Quantitative Deviation of Spatial Parameters of Gait in Parkinson's Disease

Adharaa Neelim Dewanjee[1], Quazi Delwar Hossain[2], and Anik Muhury[3]

[1]Department of Electrical and Electronic Engineering, Chittagong University of Engineering and Technology, Chittagong -4349, Bangladesh

[3]Department of Electrical and Electronic Engineering, Bangladesh University of Engineering and Technology, Dhaka -1205, Bangladesh

Emails: [1]adharaa.neelim.dewanjee@gmail.com [2]qdhossain@yahoo.com [3]anik.eee.buet@gmail.com

***Abstract*—Parkinson's disease is a neurological disease which prevails in a patient for the long term. Losing control over the gait cycle is a common phenomenon which leads to a deviation in the gait cycle of the patient. The variation of the gait cycle can be explained in two approaches: temporal variation and spatial variation. In this paper, an analysis which exclusively focuses on the spatial variation is done to determine the gait cycle deviation of Parkinson patients from a healthy person. This work analyzes the step lengths and stride lengths of the patients without the help of any external influence and compares the results against the healthy subjects. From the study, it ends up clear that on account of a Parkinson disease, step lengths, and stride lengths both are shorter than healthy individuals and a quantitative connection between these parameters are determined here.**

***Index Terms*—Parkinson's Disease, Gait Analysis, Stride Length, Step Length, Median Filter.**

I. Introduction

Parkinson's disease is a long-term neurological disorder which was first described by Dr. James Parkinson [1]. According to the Parkinson's foundation, about 10 million people around the globe are affected by this disease. And the number of male Parkinson's patients is 1.5 times higher than the number of female Parkinson's patients [2]. Parkinson's disease affects the neurons of an area of the brain called the Substantia Nigra. The neurons found in that particular area of the brain create dopamine which helps human to control the movement of different limbs. As Parkinson's disease affects the neurons which control dopamine, the patients lose proper control of movement due to the decrease in the creation of dopamine [3].

As Parkinson's patients' loss control over movement, they seem to develop symptoms such as- tremors, bradykinesia, the stiffness of limbs and postural instability [3], [4]. Loss of control over the gait cycle is one of the common symptoms of Parkinson's patients. Gait cycle is usually termed as the walking cycle.

Gait cycle consists of two phases – the stance phase (weight bearing phase) and the swing phase (non-weight bearing phase). Stance face begins when the heel strikes (HS) and the phase is completed when the toe is off (TO) the ground. After the completion of the stance phase, the swing phase starts. The fundamentals of the gait cycle are being depicted in Fig. 1.

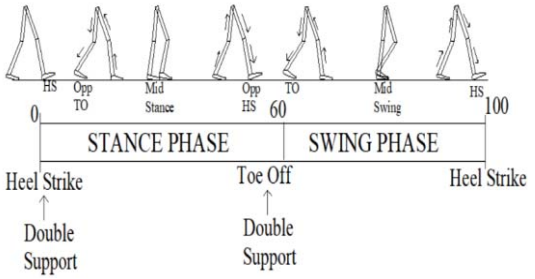

Fig. 1. Gait Cycle [HS = Heel Strike, TO = Toe Off, Opp = Opposite] [5].

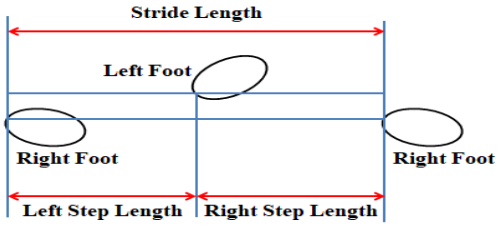

Fig. 2. Distance Variables of Gait Cycle [8].

Temporal variables and distance (spatial) variables are the two defining parameters of the gait cycle which depends on time and distance respectively. The distance variables consist of two parameters- the step length and the stride length. Step length is the distance between the contact points of the heel of the two feet and stride length is the span between the contacts of the heel of the same foot [7]. Distance variables are shown in Fig. 2.

