Quantitative Evaluation of Parkinson's Disease using sensor based smart Glove

K. Niazmand, K. Tonn, A. Kalaras, U. M. Fietzek *, J. H. Mehrkens ◊ and T. C. Lueth

Dept. Micro Technology and Medical Device Technology
Technische Universität Muenchen, Garching, Germany
* Neurologisches Krankenhaus Muenchen, Schoen Klinik München Schwabing,
Center for Parkinson's Disease and Movement Disorders, Munich, Germany
◊ Dept. of Neurosurgery, Ludwig-Maximilian Universität Muenchen,
Klinikum Großhadern, Germany

Abstract

Parkinson's disease (PD) is a chronic neurodegenerative movement disorder. The motor status of patients with PD can be characterized by the Unified Parkinson's disease rating scale (UPDRS). However, the UPDRS evaluates the movement disorders on a descriptive level only. Diagnosis and therapy of PD could be augmented if a quantitative assessment could be implemented. Thus, a wireless wearable sensor system for the evaluation of severity of motor dysfunction in PD was developed. The system was integrated into a smart glove[1]. This glove has two touch sensors, two 3D-accelerometers and a force sensor to assess the cardinal motor symptoms of PD (bradykinesia, tremor and rigidity of hand and arm). In this paper we describe the setup of the glove and initial results.

Keywords: smart glove; accelerometer; touch sensor; force sensor; Parkinson's disease quantification; tremor; bradykinesia; rigidity.

1. Introduction

Parkinson's disease (PD) is a neurodegenerative disorder causing progressive loss of dopamine-producing brain cells. The loss of dopamine in the midbrain induces characteristic motor symptoms: rigidity (increase of muscle tone that causes resistance to passive movement throughout the whole range of motion), tremor (involuntary rhythmic oscillations of one or more body parts), bradykinesia (slowness of motion) and hypokinesia (decreased amplitude of motion). Levodopa, a precursor to dopamine, is the medication of first choice throughout the course of the disease. Modern treatment of PD also comprises electric deep brain stimulation (DBS) of motor centers for suitable patients, thereby providing treatment around the clock, reducing the need for medication, and increasing quality of life [1]. The stereotactic introduction of the stimulating electrodes is highly dependent on precise brain imaging, and exact assessment of motor responses to test stimulation during the operation.

So far, no technical device to objectively assess the PD specific movement disorders is available. A quantifiable, objective and continuous data acquisition providing information on the characteristic movement disorders could improve diagnosis and therapy monitoring. Ideally, such a data acquisition should be location-independent without any discomfort for both patient and care-giver and should be movable.

2. State of the art

To evaluate different disorders of a PD patient, the Unified Parkinson's Disease Rating Scale (UPDRS) [2] is most commonly used. Motor functions examined by a physician evaluate tremor, hypo- and bradykinesia and rigidity of finger-, hand- and arm movements. Post et al. [3] assessed the rater variability of the UPDRS Motor examination finding out considerable inter-rater disagreement.

To objectively assess movement disorders sensor technology is used. Fabric sensors are integrated in

This work has received funding from the Bavarian Research Foundation (BFS) under contract number AZ-780-07. The views expressed here are thoseof the authors only. The BFS is not liable for any use that may be made of the information contained therein

textiles by knitted in a Lycra-containing belt [4, 16]. Sensors and electronics are glued inside a garment using silicone gel [6]. Sensors are fastened to the body [5], to a shirt [7] or integrated into a belt [8, 9]. In [10] embedded wires and sensors are woven into the internal layer of a pullover.

Fastened sensors to the body using bands or belts are not comfortable for long-term measurement. The integration of sensors and electronics in textiles is expensive and costly in terms and times, but convenient to wear and the garments are washable. Fixing sensors to a textile by using push-button clips is a simple solution, because it is cheap, fast to manufacture and the textile is washable after removing the electronics.

