http://dx.doi.org/10.6493/SmartSci.2014.266

A Smart Tool for the Diagnosis of Parkinsonian Syndromes using Wireless Watches

Andreas Goll[1] and Hongying Meng[1*]

[1]Department of Electronic and Computer Engineering, Brunel University London, London, United Kingdom
* Corresponding Author / E-mail: hongying.meng@brunel.ac.uk, TEL: +44-1895265496

KEYWORDS : Parkinson disease, Diagnosis, Parkinson screening and scales, Health monitoring, Wireless watches

Early detection and diagnosis of Parkinson disease will provide a good chance for patients to take early actions and prevent its further development. In this paper, a smart tool for the diagnosis of Parkinsonian syndromes is designed and developed using low–cost Texas Instruments eZ430-Chronos wireless watches. With this smart tool, Parkinson Bradykinesia is detected based on the cycle of a human gait, with the watch worn on the foot, and Parkinson Tremor shaking is detected and differed by frequency 0 to 8 Hz on the arm in real-time with a developed statistical diagnosis chart. It can be used in small clinics as well as home environment due to its low-cost and easy-use property.

Manuscript received: June 17, 2014 / Accepted: September 09, 2014

1. Introduction

Movement disabilities often occur sudden and unexpected in life. Movement disabilities can have multiple causations such as surgery, drug dependencies, accidents or apoplexy. The Parkinson Disease, discovered by the British surgeon James Parkinson in 1817 [1], is a heavily and slowly decreasing neuronal disease. It was estimated that “1% of 70 year olds, 1 in 50 over 80 years, 10% case before the age of 50, 200 per 100,000 populations are affected. In the United Kingdom, there are approximately 120,000 to 130,000 diagnosed cases, but there may be many more that remain undiagnosed” [2].

Marked by the die of dopamine producing neurons, the disease symptoms can be split into non-motor symptoms and motor-symptoms. The focus here is the cardinal motor-symptom Parkinson Bradykinesia, a slowness of movement and the additional motor-symptom Parkinson Tremor, which is a kind of muscle shaking.

The technical progress in semiconductor device fabrication made compact, boxed, low price, wireless development system available such as Texas Instruments eZ430-Chronos [3] as shown in Fig. 1. The watch has various electronic components inside such as an acceleration sensor, a pressure sensor, a RISC signal processor and a radio chip. The measured value for acceleration can be continuously and wirelessly sent from the watch to an included USB Access Point. A PC program can receive the data from the USB Access Point by a virtual serial port.

In this paper, a portable, smart, cheap tool was designed and developed for the diagnosis of Parkinsonian syndromes in real-time. The slowness of movement, caused by the Parkinson Bradykinesia, is detected by analyzing the human gait. The vibration, caused by Parkinson Tremor is measured by the acceleration sensor.

Fig. 1 Wireless watch eZ430-Chronos with a mobile computer

2. Methodology

2.1 Medical diagnosis of the Parkinson disease

For Parkinson disease, there exist a lot of organizations over the world such as “British National Parkinson Association” (BNPA), “European Parkinson Disease Association” (EPDA) and “International Parkinson and Movement Disorder Society” (IPMDS). They develop recommendations and rating scales for the diagnosis. The British “National Institute for Health and Clinical Excellence” (NICE) recommends the use of the “UK Parkinson's Disease Society Brain Bank Criteria” in its guideline [4]. The UK PDS Brain Bank Criteria diagnosis Parkinson with three steps: 1). Diagnoses of Parkinsonian Syndrome; 2). Exclusion criteria for Parkinson’s disease; 3). Supportive prospective positive criteria for Parkinson’s disease [5].

The first step “Diagnoses of Parkinsonian Syndrome” contains two parts: 1). Diagnosis of Parkinsonian Syndrome Bradykinesia: slowness of initiation of voluntary movement with progressive reduction in speed and amplitude of repetitive actions; and 2) At least one of the following: Muscular rigidity; 4-6 Hz rest tremor; postural instability not caused by primary visual, vestibular, cerebellar, or proprioceptive dysfunction [5].