As the gradual loss of dopamine-producing cells occurs, the gait disorder becomes prominent among the Parkinson's patients. The patients usually carry the symptoms of slowness, akinesia, or freezing of gait [6]–[7], [9]. With the increasing duration of the disease, the gait disorder becomes more acute and it starts to hinder the lifestyle of parkinsonians [10]. A few notable features of the Parkinson's patients are the reduction of the stride length, the reduced walking speed and the elongated double support phase [7], [11]. In some studies, it became evident that if influences like cues are used, the gait disorder of Parkinson's patients can be improved [12]–[15].

Most of the studies on Parkinson's gait analysis focused on the spatiotemporal changes of gait at baseline rather than

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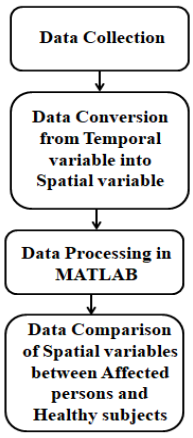

Fig. 3. Overview of proposed work.

focusing on the kinetic parameters. However, two studies have been conducted on the kinetic features of the Parkinson's patients gaits. One of these tested the gait of one Parkinson's patient by introducing an external cue. With the cue, it was possible to correct the spatiotemporal and the kinematic parameter but anomaly in the kinetics was still present [14]. In the second study, Lewis observed largely variable patterns in the kinetics and the kinematics [15]. Some researchers used EMG patterns of the leg muscles of Parkinsonians in their studies. They analyzed the Gastrocnemius Medialis (GM) and the Tibialis Anterior (TA) activity. These studies showed overactive TA and reduced GM activity at lower speeds compared with controls [16], [17]. Another work performed a quantitative analysis of gait and their target was to discriminate between Dopa-sensitive and dopa-resistant kinematic gait parameters. It showed that the parameters related to the kinematic were Dopa-sensitive whereas, the temporal parameters were dopa-resistant [18]. But, specific variation in the gait cycle parameter of patients was not introduced clearly.

In this paper, a technique is proposed to determine the gait cycle variations of Parkinson's patients with respect to the distance or spatial variables such as- the stride length and the step length. The proposed technique compares the spatial data of patients against the spatial data of healthy subjects to have a clear picture of gait analysis of patients.

II. Methodology

The proposed technique can be categorized into four parts: data collection, data conversion from temporal variables into spatial variables, data processing and the comparison of distance variables data against the standard values. Fig. 3 shows the overview of proposed work.

In the data acquisition part, data were amassed from Physionet's database of gait in Parkinson's disease [19]. This study acquires data only for male patients and healthy subjects. In total, data for 13 healthy subjects and 12 patients of different ages were collected. The aim is to develop a comparative study between distance variables of gait in Parkinson's patients and healthy subjects. The speed of the gait cycle of patients without any external influence was considered in this study.

As the proposed work intends to present the comparison in spatial context, temporal data are converted into the spatial form using the speed data with the help of MATLAB tools. The step lengths and stride lengths of the gait in Parkinson's disease are then calculated. After calculating the step lengths and stride lengths, they are compared against the data of the healthy subjects. The comparison indicates the deviation in distance variables of the gait cycle in case of Parkinson's patients.

III. Result and Analysis

A. Data Analysis

In this study, at first, the vertical ground reaction force signal for both left and right foot are collected from Physionet's website. After that, left and right foot signals are analyzed separately to calculate the stride lengths. On the other hand, to find out the step lengths both foot signals are used. In both cases, the signals are normalized and further processed by using difference equation. And then the unwanted data are nullified for the ease of further processing. After the completion of the processing, the indexes of consecutive steps of the same foot are calculated and then the difference between the indexes of consecutive steps is calculated to obtain stride time for a certain foot. For the smoothing and better result, the median filter is used. As the sampling rate of the data is 100 Hz, the processed data is converted into the time domain by using this sampling rate. In this way, we get stride time for a particular foot. To obtain stride length, the speed of the particular person is multiplied by the stride time. For calculating the step length, the same procedure is followed except that here the difference of the indexes of the different foot is used.

Table I and Table II analyze the spatial parameters of healthy subjects and Parkinson's patients respectively along with physical information like heights, weights, and ages.

