TREMOR AND GAIT SCREENING AND REHABILITATION SYSTEM FOR PATIENTS WITH NEURODEGENERATIVE DISORDERS

BY

OANA GEMAN and HARITON COSTIN

1“Ştefan cel Mare” University of Suceava, Faculty of Electrical Engineering and Computer Science
2“Grigore T. Popa” University of Medicine and Pharmacy, Iaşi, Faculty of Medical Bioengineering
3Institute of Computer Science of Romanian Academy Iaşi Branch

Received: May 10, 2013
Accepted for publication: June 14, 2013

Abstract. Parkinson’s disease is a severe neurodegenerative disorder, and “benefits” from the classical triad of motor symptoms: rigidity, akinesia and resting tremor. Tremor in Parkinson’s disease has several features: it can be first a benign symptom of Parkinson’s disease, its frequency can vary from low 4-5 Hz to high 8-10 Hz, can vary according to different circumstances, tremor may occur at rest, it can be seen in the hands, feet or other body parts. Parkinson's disease is a chronic disease with the need to adapt ongoing treatment in relation to a multitude of symptoms present. Each case has to be diagnosed and analyzed by a complex team (neurologist, family doctor, physiotherapist, psychologist) to initiate the most appropriate treatment and rehabilitation approaches. In this paper we present a proposed system for disease detection, screening and motor rehabilitation of Parkinson's patients for tremor symptom correction.

Key words: data mining, Parkinson’s disease, graphic user interface, nonlinear signal processing, SVM.

2010 Mathematics Subject Classification: 92C55, 97R40.

*Corresponding author; e-mail: hcostin@gmail.com
1. The Symptoms of Parkinson’s Disease

Parkinson's disease (PD) is a progressive neurodegenerative disease that affects multiple areas of the central nervous system. Some of these lesions precede for many years the first signs of the primary Parkinsonism, that still represent the moment when the diagnosis of Parkinson's disease becomes a clinical certainty. PD is a chronic, progressive, neurodegenerative disorder, with an unknown aetiology, characterized by a slow loss of dopaminergic neurons in the “substantia nigra” (Less et al., 2009). It occurs in approximately 100-250 cases per 100,000 people. In Europe, approximately 1.2 million Parkinson's patients have been reported, of which about 16,000 in (Parkinson.org).

The disease affected, in 2003, only in North America, roughly 1 million people, almost 1% of population aged above 65 (Dorsey et al., 2007; Physionet.org). In The United States of America, in 2006, about 1 million cases were reported and annually just about 50,000 patients are identified as suffering from Parkinson's disease (Physionet.org).

Thus, the crucial element in the definition and clinical identification of PD are the motor symptoms – Parkinsonism – with multiple and devastating functional consequences. Therefore, in PD we analyze two types of motor symptoms (Dorsey et al., 2007):

- motor symptoms belonging to the disease itself and its natural evolution;
- motor symptoms that are complications of drugs therapy.

Akinesia, bradykinesia, rigidity and tremor are primarily related to dysfunction of the “motor loop”, found in the basal ganglia circuits, loop that plays a role in movement control (Hodgins, 2008). According to the UK Brain Bank, to clearly identify the disease bradykinesia and at least two other symptoms are required (Physionet.org). Tremor, the positive symptom, is usually the first symptom noticed by the patient at rest, although it may be absent in up to 30% of patients.

Parkinsonian tremor is a regular frequency of 4-6 Hz and distribution surveyors have that feature: common-interest predominantly distal limbs and rest, as has been observed mainly in the fingers (thumb has a rhythmic movement relative to the index movement associated with “counting money” - “pill rolling” and the leg movement is described as “cycling”).

In this paper we present a proposed system and results, both for screening and motor rehabilitation of PD patients, for tremor symptom correction. Section 2 treats the screening system for tremor and gait analysis, Section 3 shortly presents the used analysis software for Parkinsonian tremor signals, then Section 4 is dedicated to automatic gait classification – Parkinsonian and normal gait, Section 5 shows an experimental system for PD patients rehabilitation, and last section draws some conclusions of our study.
2. Tremor and Gait Screening System

In a recent research done by one of the authors of this paper (Pohoata et al., 2012), 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 monitoring. We demonstrate that nonlinear dynamics parameters of PD gait or tremor signals can be used on knowledge discovery domain.