2.2 Parkinson bradykinesia symptom

Bradykinesia in Parkinson's disease means slowness of movement and is one of the cardinal manifestations of Parkinson's disease. Weakness, tremor and rigidity may contribute to but do not fully explain Bradykinesia [6]. Strictly speaking, Bradykinesia describes the slowness of a performed movement (e.g. in facial expression) or associated movement (e.g. arm swing during walking). It is mentioned that patients' problem in performing more than one task at the same time could result from lack of sufficient resources [6].

2.2.1 Parkinson bradykinesia detection

Human motion consists of motion patterns. For the Parkinson Bradykinesia detection, a human gait walking cycle is normally analyzed. The positions of a foot during a human gait cycle are interpreted in Fig. 2. Correspondent a human gait cycle can be divided to the major events Initial Contact (IC), Opposite Toe Off (OT), Heel Rise (HR), Opposite Initial Contact (OL), Toe Off (TO), Feet Adjacent (FA), Tibia Vertical (TV) and again Initial Contact (IC) [7].

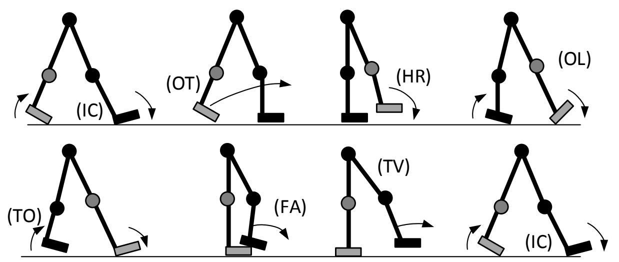

Fig. 2 Major events of the human gait [7]

Human gait can be analyzed using a proper signal diagram [8] as shown in Fig. 3. The letters A and G are the measured heel strike at the initial contact with the floor. At the heel strike the foot with the watch is slow down very fast, this equates a shock. A shock results comparatively high g values. With the assistance of the heel strike peak signal, the single motion cycles of the human gait can be split from the continuous measured acceleration signal. This makes an evaluation of change in motion for Parkinson Bradykinesia possible. The letter B is some oscillation after the heel strike, the letter C is the baseline during standing phase (OT and HR black foot Fig. 2), D and E is acceleration during foot movement (OL to TV black foot Fig. 2). For a basic diagnosis on Parkinson Bradykinesia, the single gait cycles are detected, counted and the time per gait cycle is calculated for evaluation of the slow motion.

In the broader sense the change of acceleration duration and acceleration maximum with the single gait phases A to E can be monitored for Parkinson diagnosis. For this the yet included gravity shall be subtracted.

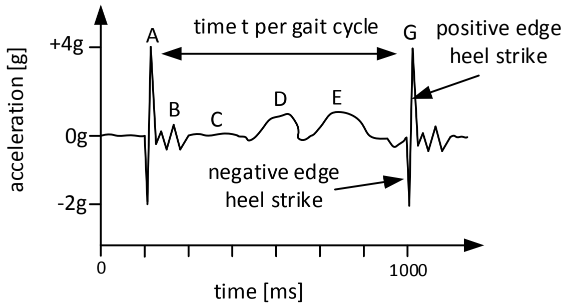

Fig. 3 Vertikal acceleration calcaneus one gait cycle [8]

2.2.2 Diagnosis of the Parkinson Bradykinesia disease with the Lindop assessment scale

For diagnosis on the Bradykinesa, a rating scale gives the opportunity to evaluate, document, monitor and compare the disease's degree of progression in a standardized way. There are multiple rating scales for diagnosis on the market like the UPDRS (Unified Parkinson Disease Scale), the Modified Hoehn and Yahr Scale, the Schwab and England Activity of Daily Living Scale [9] or the Lindop Parkinson's Assessment Scale (LPAS) [10]. The LPAS is a "validated, physiotherapy-specific, objective measure of functional mobility. Physiotherapists can use the scale as a base-line measurement and also at intervals to determine whether problems have developed. The scale can indicate where intervention should be targeted. It can also be used in the reassessment for determining the effectiveness of both physiotherapy intervention and changes in medication" [10]. The assessment of a patient with the Lindop is estimated with 15 minutes. During the assessment six tasks on gait mobility and 4 tasks for on the bed mobility are examined. The gait mobility tasks are, sit to stand, timed unsupported stand, 180° turn to right, 180° turn to left, walking through doorway. The bed mobility tasks are sit to lie, turn to left on bed, turn to right on bed and lie to sit on bed as shown in Table 1.

