

ACQUISITION AND PROCESSING DATA FOR EARLY STAGE OF PARKINSON'S DISEASE

OANA GEMAN, SORIN POHOAȚĂ, ADRIAN GRAUR

Key words: Parkinson's disease, Gait, Tremor, Intelligent sensors, Screening.

Parkinson's disease (PD) is a neurodegenerative disease that occurs due to loss of dopamine, a neurotransmitter and slow destruction of neurons. Brain area affected by progressive destruction of neurons is responsible for controlling movements, rigid gestures of patients with PD, uncontrollable position, postural instability, and tremor. Commercial activity-promoting gaming systems such as the Nintendo Wii™ and Xbox Kinect™ can be used as tools for tremor, gait or other biomedical signals acquisitions, also to aid and in rehabilitation in clinical settings. This paper emphasizes the importance of using intelligent optical sensors or accelerometers in biomedical signal acquisition, and the specific dynamics of nonlinear parameters in parkinsonian gait and tremor analysis.

1. INTRODUCTION

There is insufficient data in the literature that describes the methodology of obtaining new meta-knowledge specific to nonlinear dynamic processes, such as biomedical signals (tremor and gait). Success in knowledge discovery depends on its ability to analyze various classes of specific data and apply appropriate methods to extract main features. This paper analysis the processing of biomedical signals (tremor, gait) acquired through modern methods (using sensors Wii™ and Xbox™), processing them and finding data and knowledge that can be used and included in new rules for the quantity and performance medical diagnosis. Information on biomedical signals are available in the form of time series that can be analyzed with chaotic dynamics specific parameters (Lyapunov exponents, fractal dimension of attractor dynamics generated in phase space). The data obtained from nonlinear analysis were classified by specific data mining algorithms, thus obtaining two separate classes: "normal" and "Parkinsonian".

In Europe, there were reported about 1.2 million Parkinson patients, a number predicted to more than double by 2030, as populations age [1]. In Romania there are over 72.000 PD patients and the lack of a good clinical test (inexistence of biomarkers for PD diagnosis) combined with the patient's reticence to attend a

“Ștefan cel Mare” University of Suceava, Universității 13, RO-720229, Suceava, geman@eed.usv.ro

physician determines late correct diagnosis [2]. “Tremor is the first symptom that people with Parkinson's disease notice. The typical Parkinson's gait develops over time as a result of the features of Parkinson's disease such as *bradykinesia* (slowness of movement and difficulty with walking or gait disturbance), *postural instability* (balance), and *rigidity* (increased tone)” [3].

The aim of this paper is to find an instrument for PD screening, using gait and tremor signals. Nowadays, there are insufficient evidences in the literature about the application of dynamical time series analysis for tremor evaluation on one hand and evaluation of the changes in brain rhythms in connection with the body movement impairment on the other hand [4, 5]. This vital information may be combined with the meta-knowledge system designed for archiving clinical and physiological inductions and other information about tremor and the prescribed trajectory of hand (or leg) movement to be used for Parkinson's disease screening [6]. Our contribution, therefore, has major impact as currently there is no clinically approved automatic system for monitoring Parkinson's disease patients [7]. Though a method to assess and predict PD, based on the automatic processing of the image of the handwritten text belonging to a candidate of PD was proposed [8], in fact “there is still no reliable screening test to Parkinson's disease early identification” [9], and this is a major roadblock to our study design.

2. GAIT AND TREMOR – DATABASE STRUCTURE

In a recent research conducted by the authors of this paper (a preliminary version of this paper has presented by the authors at SNET 2012 [7]), the physiological information and the time series parameters measured from gait and tremor have been combined in developing an automatic diagnostic system for Parkinson's disease monitoring. Our database contains gait and tremor measures from 32 patients with PD (from Suceava Hospital, Neurology Clinic), 58 healthy subjects and 14 “suspicious” PD subjects. Young adults ($n = 42$; ages: 20–35 yrs, 28 males and 14 females) and older adults ($n = 62$; ages: 65–87 yrs, 41 males and 21 females) participated in this study.