B. Comparative Analysis

After the acquisition of data and converting temporal variables into spatial variables, the spatial parameters: step lengths and stride lengths, are compared between healthy subjects and Parkinson's patients. Fig. 4 shows the gait analysis data of the healthy subject 11. The gait analysis is conducted using MATLAB tools.

Fig. 4 consists of spatial variables. The spatial parameters: step length and stride length of the healthy subject are found to be in the range of 0.5 m–0.9 m with mean value 0.6051 m and 1.1 m–1.6 m with mean value 1.2064 m. In Fig. 5, the step lengths and the stride lengths of another healthy subject (No. 5) are provided which shows the step length range to be between 0.25 m and 0.8 m with mean value 0.6479 m and stride length range to be between 1.2 m and 1.4 m with mean value 1.2951 m.

In Fig. 6 and Fig. 7, gait analysis of two patients is presented. In Fig. 6, gait analysis of patient-06 is presented which shows that the step lengths and stride lengths are around 0.42 m to 0.58 m with mean value 0.4996 m and 0.96 m to 1.10 m with mean value 0.9993 m, respectively. The gait analysis of patient-08 is elucidated in Fig. 8, which shows that the

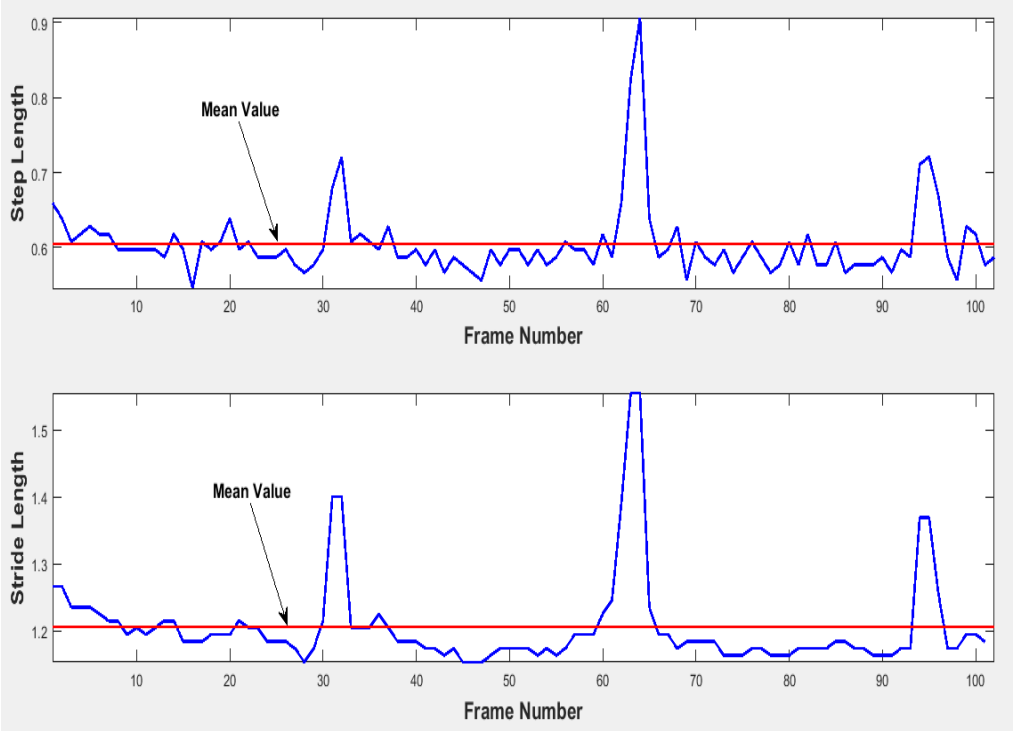

Fig. 4. Stride length and Step length of Healthy Subject 11.