2.3 Parkinson tremor symptom

The definition of a tremor is a "rhythmic oscillation of at least one functional body region" [11]. The appearance of a Tremor at a human being can have various medical causations. A drug-induce is one, traumatic incidents like accidents or fear are possible. Therefore there are many ways of classifying the different kinds of Tremors. The Movement Disorder Society differs amongst others the Resting Tremor, the Postural Tremor, the Kinetic Tremor, and the Intention Tremor [11]. The Parkinson Tremor is classified as a static or rest tremor. "Resting Tremor occur in body part that is not voluntary activated and is completely supported against gravity. The amplitude of tremor must increase during mental and sometimes motor activation. The tremor amplitude must diminish or disappear during the onset of voluntary activation. The tremor can reoccur after a certain time period [11]. At the Parkinson Disease the dopamine producing neurons die, which leads to various health threats, beneath the Parkinson Tremor.

Table 1 Gait mobility check, part of the Lindop Parkinson's Assessment Scale first four tasks [10]

Task	Achieved Result	Points
Sit to stand	Unaided with ease	3
	Unaided with effort	2
	Help of one	1
	Help	0
Timed unsupported stand	60+ sec	3
	49-59 sec	2
	30-44 sec	1
	0-29 sec	0
Timed up & go	10-20 sec	3
	21-35 sec	2
	36-60 sec	1
	60+ sec	0
180 turn to right	4-6 steps	3
	7-8 steps	2
	9-10 steps	1
	11+ steps	0

2.3.1 Diagnosis of the Parkinson tremor disease by frequency

The Parkinson Tremor shaking has typically ON and OFF phases. The shaking frequency is commonly diagnosed from 0 to 4 Hz with low, from 4 to 7 Hz with medium, and more than 7 Hz with high [11].

2.3.2 Parkinson tremor detection

A Parkinson Tremor shaking is basically a forward and backward movement. The forward and backward motion generates acceleration peaks on the line chart. If you count the number of peaks per second, you got the current shaking frequency [12] as shown in Fig. 4.

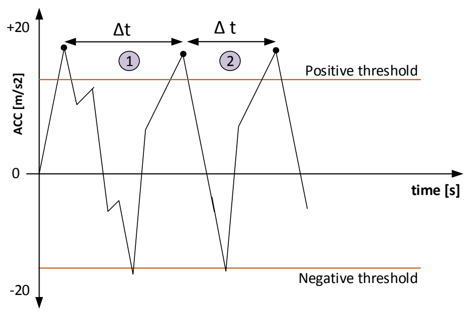

Fig. 4 Frequency counting with peak counting [12]

3. System design and implementation

3.1 Overview of the proposed system

The system consists of the following components: wireless acceleration sensor watch eZ430-Chronos, the USB Access Point, a proprietary personal computer with Microsoft Windows 7 and the designed Parkinson diagnosis software as shown in Fig. 5.

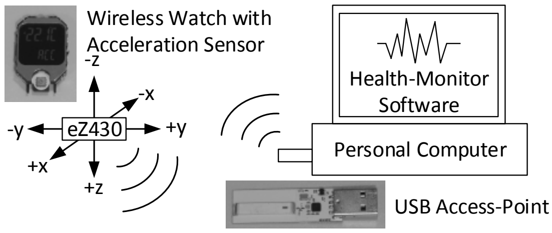

Fig. 5 Overview of the system components

3.2 Data capturing device

The used eZ430-Chronos watch has the following main components as shown in Fig. 6. A three axis accelerometer type Bosch Sensortec BMA250, a pressure sensor type Bosch Sensortec BMP085, a 96-segment LCD display with backlight, a Buzzer and five pushbuttons to operate. The processor of the watch is a CC430F6137 Texas Instruments 16-Bit RISC processor, operating with up to 20 MHz [13]. The CC430F6137 processor has an integrated proprietary sub 1 GHz radio system for wireless transmitting data. The processor can achieve a very low power consume in active, standby and off mode, which saves the power of the watch's button cell. A compact USB Access Point is also provided. Its circuit board contains a second 16-Bit RISC processor with an integrated Full-Speed USB Interface and an external radio chip.