In Fig. 1 we described the “i-Parkin Screening System”. Our Screening System (i-Parkin Screening System) consists of four components: the first component records the skeletal information, gait parameters and tremor information using Kinect™ and Wii Remote™. This information is then analyzed using linear dynamics, nonlinear dynamics and statistical tools – the second component; and the third and fourth steps consist in feature extraction and classification. For the last stage of our research, we used K-means – one of the simplest unsupervised learning algorithms to identify a “normal” or a “Parkinsonian” subject (Fig. 1).

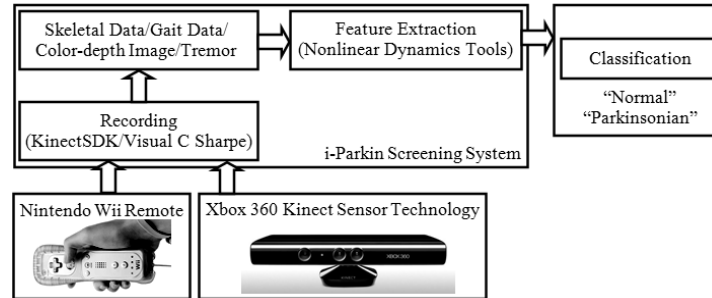


Fig. 1 – The workflow of this research and i-Parkin Screening System blocks.

Human gait has been shown to be an important indicator of health, and is applicable in a wide range of settings, such as diabetes [10], neurological diseases [11–12], and fall detection and prediction [13–14]. Accurate, non-intrusive, low cost clinical gait analysis systems have many applications in diagnosis, monitoring, treatment and rehabilitation [15–17]. Such applications include early diagnosis and assessment [11–16]. Stone and Skubic [17–19] were the first to propose the use of Kinect™ for clinical gait analysis. The gait database includes the vertical ground reaction force records of subjects as they walked at their usual pace. Also, we studied the stride-to-stride dynamics, the variability of these time series and nonlinear dynamic parameters, using the methodologies described in [17–19]. Grasp, move, and release trajectory is another gait signal to be processed. The dynamics of the gait movement will be estimated using the trends in chaos measurement and included for further analysis and data fusion. A graphical user interface (GUI) has been designed using Microsoft Visual Studio 2010, as shown below in Fig. 2.

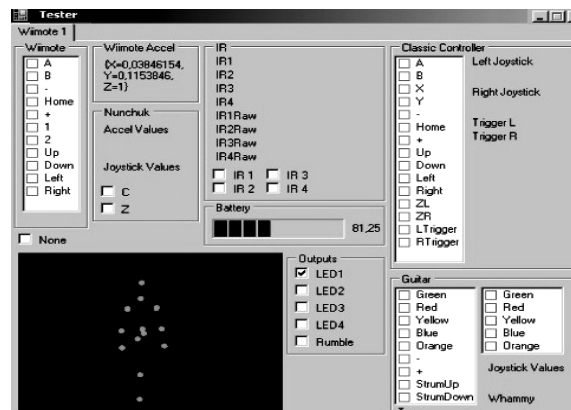


Fig. 2 – Interactive GUI using Kinect™ (gait application).

We computed the average difference standard deviation of stride length, time, and velocity for each walking sequences (the results are shown in Table 1).

Table 1

Stride-to-Stride Standard Deviation with Kinect™

Stride-to-Stride Standard Deviation of Stride Length with Kinect™ (for 40 subjects)	Normal gait	Parkinsonian gait
Standard Deviation (cm)	2.54	1.26
Mean Difference (cm)	2.82	0.53

The tremor data used in this paper are recorded using a box including accelerometers (such as those in a Wii™), pressure sensors, and inevitably a microcontroller which runs the data acquisition, analogue to digital conversion, and transmits the data through a Bluetooth™ wireless communication system. This postural tremor cannot be differentiated on clinical features (frequency, amplitude).

