Neurological Diseases Differentiation Analysis using Inertial Measurement Units

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Abstract — **Human gait is cyclic process, which is affected by various neurological disorders like Parkinson's disease (PD) or multiple sclerosis (MS). Instrumented gait analysis facilitate monitoring and diagnosing motor deficiencies; it may serve as a tool for clinicians evaluating the patients. This study aims at finding biomechanical parameters that allow separating pathological gaits via application of inertial sensors to capture the gait. The experiment involved 33 subjects divided in three groups PD, MS and healthy controls (CO). The analysis showed the statistically significant difference between stride time of the right leg in MS and CO groups, left stride time between PD and CO, stance time difference between PD and CO group, right and left leg. Hip flexion and extensions amplitudes difference was between CO and PD group, left hip flexion and extension.**

Keywords—IMU; Gait analysis; Lower limb; pathological gait

I. INTRODUCTION

Human gait is a cyclic movement of lower limbs, which requires coordination of a neuro-muscular system consisting of muscles, bones and joints. Gait analysis is widely used in various fields, ranging from robotic to applications in clinical practice [1].

Instrumented gait analysis is performed using multi-camera optical 3D motion capture system, force plate [2], electromyography. However, such systems are large, expensive and require special accommodations. The alternative is inertial measurement units, which are relatively inexpensive, small size, do not require special facilities and are easily attached to the subject's body.

The analysis of gait can identify certain phases of gait; kinematic and kinetic gait parameters characterize the human gait and allow evaluating activity of the skeletal muscle [3]. Inertial sensors can be used at home and follow the human daily activities.

Many scientists use only gyroscope data from inertial sensor for measuring angular velocity of body segment [4]. During walking one can assume that lower limb is moving in sagittal plane, so it is sufficient to use uniaxial sensor to record the procession. Gait cycle is defined as the time interval between initial contacts of one foot to the other foot contact [5].

Gait phase identification can be used in various applications, such as gait assessment after rehabilitation [6]; classification of daily activities [7]; separation between normal and pathological gait [8]. The gait cycle peaks (characteristic point) is the heel strike, toe off and mid – swing form angular velocity [9]. In order to detect positive and negative peaks various algorithms are developed, but there is an alternative to using MATLAB function to find these peaks [10].

The purpose of this work is by using an inertial measurement unit to analyze the human lower limb movement and compare subjects with pathological and normal gait. The study analyzes movement in sagittal plane of two joints of lower limb via application of angular velocity signal from gyroscope to detect characteristic points of gait signal and analyze knee angular velocity and hip joint flexion and extension angles.

II. MATERIAL AND METHOD

A. Inertial measurement unit

The study used six unit, nine degrees of freedom inertial measurement sensors. Each IMU has a tri – axial accelerometer (freescale MMA7361, accelerometer limit ±1,5 g), gyroscope (InvenSense 500 MEMs Gyro, angular velocity limit ± 500 °/s, sensibility 2 mV/°/s) and magnetometer (Honeywell HMC5843, input field boundaries =/-0,7 – 4,5 Ga). Data from the sensors to the PC transmitted using IEE 802.15.2 standard low – intensity radio waves (Shimmer Research SR7 (CC2420). Inertial sensor size 53 x 32 x 12 mm, weight ~ 30 g, powered with 450-mAh battery. The data from the sensors were received via a Bluetooth wireless connection at a sampling frequency of 51.2 Hz and stored on the computer.

Research was carried out on volunteers who were divided into three groups – 11 control (CO) subjects, 11 Parkinsonian (PD) subjects and 11 multiple sclerosis (MS) subjects. None of the participants had any other injuries or disease affecting movement or coordination other than PD

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or MS and all provided informed consent prior to participating in the study. Subjects' data is presented in Table 1. Measurements were performed in cooperation with Vilnius University Hospital, Department of Neurology.

Sensors were attached on each subjects' right and left thigh, shank and foot using elastic straps.

Fig. 1. Position of the inertial measurement units on a subject lower limb.