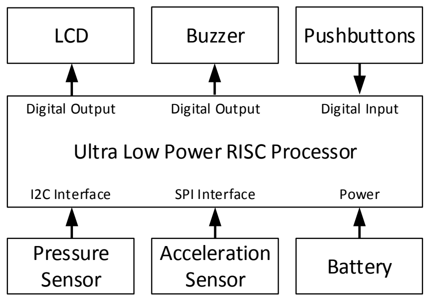

Fig. 6 Block schematic eZ430-Chronos Watch

3.3 Data transmission

The radio core of the watch is Texas Instruments CC1101. It is specially designed for battery driven, low power radio below 1GHz. The watch is available with the frequency bandwidth 433MHz, 868MHz and 915MHz. The 868MHz bandwidth is used. The symbol data rate of the CC1101 radio core is up to 600KBps and a maximum transmit power of +12dBm ~ 16mW [14]. The chip has implemented mechanisms for detecting busy radio channels and uses frequency hopping mechanism for guarantying an effective data transmission. The transmitted packet diagram allows the build-up of peer-to-peer and star networks. The data connection modes asynchronous and synchronous are available [14]. With the radio core CC1101 the communication protocol Texas Instruments SimpliciTI is used [15]. The SimpliciTI protocol is proper for low power RF networks. The required Flash-ROM size is with approximately 8Kbytes compact, also the required RAM size is small with 1 Kbyte RAM. The Programming Interface of the protocol is basic. On the aspect of saving battery cell power, it is potential to transmit the user data fast and then descend the transmitter.

3.4 Capacitive acceleration sensor

The watch's acceleration sensor is a Bosch Sensortec BMA250. It is a 3 axial, low-g acceleration sensor for consumer market applications. The sensor consists of a sensing part with three independent senor axis x, y, z and a programmable logic part for the processing of the measured acceleration. The chip can be programmed with the acceleration ranges ±2g, ±4g, ±6g, ±8g, ±16g. The acceleration data is digital delivered by Serial Peripheral Interface (SPI) or Inter-Integrated Circuit (I2C) to the microprocessor [16]. To determine whether the Parkinson Tremor with its minimal accelerating vibration can be detected by the device, the acceleration measurement process of the sensing part is investigated. The acceleration sensing component is a micro machined semiconductor product, which works with the differential capacitive sensing mechanism. A differential capacitive sensor is similar to a moving plate capacitor, except there is an additional fixed electrode as shown in Fig. 7 [17]. This cancels out temperature effects and is less noisy in comparison with other semiconductor design methods. The sensing device can be sampled with a sampling rate up to 2 kHz, with an adjusted acceleration range of ±2g at a device resolution of 3.91mg ~ 0.04m/s². This is proper for an experimental detecting of Parkinson Tremor shaking with the consumer product. However each acceleration sample requires energy of the battery cell, therefore an energy efficient sampling of the acceleration sensor for days of work is suggested. The watch measures with its three axes also the earth gravity. The vertical z-axis measures in upright position 1g = $9.81 m/s^2$. Depending on the tilt to the vertical gravity line, all three axes can contain parts of gravity in their measurement. This error in acceleration measurement can be compensated by software algorithm or hardware in combination with an additional angle measuring three-axis gyroscope.

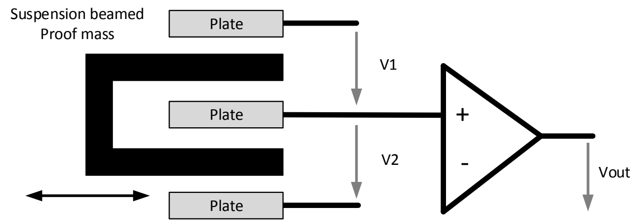

Fig. 7 Electric functional principle differential capacitive sensing mechanism

3.5. Software design

The software is graphical software specified for operating on home PCs as shown in Fig. 8. The Microsoft Windows 7 operation system is therefore selected. For graphical programming the Microsoft .NET Framework library Windows Presentation Foundation (WPF) is selected. The software stores each sample directly in a WPF Data Grid Table row. The acceleration data from the axis x, y, z is displayed in real-time with a line graph. With the line graph, the Microsoft research project D3 Dynamic Data Display is used. The developed statistical diagram for Parkinson Tremor Diagnosis also uses the Dynamic Data Display Project. The data capturing cycle is processed by a Windows Timer, which works in the milliseconds range. Additionally the software can store and load the captured data in XML files. It is also possible so send the captured health data by Email or export it by a comma separated values file (csv) to MATLAB.