The Wii™ Remote known as the Wiimote™ is the primary controller for Nintendo's Wii™ console [20]. A main feature of the Wii™ Remote is its motion sensing capability, which allows the user to interact with and manipulate items on screen via gesture recognition and pointing through the use of accelerometer and optical sensor technology [21–23]. The device records both acceleration induced by hand movement and by the gravitational force. If the controller is rotated, the gravity accelerometer affects the values on the x , y , and z axes. The Wii™ Remote and PC are connected by Bluetooth™ – Human Interface Device Profile. The tremor analysis program was developed using Visual C 2010 Professional (Fig. 3). The acceleration sampling period was set at 10 ms in the Nintendo device.

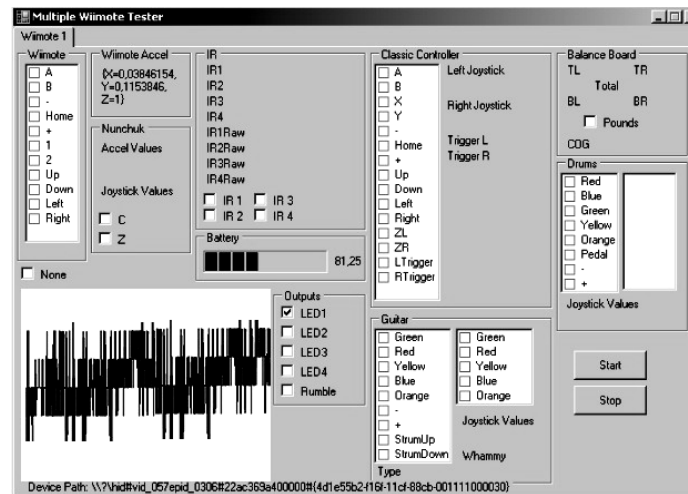


Fig. 3 – Interactive GUI using Wii™ Remote (tremor application).

The accelerometer built into Wii™ Remote (Nintendo) measures gravitational and non-gravitational acceleration and the results of this paper suggest that Nintendo will be useful for measurement and analysis of tremor using the methodologies described in [21–23].

3. DATA PROCESSING – LINEAR AND NONLINEAR ANALYSIS

Linear analysis of the signal mainly uses Fourier analysis and reporting made comparison of the amplitude frequency bands. Based on the Fourier spectrum in the range of 0–25 Hz and amplitude-time representation, a number of parameters are used to characterize the tremor signal. For each time series (2131 samples) of analysis we choose the following parameters: the autocorrelation function – ACF (Correlation length = 524), power spectrum – FFT (60 dB resolution), deviation, fast mutual information, conditional entropy. We computed the average difference standard deviation of stride length (Table 1), time, and velocity for each walking sequences. Filtering a time series may be thought of as removing some components of its Fourier transform and then taking the inverse Fourier transform to get a new time series that is a filtered version of the original.

Aside from amplitude, the most often used measure of tremor is frequency. Many reports suggest that Parkinsonian tremor is typically in the range of 4–6 Hz, and the essential tremor is in the range of 4–12 Hz. There is evidence that physiological tremor is a linear stochastic process and it has been suggested that pathological tremor are more nonlinear and possibly more deterministic [7]. For the nonlinear analysis of tremor signals, we used several software packages such as CDA (Chaos Data Analyzer Programs), NLyzer (Nonlinear Analysis in Real Time), and TISEAN (Nonlinear Time Series Analysis) [24–26]. 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 Poincaré sections can be analyzed.

A very first phase of non-linear analysis is to draw the phase diagram. This represents the signal derivative against the signal itself. If the signal is periodical, the phase diagram is a closed curve. If the signal is chaotic, the diagram is a closed curve called “strange attractor” [27]. The positive Lyapunov exponent is the main chaotic dynamic indicator [28].

We also used NLyzer, Nonlinear Analysis in Real Time software solution as well (Fig. 4), for identifying the nonlinear specific elements. There were obtained various values for the fractal dimension and various shapes for the autocorrelation function or attractors. The Lyapunov exponent value varies between 0.08 and 0.7 (normal tremor) and for the Parkinson’s disease patients (Parkinsonian tremor) it varies between 0.02 and 0.06.

