Temporal Variables Disorder of The Gait Cycle in Parkinson's Disease

Adharaa Neelim Dewanjee[1], Quazi Delwar Hossain[2], Mohammed Shahriar Arefin[3]
Department of Electrical and Electronic Engineering
Chittagong University of Engineering and Technology, Chittagong -4349, Bangladesh
Email: [1]adharaa.neelim.dewanjee@gmail.com, [2]qdhossain@yahoo.com, [3]shahriar.cuet2013@gmail.com

***Abstract*— The biometric method which is involved with defining pattern of movement of human limbs is called Gait. Though gait has a fixed rhythmic pattern, in case of people who are affected with neurological disease such as- Parkinson's disease (PD) the gait pattern gets distorted from normal gait pattern. In this paper, temporal variables of gait cycles are analyzed to determine the deficit in the gait cycle in PD patients. Gait cycle of 10 PD patients and 10 Controlled subjects are examined in this paper. A comparative analysis was done in respect of temporal variables such as- Single Limb Support Time and Double Limb Support Time. From the examination and investigation, it is apparent that the temporal factors of the gait cycle of PD patients are sufficiently changed in regard to the controlled subjects, all the more explicitly PD patients invest more energy in the two limbs than a single limb of a gait cycle which is absolutely in switch of the controlled subject.**

Keywords*— *Parkinson's Disease, Gait Analysis, Temporal Variables, Signal Processing, Limb Support Time

I. INTRODUCTION

Parkinson's disease which was first discovered by Dr. Parkinson is a chronic neurological disorder which predominately occurs in elderly people and associated with different neurological difficulties [1], [2]. From an in-depth survey, Parkinson's foundation stated that about 10 million people are affected by Parkinson's disease around the globe [3].

Neurons found in Substantia Nigra, a region in the brain gets infected as a result of Parkinson's. These neurons are responsible for creating dopamine which in turn controls limb movement of a human. As dopamine secretion gets distorted due to damaged neurons, the people affected by Parkinson's lose control over their movement [3]. A person affected with Parkinson's may suffer from different difficulties such as- Tremors, Muscle rigidity etc. [4]. A common phenomenon occurs among Parkinsonians is the loss of control over the gait cycle.

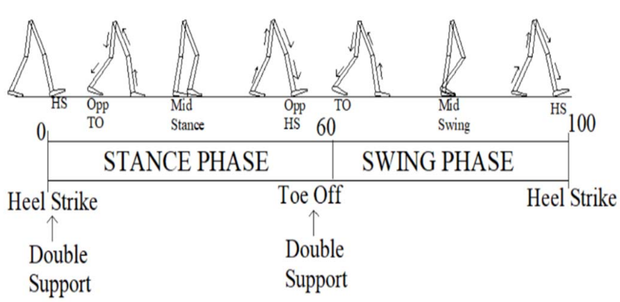

Fig 01- Illustration of Gati Cycle [HS=Heel Strike, TO=Toe Off, Opp=Opposite] [5]

Gait cycle is commonly defined as the walking cycle. In Fig. 01 a typical gait cycle is being portrayed, where stance phase (60% of gait cycle) of gait cycle is started when heel strikes and ends up when the toe is off to the ground and then swing phase (40% of gait cycle) starts [5]. Gait cycle is an important parameter to study human movement especially in the case of Parkinson's affected person. The extent of distortion can be determined by analysis of gait cycle.

The Gait Cycle can be described through two parameters: Spatial Variables and Temporal Variables. Spatial variable defines the gait cycle in terms of step length and stride length. Whereas, the temporal variable consists of several parameters: Single Limb Support Time, Double Limb Support Time and Speed. Single limb support time is defined as the time in which only one foot acts as body support. On the other hand, when body mass is carried by both feet the situation is considered as double limb support. The time spent in this posture is considered as double limb support time. In Fig. 02, temporal variables of gait cycle have been depicted.

