Data Processing for Parkinson's Disease: Tremor, Speech and Gait Signal Analysis

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***Abstract-* The Parkinson has been placed on the second position of the most frequent neurodegenerative illnesses list, after Alzheimer, consisting in slowly and progressive neurons damage. Parkinson's disease is associated with motor symptoms, including tremor, postural instability, rigidity, bradykinesia and dysphonia. The time series specific to tremor, speech and gait Parkinson’s Disease signals were firstly analyzed, by tools derived from chaotic analysis, such as: correlation dimension, recurrence plot, recurrence quantification analysis or Lyapunov exponent, as well. From the tremor management point of view and based on the results, this paper emphasizes the importance of the non-linear dynamics specific parameters in Parkinson tremor analysis. Currently, there hasn’t been underlined any “gold standard” method, by which quantitative and qualitative evaluation of symptoms’ gravity for patients with Parkinson are observed. The goal of the research carried out in this way consists in finding a screening test, in order to identify early the Parkinson’s disease. By analyzing the tremor, gait and speech signals for patients with Parkinson’s disease, this paper brings an approach over the most important information that can be used within a knowledge based system, specific to Parkinson’s disease diagnosis.**

Keywords: Parkinson, Tremor, Gait, Speech, Data Processing

I. INTRODUCTION

Parkinson's disease is a slow, but inexorably progressive disorder, with unknown origin (only about 10% cases are genetically based). It is a chronic neurological disease, defined by tremor, slow motion and stiffness. The neurons do not produce dopamine anymore or produce very low level of this chemical mediator, necessary on movement coordination. At a certain moment the patients cannot walk, cannot talk or cannot drink anymore. The age of the very first and small Parkinson symptoms start up is around 30 years. After 50 years old the symptoms are getting more important. The diagnostics is exclusively established by clinical signs. The early diagnostic depends very much on the neurologist experience [1].

The Parkinson’s disease seems to occurs in about 100-250 cases on 100000 individuals. In Europe were reported about 1.2 million Parkinson patients. Every year, about 50000 patients are identified with Parkinson’s disease. Studies revealed different correlations between different factors and Parkinson. In Romania there are over 70.000 Parkinson patients. The government spends over 1 billion Euros every year on medication. The Parkinson’s disease prevalence (the total cases on population) in Europe, based on an OMS current statistic, is of 16 patients for every 1000 individuals.

The missing of a good clinical test, combined with the patient’s reticence to attend a physician, make the diagnostic to be established very often too late [2], [3].

Parkinsonian tremor is a rhythmic, involuntary muscular contraction characterized by oscillation of a part of the body. Initial symptoms include resting tremor beginning distally in one arm at a 4 - 6 Hz frequency. The tremor is a flexion-extension of the forearm, or a pill-rolling movement.

The most common speech problems experienced by people with PD involve reduced volume (hypophonia), reduced pitch range (monotone), and difficulty with articulation of sounds or syllables (dysarthria). In essence, you can’t speak as loudly as others, you find it more difficult to convey emotion when you do speak, and you find it difficult to form the words you are trying to pronounce [4], [5].

The typical Parkinson’s gait develops over time as a result of the features of Parkinson’s disease such as *bradykinesia* (slowness of movement), *loss of postural reflexes*, and *rigidity* (increased tone). The gait of a person is his manner of walking and normally, a person will walk upright, with steady steps and even strides, and arms swinging by his sides. The distinctive gait of a person with Parkinson’s disease comprises of features such as stooped posture, slowness to start walking, short shuffling steps and a tendency to run with reduced arm swing [6].

Since the causes are confused, the treatment slows down the illness evolution and attenuates the invalidating symptoms (the tremor). The mechanism by which chronic, high frequency, electrical Deep Brain Stimulation suppresses Parkinsonian tremor is unknown. Alternative treatments and techniques were proposed and developed.

II. CLINICAL DATA BASE

The surgical procedure (Deep Brain Stimulation) involves electrode implantation into sub-cortical structures (Gpi - Globus Pallidus intern, Vim - the Ventral - intermediate nucleus of the thalamus, Stn - the sub-thalamic nucleus) for the long-term stimulation at frequency greater than 100Hz, stimulus pulse amplitude of 3V and stimulus pulse duration of 0.1 ms. The raw data available on [7] are obtained using a low intensity velocity-transducing laser that was directed at a piece of reflective paper on the subject's index finger, with the output voltage proportional to the velocity of the finger.