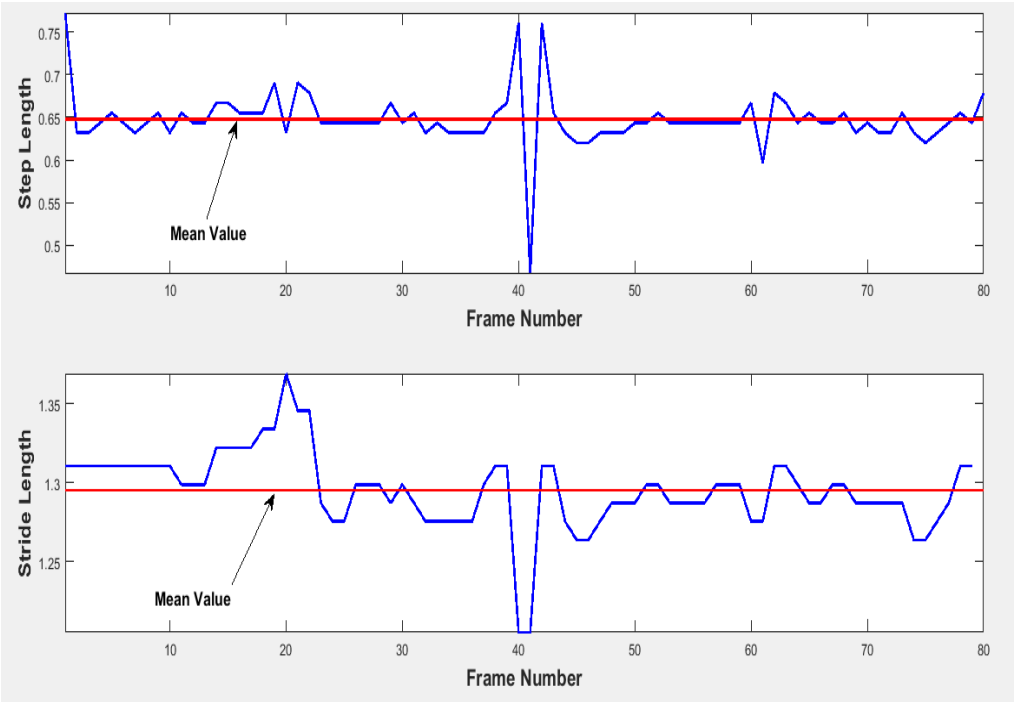

Fig. 5. Stride length and Step length of Healthy Subject 5.

step lengths for patient-08 is approximately between 0.4 m and 0.6 m with mean value 0.4401 m and the stride lengths are between 0.82 m and 0.94 m with mean value 0.8618 m.

From Fig. 4–Fig. 7, mean value of the step and the stride lengths are shown and it is noticeable that for the healthy subjects (Fig. 4 and Fig. 5) the step length and stride length signals vary closer to their mean. On the other hand, for the Parkinson's patients (Fig. 6 and Fig. 7), step length and stride length vary a lot from their mean.

From the aforementioned analysis, it can be concluded that there is enough evidence of deviation from the standard value in terms of spatial variable parameters of the gait cycle, in