Parkinson's disease is associated with different movement deficiencies. As Parkinson's is a chronic and long term disease, along with the time the disease gets more prominent and thus affects Parkinsonians lifestyle [7]. The Parkison's disease is responsible for truncated stride length, low walking speed and buffed double support phase [8], [11]. The situation can be improved by employing external influences such as cues [9]-[11].

There have been quite a number of studies on Parkinson's gait analysis but few of those studies focused on kinetic parameters. In one of the studies based on kinetic features, the authors examined patients under influence of external cues to rectify the spatiotemporal and kinematic parameters [12].

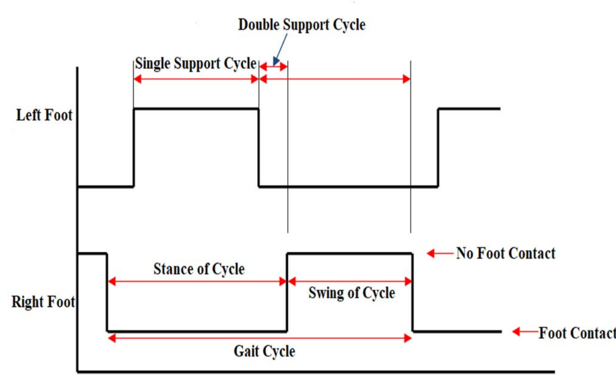

Fig. 02- Illustration of Limb Support Time [6]

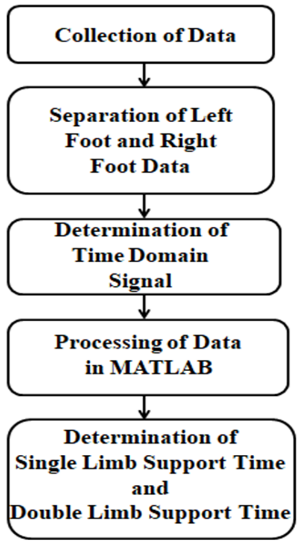

Fig. 03- Overview of Proposed Technique

Lewis showed that there is a large amount of variability present in kinematics and kinetics [13]. A quantitative analysis of gait was performed to show the difference between dopa-sensitive and dopa-resistance kinematic gait parameters. The result showed that the temporal variables are related to dopa-resistance [7]. The study lacked clarification in case of specific gait cycle parameter.
Another researcher observed an altered gait pattern in Parkinsonians. They showed that there is asymmetric timing and increased variability in gait which can be regarded as principal evidence of motor programming deficit in gait due to Parkinson's [14]. After that, it was observed that the movement time of PD patients is greater than the controlled healthy subject. External cues can improve temporal variability in case of Parkinson's disease affected person but still, there was evidence of distortion from normal subject [15]. Another researcher Pasluosta proposed a time series approach to focus on the human gait characteristics that shows a few unnecessary occasions, which are basically gait signals with pseudo-tedious nature [16]. On the other hand, researcher Chen depicted different methods for recognizing critical gait occasions which are recurring [17]. Besides, Mirelman investigated a unique signal for identification of specific parts of body with gait stability and normality [18].

In this paper, a method is proposed to quantify the gait cycle fluctuations of Parkinsonians in terms of temporal variables like- single limb support time, double limb support time and speed. The analysis also consists of a comparative study of temporal variables between controlled subjects and Parkinsonians to portray the difference between healthy subject and parkinsonians.

II. Methodology

The proposed procedure can be separated into three sections: Data Collection, Analysis of Data and Comparative Study between Healthy Subjects and Parkinson influenced people. The overall components of this investigation are portrayed in Fig. 03.