B. Filtering

Before further processing, the raw gyroscope signal was low pass filtered using fifth order Butterworth filter (order 5, F_{cutoff} = 5 Hz). In order to reduce the integration drift, partially due to a continuous component, we performed also a high pass Butterworth filtering (order 1, F $_{cutoff}$=0.5 Hz).

TABLE I. DEMOGRAPHIC AND CLINICAL CHARACTERISTICS OF SUBJECTS

Group	*n*	*Age (mean ± SD)*	*UPDRS score (mean ± SD)*	*EDSS score (mean ± SD)*
PD	11	57.90 ± 9.27	45.63 ± 21.24	—
MS	11	35.55 ± 11.91	—	3,59 ± 1,81
CO	11	29,45 ± 4,25	—	—

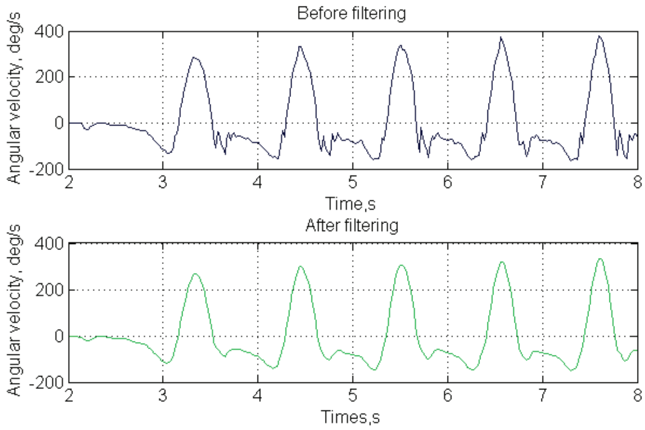

Fig. 2. Angular velocity of the hip before and after filtering.

C. Metrics and Statistical Analysis

The following metrics for the analyses were selected: right, left leg stride, swing and stance time's, right, left hip joint flexion, extension angles (see Fig.3).

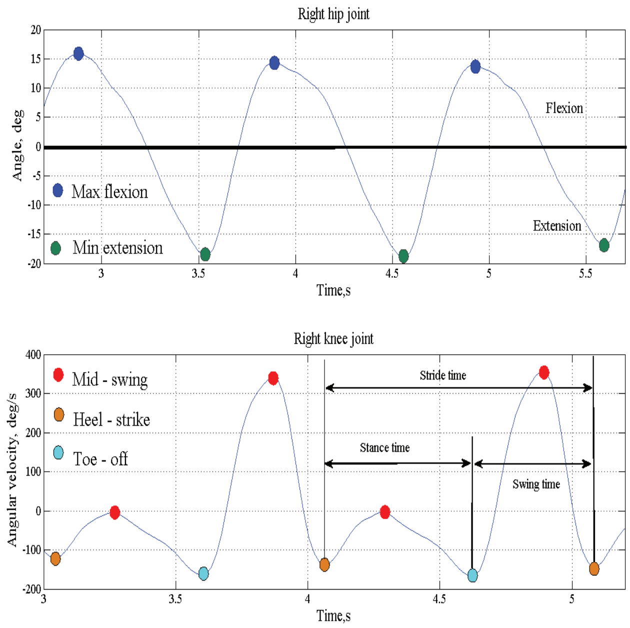

Fig. 3. Top figure shows right hip joint flexion and extension angles, bottom figure is showing knee joint angular velocity and basic points of gait phase.

The hip joint angle calculated using following equation:

$$\theta_{hip} = \int \omega_{hip}(t)\, dt. \quad (1)$$

Calculation of stride, swing and stance time was performed using following equations:

$$t_{\text{stride}} = t_{hs,i} - t_{hs,i+1}, \quad (2)$$

$$t_{\text{stance}} = t_{to} - t_{hs,i+1}, \tag{3}$$

$$t_{\text{swing}} = t_{hs} - t_{to}, \tag{4}$$

where $t_{hs,i}$ is the time of a heel strike and $t_{hs,i+1}$ is the time of successive heel strike, t_{to} is the toe off time.