The recordings of this database are of rest tremor velocity in the index finger of 16 subjects with Parkinson's disease (PD) who receive chronic high frequency electrical deep brain stimulation (DBS) either uni- or bi-laterally within one of three targets (GPi, STN or Vim [7]. In [7] laser techniques are used in order to measure tremor amplitude, or time and frequency domain characteristics.

The Parkinsonian tremor recording can be classified in two categories: subjects with high amplitude tremor and with low amplitude tremor. Tremor was recorded under four conditions: no DBS and no medication (Parkinsonian tremor) (1); on DBS and no medication (2); no DBS and on medication (3); on DBS and on medication (4).

We analyzed tremor signals from 16 subjects with Parkinson's disease, ages between 37 and 71 years, 11 men and 5 women, which resulted in a number of over 100 recordings. [7].

Neurodegenerative disease often affects gait and mobility. To understand better the pathophysiology of these diseases and to improve our ability to measure responses to therapeutic interventions, it may be helpful to quantify gait dynamics accurately. We consider the database records from patients with Parkinson's disease (n = 15), Huntington's disease (n = 20), or amyotrophic lateral sclerosis (n = 13), and records from 16 healthy control subjects [7].

Other database contains measures of gait from 93 patients with idiopathic PD, and 73 healthy controls, and includes the vertical ground reaction force records of subjects as they walked at their usual, self-selected pace for approximately 2 minutes on level ground. The output of each of 16 sensors has been digitized and recorded at 100 samples per second, and the records also include two signals that reflect the sum of the 8 sensor outputs for each foot [7].

The speech data explored in this paper contained biomedical measurements from 42 people, 23 with Parkinson's Disease [8].

III. Tools For Investigating Time-Series Data

For the linear and nonlinear analysis of tremor signals, using linear and nonlinear dynamic parameters, we used several software packages such as CDA (Chaos Data Analyzer Programs), NLyzer (Nonlinear Analysis in Real Time) TISEAN (Nonlinear Time Series Analysis), WFDB Software, Matlab Software and Physio Toolkit Software [9] - [12].

The CDA software allows us to study the phase diagram, the probability distribution, power spectrum, Lyapunov exponent, correlation dimension, capacity dimension, self-correlation function and Poincare sections. The NLyzer is a software package used for both linear and nonlinear signal analysis. The TISEAN package contains a number of tools for linear time series analysis (spectrum, autocorrelation function, histograms, etc.). These are only suitable for a quick inspection of the data.

IV. Data Processing

Chaotic regimes suppose finding different specific parameters of chaotic dynamics, such as the capacity dimension, the information dimension, the correlation dimension, the Lyapunov coefficient, the Kolmogorov entropy, the Shannon entropy, etc. [13] - [15].

The central chaotic regime analysis aim is to obtain information from the system that generated the output by studying a time series generated by a chaotic dynamic, or even the analyzed signal modeling and prediction.

The difficulty of analyzing such signals is based on the fact that the time series come from biomedical signals (for instance the tremor, gait or speech signals) and are strongly affected by noise and are strongly connected with their original medium (the tremor signal is strongly correlated with the respiration). These signals are of superior orders and can be very difficult analyzed with low order non-linear dynamics.

Special cares must be taken when analyzing the time series. The origin is one factor, the chaotic or not source is another one and is important to know if the time series is random. That is why certain parameters specific to chaotic dynamics are tested out, such as the Lyapunov coefficient, the fractal dimension and the correlation dimension of the attractor generated by the dynamics in the phase space [16]. The time series chaotic analysis allows determining the strange attractor fractal dimension. The more the fractal dimension is bigger, the more the system complexity level producing the analyzed time series is bigger. In general, the strangest attractors generated by the chaotic dynamics are characterized by a fractional capacity/fractal dimension [17].

On the next research step we performed the non-linear analysis of the tremor signals, using usual non-linear dynamics parameters. We used CDA (Chaos Data Analyzer Programs). With this software solution the phase diagram, the probability distribution, the tremor signal power spectrum, the dominant frequencies, the maximal Lyapunov exponent, the correlation dimension, the capacity dimension, the correlation function and the Poincare sections can be analyzed. A very first phase on non-linear analysis is to draw the phase diagram. This represents the signal derivate against the signal itself.