The data acquisition part comprises the gathering of information from Physionet Database named Gait in Parkinson's disease [19]. The obtained signals are vertical ground reaction force signals. The signals are fetched from 16 sensors divided into two equal number portions placed beneath both the right and left foot. The acquired data are separated into left foot and right foot data. The information is investigated independently in MATLAB to decide Time Domain Signal. By analyzing the stance phase and swing phase, it is discovered that there are just two positions in a Gait cycle when a subject needs double limb support: Heel strike position and Pre-swing Position. In light of these perceptions, time for single limb support and double limb support are determined for concerned subjects. For double limb support time, the vertical ground reaction force of left foot and the vertical ground reaction force of right foot must be greater than zero because both feet must exert the force on the ground on this case. Utilizing this logic, a square wave is created which represents double limb support. Then, difference equation topology is applied to generate a spike which represents changes of square waves of two foot. Basically, for a gait cycle, four spikes are found because in one gait cycle there are two positions when a person is in double limb support and for one double limb support there are two spikes. By using this logic, the index of the spikes is found and then the index of the first spike is subtracted from the second spike and again the same procedure is followed for fourth spike and third spike. After that, both index differences are added. As the sampling rate (100Hz) is known beforehand from the data website, the index is divided with sampling frequency to get the double limb support time. Single limb support time for a gate cycle is the difference between the stride time of a foot and double limb support time. Stride time of a certain foot is calculated by using the difference between the indexes of consecutive steps.

III. Result and Discussion

A. Data Delineation

Total data of 20 subjects were taken from the database. Among 20 subjects, 10 of the subjects were affected by Parkinson’s and the rest 10 people were controlled subjects. The gender of considered subjects is male. The subjects were not under any external cues during the data acquisition phase. The age range of Parkinson’s disease affected subjects is between 55 years to 70 years, whereas, the controlled subjects age spans from 60 to 75 years.

Table I: Temporal Data of Controlled Subjects

Controlled Subject Number	Mean(Double Limb Support Time) (second)± Variance	Mean(Single Limb Support Time) (second) ± Variance	Speed (m/s)
Subject 1	0.2949±0.0152	0.9518±0.0081	1.051
Subject 2	0.2338±0.0038	0.9434±0.0015	1.121
Subject 3	0.2093±0.0011	0.8595±0.0011	1.164
Subject 4	0.3112±6.6859e-04	0.9232±5.0630e-04	1.073
Subject 5	0.2441±9.9912e-05	0.8825±2.0202e-04	1.16
Subject 6	0.2901±2.7856e-04	0.9299±5.0205e-04	1.00
Subject 7	0.3073±5.2308e-04	0.8776±9.4772e-04	0.99
Subject 8	0.2014±4.7058e-04	0.8512±5.0585e-04	1.29
Subject 9	0.1918±0.0022	0.8254±0.0013	1.515
Subject 10	0.1720±0.0053	0.9262±0.0046	1.415

Table II: Temporal Data of Parkinson's Patient

Parkinson's Patient's Number	Mean(Double Limb Support Time) (second)± Variance	Mean(Single Limb Support Time) (second)± Variance	Speed (m/s)
Patient 1	0.8388±0.0012	0.3177±0.0023	0.848
Patient 2	0.9830±0.0013	0.2705±9.7951e-04	0.802
Patient 3	0.8044±0.0042	0.3111± 0.0043	0.987
Patient 4	0.8690±0.0025	0.3667±0.0034	0.825
Patient 5	0.9113±5.8292e-04	0.1941±9.9563e-04	1.013
Patient 6	0.7786±0.0032	0.2657±0.0033	0.832
Patient 7	0.7179±0.0086	0.2500±0.0044	0.785
Patient 8	0.8202±0.0080	0.2047±0.0057	1.112
Patient 9	1.0127±0.0229	0.5070±0.0291	0.413
Patient 10	0.7657±0.0053	0.2186±0.0063	0.894

The collected data were then converted into temporal variables such as- Single limb support time, Double limb support time and Speed. The temporal data are presented in Table-I and Table-II. Table-I represents controlled subjects and Table-II narrates data of Parkinson's disease affected persons and Table-III demonstrates the comparative study of temporal data. The single limb support time and double limb support time data for all subjects are depicted in Fig. 04 and Fig. 05. Fig. 04 illustrates data of controlled subjects, whereas, Fig. 05 delineates data of Parkinson's affected patients.

B. Comparative Analysis

After calculating the temporal variable data, the time required for single limb support and double limb support were compared between healthy controlled subjects and disease affected subjects.