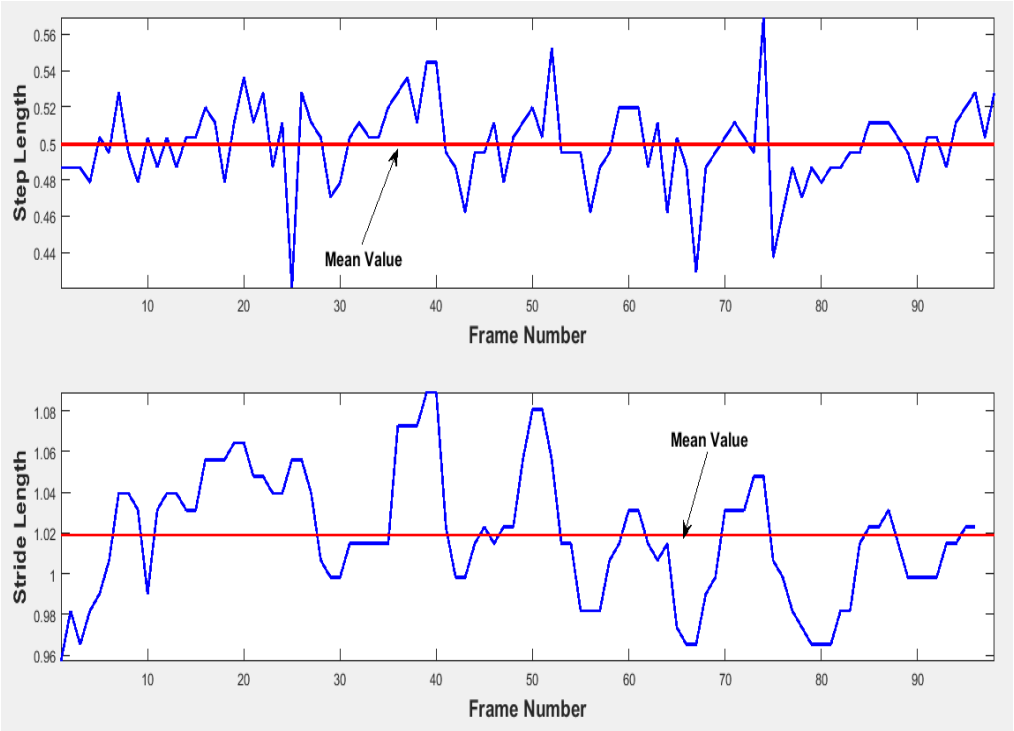

Fig. 6. Stride length and a Step length of Parkinson's Patient 6.

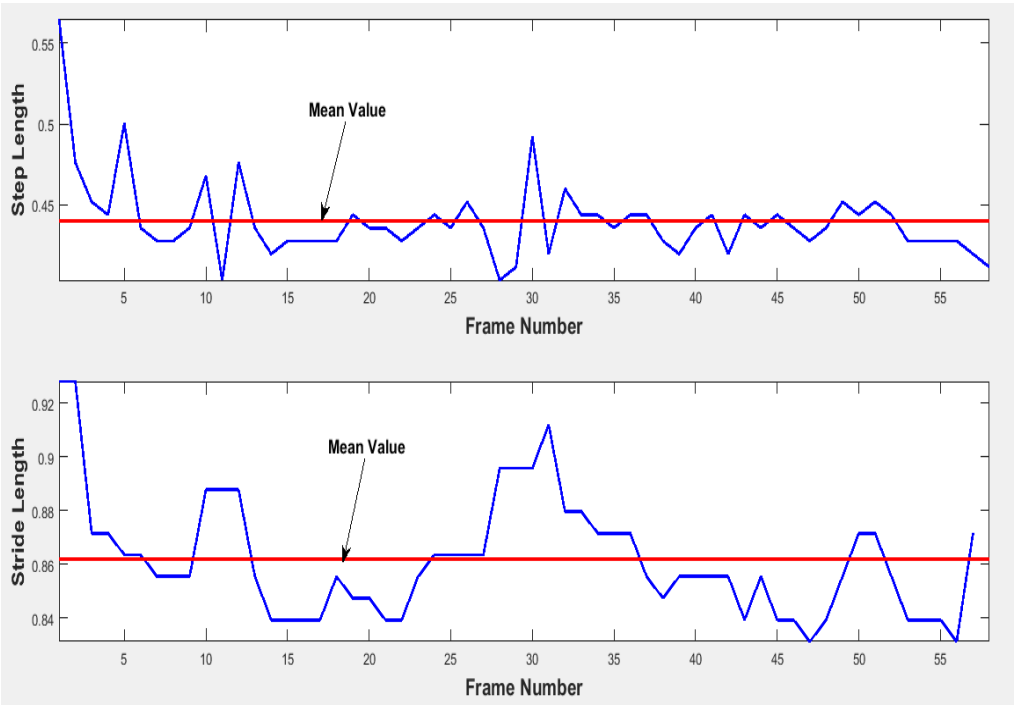

Fig. 7. Stride length and a Step length of Parkinson's Patient 8.

the case of patients suffering from Parkinson's disease. The step lengths of normal person is in the range of 24 inches to 27 inches and stride lengths of normal person are almost in the range of 47.5 inches to 53.5 inches whereas the step lengths of Parkinson's patients are in between 13 inches and 21 inches and stride lengths of Parkinson's patients are in between 25 inches and 45 inches, which are always lower than healthy subjects. It is found that the step lengths and the stride lengths of the patients are less than a healthy subject, and in both cases, the stride lengths of patients are almost double of step lengths. The step lengths of Parkinson's patients deviate from the controlled subject in the range between 6 inches to 11 inches and stride lengths deviate in between 8.5 inches to 22.5 inches. These results reveal that Parkinson's patients