In [24] accelerometers are used to detect activities. To measure motor dysfunction of PD accelerometers, touch sensors, force sensors, optic sensors, fiber optics and keyboards are utilized. Bradykinesia [11, 12, 13, 14, 15, and 16], rigidity [17] and tremor [18, 19, and 20] of finger-, hand- and arm movements are detected, while different motor tasks are performed according to UPDRS. Brady- and hypokinesia are assessed by finger tapping using keyboards [11, 13], optic sensors with markers [14], touch sensors [12, 15], gloves with fiber optics [16] and accelerometers [15]. To record rest- and postural tremor fingers, hands and arms remain in a calm position or they are stretched and movements are measured by accelerometers [18, 20] and inertial sensors [19]. To examine rigidity passive movements of the elbow joint are performed and measured by force sensors [17].

There are some drawbacks in the above mentioned systems and methods to evaluate motor dysfunction of PD patients quantitatively. Results of motor examination assessed according to scales are subjectively affected [3]. The systems in [11, 12, and 13] are particularly for the use on laboratory conditions. Subjects sit in front of the keyboard, elbow joints are flexed on 90° and they tap only the index finger on the keyboard. Therefore this method cannot measure finger tapping with index finger and thumb, a standardized task of UPDRS movement examination. In [14] markers attached on the moving subject must have optic contact with the camera during the measurements. These measurement systems need longer time to set up and they are not suited for a time- and place-independent data acquisition. In [15, 18, and 20] sensors are fixed on the subjects body by a technician, because the direction of the sensors is very important for the correct assessment of movement disorder, but fixed sensors often are uncomfortable for long-term measurements. In [16] there is no wireless communication between the glove and a PC to evaluate sensor data and the cables of the systems can restrict the movements of patients. Furthermore the systems mentioned above do not evaluate movement disorders in real time. Online measurement would be necessary to assess movement dysfunction in that moment when the subject performs UPDRS motor-tasks.

Table 1. Summary of the state of the art

Ref.	Measure System	Parameters for Evaluation of Symptoms	Symptom
[11], [13]	keyboard	rhythm of finger taps	bradykinesia
[12]	touch sensors	rhythm of finger taps	bradykinesia
[14]	camera & markers	amplitude and velocity of finger taps	bradykinesia
[15]	accelerometer, touch sensors	duration, amplitude and velocity of finger taps	bradykinesia
[16]	fiber optics	angular velocity and frequency	bradykinesia
[17]	force sensors	impedance	rigor
[18]	1D-accelerometers	amplitude and frequency of tremor	tremor
[19]	inertial sensors	Teager Energy	Tremor
[20]	3D-accelerometers	average acceleration	Tremor

For “Deep Brain Stimulation” (DBS) the stereotactic introduction of the stimulating electrodes highly depends on exact assessment of motor responses to test stimulation during the operation. Tremor, bradykinesia and rigor should be tested in time to monitor the precise place of stimulation. The development of smart clothes with integrated acceleration sensors and algorithms to detect movement disorders independent of the sensor direction is a challenge. Such a washable measurement device would be comfortable to wear and to put on and records data independent from a laboratory. Patients can move without restriction during measurements.

3. Task and approach

To integrate the components of a measurement device into a wearable and washable textile movement disorders could be quantitatively analyzed without the disrupting effects of an extensive measurement installation mentioned above.

In [10, 21] we describe the function and set-up of the MiMed-Pullover, a textile integrated measurement device, which identifies clearly movement disorder like fall, and tremor by recorded sensor data. It has integrated acceleration sensors, a unit for data acquisition and processing and it can be washed in a washing machine. Data acquisition is provided by wireless communication.

On the basis of the MiMed-Pullover we developed the smart glove to detect and analyze movement disorders of hands and arms like tremor, bradykinesia and rigidity. The system operates with battery. Storage of the sensor data in an integrated storage unit and wireless communication between the glove and a basis station are very important features.