The limb support times of controlled subject 01 and 02 are elucidated in Fig. 06 and Fig. 07. It is visible that single limb support time is greater than double limb support time in case of the controlled subject which validates the observation where it was found that only two positions in a gait cycle are based on double limb support. In Fig. 06, it is observed that for controlled subject 01 single limb support time is in between 0.3s to 1.1s with mean value 0.9518s and double limb support time is in between 0.2s to 1.2s with mean value 0.2949s. Similarly, in Fig. 07 for controlled subject 02 single limb support time is in between 0.75s to 1.5s with mean value 0.9434s and double limb support time is in between 0.19s to 0.55s with mean value 0.2338s, whereas, the speed of controlled subject 01 is 1.051m/s and controlled subject 02 is 1.121m/s.

Fig. 08 illustrates the temporal variables for Patient-03 which shows that the double limb support time is higher than single limb support time. The mean values of times are 0.8044s and 0.3111s respectively for double limb and single limb. The average speed clocks at 0.987m/s which are evidently lower than controlled subjects.

Table III- Comparative Analysis of Temporal Data

Subject	The range of Double Limb Support Time (second)	Range of Single Limb Support Time (second)	The range of Speed (m/s)
Controlled Subjects	0.1720-0.3112	0.8254-0.9518	0.99-1.515
Patients	0.7179-1.0127	0.2047-0.3667	0.413-1.112

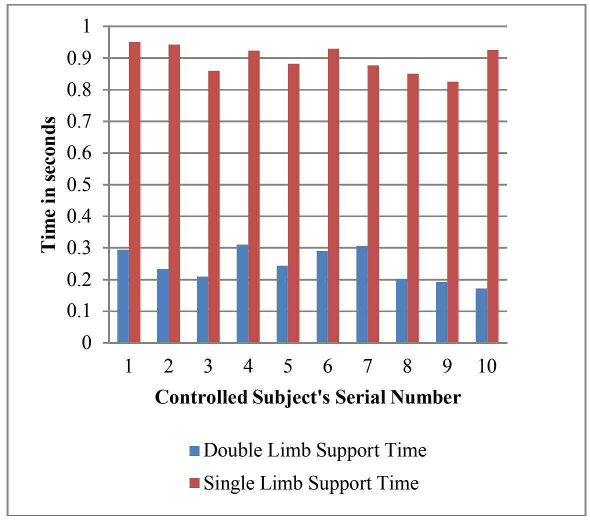

Fig. 04- Temporal Variable Data of Controlled Subjects

Fig. 09 renders the single limb support time and double limb support time for Patient 10. The figure shows that the mean value of time taken for single and double limb support is 0.2186s and 0.7657s respectively, whereas the calculated average speed is 0.894m/s.

From Fig. 6 – Fig. 9, mean value of the single limb support time and double limb support time are shown and it is noticeable that for the healthy subjects (Fig. 6 and Fig. 7) the single limb support time and double limb support time vary closer to their mean but in case of the Parkinson's patients (Fig. 8 and Fig. 9) they vary a lot from the mean.