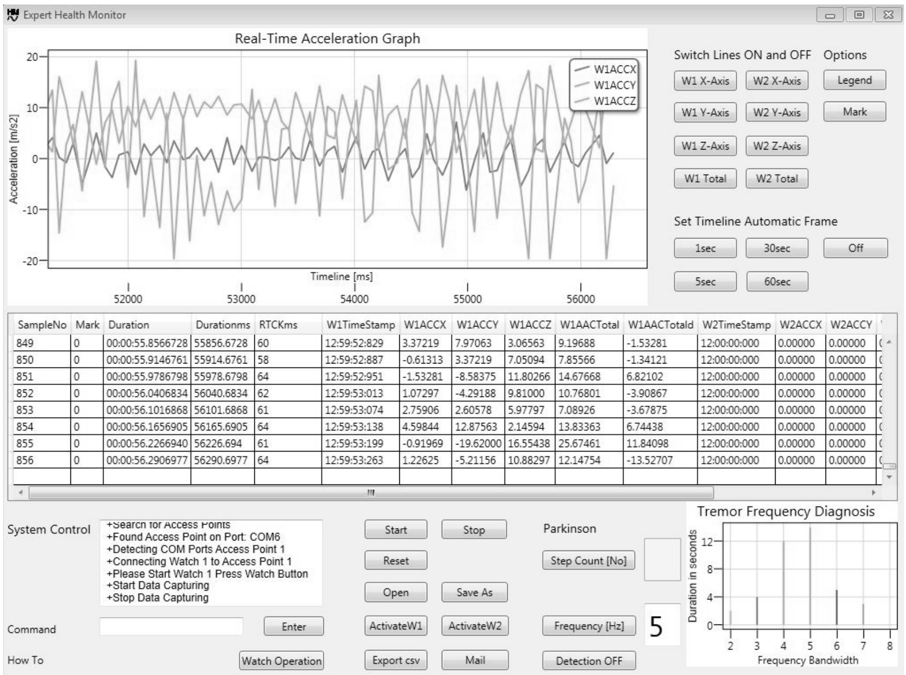

Fig. 8 Software GUI with Data Table, Real-Time Acceleration Graph and statistical Tremor Frequency Diagnosis

3.6 Design of the Parkinson bradykinesia detection

Human motion is a three dimensional motion measured by the three sensor-axis of the acceleration sensor. Especially at the Parkinson disease, motion on axis can be detected, which due not occur at a healthy person. The Bradykinesia detection state machine detects the single gaits cycles of the human gait, counts them and calculates the time duration per gait cycle as shown in Fig. 9. For this, the watch is mounted at the lower leg. The state machine human gait cycle detection, detects each step by the heel strike's first negative edge by a trigger level and the second following larger positive edge also by a trigger level. For testing the state-machine, the Lindop 180° turn right exercise is performed.

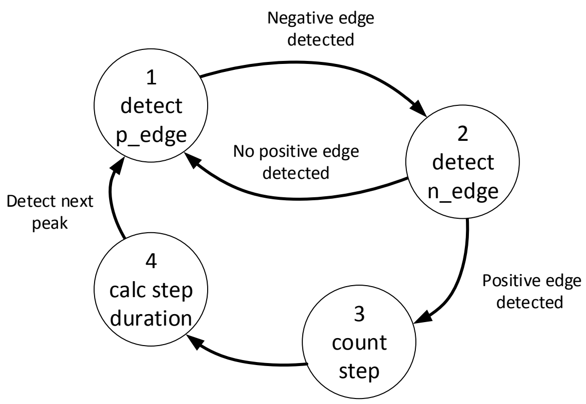

Fig. 9 State machine human gait cycle detection for Parkinson Bradykinesia

3.7 Design of the Parkinson tremor detection

The watch has adjusted a low acceleration sampling rate of approximately 15Hz, which saves power. The sampling rate is due to the Nyquist-Shannon sampling theorem twice as much the targeted bandwidth of 8Hz. The state machine detects and counts the positive signal peaks per second as shown in Fig. 10 and 11. At level one a positive signal edge larger than $0.3 m/s^2$ must be detected to get to level two, at level two and three a total negative signal edge value of -2 m/s^2 must be detected for a valid peak count.

