Parkinson Disease diagnosis using Empirical Mode Decomposition
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Abstract—Parkinson Disease is a neurological syndrome, characterized by resting tremor, reduced body movement and difficulty in maintaining proper posture. In this article I demonstrate a new method of parkinsonism diagnosis using Empirical Mode Decomposition (EMD) based on body movement synchronization analysis. EMD is a new method of signal decomposition into its monocomponents, so called Intrinsic Mode Functions (IMFs). Analysis of synchronization between signals’ IMF components is named Empirical Mode Decomposition Phase Locking (EMDPL). I show that applying this method to psycho-motorical tests or posturographical data is a good tool for Parkinson disease diagnosis.

Keywords—Parkinson, Empirical Mode Decomposition, EMD, Phase Locking, EMDPL.

I. INTRODUCTION

Empirical Mode Decomposition (EMD) is a new method of breaking down a nonstationary, multicomponent signal into its monocomponents, method developed by Norden E. Huang [1]. EMD is a entirely data-driven algorithm and it does not depend on any predefined basis function. Such monocomponents are called Intrinsic Mode Functions (IMFs); (see paragraph II-A). Analyzing of synchronization between selected IMFs of signals (see paragraph III) could give additional information that might be not noticeable when using basic analysis of synchronization between signals without EMD. This method is named Empirical Mode Decomposition Phase Locking (EMDPL).

I have tested above method on two data sets:
- Psycho-motorical Test - test developed by Prof. E. Gorzelanczyk’s (Collegium Medicum, Nicolaus Copernicus University, Bydgoszcz) group. The test is based on drawing by the patient series of figures on the tablet in the correct order according to the pattern shown in Fig. 1 (arrows marked the starting point and direction of drawing the figure). Tablet saves the data in the form of points \((x, y)\) and time \(t\). As a parameter describing the level of psychomotor abilities I took the variance of synchronization between signals \(x(t)\) and \(y(t)\).
- Posturography - posturographic data are obtained from a special platform that reacts to balance of the patient’s body by measuring the coordinates \((x, y)\) of the center of gravity or the center of pressure. Data used in this work were obtained from Prof. J. Błaszczyk (Nencki Institute of Experimental Biology, Warsaw).

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Mean value is subtracted from original data:

\[ imf_1(t) = x(t) - m(t). \]  \hspace{1cm} (2)

This procedure is named **sifting process**.

In ideal case \( imf_1(t) \) could be IMF, but usually it is still asymmetric signal. In such case we need to repeat above procedure and \( imf_1(t) \) is treated as input data for next sifting process, so mean value \( m(t) \) of envelopes of \( imf_1(t) \) is calculated and this value is subtracted from \( imf_1(t) \):

\[ imf_1(t) = imf_1(t) - m(t) \]  \hspace{1cm} (3)

This procedure is repeated till \( imf_1(t) \) satisfies conditions of IMF signal (\( m(t) \approx 0 \)). After extraction of first IMF original data is reduced by \( imf_1(t) \):

\[ r(t) = x(t) - imf_1(t). \]  \hspace{1cm} (4)

The residue \( r(t) \) is treated as input data for extraction of next IMF (next sifting loop). Procedure is looped to obtain all IMFs. Decomposition is finished when residue:

\[ r_i(t) = r_{i-1}(t) - imf_i(t) \quad i - current\ mode \]  \hspace{1cm} (5)

has less than three extrema or all its points are equal zero.

Summing of all IMF components and the residue gives the original signal:

\[ r_n + \sum_{i=1}^{n} imf_i(t) = x(t) \quad n - number\ of\ modes \]  \hspace{1cm} (6)

**C. Hilbert-Huang spectrum**

Signal decomposed into IMFs can be easily displayed as time-frequency characteristic by obtaining Hilbert-Huang spectrum. First step is to create, for each decomposition mode, analytic signal:

\[ imf_{ak}(t) = imf_k(t) + iH(imf_k(t)) \]  \hspace{1cm} (7)

where \( H(imf_k(t)) \) is Hilbert transform of \( k \) IMF. From analytic signal we can obtain instantaneous amplitude as a module of this signal:

\[ a_k(t) = |imf_{ak}(t)| \]  \hspace{1cm} (8)

and instantaneous frequency as a differential of argument of this signal:

\[ f_k(t) = \frac{1}{2\pi} \frac{d}{dt} \arg(imf_{ak}(t)). \]  \hspace{1cm} (9)