Our database contains gait and tremor measures from 20 patients with PD (from Suceava Hospital, Neurology Clinic) and 20 healthy subjects. Young adults (n = 15; ages: 20-35 yrs, 10 males and 5 females) and older adults (n = 25; ages: 65-82 yrs, 14 males and 11 females) participated in this study. The Screening System used in previous research is presented in Fig. 1.

Fig. 1 – Parkinson’s disease Screening System.

Our Parkinson’s Disease Screening System consists of four components: the first component records the skeletal information, gait parameters and tremor information using Kinect™ and Wii™ Remote devices. These information are then analyzed using nonlinear dynamics tools (the second component), and the third and fourth steps consist in feature extraction and classification. For the last stage of our research, we use the machine learning framework WEKA to identify a “normal” or a “Parkinsonian” subject (Fig. 1).

Human gait has been shown to be an important marker of health, and is applicable in a wide range of settings, such as diabetes (Hodgins, 2008), neurological diseases (Keijzers et al., 2006; Hangan et al., 2010; Wren et al., 2011; Frenkel-Toledo et al., 2005), and fall detection and prediction (Hausdorff et al., 2007; Yogev et al., 2007).

Accurate, non-intrusive, low cost clinical gait analysis systems have many applications in diagnosis, monitoring, treatment and rehabilitation.
Such applications include early diagnosis and assessment (Wren et al., 2011; Hausdorff et al., 2007).

Stone and Skubic (2011a, 2011b) were the first papers that proposed the use of Kinect device for clinical gait analysis. Kinect for Xbox 360 is “a new way to control games through your speech, gestures, and your full body”, as it was declared at the E3 video game conference on June 1, 2009, by Shane Kim, the corporate vice president for strategy and business development at Microsoft’s game division.

The gait database includes the vertical ground reaction force records of subjects as they walked at their usual pace. We used a Xbox™ 360 250 GB with Kinect™ Sensor, system which includes an advanced video camera that analyses the position and movement of the body with 30 frames per second and captures the motions of the subject from the patient examination process. Also, we studied the stride-to-stride dynamics, the variability of these time series and nonlinear dynamics parameters, using the methodologies described in (Stone & Skubic, 2011a; Stone & Skubic, 2011b).

The Kinect SDK offers the detection and tracking of 20 different skeletal points, from head over hips to the feet. Using these points, we define thirteen biometric features for the identification of a person (Wang et al., 2010): the height, the length of legs, torso, both lower legs, both thighs, both upper arms, forearms, the step length, and the speed. The Kinect, released by Microsoft, uses actively emitted structured infrared (IR) light to estimate depth at each pixel using a single IR sensitive camera. The depth image (640×480, 11 bit) is generated at 30 fps, and is invariant to changes in visible light. The device was designed to allow controller free game play on the Microsoft Xbox, which is able to perform skeletal tracking, gesture recognition, and more using the depth image.

A graphical user interface (GUI) has been designed using Microsoft Visual Studio 2010 as show below in Fig. 2. We computed the average difference and standard deviation of the stride-to-stride time series, standard deviation of stride length, time, and velocity for each walking sequence.

The tremor data used in this paper were 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 transmitting the data through a Bluetooth wireless communication system. In this study, 20 PD (Parkinson’s disease tremor), and 20 NT (Normal tremor) subjects were analyzed. All patients are suffering from moderate to severe postural tremor. This postural tremor cannot be differentiated on clinical features (frequency, amplitude). Tremor is characterized by involuntary, rhythmic and alternating movements of one or more body parts (Wang et al., 2010). Parkinson’s disease tremors (markers of benign PD) can vary according to the circumstances under which they occur, the body part that is involved and the frequency at which the tremor occurs (Helmich et al., 2012).
The Wii™ Remote known as the Wiimote™, is the primary controller for Nintendo’s Wii™ console (Nintendo). 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 (Mamorita et al., 2009; Clark et al., 2010).