For visualization of Parkinson Tremor shaking detection, the different shaking frequency with their duration are displayed in a diagram using Microsoft D3 Dynamic Data Display's dynamic bar chart as shown in Fig. 12 where the detected frequency one to eight Hz is visualized.

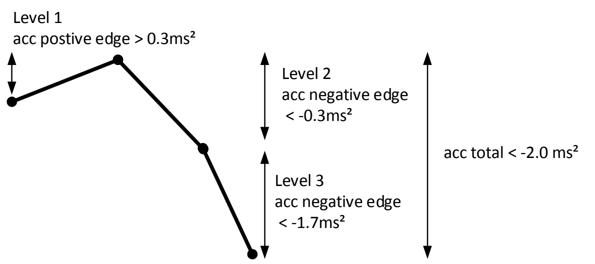

Fig. 10 Peak detection with signal edge

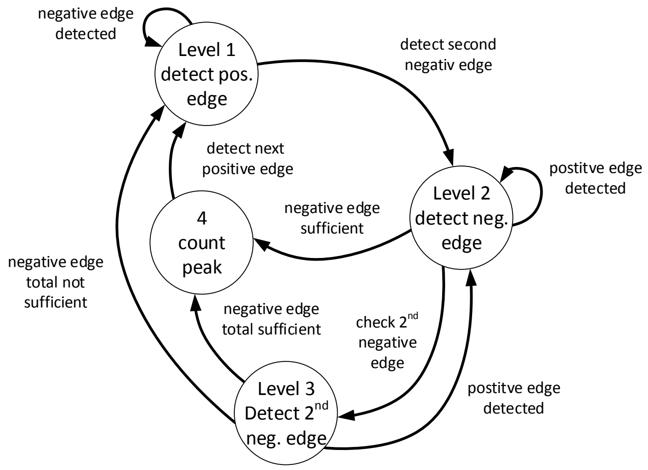

Fig. 11 State machine tremor frequency detection

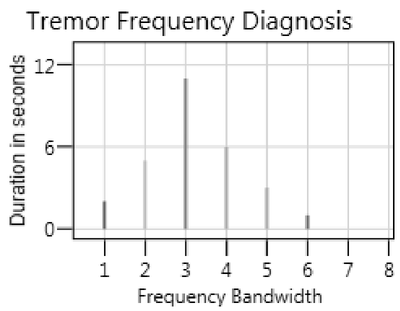

Fig. 12 Parkinson Tremor Diagnosis with dynamic bar chart

4. Experimental evaluation

4.1 Parkinson bradykinesia measurements

To test the designed measurement principle, an experiment with two subjects is carried out. The first subject, a 67 years old man has a movement disability due to a cerebral apoplexy (Fig. 13). The second subject, a 64 year old woman is healthy. Both perform the Lindop 180° turn task several times, while the watch is mounted on the lower leg. For result, the disabled first subject needs by trend three steps for the 180° turn, while the healthy subject needed two steps. The Health Monitor calculates during the Lindop 180° turn exercise, besides the total number of steps, also the length of time for each step. With it the slowness of movement per step can be monitored (Fig. 14). The realization of the test makes aware, that the heel strike can be damped due to a wood floor and thick socks. Also motor disabled people have slower motion than a healthy one. The trigger levels for counting the steps must therefore be yet manually adapted to the person and the test environment. The testing results, that motion cycles of the human gait can be detected and evaluated automatic.

4.2 Parkinson tremor frequency measurement

For testing the frequency detection state machine, the watch is mounted on the arm. In practice a Parkinson shaking signals can be distributed at once over all three axes and additionally be admixed with parts of gravity. For testing the detection state machine the shaking signal is detecting acceleration on one horizontal axis. The Health-Monitor real-time line graph is set to a timeframe of one second. With it, all amplitude per second can be visualized in real-time. The wireless watch samples with its standard firmware at an energy saving sampling rate of 15 Hz. The automatic frequency detection is tested manually by visual comparison of the line graph and the computer's calculated frequency display from 1 to 8 Hz. For result, the automatic frequency detection works well.