Moreover, an intuitive operable application was programmed in order to request, achieve and display the sensor data and results. This application can accomplish:

1. Wireless communication with the glove
2. Storage of the sensor data
3. Measurement results export
4. Analysis of data as well as a proper statement about assessment of Parkinson's Symptoms

4. System concept description

The system (fig. 1) consists of a glove with a control and transmit unit (1), a receiver unit (7) and a computer (8) for storage and analysis of data. The sensors of the glove are two integrated triaxial acceleration sensors fixed on the middle finger (4) and accordingly on the dorsal wrist (2) for the evaluation of tremor. A force sensor (3) measures evidence of rigidity and two touch sensors placed on the thumb and accordingly on the index finger (5) detect bradykinesia. Sensor data received from the glove are saved on a MicroSD-card or sent wireless to a computer. The sensors and the cables of the system can be integrated by use of a second glove above or they can be encapsulated. Both systems would be washable.

The algorithms for the assessment of Parkinson's symptoms run on the computer, which serves in the processing of acceleration values and giving feedback about the severity of Parkinson's symptoms on the monitor. After the registration of a patient in the system the patient should put on the glove.

Frequency of tremor at wrist and middle finger, force-data indicating rigidity at wrist and movement time of finger tapping can be calculated by the glove. The result can be displayed on the monitor (8).

The acceleration sensors measure values within a range of ±2gm ($1g_m$=9.81m/s2) in three spatial directions with a resolution of $0{,}004g_m$. Frequency of tremor is usually below 10Hz (fmax) [1]. According to the Nyquist theorem the acceleration values should be sampled with a frequency of at least 20Hz [22]. When index finger and thumb get in touch, sensors detect the contact. Healthy people are able to tap their fingers up to five times per second. The subjects should execute the finger taps movements as quickly and widely as possible for 30 seconds. Rigidity is measured by gripping the patient's wrist and imposing movements on the elbow joint of PD patients. The patient should relieve any tension during passive movements.

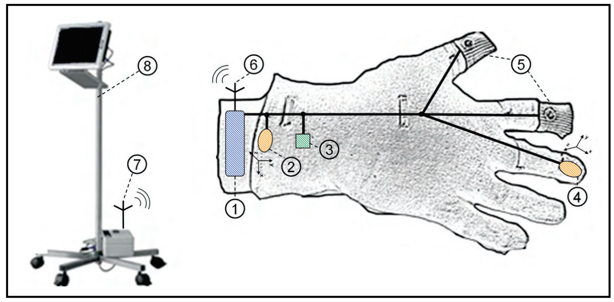

Figure 1. Solution system

4.1. Calculation of the frequency of activity at the wrist and middle finger

To calculate frequency and movement amount (value), first the relative acceleration (an activity value) X[k]' based on the absolute acceleration x[k] is calculated as follows [21]:

$$x[k] = a[k] - g_m$$

$$x[k]' = x[k] - \frac{1}{20}\sum_{k=1}^{k=20} x[k]$$

$$X[k]' = \begin{cases} x[k]', & |x[k]'| > \mathrm{N_{THLD}} \\ 0, & |x[k]'| \le \mathrm{N_{THLD}} \end{cases}$$

where N_{THLD} refers to the maximum noise level.

The system's noise is caused by the MiMed-glove electronic parts (the microcontroller, the sensors, the wires). The maximum noise level N_{THLD} is determined empirically recording data while the glove was lying on a table. The resulting maximum noise level was (3·resolution) or $0.012g_m$ (N_{THLD} = 3). During normal walking, the relative acceleration reaches up to 1.2 g_m (= 100 times greater than the maximum noise level).

