	0,0242	0,0136	-0,0022	-0,0073	0,0039	-0,0121	-0,0094	-0,0035	0,0004	-0,0002
IMF6	-0,0035	0,0122	-0,0848	-0,0146	-0,0208	-0,0126	-0,0092	-0,004	0,0033	0,0118	-0,0085	0,0039
IMF7	0,0012	-0,034	-0,0521	-0,0921	-0,0617	-0,0077	0,0006	0,0295	0,0054	-0,0023	-0,0046	0,0071
IMF8	-0,0001	-0,0043	-0,0041	0,0485	-0,1339	0,1461	0,0482	-0,0095	-0,0236	0,015	0,0109	-0,0116
IMF9	0,0033	0,017	0,0025	-0,033	0,0922	-0,0727	0,1082	0,1992	0,0294	0,0213	0,0028	0,0717
IMF10	0,0062	-0,0098	-0,0112	0,0049	0,045	-0,0576	0,2995	0,1749	0,0101	0,091	-0,0372	0,1052
IMF11	0,0063	-0,0122	-0,0011	-0,0086	0,0192	0,0221	0,4114	0,1133	-0,1851	-0,1592	0,0588	-0,0885
IMF12	0,0025	0,0035	-0,0007	-0,0178	-0,0406	0,0189	0,1423	0,543	0,2955	-0,2363	-0,0114	-0,1018

The filtered EEG is shown in Fig.4. This filtered signal is suitable than the previous one and the main content has not been removed.

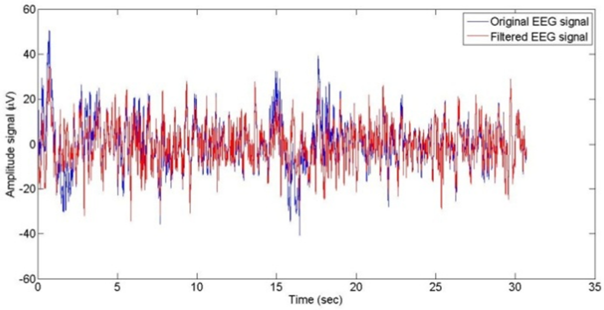

Fig.4. Original EEG signal and filtered EEG with the removed component related to EMG signal

V. CONCLUSIONS

In this work a first step of analysis and processing of sleep EEG is performed. Empirical Mode Decomposition method is used on EEG signals obtained during polysomnography examination in order to remove components related to electromyographic (EMG) signal. The particularity of EMD method is that it is well adapt to process nonstationary and nonlinear signals as EEG signals. The objective of the work is to define an automatic method to detect transient events, changes of sleep stage in EEG signals which can allow an evaluation of the state of the patient in a more accurate way. Thus, in the first step to define a method to remove artifacts as EMG is very important to obtain consequently significant information by processing of the EEG signals. A correlation coefficient is taken in consideration to evaluate the EMG contribute to remove in EEG signal by analysis of the IMFs calculated with the EMD method. The obtained results are encouraging in the definition of a future multivariate approach to quantify brain activity by evaluating correlation of the IMFs calculated for each channel and in order to analyze the sleep process as a function of brain region.

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