**III. EMPIRICAL MODE DECOMPOSITION PHASE LOCKING**

**A. Single Trial Phase Locking Value**

Synchronization between two signals can be characterized by parameter **Single Trial Phase Locking Value** given by equation [3]:

\[ SPLV(t) = \frac{1}{\delta} \left| \int_{t-\delta/2}^{t+\delta/2} e^{j(\phi_x(t)-\phi_y(t))} dt \right|. \]  \hspace{1cm} (10)

where \( \phi_x(t) \) is phase of signal \( x(t) \) at \( t \), \( \phi_y(t) \) - phase of signal \( y(t) \), \( \delta \) - length of \( SPLV(t) \) calculation time window. \( SPLV \) takes values in range \([0,1]\) - \( PLV \approx 1 \) means perfect synchronization between signals, \( PLV \approx 0 \) - no synchronization.
B. Empirical Mode Decomposition and Single Trial Phase Locking

For characterization of synchronization between multicomponent signals it is a good idea to decompose each signal into its components with EMD and to calculate their synchronization [3]:

\[ SPLV(t) = \frac{1}{N} \sum_{k=1}^{N} SPLV_k(t), \]  

(11)

where \( N \) - number of modes, \( SPLV_k(t) \) - value of \( SPLV \) (according to (10)) between mods of \( k \) order of signals \( x(t) \) and \( y(t) \). Phase of mode is calculated as the angle of analytic signal created from \( IMF \) according to (7).

IV. RESULTS

A. Psycho-motorical Test

Tests were performed on two groups of patients suffering from Parkinson’s Disease - people who are undergone pallidotomy (first group - 27 cases) and persons who are undergone thalamotomy (the second group - 27 cases). Each patient was studied before and after surgery. For each group an appropriate control group was assigned, 27 cases each, consisting of healthy individuals in the same age category as people who are in the parkinsonic group. Clinical examinations have shown improvement in patients after surgery.

Each of tablet’s signals: \( x(t) \) and \( y(t) \) was decomposed by EMD into 5 \( IMF \)’s. As a parameter characterizing the psychomotor disturbances I took the variance of synchronization of modes 3 and 4, calculated according to (11). Fig. 4 shows median value of \( SPLV \)’s variance (and its standart error) for group of patients before and after pallidotomy and its control group (left side) and, respectively, thalamotomy group (right).

B. Posturography

The study was made on 6 persons suffering from Parkinson Disease and a 6 person control group. Each person was examined at both open and closed eyes. In analyzing of posturographic data parameters such as distance traveled by the center of gravity (or pressure), its average speed, etc. were traditionally used. In this case, these parameters did not yield any statistically significant differences between the group of patients and controls. Therefore I applied the \textit{EMDPL} method in the same way as in the analysis of data from the tablet (see paragraph IV-A). The variance of synchronization between mods of signals \( x(t) \) and \( y(t) \). The signals were decomposed into three mods. To analyze synchronization, the second and third modes were selected. The results shows Fig 5 for persons with closed eyes (\( EC \), left side) and open eyes\( (EO \), right side). There are no significant differences between patients and healthy subjects with closed eyes. For people with open eyes, there is significant increase of the variance of synchronization in the control group comparing to the sufferers of Parkinson Disease.

For comparison, Fig. 6 presents the results of synchronization’s calculation without EMD. The parameter \( SPLV \) between the signals \( x(t) \) and \( y(t) \) does not show any significant differences between the two groups.

V. CONCLUSION

Presented results indicate that the combination of EMD and synchronization factor is a promising method of Parkinson Disease diagnosis.

Significant difference is noticed in value of synchronization between sufferers of Parkinson Disease and control group in psycho-motorical test. This difference is reduced after surgery, indicating the improvement in motor skills of patients, which agrees with clinical tests. The same results was obtained using 
Higuchi’s Fractal Dimension [4].

The results for posturography show significant difference between healthy subjects with open and closed eyes. Synchronization value for the group of patients suffering from Parkinson’s Disease does not depend, within the limits of statistical error, on whether eyes are open or closed. The results may indicate a lack of eye-motor coordination in Parkinson Disease sufferers.

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REFERENCES


Fig. 4. The variance of EMD modes’ synchronization for sufferers of Parkinson’s Disease and control group in psycho-motorical test.

Fig. 5. The variance of EMD modes’ synchronization in posturographic data for sufferers of Parkinson Disease and control group with closed and open eyes.

Fig. 6. The synchronization’s variance of posturographic data for sufferers of Parkinson Disease and control group with closed and open eyes calculated without EMD.