The signal of activity is a sporadic signal and therefore cannot be analyzed by means of Fast Fourier Transformation (FFT). In [21] a proper method for frequency analysis is presented. Initially, the relative accelerations of a movement are calculated. Time points of maximum values of the relative accelerations are detected. Therefore, an upper and a lower threshold (red lines in fig. 2) are calculated. In a signal a peak is detected, if the signal initially passes under the lower threshold, after passing over the upper threshold and finally passing again under the lower level. The maximum, which is achieved during this process, is a signal peak. For the calculation of the upper and lower threshold, mean value and standard deviation of the relative accelerations are taken into account; in order to detect all the peaks of the signal, even if the peaks have different dimensions (fig. 2). When the time points of peaks are detected, the distances between these points are calculated (ΔT1, ΔT2 ...). The frequency of the signal is calculated as follows (1):

$$f = \frac{1}{\frac{\sum \Delta T}{N}} \tag{1}$$

ΔT: distance between the points of time of the peaks
N: number of the distances

The longer a measurement lasts, the more precise this method is. In this project we calculate the range and frequency of relative acceleration during a period of 15s to assess the rest and posture tremor (2). But since the glove should analyze tremor over brief periods of time as well, we modified the mentioned method. The new algorithm needs a buffer time of 5 seconds at the beginning of a measurement. Moreover the upper and lower thresholds are calculated over a period of 5seconds. On the other hand the frequency is calculated each time when the sensors receive a new value. Thus, the frequency is calculated 20 times per second. The acceleration values of the last 2 seconds are taken into account for the calculation of the frequency each time (moving average).

$$Tremor = f(range, frequency) \tag{2}$$

4.2. Calculation of rigitidy at the wrist

A force sensor is used for the assessment of rigidity (fig. 3.1). The examiner grips the patient's wrist and performs passive movements of the elbow joint with constant force. The examiner's thumb must be placed on the force sensor. During the movements the force sensor measures the used force in Newton.

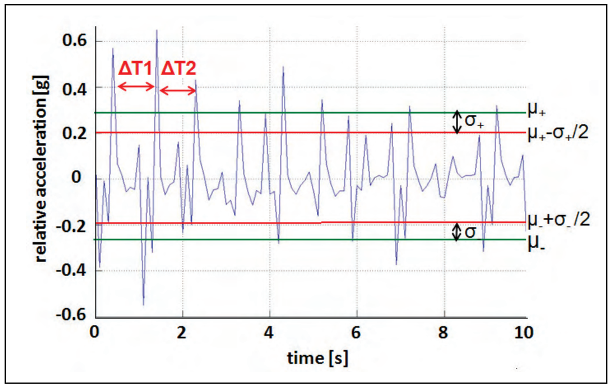

Figure 2. Calculation of frequency

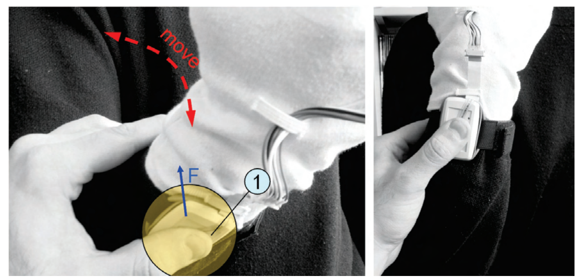

Figure 3. Force sensor

This force normally should be constant and low for health people. In contrast the measured force should be irregularly higher for patients with rigidity (3).

$$Rigidity = f(F) \tag{3}$$

F: force

4.3. Assessment of bradykinesia by means of movement time of thumb and index finger

The movement time during taps of fingers is measured by means of the touch sensors (Fig. 4.1) in order to assess the bradykinesia. The subjects should execute the finger taps movements as quickly and widely as possible. The touch sensors can detect when the thumb and finger index are getting in contact. The time between two times of touch is calculated and is equivalent to movement time. Health subjects can tap their fingers on average 3 to 5 times per second with a low standard deviation. The lower a standard deviation is, the more periodic the movement is. Bradykinesia depends on the average movement time and the standard deviation of movement time (4).

$$Bradykinesia = f(average(\Delta t), stdev(\Delta t)) \tag{4}$$

Δt: movement time
Stdev(Δt): standard deviation of Δt

5. Evaluation

5.1. Materials and Methods

A measuring-glove was constructed and its accuracy was investigated. Two 3-Axis acceleration sensors (SMB380, Robert Bosch GmbH)(fig. 5.3) deliver digital values that are read over an SPI-interface. Their measuring range can be set to ±2g, ±4g or ±8g. The two sensors are connected to the electronic unit through a cable network (cross section: 0.1 mm² with PVC isolation).