MATLAB software was used to process measurement data and calculation of abovementioned metrics. Statistical analysis of the metrics was performed using IBM's SPSS v22 software. A one – way ANOVA with a significance level of $\alpha = 0.05$ was used to test the null hypothesis that the mean of calculated are the same between the PD, MS and CO groups.

III. Results

Total 10 parameters were calculated. The results are presented in Table 2 (bold and underline value have statistical significant).

TABLE II. CALCULATED PARAMETERS

Parameters	Group	Mean	SD
Right leg stride time, (s)	PD	**<u>1.1395</u>**	**<u>0.1122</u>**
	MS	**<u>1.0413</u>**	**<u>0.0817</u>**
	CO	**<u>1.0055</u>**	**<u>0.0735</u>**
Left leg stride time, (s)	PD	**<u>1.1523</u>**	**<u>0.1110</u>**
	MS	1.0596	0.0749
	CO	**<u>0.9915</u>**	**<u>0.1000</u>**
Right leg stance time, (s)	PD	**<u>0.5663</u>**	**<u>0.0572</u>**
	MS	0.5146	0.0395
	CO	**<u>0.5120</u>**	**<u>0.0498</u>**
Left hip joint flexion angle, (°)	PD	**<u>30.6110</u>**	**<u>5.5122</u>**
	MS	31.1249	3.0168
	CO	**<u>35.6998</u>**	**<u>3.7530</u>**
Left hip joint extension angle, (°)	PD	**<u>30.9402</u>**	**<u>5.3526</u>**
	MS	32.8224	4.2432
	CO	**<u>36.3950</u>**	**<u>3.5257</u>**

Statistically significant difference was found between the right leg stride time, between PD, MS and CO groups ($F = 6.44$, $p = 0.0047$), left leg stride time was difference between PD and CO ($F = 7.69$, $p = 0.002$). Stance time right leg difference between PD and CO group ($F = 4.23$, $p = 0.0242$), left leg – between PD and CO ($F = 6.9$, $p = 0.0034$).

Calculation of hip flexion and extension amplitudes, significant difference was detected between left hip extension ($F = 3.4$, $p = 0.0465$) and left hip flexion – between PD and CO ($F = 4.62$, $p = 0.0178$).

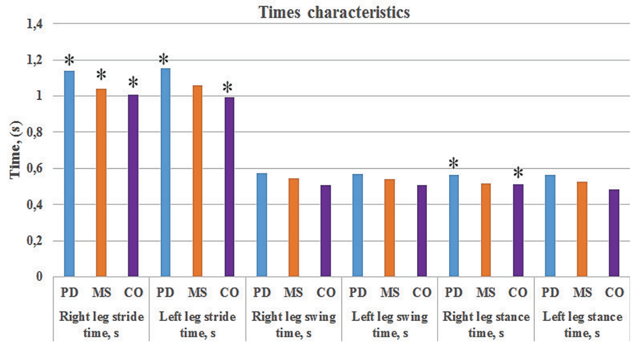

Fig. 4. Gait time characteristic between PD, MS and CO groups (*statistically significant differences between groups).

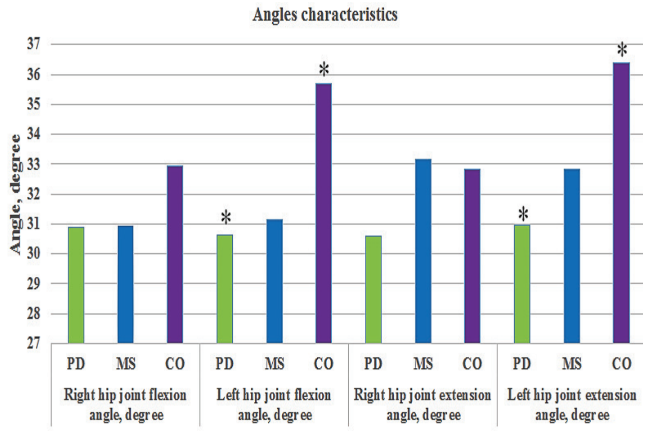

Fig. 5. Joint angles between PD, MS and CO groups (*statistically significant difference between groups).