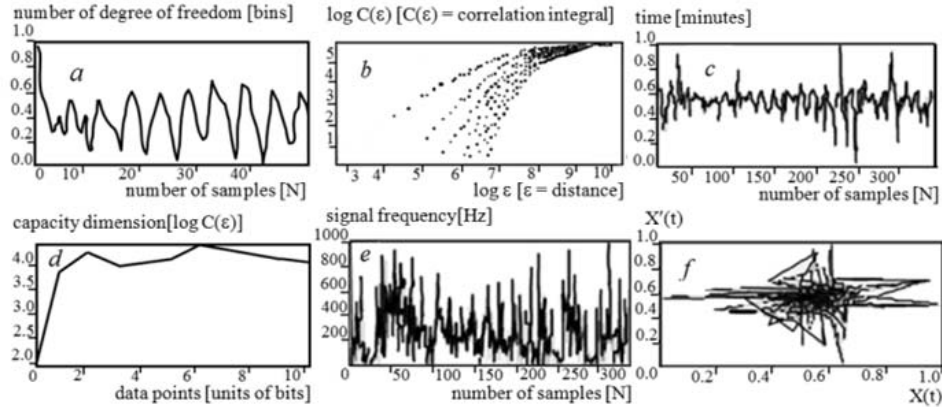


Fig. 4 – The nonlinear analysis for a PD gait time series: a) fast mutual information; b) the correlation dimension; c) the normalized gait time series; d) the capacity dimension; e) the gait time series; f) and the time series “strange”.

The program calculates embedding/correlation dimensions between 1 and 10, and a dimension greater than about five implies essentially random data (Fig. 4b). The mean of frequency $X(t)$ is plotted as a function of time (second) on the horizontal axis (Fig. 4c). The capacity dimension is calculated by successively dividing the phase space with embedding dimension into equal hypercube and plotting the log of fraction of hypercube that are occupied with data points versus the log of the normalized linear dimension of the hypercube (Fig. 4d). The frequency is plotted as a function of time (second) on the horizontal axis (Fig. 4e) and the two-dimensional plot in which the derivative X' is plotted versus X at each data point (Fig. 4f). As it can be seen in Fig. 5a–c, the studied parameters have different evolutions for Parkinson's disease tremor; moreover, significant differences appear between the “normal” (N), respectively, “Parkinsonian” (P) or “suspicious” PD (S).

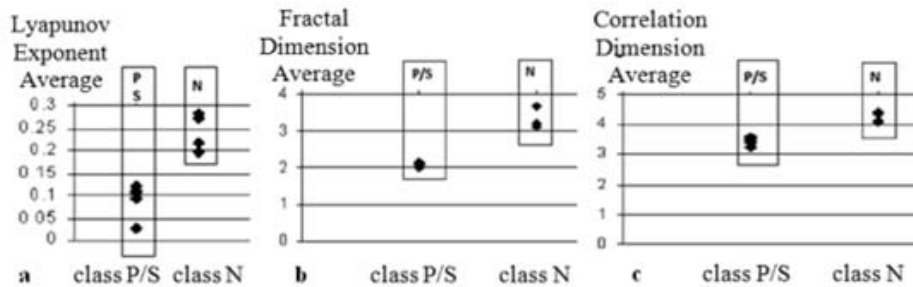


Fig. 5 – Graphical values representations for: a) Lyapunov exponent; b) fractal dimension; c) correlation dimension for “normal” (N), “Parkinsonian” (P), “suspicious” (S).

We observed that the fractal dimension allows us to recognize with good accuracy the “normal” tremor class [26]. Analyzing the data, we observed that the fractal dimension allows us to recognize with good accuracy the “suspicious” tremor classes. Using the other parameters/rules, the classification becomes more accurate.