We choose to use a computer game device, the Nintendo, as a simple wireless accelerometer. We consider that Wii™ Remote Nintendo may be an attractive tool to be used as an accelerometer for tremor monitoring by physicians and laboratory technicians. The Wii™ Remote contains an accelerometer that has a range of ±3 g, which is enough for tremor recording (Mamorita et al., 2009), (Clark et al., 2010). Nintendo has three axes: x – lateral, y – anteroposterior, and z – vertical. 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 (Nintendo). Using a Wii™ Remote this system is capable to analyze frequency and to estimate the amplitude of tremor between 3-15 Hz (NT tremor is between 6-12 Hz, and PD tremor is between 4-6 Hz).

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 (Geman, 2011a).
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 (Mamorita et al., 2009; Clark et al., 2010; Geman, 2011b).

3. Data Processing

For the nonlinear analysis of tremor signals, we used several software packages such as CDA (Chaos Data Analyzer), NLyzer (Nonlinear Analysis in Real Time) (NLyzer), TISEAN (Nonlinear Time Series Analysis) (TISEAN).

We used CDA for nonlinear signal analysis. 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 (Teodorescu & Kandel, 1999; Titcombe et al., 2011).

A very first phase on non-linear analysis is to draw the phase diagram. This represents the signal derivate against the signal itself (Titcombe et al., 2011). 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” (Teodorescu & Kandel, 1999). 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 (Zamfir & Geman, 2004; Geman, 2004). The main nonlinear dynamic determinant is the Lyapunov exponent that must be positive for a chaotic process. Using the CDA software solution on the gait
signals of our database, we found that the Lyapunov exponent value varies between 0.05 and 0.92, depending on the analyzed signal.

The Lyapunov exponent values vary between 0.05 and 0.92 (normal gait) and for the Parkinson patients the variation is between 0.01 and 0.04. We used NLyzer, Nonlinear Analysis in Real Time software solution as well, for identifying the nonlinear specific elements (Zamfir & Geman, 2004; Geman et al., 2004). 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 (normal tremor) and for the Parkinson patients (Parkinsonian tremor) it varies between 0.02 and 0.06. In order to reduce the representation parameter numbers and keeping the essential information, we used numerical parameters for analysis (Geman & Zamfir, 2010; Geman, 2011a; Geman, 2011b).

4. Data Mining Tools

For this phase of the work we used Weka, a free collection of learning algorithms for Data Mining. We used Weka tools for preprocessing, using data classification, regression, association rules, and visualization (Weka). Weka is an open source under the GNU General Public License.

Fig. 4 illustrates Parkinsonian gait – A class, and normal gait – B class. The points \( x \) in the feature space are mapped into the hyperplan defined by the relation:

\[
\sum \alpha_i K(x_i, x) = \text{constant}
\]

(1)

Fig. 4 − Weka Classification using SVM (Support Vector Machine).

5. Motor Rehabilitation of Patients with Parkinson's Disease

In Parkinson's disease it is initiated the most appropriate therapeutic approach and rehabilitation, depending on each patient diagnosed.

For rehabilitation process the following topics are of interest: functional mobility; slow evolution of functional limitation confidence; maintaining
independence; improving patients quality of life; individualized therapy; thorough evaluation general and neurological disability; establishment of goal setting recovery in the degree of invalidation of patient oral therapy; assessment for patient involvement in therapy; establishing the conditions for rehabilitation.

Licensed physical therapist initiates and oversees the development of mobility exercises; he/she is documented in with the patient's motor act within Parkinson’s disease, is able to analyze the movement biomechanically and neurologically, and assesses problems with fluctuations in muscle tone.