The force sensor is a sheet force sensor (IEE GmbH, fig. 5.1). This sensor consists of electric conductive ink and a coal covering on the sheet. To assess bradykinesia two washable conductive textiles (Textronics Inc.) are attached to the glove (fig. 5.4). This technology always detects tapping of fingers and conductive textiles are convenient for the patients. The textiles are connected with the cable network by push-buttons (fig. 5.5). The cable network connects all sensors with the electronic unit.

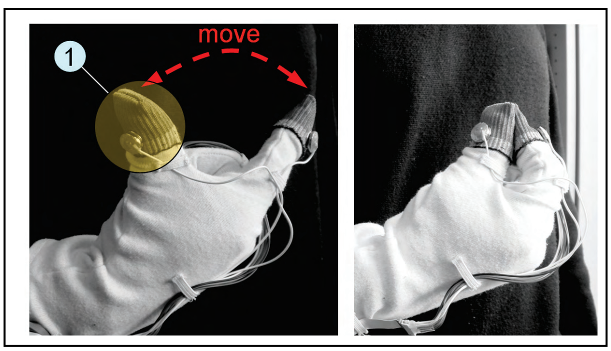

Figure 4. Tapping of fingers

In [23] the construction of the electronic unit (fig. 5.2) is described in detail. The electronic unit consists of an integrated accelerometer (SMB380, Robert Bosch GmbH), a NanoLoc-module (microcontroller and 2.4 GHz radio transceiver, Nanotron Technologies GmbH), a RV-8564-C2 real-time clock (Micro Crystal AG), a MicroSD-card slot, a status LED and the components necessary for power management. Sensor data are received from the glove and are saved on a SD-card or sent wireless to a computer. The sensors and the electronic unit should be removed before washing the glove and can be replaced again in right position by push-buttons.

5.2. Experiment

The accuracy of the glove should be tested and evaluated with a restricted number of subjects in a pre-field experiment. Four different experiments were executed. Subjects (healthy subject and patients with PD) took part in the experiments. The subjects were videotaped during the experiments. An examiner evaluated off-line the severity of symptoms through the videos. The examiner's evaluation was compared with the calculated parameters from the glove. The process of experiments is presented in the following paragraphs:

1) *Accurancy of the measurement of the rest and posture tremor:*

a) Setup:

The algorithms and the user interface of the smart pullover assessing tremor [21] were customized in order to evaluate tremor by the glove. The subject should perform two standardized motor tasks according to UPDRS.

First, hands and arms were kept at rest, afterwards stretched out, each task for 15s. During the first task rest tremor can be assessed, during the second task postural tremor of hand. The acceleration values are the basis for the evaluation of tremor.

Results about the recorded severity of tremor are compared with the corresponding statements of a doctor. The 5 subjects (1 healthy subject and 4 patients with PD) executed the two tasks according to UPDRS. The assessment of the tremor is based on the measured frequency during these motor tasks. The correspondent between the measured frequency and the UPDR-Scale is presented in [21]. The range of relative acceleration should range from 0.07 to 0.9gm for the tremor [21]. We took into account the sensor values from the accelerometer on wrist.