Based on the information in Fig. 4a-f and Fig. 5a-c we may conclude: I – using the values of the Lyapunov exponent, we may distinguish “normal” class from all the other classes (“suspicious” or “Parkinsonian”), in this case the values of Lyapunov exponent are between 0.02 and 0.14 (1); II – using the values of the fractal dimension, we observe that in case of “normal” class there are important differences relative to other classes (for “normal” class, values between 3.2 and 3.8); III – using the correlation dimension, we notice that for “Parkinsonian” class, its values are between 3.1 and 3.7, and for “normal” class the correlation dimension can reach a value of 4.5 (this value does not exist for any other class); IV – to establish a set of rules for the analyzed classes (“normal” / “suspicious” / “Parkinsonian”), we cannot use the correlation dimension; its values are not specific (4).

4. DATA MINING – CLUSTER ANALYSIS

For this phase of the work we used K-means algorithm using STATISTICA [29]. Given a data set of n objects, and K = the number of clusters to form, a partitioning algorithm organizes the objects into K partitions, where each partition represents a cluster. We adopt one of a popular heuristic method: the K-means algorithm, where each cluster is represented by the mean value of the objects in the cluster. If the components of the data instance vectors are all in the same physical units then it is possible that the simple Euclidean distance metric is sufficient to successfully group similar data instances. However, even in this case the Euclidean distance can sometimes be misleading. The main idea is to define K centroids, one for each cluster.

This algorithm aims at minimizing an objective function, in this case a squared error function. The K-means algorithm is composed of the following steps: 1 – place K points into the space represented by the objects that are being clustered; these points represent initial group centroids ; 2 – assign each object to the group that has the closest centroid; when all objects have been assigned, recalculate the positions of the K centroids; 4 – repeat Steps 2 and 3 until the centroids no longer move; this produces a separation of the objects into groups from which the metric to be minimized can be calculated. Although it can be proved that the procedure will always terminate, the K-means algorithm does not necessarily find the most optimal configuration, corresponding to the global objective function minimum. The algorithm is also significantly sensitive to the

initial randomly selected cluster centers. The K-means algorithm can be run multiple times to reduce this effect. After statistical analysis of data, we obtained a description of prototypes for each class.

We notice that between the Parkinson's disease tremor and the "suspicious" tremor there are visible similarities up to the time scale (Fig. 6). We also used Weka tools for data preprocessing, using data classification, regression, association rules, and visualization [7]. The result using K-means algorithm shows that the Parkinson's disease tremor can detect with accuracy up to 98.25%. Test case results also show an error percentage of around $\pm 0.26\%$ and $\pm 0.48\%$ for "normal" and "suspicious" tremor detection.

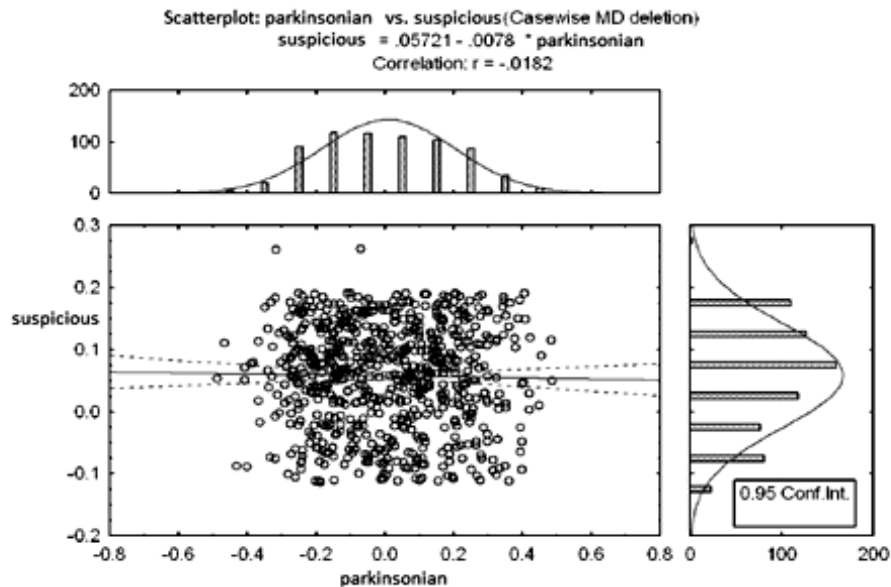


Fig. 6 – Parkinson's disease tremor vs. "suspicious" tremor – statistical analysis.
 Confident Interval (Conf. Int.) is 0.95.