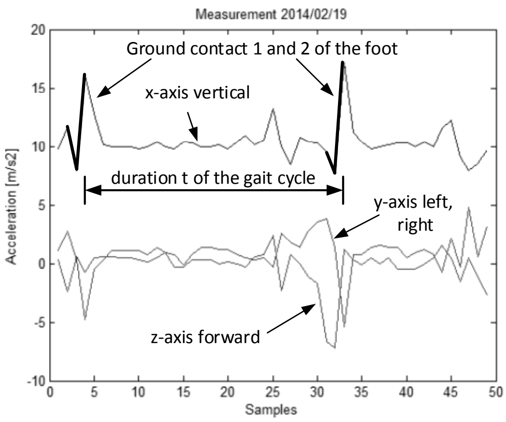

Fig. 13 Test person performing the 180° turn task of the Lindop Test

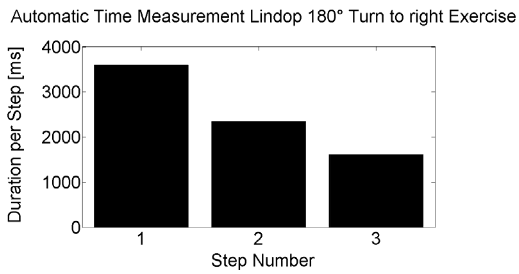

Fig. 14 Automatic time measurement of steps during the Lindop Exercise

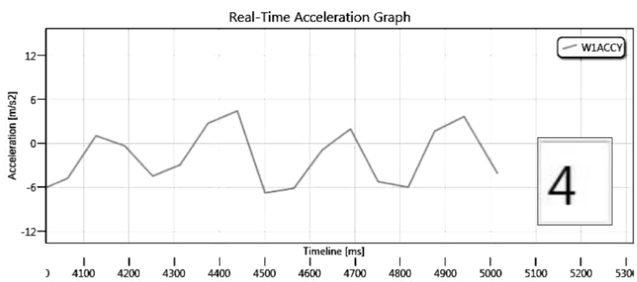

Fig. 15 Automatic frequency detection at 4 Hz

4.3 Testing the data processing of a hand move

For evaluating the real-time capabilities of the capturing, the Health-Monitor stores timestamps with its data table. With it, the duration between two samples can be determined. For testing the data capturing a simple move on the horizontal axis is performed with a revolution of about 130 samples. The average time per sample is determined at 68 ms, the minimum time per sample is at 56 ms and the maximum time per sample is at 132 ms of the developed application. Therefore a constant sampling rate is targeted.

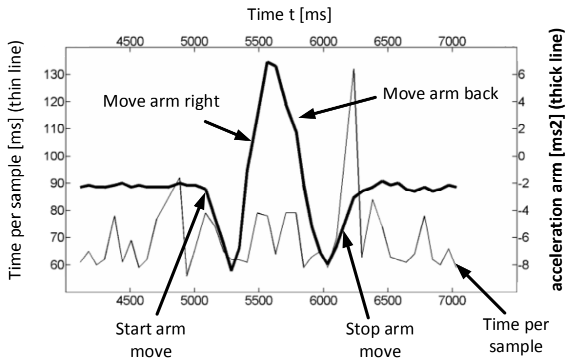

Fig. 16 Data processing of a horizontal hand move

5. Conclusion

In this paper, a smart tool for the Diagnosis of Parkinsonian Syndromes in real-time was designed and developed using Texas Instruments eZ430-Chronos wireless watches. The Parkinson Bradykinesia is detected based on the cycle of a human gait. The Parkinson Tremor shaking is detected and differed by frequency 0 to 8 Hz. A change of frequency and duration is diagnosed in real-time with a developed statistical diagnosis chart. The watch acceleration sensor detection method can improve the medication of the medicated Parkinson Disease patients and specially reduces the number of the yet undiagnosed cases. Due to its low-cost and easy-use property, the whole system can be used in small clinics as well as home environment.

ACKNOWLEDGEMENT

The authors thank Derby Hospitals NHS Foundation Trust for the LPAS form used in this paper.

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