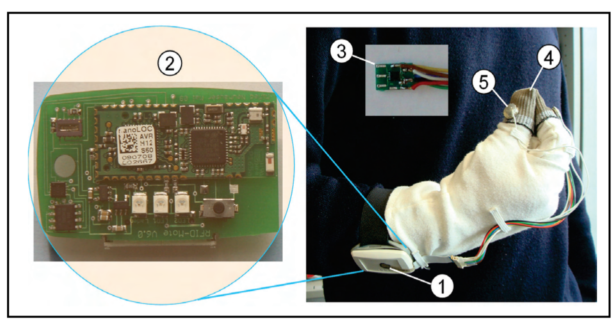

Figure 5. Components of glove

b) Results:

The presented algorithm showed a sensitivity of 100% and a specificity of 83% compared with the physician's statement.

2) Accuracy of near term measurement of frequency:

To gain information about the severity of tremor during target stimulation in DBS surgery, changes of tremor frequency at the middle finger and wrist should be calculated online with a short delay. In the developed system the delay is 0.05s (=1/frequency).

a) Setup:

To assess the reliability of this method, we calculated the average of the frequency every 5 seconds during the execution of the tasks for rest and postural tremor. At the same time a doctor assessed the severity of tremor every 5 seconds. At the end we compared the assessment of the system based on the average of the frequency with the assessment of the doctor. The 6 subjects (1 healthy subject and 5 patients with PD) executed the two relevant tasks for the rest and postural tremor.

b) Result:

Assessment of the tremor with a maximal deviation of one point from the assessment of doctor took place with sensitivity of 95%. The specificity is 96%.

Figure 6. Two tasks according to UPDRS

3) Accuracy of measurement of bradykinesia:

The average and the standard deviation of movement time during finger tapping was calculated and provided the basis for the assessment of bradykinesia.

a) Setup:

Nine subjects (3 healthy subjects and 6 patients with PD) should execute finger tapping as quickly and widely as possible for 30 seconds. The average time of movement time corresponds to the velocity of movement and the standard deviation to the homogeneity of movement. Healthy subjects should have a low average and standard deviation of movement time. In contrast patients with bradykinesia should have at least one of the two parameters high. The parameters, calculated of the system, were compared with the rating of a doctor.

b) Result:

The three healthy subjects have an average of movement time of 328ms and a standard deviation of 56ms. Healthy subjects can tap their fingers on average three times per second. The parameters values are presented in table II. Table 2 shows, the higher the severity of bradykinesia, the higher are the average and standard deviation of movement time.

Patients with bradykinesia have a higher standard deviation and/or average of movement time than healthy subjects. There are also patients (for example patients 6&7), whose average of movement time is lower compared to healthy subjects. The reason is that these patients can not reach great amplitudes during finger tapping. Therefore they are able to tap their finger faster than healthy subjects.

4) Accuracy of measurement of rigidity:

a) Setup:

The examiner grips the patient's wrist and performs passive movements of the elbow joint with constant force. Severity code of rigidity is calculated by value of force. This assessment is compared with a physician's evaluation. Seven subjects (2 healthy and 5 patients with PD) took part in the measurements.

b) Result:

There is no correlation between severity code of rigidity and value of force, because:

1. The size of examiner's hand influences the position of thumb on the force sensor and the exercised force.
2. The individual unconscious imposed force by examiner influences the measured results.
3. The weight of patient's arm also influences the imposed force by examiner.
4. The patient does not always relieve any tension during passive movements.

6. Conclusions

The first prototype of a glove with integrated sensors for the assessment of tremor, bradykinesia and rigidity of the hand and arm was presented and tested in healthy subjects and PD patients. The system differs from other measurement systems because it is easy to wear, washable and usable without a technician's help. It delivers reliable results in first tests. Tremor was assessed by means of range and frequency of the relative acceleration with a sensitivity of 100% and a specificity of 83%.