Physical therapy may influence the disease but provides strategies to improve mobility in existing pathological conditions, taking into consideration the environment in which the patient carries out his life. In the initial period of the disease, with a good response to oral therapy it is established patient needs training in mental and physical daily activities with full responsibility. The family is encouraged to contribute to maintain a relaxing atmosphere, if there is no special medical problem, and if the disease becomes apparent, concern for the patient to discuss all issues and try to improve the situation.

For early stages of Parkinson’s disease we have proposed for improving upper limb reflexes and mobility the following system for motor rehabilitation of patients - iParkin (Fig. 6).

For the hardware part we used as interface the integrated circuit FT232RL to capture the data processed by the used microprocessor – ATMEGA328. This processor has the role to capture the analog signal offered by the fill factor of the capacitor, converting it into a numeric signal. Placing the hand within the electric field of the capacitor will change the capacitance value and the corresponding time constant.

Nearly all sensing of this kind depends upon how long it takes the capacitor to charge (known as the time constant). The sensors are made out of a RC circuit (Fig. 5), whose time constant equals the multiplication of a circuit resistance (in ohms) and the circuit capacitance (in farads):

$$\tau = R \times C$$  \hfill (2) 

The time required to charge or discharges the capacitor through the resistor is by $\approx 63.2$ percent of the difference between the initial value and the final value. This value is derived from the mathematical constant $e$ (Euler’s number). RC delay (Resistive-Capacitive delay) hinders the further increasing of speed in microelectronic integrated circuits. In order to increase the clock speed, the feature becomes smaller and smaller and the RC delay plays an increasingly important role.

By using a sensor made by copper, the delay will be reduced. It can also be reduced by changing the interlayer dielectric (typically silicon dioxide) to low-dielectric-constant materials, thus reducing the capacitance.
Fig. 5 – i-Parkin RC circuit design.

iParkin System uses coaxial cables, which are a very good choice for carrying the weak signal from the sensor to the processing unit. In order to discharge the capacitor, a pin to output mode may be set to digital “low”, and that means that both sides of the capacitor are grounded.

Now, setting the pin to input mode, we count how much time it takes for the capacitor to charge by waiting for the pin to go “high”. Since we fixed the resistors, a change in capacitance will be measurable. The primary variable contributing to the capacitance is the distance to the hand.

Fig. 6 – Rehabilitation System - the experiment.

On the screen in Fig. 6 we can see the 3D computer model of the box, which holds 27 small cubes, and the hand position which is represented by a small yellow box (the central lighter box in Fig. 7). When the yellow box is in the same position as one of the 27 boxes, it turns green (Fig. 7).
Pressing the “TAB” key when activating one of the cubes, will change the color and the state of the cube to red. It will stay in that state until the program is reset (Fig. 8). There is a RESET function implemented in the program, which can be activated by clicking the right mouse button.

Fig. 7 – The Parkinson’s disease patient hand position (a small yellow box) (I).

Fig. 8 – The Parkinson’s disease patient hand position (a small yellow box, i.e. lighter small box in the bottom part) (II).

6. Conclusions

Because Parkinsonian tremor or gait are still almost unknown and very difficult issues we argue that nonlinear dynamic parameters of Parkinsonian gait and tremor have certain peculiarities and can be used in knowledge-discovery (Zamfir & Geman, 2004; Geman et al., 2004; Geman & Zamfir, 2010).

These data and new knowledge will be integrated in a Knowledge-based System aimed to 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 and data fusion (Geman & Turcu, 2011; Geman, 2011a; Geman, 2011b).
The data used in this study were recorded using a box including accelerometers (such as those in a Wii™), pressure sensors, and inevitably a microcontroller which runs the data acquisition, analog to digital conversion, and transmits the data through a Bluetooth wireless communication system. Nonlinear parameters can provide essential information in the differential diagnosis, in comparison with classical linear parameters. We present an accurate tremor and gait analysis system (Parkinson’s disease Screening Systems) that is economical and non-intrusive. Our system is based on the Kinect™ sensor and Wii™ sensors and thus can extract tremor or gait information from subjects.