5. CONCLUSIONS

Because Parkinsonian tremor or gait are still quasi-unknown issues we argue that nonlinear dynamic parameters of Parkinsonian gait and tremor have certain peculiarities and can be used in knowledge-discovery [26]. These data and new knowledge will be integrated in a Knowledge-based System aimed at screening Parkinson's disease. Finally, the dynamics of the gait movement or tremor will be estimated using the trends in chaos measurement and included for further analysis.

Knowledge was extracted from data analysis algorithms and specific methods of nonlinear dynamics (Lyapunov exponents, correlation dimension, size, capacity).

The data used in this study are recorded by means of a box including accelerometers (such as those in a Wii™ console), pressure sensors, and a microcontroller which runs the data acquisition, analog to digital conversion, and transmits the data through a Bluetooth wireless communication system. Alternatively, telemonitoring systems based on wearable area sensors may be used for permanent surveillance of Parkinsonians [30]. Nonlinear parameters can provide essential information in the differential diagnosis, in comparison with classical linear parameters [31]. Our system is based on the Kinect™ sensor and Wii™ sensors and thus can extract tremor or gait information from subjects.

Advanced signal processing methods involved in data fusion and constrained optimization may be used in combining physiological information within the algorithms and mathematical expressions. Patient examination can be done using advanced video systems and analyzing patient's surprised movements in the stored images. We present an accurate tremor and gait analysis system (i-Parkin Screening System) that is economical and non-intrusive.

ACKNOWLEDGEMENTS

This paper was supported by the project "Progress and development through post-doctoral research and innovation in engineering and applied sciences – PRiDE – Contract no. POSDRU/89/1.5/S/57083", project co-funded from European Social Fund through Sectorial Operational Program Human Resources 2007-2013.

We are also very grateful to Dr. Radu VASILCU and the subjects with PD who took part in this research.

Received on January 8, 2013

REFERENCES

1. A.J. Less, J. Hardy, T. Revesz, *Parkinson's disease*, Lancet, 2009, pp. 2055-2066.
2. E.R. Dorsey, R. Constantinescu, J.P. Thompson, *et al.*, *Projected number of people with Parkinson disease in the most populous nations, 2005 through 2030*, Neurology, **68**, pp. 384-386 (2007).
3. * * *, National Parkinson Foundation, <http://www.parkinson.org>.
4. * * *, EuroPa, <http://www.europarkinson.net>.
5. A. Shtilbans, C. Henchcliffe, *Biomarkers in Parkinson's Disease*, Curr. Opin. Neurol., **25**, 4, pp. 460-465 (2012).
6. L.M. Chahine, M.B. Stern, *Diagnostic markers for Parkinson's disease*, Curr. Opin. Neurol, **24**, pp. 309-317 (2012).
7. S. Pohoată, O. Geman, A. Graur, *Dual tasking: gait and tremor in Parkinson's disease – acquisition, processing and clustering*, National Symposium of Theoretical Electrical Engineering (SNET 2012), Bucharest, Romania, 2012.