TABLE I
GAIT ANALYSIS DATA OF HEALTHY MALE SUBJECTS

Healthy Subject SL. No.	Speed (m/s)	Height (m)	Age (yrs)	Weight (kg)	Mean (Step length) (m) ± Variance	Mean (Stride length) (m) ± Variance
1	1.051	1.8	69	101	0.6653 ± 0.0037	1.3113 ± 0.0043
2	1.121	1.68	82	82	0.6496 ± 0.0012	1.3161 ± 0.0016
3	1.164	1.72	69	70	0.6204 ± 0.0015	1.2442 ± 0.0026
4	1.089	1.67	78	75	0.6591 ± 0.0017	1.2902 ± 0.0013
5	1.17	1.77	61	72	0.6479 ± 0.0012	1.2951 ± 6.0145e-04
6	1.13	1.85	60	88	0.6648 ± 6.8897e-04	1.3431 ± 4.6276e-04
7	1.151	1.64	52	64	0.6725 ± 0.0013	1.3090 ± 0.0010
8	1.073	1.85	60	88	0.6563 ± 7.1618e-04	1.3248 ± 7.1492e-04
9	1.086	1.67	51	80	0.6396 ± 0.0014	1.2732 ± 7.6987e-04
10	1.16	1.7	53	76	0.6498 ± 1.9798e-04	1.3068 ± 2.5641e-04
11	1.03	1.7	54	73	0.6051 ± 0.0024	1.2064 ± 0.0049
12	1.13	1.76	57	80	0.6351 ± 8.2382e-04	1.2723 ± 0.0019
13	1.29	1.7	53	87	0.6894 ± 5.3910e-04	1.3580 ± 0.0014

TABLE II
GAIT ANALYSIS DATA OF MALE PATIENTS AFFECTED BY PARKINSON'S DISEASE

Parkinson's Patient's SL. No.	Speed (m/s)	Height (m)	Age (yrs)	Weight (kg)	Mean (Step length) (m) ± Variance	Mean (Stride length) (m) ± Variance
1	0.642	1.71	68	NaN	0.3992 ± 0.0044	0.7922± 0.0018
2	0.848	1.7	72	82	0.3216 ± 8.5159e-04	0.6697 ± 0.0012
3	0.802	1.78	78	65	0.5054 ± 6.2963e-04	1.0057 ± 6.5333e-04
4	0.987	1.79	61	101	0.5390 ± 0.0011	1.1001 ± 6.7760e-04
5	1.092	1.63	68	80	0.5439 ± 0.0018	1.0960± 0.0011
6	0.825	1.86	63	80	0.4996 ± 5.4600e-04	0.9993 ± 9.6720e-04
7	1.013	1.83	77	85	0.5346 ± 9.3431e-04	1.1194 ± 0.0013
8	0.807	1.73	70	80	0.4401 ± 6.1518e-04	0.8618 ± 4.9713e-04
9	0.832	1.75	78	82	0.4056 ± 0.0011	0.8659 ± 7.8668e-04
10	0.785	1.75	74	80	0.3777 ± 0.0062	0.7594 ± 0.0027
11	1.112	1.78	64	75	0.5287 ± 0.0095	1.1408 ± 0.0044
12	0.413	1.60	82	65	0.4764 ± 0.0850	0.6280 ± 0.0012

suffer from low stride and step lengths than the healthy subject and at the same time they showed high variability in stride and step lengths.

In this study, fluctuations in the gait cycle from the standard gait cycle in terms of spatial variables for Parkinson's affected patients have been successfully portrayed. In the future, the analysis can be further developed by employing temporal variables along with the spatial variables to obtain a clearer picture of the overall gait analysis of Parkinsonians. A mathematical model can also be developed from these variables to assess the problem more accurately. All these modifications might provide the requisite tools to establish a predictive model in future to predict and fight against the Parkinson's disease from the earliest stage.

IV. CONCLUSION

In this paper, a technique to determine the deviations in gait parameters from the standard value in case of Parkinson's patients have been represented in terms of spatial variables of the gait cycle. A substantial amount of digression in spatial parameters from the standard for affected patients is found in this study. The stride length is found to be double of step length in case of every patient. The findings from this study have the potential to be used for further analysis to assess the situation of Parkinson's affected patients.