Table 2. Results for Bradykinesia

Subjects	Average of Movement Time [ms]	Standard Deviation of Movement Time [ms]	UPDRS Assessment of Bradykinesia [0-4]
Healthy 1	386	56	0
Healthy 2	332	55	0
Healthy 3	265	56	0
Patient 1	298	96	1
Patient 2	478	87	2
Patient 3	546	327	3
Patient 4	258	83	1
Patient 5	551	64	2
Patient 6	243	94	2
Patient 7	221	117	2
Patient 8	666	428	3
Patient 9	302	92	2

red: discrimination values of parameters

Bradykinesia was assessed by measuring the movement time during finger tapping. Rigidity could not be detected by means of just one thin film force sensor. To improve the evaluation of rigidity the number and placement of force sensors should be adapted. This will be tested further on in clinical setting, and later on e. g. intraoperatively in brain stimulation surgery to analyze qualitatively movement disorders.

Sensors integrated into different garments extend the possibility to measure movement disorders. The pants [25] could be used e.g. for gait analysis of PD patients.

7. Acknowledgement

We thank the patients of the Schoen Klinik Muenchen Schwabing for their support and cooperation.

Within the research consortium of the Bavarian Research Foundation (BFS) „FitForAge“ a team of scientists and engineers affiliated to 13 departments of the Bavarian universities Erlangen-Nuernberg, Muenchen, Regensburg and Wuerzburg works together with 25 industrial partners on the development of products and services for the aging society. The scope of the research consortium is to develop technology based solutions which will help elderly people in their future living environment comprising home and workplace as well as in communication and transportation. Eventually not only elderly people but also all social groups should profit from these solutions.

References

[1] G. Deuschl et al., „A Randomized Trial of Deep-Brain Stimulation for Parkinson’s Disease“ N Engl J Med, 355, pp.896-908, 2006.

[2] J. Schwarz, A. Storch, “Parkinson-Syndrome“, W. Kohlhammer, p. 367-379, 2007.

[3] B. Post et al., “Unified Parkinson’s Disease Rating Scale Motor Examination: Are Ratings of Nurses, Residents in Neurology and Movement Disorders Specialists Interchangeable?”, Movement Disorders, Vol.20, Nr. 12, pp.1577-1584, 2005.

[4] M. Catrysse, R. Puers, C. Hertleer, L. Van Langenhove, H. van Egmond, D. Matthys, „Towards the integration of textile sensors in a wireless monitoring suit“, Sensors and Actuators A, vol. 114, issue 2-3, pp. 302-311, 2004.

[5] S. Patel, K. Lorincz, R. Hughes, N. Huggins, J. Growdon, D. Standaert, M.Akay, J. Dy, M. Welsh and P. Bonato, “Monitoring Motor Fluctuations in Patients With Parkinson’s Disease Using Wearable Sensors”, IEEE Transactions on information technology biomedizin vol. 13, No. 6, pp.864-873, November 2009.

[6] H. Harms, O. Amft, D. Roggen, G. Tröster, “Smash: A distributed sensing and processing garment for the classification of upper body postures”. Third international conference on body area networks, 2008.

[7] M. Guler, S. Ertugrul, “Measuring and Transmitting Vital Body Signs Using MEMS Sensors”, RFID Eurasia, pp. 1-4, 2007.

[8] T. Reinvuo, M. Hannula, H. Sorvoja, E. Alasaarela & R.Myllylä, “Measurement of respiratory rate with high-resolution accelerometer and emfit pressure sensor”, IEEE Sensors Applications Symposium, 7-9 February, USA, pp. 192-195, 2006.

[9] M. Sung, R. DeVaul, S. Jimenez, J. Gips, A.S. Pentland, „A Shiver Motion and Core Body Temperature Classification for Wearable Soldier Health Monitoring Systems“, IEEE International Symposium of Wearable Computers, 2004.

[10] K. Niazmand, C. Jehle, L.T. D'Angelo, T.C. Lueth, “A New Washable Low-Cost Garment for Everyday Fall Detection”, 32nd Annual International IEEE EMBS Conference, 2010.