8. H. Costin, C. Rotariu, *Tremor assessment by means of handscript analysis and fuzzy logic*, Biomedical Softcomputing & Human Sciences Journal, **7**, 1, pp. 39-45, (2001).
9. M.B. Stern, A. Siderowf, *Parkinson's at risk syndrome: can Parkinson's disease be predicted?*, Mov. Disord., **25**, pp. 89-93, (2010).
10. D. Hodgins, *The importance of measuring human gait*, Med. Device Technol, 19(5):42, **47**, pp. 44-42 (2008).
11. C. Coroian, R. Lemoyne, *The merits of artificial proprioception, with applications in biofeedback gait rehabilitation concepts and movement disorder characterization*, Biomedical Engineering, pp. 165-198, 2009.
12. M. Hăgan, H.-N. Teodorescu, A. Sîrbu, *Data Processing for Posturography and Gait Analysis*, The 3rd International Symposium on Electrical and Electronics Engineering, 2010.
13. T. A. Wren, G. E. Gorton III, C. A. Tucker, *Efficacy of clinical gait analysis: A systematic review*, Gait & Posture, **34**, 2, pp. 149-153 (2011).
14. J.M. Hausdorff, J. Lowenthal, T. Herman, L. Gruendlinger, C. Peretz, N. Giladi, *Rhythmic auditory stimulation modulates gait variability in Parkinson's disease*, Eur. J Neuroscience, **26**, pp. 2369-2375 (2007).
15. G. Yogev, N. Giladi, C. Peretz, S. Springer, E.S. Simon, J.M. Hausdorff, *Dual tasking, gait rhythmicity, and Parkinson's disease: Which aspects of gait are attention demanding?*, Eur J Neuroscience, **22**, pp. 1248-1256 (2007).
16. J. Wang, M. She, S. Nahavandi, and A. Kouzani, *A Review of Vision-Based Gait Recognition Methods for Human Identification*, International Conference on Digital Image Computing: Techniques and Applications, 2010.
17. E.E. Stone and M. Skubic, *Evaluation of an inexpensive depth camera for passive in-home fall risk assessment*, in *Pervasive Health Conference*, 2011.
18. E.E. Stone and M. Skubic, *Passive in-home measurement of stride-to-stride gait variability comparing vision and Kinect sensing*, in *EMBC*, 2011.
19. R. C. Helmich, M. Hallett, G. Deuschl, I. Toni, R. B. Bloem, *Cerebral Causes and Consequences of Parkinsonian Resting Tremor*, Brain, **135**, 11, pp. 3206-3226 (2012).
20. * * *, http://www.nintendo.co.uk/NOE/en_GB/systems/technical_details_1072.html (01.02.2013).
21. N. Mamorita, T. Iizuka, A. Takeuchi, M. Shirataka, N. Ikeda, *Development a System for Measurement and Analysis of Tremor Using a Three-axis Accelerometer*, Methods Inf. Med., **48**, pp. 589-594 (2009).
22. R.A. Clark, A.L. Bryant, Y. Pua, P. McCrory, K. Bennell, M. Hunt, *Validity and reliability of Nintendo Wii Balance Board for assessment of standing balance*, Gait & Posture, **31**, pp. 307-310 (2010).
23. R. Lemoyne, *Implementation of an iPhone for characterizing Parkinson's disease tremor through a wireless accelerometer application*, 32 Annual Conference of the IEEE EMBS, 2010, pp. 4954-4958.
24. * * *, Chaos Data Analyzer, CDA, <http://sprott.physics.wisc.edu/cda.htm>.
25. * * *, Nonlinear Analysis in Real Time, NLyzer, <http://www.iap.tu-darmstadt.de/NLyzer>.
26. * * *, Nonlinear Time Series Analysis, TISEAN, <http://www.mpi-pks-dresden.mpg.de/~tisean/>
27. Oana Geman, *Data Processing for Parkinson's Disease Tremor, Speech and Gait Signal Analysis*, Proceedings IEEE International Conference E-Health and Bioengineering Conference, Iasi, 2011.
28. H.N. Teodorescu, A. Kandel, *Nonlinear Analysis of Tremor and Applications*, JJME Japanese Journal of Medical Electronics and Biological Engineering, **13**, 5, pp. 11-19 (1999).

-
29. * * *, STATISTICA, <http://www.statsoft.com/support/free-statistica-10-trial/>.
30. H. Costin et al., *Complex Telemonitoring of Patients and Elderly People for Telemedical and Homecare Services*, in *New Aspects of Biomedical Electronics and Biomedical Informatics*, Proc. of the Int. Conf. Biomedical Electronics and Biomedical Informatics-BEBI'08, Greece, 2008, pp. 183-187.
31. Oana Geman, Corneliu-Octavian Turcu, Adrian Graur, *Parkinson's disease Screening Tools using a Fuzzy Expert System*, *Advances in Electrical and Computer Engineering*, **13**, 1, pp. 41-46 (2013); Digital Object Identifier: 10.4316/AECE.2013.01007.