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REFERENCES

[1] G. DeMaagd and A. Philip, "Parkinson's disease and its management: Part 1: Disease entity, risk factors, Pathophysiology, clinical presentation, and diagnosis," *P T*, vol. 40, no. 8, pp. 504–532, 2015.
[2] Parkinson's Foundation Statistics. [Online]. Available: http://parkinson.org/Understanding-Parkinsons/Causes-and-Statistics/Statistics, 2018.
[3] Parkinson's disease Foundation. [Online]. Available: http://www.pdf.org/about_pd, 2018.
[4] National Institute of Neurological Disorders and Stroke website. [Online]. Available: www.ninds.nih.gov/Disorders/All-Disorders/Parkinsons-Disease Information- Page, 2018.
[5] Definition and Description of gait cycle. [Online]. Available: http://www.gla.ac.uk/ibls/US/fab/tutorial/anatomy/hfgait.html, 2018.
[6] M. E. Morris, R. Iansek, T. A. Matyas, and J. J. Summers, "The pathogenesis of gait hypokinesia in Parkinson's disease," *Brain*, vol. 117, no. 5, pp. 1169–1181, 1994.
[7] S. Fahn, "The freezing phenomenon in Parkinsonism," *Adv Neurol.*, vol. 67, pp. 53–63, 1995.

[8] Different types of distance variables in Gait Cycle. [Online]. Available: https://www.utdallas.edu/atec/midori/Handouts/walkingGraphs.htm, 2018.

[9] A. Nieuwboer, W. De Weerdt, R. Dom, and E. Lesaffre, "A frequency and correlation analysis of motor deficits in Parkinson patients," *Disabil. Rehabil.*, vol. 20, no. 4, pp. 142–150, 1998.

[10] M. E. Morris, "Movement Disorders in People With Parkinson Disease: A Model for Physical Therapy," *Phys. Ther.*, vol. 80, no. 6, pp. 578–597, 2000.

[11] O. Blin, A. M. Ferrandez, J. Pailhous, and G. Serratrice, "Dopa-sensitive and dopa-resistant gait parameters in Parkinson's disease," *J Neurol. Sci*., vol. 103, pp. 1–54, 1991.

[12] M. H. Thaut, et al., "Rhythmic auditory stimulation in gait training for Parkinson's disease patients," *Mov. Disord.*, vol. 11, no. 2, pp. 193–200, 1996.

[13] M. E. Morris, J. McGinley, F. Huxham, J. Collier, and R. Iansek, "Constraints on the kinetic, kinematic and spatiotemporal parameters of gait in Parkinson's disease," *Hum. Mov. Sci.*, vol. 18, no. 2–3, pp. 461–483, 1999.

[14] G. C. Mcintosh, S. H. Brown, R. R. Rice, and M. H. Thaut, "Rhythmic auditory-motor facilitation of gait patterns in patients with Parkinson ' s disease," *J. Neurol. Neurosurg. Psychiatry*, pp. 22–26, 1997.

[15] G. N. Lewis, "Stride length regulation in Parkinson's disease: the use of extrinsic, visual cues," *Brain*, vol. 123, no. 10, pp. 2077–2090, 2000.

[16] V. Dietz, W. Zijlstra, T. Prokop, and W. Berger, "Leg muscle activation during gait in Parkinson's disease: adaptation and interlimb coordination," *Electroencephalogr. Clin. Neurophysiol. Electromyogr.*, vol. 97, no. 6, pp. 408–415, 1995.

[17] N. Giladi, R. Kao, and S. Fahn, "Freezing phenomenon in patients with parkinsonian syndromes," *Mov. Disord.*, vol. 12, no. 3, pp. 302–305, 1997.

[18] O. Blin, A. M. Ferrandez, J. Pailhous, and G. Serratrice, "Dopasensitive and Dopa-resistant gait parameters in Parkinson's disease," *J. Neurol. Sci.*, vol. 103, pp. 51–54, 1991.

[19] Physionet Database of Gait in Parkinson's Disease. [Online]. Available: https://physionet.org/pn3/gaitpdb/, 2018.