IV. Conclusions

Inertial sensors has significant prospects compared with other movement recording system. An experimental study showed that neurological disease potentially could be separated using the IMU. The analysis of spatial and temporal gait parameters can be found in the specific parameter that describe the neurological disease. Statistical significant differences were found:

1. Right leg stride time between PD, MS and CO groups (PD: mean ± SD = 1.1395 ± 0.1122; MS: mean ± SD = 1.0413 ± 0.0817; CO: mean ± SD: 1.0055 ± 0.0735).
2. Between PD and CO groups: left leg stride time (PD: mean ± SD = 1.1523 ± 0.1110; CO: mean ± SD = 0.9915 ± 0.100); right leg stance time (PD: mean ± SD = 0.5663 ± 0.0572; CO: mean ± SD: 0.5120 ± 0.0498); left hip joint flexion angle (PD: mean ± SD = 30.6111 ± 5.5122; CO: mean ± SD = 35.6998 ± 3.7530); left hip joint extension angle (PD: mean ± SD = 30.9402 ± 5.3526; CO: mean ± SD = 36.3950 ± 3.5257).

V. Future Work

Search for sensitive biomechanical parameters that allow separating subjects' groups based on data classification algorithms is one of the task of future research, which could result in improvement of diagnostics accuracy or facilitate neurological disease progression monitoring and help medical doctor evaluate them quantitatively.

References

[1] Greene BR, Foran TG, McGrath D, Doheny EP, Burns A, Caulfield B. A comparison of algorithms for body-worn sensor-based spatiotemporal gait parameters to the GAITRite electronic walkway. J Appl Biomech. 2012 Jul;28(3):349-55. Epub 2011 Nov 14.

[2] Lee SW, Mase K, Kogure K. Detection of spatio-temporal gait parameters by using wearable motion sensors. Conf Proc IEEE Eng Med Biol Soc. 2005;7:6836-9.

[3] Weijun T, Tao L, Rencheng Z, Hutian FGait Analysis Using Wearable Sensors. Sensors (Basel). 2012; 12(2): 2255–2283.

[4] Tong K, Granat MH. A practical gait analysis system using gyroscopes. Med Eng Phys. 1999 Mar;21(2):87-94.

[5] Taborri J, Palermo E, Rossi S, Cappa P. Gait Partitioning Methods: A Systematic Review. Sensors (Basel). 2016 Jan 6;16(1).

[6] Fraccaro, P., Coyle, L., Doyle, J. & O'Sullivan, D. Real-world Gyroscope-based Gait Event Detection and Gait Feature Extraction. Paper presented at the Proceedings of eTELEMED, The Sixth International Conference on eHealth, Telemedicine, and Social Medicine, 24-03-2014 - 27-03-2014

[7] Yundong X, Zhan Z, Zhen F·Fangmin S, Zhihong X, Lidong D, Shaohua W. Gait Cycle Recognition based on Wireless Inertial Sensor Network. IERI Procedia Volume 4, 2013, Pages 44-52

[8] Abaid N, Cappa P, Palermo E, Petrarca M, Porfiri M. Gait detection in children with and without hemiplegia using single-axis wearable gyroscopes. PLoS One. 2013 Sep 4;8(9).

[9] D McGrath, BR Greene, KJ O'Donovan, B Caulfield. Gyroscope-based assessment of temporal gait parameters during treadmill walking and running. Sports Engineering 15 (4), 207-213

[10] Casamassima F, Ferrari A, Milosevic B, Ginis P, Farella E, Rocchi L A wearable system for gait training in subjects with Parkinson's disease. Sensors (Basel). 2014 Mar 28;14(4):6229-46.