[11] G. Giovannoni, J. van Schlkwyk, V. U. Fritz, A. J. Lees, „Bradykinesia akinesia inco-ordination test (BRAIN TEST): an objective compiterised assessment of upper limp motor function“, J. Neurol. Neurosurg Psychiatry, vol 67, pp.624-629, 1999.

[12] J. S. Freeman, F. W. Cody, W. Schady,”The influence of external timing cues upon the rhythm of voluntary movements in Parkinson’s disease”, Neurol. Neurosurg Psychiatry, vol.56, pp.1078-1084, 1993.

[13] H. M. Bronte-Stewart, L. Ding, C. Alexander, Y.Zhou, G.P. Moore, „Quantitative digitography (QDG): a sensitive measure of digital motor control in idiopathic Parkinson’s disease“, Mov. Disord, vol.15, pp. 36-47, 2000.

[14] J. Konczak, H. Ackermann, I. Hertrich, S. Spieker, J. Dichgans, „Control of repetitive lip and finger movements in Parkinson's disease: influence of external timing signals and simultaneous execution on motor performance“, Mov. Disord., vol.12, pp.665-676, 1997.

[15] R. Okuno, M.Yokoe, K. Akazawa, K. Abe, S. Sakoda, "Finger Taps Movement Acceleration Measurement System for Quantitative Diagnosis of Parkinson's disease", Proc. Of 28th Annual International Conference of the IEEE EMBS, vol. Supplement, pp. 6623-6626, 2006.

[16] R.P. Iacono, R.R. Lonser, G. Maeda, S. Kuniyoshi, D. Warner, G. Mandybur, Sh. Yamada, "Chronic Anterior Pallidal Stimulation for Parkinson's Disease", Acta Neurochir, vol. 137, pp. 106-112, 1955.

[17] Arthur Prochazka, David J. Bennett, Marilee J. Stephens, Susan K. Patrick, Rosemary Sears-Duru, Ted Roberts, and Jack H. Jhamandas, "Measurement of Rigidity in Parkinson's Disease", Movement Disorders, Vol. 12, No. 1, pp. 24-32, 1997.

[18] M. Smeja, "24-h Assessment of tremor activity and posture in Parkinson's disease by multi-channel accelerometry", Journal of Psychophysiology 13, pp. 245-256, 1999.

[19] M. Hanson, H. Powell, R. Frysinger, D. Huss, W. Elias, J. Lach, C. Brown, "Teager Energy Assessment of Tremor Severity in Clinical Application of Wearable Inertial Sensors", IEEE/NIH Life Science Systems and Applications Workshop, pp. 136-139, 2007.

[20] R. LeMoyne, C. Coroian, T. Mastroianni, "Quantification of Parkinson's disease characteristics using wireless accelerometers",IEEE, 2009.

[21] K. Niazmand, K. Tonn, A. Kalaras, S. Kammermeier, K. Boetzel, J.H. Mehrkens, T.C. Lueth, „A measurement device for motion analysis of patients with Parkinson's disease using sensor based smart clothes“, IEEE, 2011.

[22] Hans Marco, „"Systemtheorie: Methoden und Anwendungen für ein- und mehrdimensionale Systeme“, Springer Verlag, pp. 129-130, 1995.

[23] A. Czabke, J. Neuhäuser, T. C. Lueth, "Recognition of Interactions with Objects based on Radio Modules", Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2010.

[24] L.T. D'Angelo, A. Czabke, I. Somlai, K. Niazmand, T.C.Lueth, "ART – a new concept for an activity recorder and transceiver," Engineering in Medicine and Biology Society (EMBC), 2010 Annual International Conference of the IEEE, pp.2123-2135, 2010.

[25] K.Niazmand, I. Somlai, S. Louizi, T.C. Lueth, "Proof of the accuracy of measuring pants to evaluate the activity of the hip and legs in everyday life", Interna-tional ICST Conference on Wireless Mobile Communication and Healthcare - Mobi-Health, 2010.