If the signal is periodic, the phase diagram is a closed curve. If the signal is chaotic, the diagram is a closed curve called "strange attractor".

The positive Lyapunov exponent is the main chaotic dynamic indicator. If at least one Lyapunov exponent is smaller than 0, the system is oscillating. In case at least one Lyapunov exponent is bigger than 0, the system is chaotic. If the Lyapunov coefficient is getting to infinite, the system is called random system.

Using CDA software solution to analyze the tremor signals from our database, we found the Lyapunov exponent varies from 0.08 to 0.7, depending on the signal type. Another parameter often used to describe the non-linear dynamics, is the correlation dimension [18].

Using the same CDA software solution, the correlation dimension was checked for various tremor signals and the values were found between 2.5 and 3. It was determined the correlation dimension varies based on the nucleus that is stimulated with DBS (GPi, Vim or STN).

The main non-linear dynamic determinant is the Lyapunov exponent that must be positive for a chaotic process. Using the CDA software solution on the tremor signals of our database, we found the Lyapunov exponent value varies between 0.08 and 0.7, depending on the analyzed signal. We used NLyzer, Nonlinear Analysis in Real Time software solution as well, for identifying the non-linear specific elements. There were obtained various values for the fractal dimension and various shapes for the auto-correlation function or attractors. The Lyapunov exponent value varies between 0.08 and 0.7 (DBS on) and for the Parkinson patients (no DBS) it varies between 0.02 and 0.06 [18].

For the patients with DBS, the fractal dimension varies from 1.75 to 2.04 and for the Parkinson patients (no DBS) it varies from 2.45 to 2.67 [18]. It was determined that this attractor is different from signal to signal, strongly related on its dynamics. If the signal is chaotic, the representation is a closed curve called "strange attractor".

For instance, in Figure 1 and 2 we picked up two time series of two Parkinson patients (the first example: the patient received DBS in Vim and the second one: the patient without DBS).

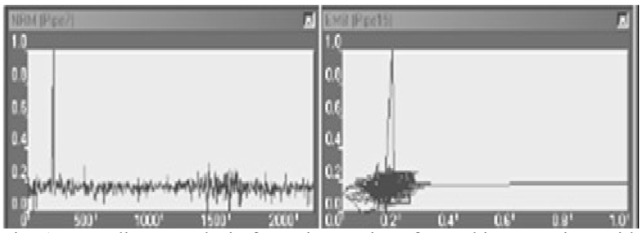

Fig. 1. Non-linear analysis for a time series of a Parkinson patient with DBS in Vim (the normalized time series, the time series attractor)

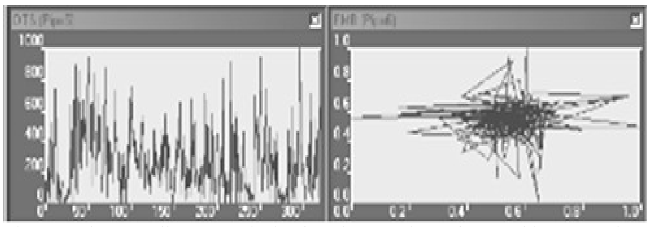

Fig. 2. The non-linear analysis for time series of a Parkinson patient without DBS (the normalized time series, the time series "strange attractor

A subset of the database includes measures recorded as subjects performed while walking, as in the Figure 3, which shows excerpts of swing time series from a patient with PD (upper panels) and a control subject (lower panels), under usual walking conditions. [7].

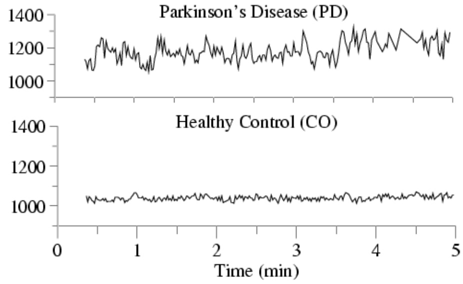

Fig. 3. Stride-to-stride measures of footfall contact times were derived from Parkinson's Disease (PD) and Healthy Control signals (CO)

Approximately 90% of Parkinson's Disease patients present speech difficulties such as dysphonia (impaired speech production) and dysarthria (speech articulation difficulties).

From the two databases of voice signals, the following parameters were analyzed: average vocal fundamental frequency, maximum/minimum fundamental frequency, Signal Fractal scaling exponent, and three nonlinear measures of fundamental frequency variation [19], [20].