As a fact, maintaining a good physical shape for a long time despite the motor handicap generated by the disease is related to the notion of “permanent movement”. Hereby, a functional equilibrium between the contracted muscle and the osteoarticular system is established depending very much on the quantity and quality of the movement. It is very important for the PD patient to acknowledge this thing or to accept this urging from the neurorehabilitation team. The patient must be stimulated to continue his/her activity (physical or psychical) despite the stage of the disease, so that (s)he can maintain his/her motor handicap independently for as long as possible. Body movement brings good blood circulation and functioning within normal parameters and other organs with maintaining of a good mental tone. In all of what concerns the rehabilitation of PD patients there is a fundamental role, which represents training the beholder and general care of the family. This element is tested in daily practice where we realize that the good evolution of a PD patient is closely linked to the support that he has from family and the effort of integrating physically and mentally into everyday life.

We intend to use this system for other diseases analysis, in which tremor is present (cerebellar tremor, alcoholic one), in cases of hemiparesis (for regaining mobility and recovery of the affected upper limb), but also for improving accuracy to perform precise movements the left-handed subjects.

Acknowledgments. The authors would like to thank Radu Vasilcu, MD, and Prof. Mihai Covaşă, PhD, MD, for their help in providing data for PD patients and for clinical evaluation of results during experiments. Also, special thanks are due to the students Victor Slavoiu and Ovidiu Timof diciuc, Stefâncel Mare University of Suceava, Faculty of Electrical Engineering and Computer Science.

Important notice. The experiments were not prejudicial in any way to the health of human subjects investigated and they were not subject to any invasive maneuvers. All the subjects were free to decide whether they wish to participate in this study. The duration of this study was 3 years. All personal information was and will be kept confidential. The information obtained in this study may help physicians to find a method of early diagnosis for those suffering from PD and to identify the best options for their treatment. It was no financial compensation during the study for the participants.
REFERENCES


Geman O., Turcu C., Partitioning Methods Used in DBS Treatments Analysis Results. Proceedings International Joint Conferences on Neural Networks IJCNN’2011, 2011.


Boala Parkinson este o boală neurodegenerativă severă, care „beneficiază” de triada clasică a simptomelor neurologice motorii: rigiditate, akinezie și tremur de repaus. Tremurul, în boala Parkinson, are câteva trăsături specifice: la început poate fi un simptom benign al bolii, frecvența sa poate varia între 4-5 Hz și 8-10 Hz, putând să se modifice în diverse situații, tremurul poate surveni în poziție de odihnă/repaus și poate fi observat la mâini, picioare sau alte părți ale corpului. Boala Parkinson este o boală cronică, având ca o necesitate adaptarea tratamentului curent în funcție de numeroase simptome posibile. Fiecare pacient trebuie analizat și diagnosticat de către un specialist, având ca o necesitate adaptarea tratamentului curent în funcție de numeroase simptome posibile. Fiecare pacient trebuie analizat și diagnosticat de către un specialist, având ca o necesitate adaptarea tratamentului curent în funcție de numeroase simptome posibile.
din două dispozitive comerciale, Kinect™ and Wii™ Remote, care folosesc la achiziția semnalelor de mers, respectiv de tremur. De asemenea, în vederea recuperării pacienților cu tremur parkinsonian autorii au dezvoltat un sistem de recuperare motorie, denumit iParkin. Partea de software este formată din programe de analiză neliniară de semnal, cum sunt CDA (Chaos Data Analyzer), NLyzer (Nonlinear Analysis in Real Time) și TISEAN (Nonlinear Time Series Analysis). De asemenea, au fost utilizate instrumente de “data mining” și clasificare, cum este pachetul de programe Weka.

În concluzie, sistemul dezvoltat de autori a permis achiziția și prelucrarea semnalelor de mers și de tremor, cu ajutorul pachetelor de programe utilizate, în colaborare cu medicii și personalul de specialitate, care au oferit interpretarea clinică a datelor obținute. Intențiile viitoare ale autorilor sunt de a integra datele și cunoștințele din domeniu într-un sistem bazat pe cunoștințe (Knowledge-Based System) și pe fuziunea datelor, destinat bolii Parkinson.