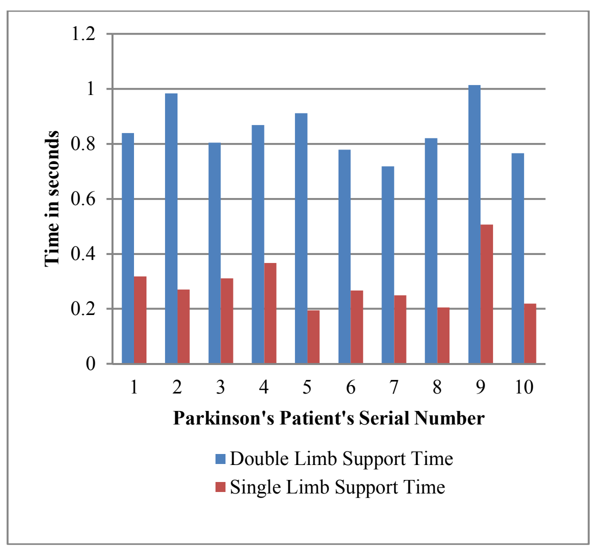

Fig. 5- Temporal Variable Data of Parkinson's Patients

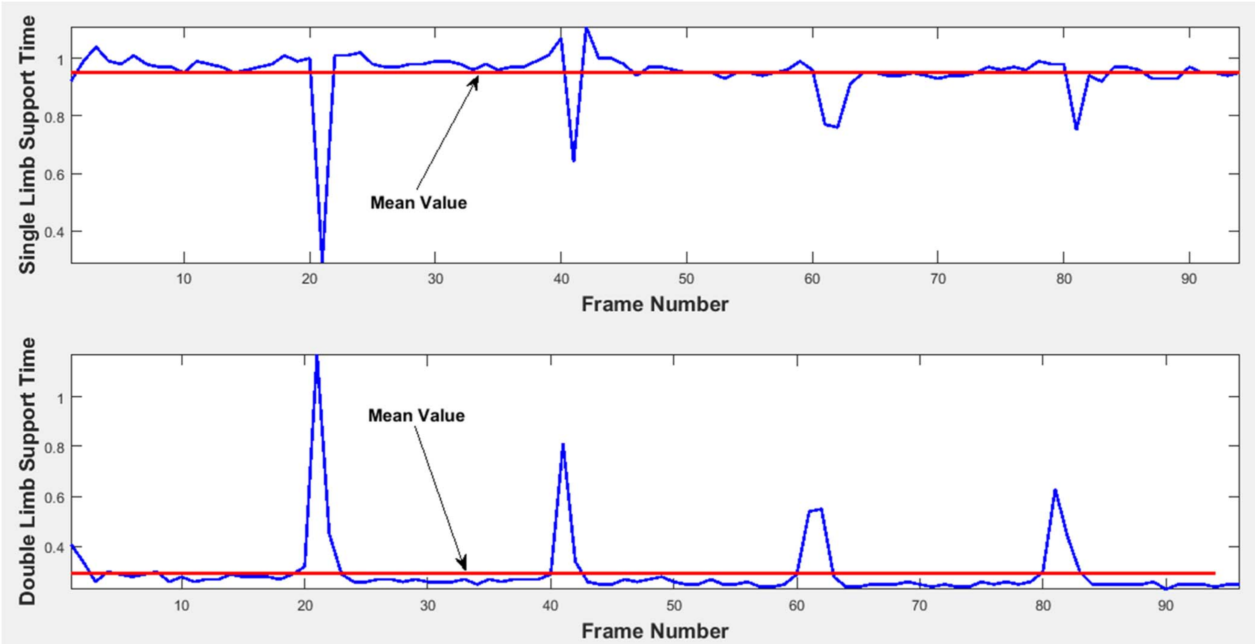

Fig. 06- Limb Support Time of Controlled Subject 01

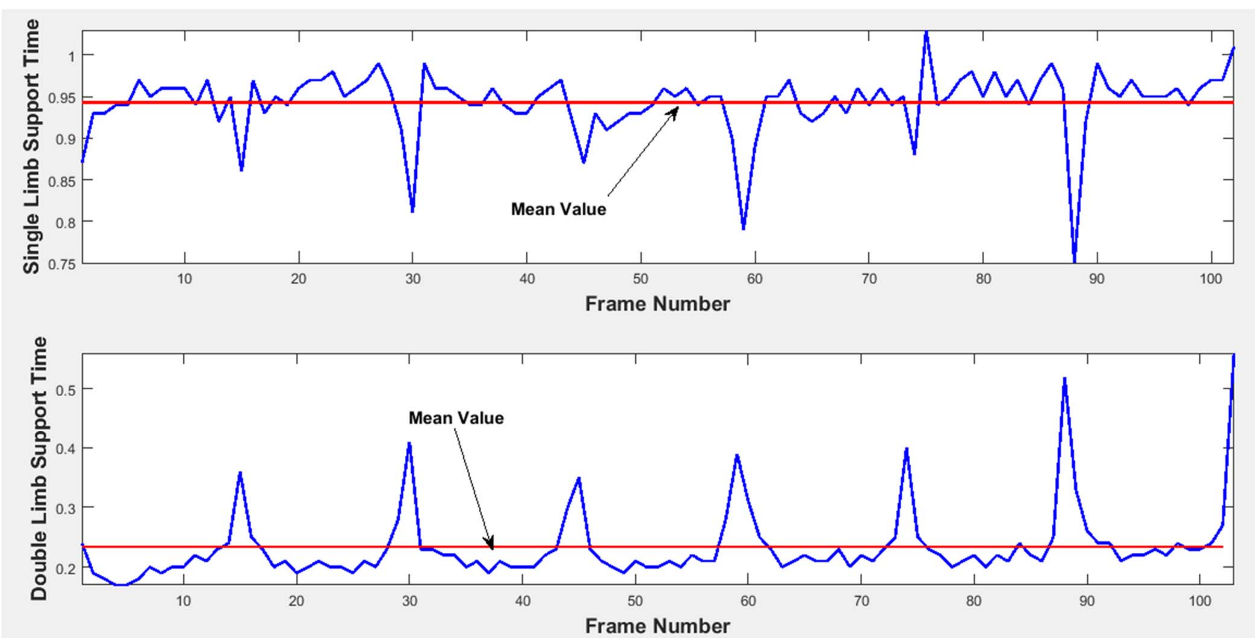

Fig. 07- Limb Support Time of Controlled Subject 02

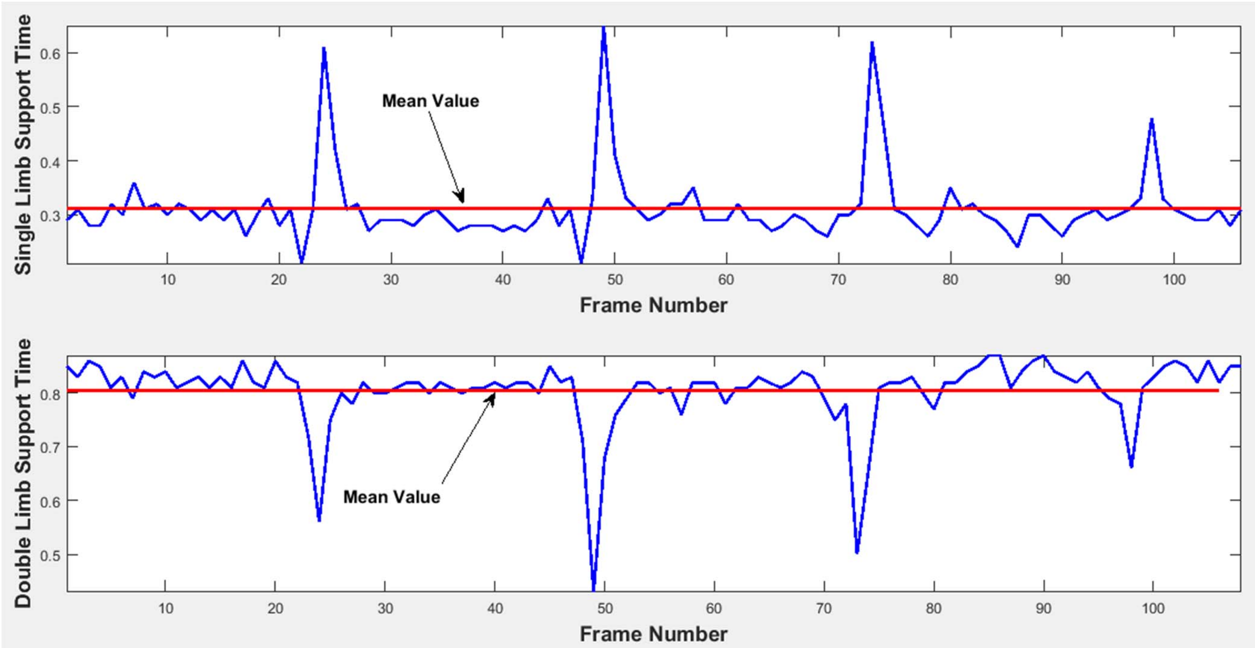

Fig. 08- Limb Support Time of Patient 03

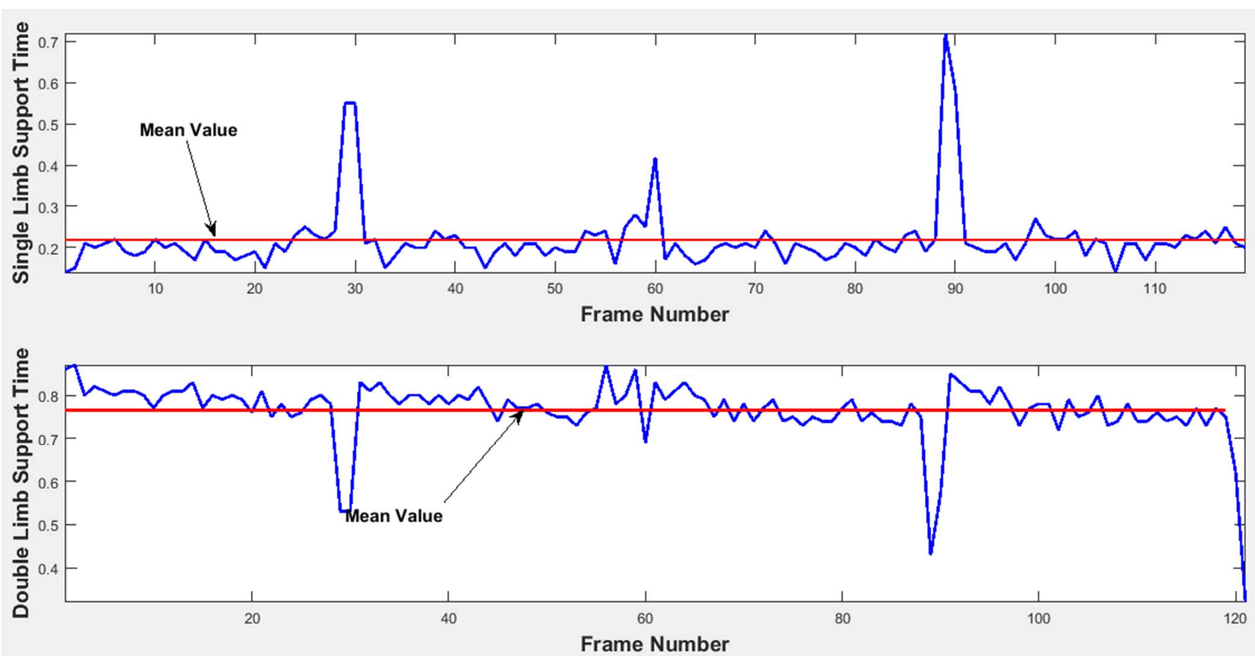

Fig. 09- Limb Support Time of Patient 10

From the precedential analysis, it is evident that double limb support time is higher than single limb support time in case of Parkinson's disease affected persons. The opposite is seen in the case of controlled subjects. The speed of Parkinson's affected subjects is lower than controlled subjects. Table-III shows discrimination among the range of temporal variables. All these data prove that the patients suffering from Parkinson's suffer greatly due to gait cycle distortion.

The results found in this comprehensive study based on temporal variable might be proved to be vital in case of assessment of gait cycle variation in Parkinsonians. In future, these data can be used with Machine Learning algorithms to predict the trend of a patient affected with Parkinson's and provide external cues according to the needs of the patient.

IV. Conclusion

In this study, a comparative analysis of temporal variable data of Parkinson's affected patients and controlled subjects are depicted. By juxtaposing all calculated data, it is discernible that the double limb support time in case of Parkinsonians is greater than controlled subjects. The reason behind this distortion is related to loss of control over the gait cycle in case of Parkinson's disease affected persons. The loss of walking speed is also visible for Parkinson's affected person. The results of this study can be used to develop assistive devices with feedback for Parkinsonians. Also, the result in conjecture with spatial variables could provide more accurate situation assessment for patients affected by Parkinson's.