Figures 4 and 5 illustrate the dependence between various parameters analyzed for speech signals to PD patients:

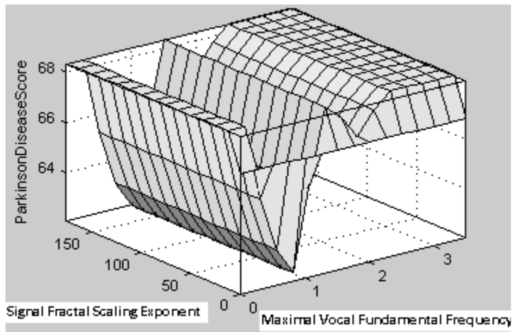

Fig. 4. The graph shows the relationship between Parkinson Disease Score and Signal Fractal Scaling Exponent or Maximum Vocal Fundamental frequency

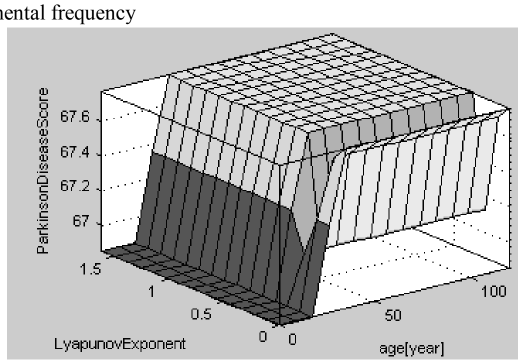

Fig. 5. The graph shows the relationship between Parkinson Disease Score, Age and Lyapunov Exponent

V. Results and Conclusions

There is evidence that physiological tremor is a linear stochastic process [13] and Parkinsonian tremor is more nonlinear and deterministic. A characteristic of linear stochastic processes is exponential decay of the extreme of oscillations in the autocorrelation function. The measure of asymmetric decay of the autocorrelation function has been useful in discriminating Parkinsonian tremor and no DBS, and Parkinsonian tremor and DBS in Vim, GPi or STN.

We argue that nonlinear dynamic parameters of Parkinsonian tremor, gait or speech have certain peculiarities and can be used in knowledge-discovery. These data and new knowledge will be integrated in a Knowledge-based System aimed to identify early Parkinson's Disease, to worn on atypical responses at DBS and to recommend the stimulation targets (Vim thalamus nucleus).

We can resume next conclusions for the DBS Parkinsonian tremor:

- size of correlation dimension is larger that 1.5 until 3.25;
- size of fractal dimension is between 0.75 and 1.25;
- Lyapunov exponents are between 0.25 and 1.5;
- using the value of Lyapunov exponent, we may distinguish DBS in Vim (Lyapunov exponent in this case are between 0.21 and 0.28) from all the other classes (GPi or STN nucleus);
- power spectral analysis has been proposed as a statistical method of qualifying the amplitude and the frequency parameters of tremors;
- cross-spectral methods provide a powerful tool to investigate the relation between simultaneously recorded signals.

Mathematical model of the effects of DBS suggest a complex combination of excitation and/or inhibition of neighboring cells, afferent inputs and fibers of passage depending on stimulus parameters and distance from the stimulus probe. Future design may be able to capitalize on this knowledge to tailor DBS electrode geometries and stimulus parameters to selectively isolate intended neural substrates and minimize side effects from stimulation induced effects on neighboring structures.

In conclusion, investigation of patients with Parkinson's disease, by methods derived from nonlinear dynamics, using the correlation dimension and calculation of Lyapunov exponents, we found a screening test to identify early stage of Parkinson's Disease.

VI. FUTURE RESEARCH

We took care only of the time series analysis from patients with Parkinson tremor, or speech/gait using methods derived from linear and chaotic dynamics and DBS evaluation from choosing sub-thalamus nucleus as stimulation target point of view. The aim was to reduce the tremor, dysphonia (impaired speech production) and dysarthria (speech articulation difficulties) or rigidity.

In the next step of our research we will validate a screening test to identify disease in a community early, thus enabling earlier intervention and management in the hope to reduce mortality and suffering from Parkinson's Disease.

Even if at the moment the DBS results seem to be well known, meaning the GPi and STN thalamus nucleus stimulation produces Parkinson symptoms control (the GPi stimulation is recommended to control the dystonia and the Vim electrical stimulation produces tremor reduction) the mechanisms of such effects apparition are not completely controlled.

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