Acknowledgments

The authors would like to express their gratitude to Department of Electrical and Electronic Engineering, Chittagong University of Engineering and Technology, Bangladesh for their continuous support and assistance throughout the completion of this study.

References

[1] DeMaagd G, Philip A., "Parkinson's Disease and Its Management: Part 1: Disease Entity, Risk Factors, Pathophysiology, Clinical Presentation, and Diagnosis.," *P T*. 2015; 40(8):504-32.

[2] Mei-Fen Hsieh, Zhao-Xiong Yan, "Symptoms and diagnosis of Parkinson's Disease", Family Medicine& Primary Medical Care, vol. 25, no.1, pp. 10 14, 2010. (DOI:10.6965/FMPMC.201001.0010)

[3] (2018) Parkinson's disease Foundation. [Online]. Available: http://www.pdf.org/about_pd.

[4] (2018) Parkinson's disease Information Page. [Online]. Available: www.ninds.nih.gov/Disorders/All-Disorders/Parkinsons-Disease Information- Page.

[5] (2018) Gait Cycle Visual Representation and Definition. [Online]. Available: https://fadavispt.mhmedical.com/Content.aspx?bookId=1862&sectionId=136086727.

[6] M. Kwon, Y. Kwon, Y. Park, and J. Kim, "Comparison of gait patterns in elderly fallers and non-fallers," vol. 26, pp. 427–436, 2018.

[7] 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.

[8] Blin O, Ferrandez AM, Pailhous J, Serratrice G., "Dopa-sensitive and dopa-resistant gait parameters in Parkinson's disease," J Neurol Sci 1991;103:1-54.

[9] 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.

[10] M. H. Thaut, G. C. McIntosh, R. R. Rice, R. A. Miller, J. Rathbun, and J. M. Brault, "Rhythmic auditory stimulation in gait training for Parkinson's disease patients," Mov. Disord., vol. 11, no. 2, pp. 193–200, 1996.

[11] L. E. Dibble, D. E. Nicholson, B. Shultz, B. A. MacWilliams, R. L. Marcus, and C. Moncur, "Sensory cueing effects on maximal speed gait initiation in persons with Parkinson ' s disease and healthy elders," vol. 19, pp. 215–225, 2004.

[12] 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.

[13] 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.

[14] R. Baltadjieva, N. Giladi, L. Gruendlinger, C. Peretz, and J. M. Hausdorff, "Marked alterations in the gait timing and rhythmicity of patients with de novo Parkinson ' s disease," vol. 24, no. July, pp. 1815–1820, 2006.

[15] N. Teasdale, J. Phillips, and G. E. Stelmach, "Temporal movement control in patients with Parkinson ' s disease," pp. 862–868, 1990.

[16] C. F. Pasluost, H. Gassner, J. Winkler, J. Klucken, B. M. Eskofier, "An emerging era in the management of parkinson's disease: wearable technologies and the internet of things," Biomed Health Inform, 19(6), 1873-1881, 2015.

[17] S. Chen, J. Lach, S. Member, B. Lo, and S. Member, "Toward Pervasive Gait Analysis With Wearable Sensors : A Systematic Review," IEEE J. Biomed. Heal. Informatics, vol. 20, no. 6, pp. 1521–1537, 2016.

[18] Mirelman A., Bernad-Elazari H., Thaler A., Giladi-Yacobi E., Gurevich T., Gana-Weisz M., Saunders-Pullman R., Raymond D., Doan N., Bressman S.B., Marder K.S., Alcalay R.N., Rao A.K., Berg D., Brockmann K., Aasly J., Waro B.J., Tolosa E., Vilas D., Pont-Sunyer C., Orr-Urtreger A., Hausdorff J.M., Giladi N., "Arm Swing as a Potential New Prodromal Marker of Parkinson's Disease," Movement Disorders, 31(10), 1527-1534, 2016.

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