IJITKM Volume 7 • Number 1 • December 2013 pp. 16-20

Neuro-Degenerative Disease Diagnosis using Human Gait: A Review

Mandeep Singh[1], Mooninder Singh[2], Paramjeet[3]
[1], [2], [3] Department of Electrical & Instrumentation Engineering, Thapar University, Patiala, INDIA
E-mail: mandy_tiet@yahoo.com, mooninder@gmail.com, paramjeet.shahi@yahoo.com

Abstract
Falls are one of the most serious implications of the gait disturbance in Neuro-degenerative disease. Some of the major Neuro-degenerative diseases include Parkinson's Disease (PD), Amyotrophic Lateral Sclerosis (ALS), and Huntington Disease (HD). These diseases are generally unpredictable in their rate of progression and exhibition of degeneration. Neuro-degenerative diseases are caused by loss or death of neurons. These diseases are characterized by progressive nervous system dysfunction. This paper reviews how the human gait is related to neuro-degenerative diseases. Gait is basically the pattern of movement, means how we move or walk. For comparison of the gait pattern of patients suffering from neuro-degenerative disease, a healthy control group is taken. The gait pattern of both left and right foot is recorded, analyzed and compared for detection of neuro-degenerative disease diagnosis, using several techniques.
Keywords: Neuro-degenerative diseases, Huntington's disease, Parkinson's disease, Amyotrophic Lateral Sclerosis, Gait.

1. Introduction

Neuro-degenerative disease produces changes in neuromuscular control. Muscle movements control, Muscle tone, involuntary movements and smoothness of movement are affected due to neuro-degenerative disease. One of the important diagnostic methods for determining Neuro-degenerative disease is study of human gait. Gait is basically the pattern of movement of limbs. Human locomotion can be described by three distinct stages: 1. Development stage (from resting position to some velocity) 2. Rhythmic stage (at some constant velocity) 3. Decay stage (back to the rest position) [1]. A step in human has two distinct parts. The first part begins when the foot strikes the ground and ends when the foot is lifted. The second part begins when the foot is lifted and ends when it strikes the ground again. Various features can be extracted from these two steps that may lead to diagnosis of several neuro-degenerative diseases.

2. Age Effect on Neuro-degenerative diseases

As the age increases, it affects balance and gait including declining strength, muscle mass and bone density. Impaired respiratory capacity also occurs. Central nervous system age-related changes include shrinkage of neural soma and processes of the central cortex. As the degree of neurologic impairment increases, the gait variability is affected. Young healthy children have an immature gait. As the growth increases, their walk becomes more stable and close to the adult one. Apart from the age, human gait is also affected by Neuro-degenerative diseases like Parkinson's disease (PD), Huntington's disease (HD) and Amyotrophic Lateral Sclerosis (ALS).

3. Analysis of Gait

Freezing of gait is the most disabling symptom of neuro-degenerative disease. Freezing of gait means the feet are stuck to the floor. Stride length gets reduce in this disease. [2] Patients take small shuffling steps and movement gets slower. Patient faces difficulty to start moving and also faces difficulty while stopping. Several researchers are working on the analysis of human gait for diagnosis of neuro-degenerative disease. J. West *et.al* developed a super central pattern generator (SCPG) for both fractal and multifractals properties of the gait. SCPG is used to simulate the stride interval of human gait and determined the basic frequency, average period of normal human gait, frequency of both slow and fast gaits. Amplitude (A=1) was chosen for normal gait, A=2 for both slower and faster gaits. For metronomically constrained gait, A=4 is used for normal gait and A=8 for both slower and faster gaits. Amplitude is lower in normal gait because it is the most relaxed position and higher in metronomically constrained because it increases the stress on subject. The histogram of distributions of the holder exponent (h) was developed. As shown in figure 1 that Lower the holder exponent, the higher randomness in sequences [2]. Mingjing Yang *et.al* worked on the gait data of the patients suffering from neurodegenerative diseases that was recorded using foot switches. Four types of feature selection and feature construction method: maximum signal-to noise ratio based feature selection method, maximum signal-to noise ratio combined with minimum correlation based feature

selection method, and maximum prediction power combined with minimum correlation based feature selection method and principal component analysis. Support vector machine (SVM) classifier was applied. SVM was used to classify gait patterns of patients using knee osteoarthritis before and after knee replacement surgery. Right Stride, Right Swing, Right Stance, Left Stride, Left Swing, Left Stance, Double Support were extracted. Right stride is the period of time from right heel contacting with the ground to the same heel contacting with the ground again .Right stance is the period of time for right foot contact with the ground (from right heel contact to right toe off) . Right swing is the period time for right foot leave form the ground (from right toe off to right heel contact again). Double Support is the period of time for two feet contact with the ground in a cycle. Feature was extracted by comparing PD versus control group, HD versus control group, ALS versus control group, PD versus HD, PD versus ALS, ALS versus HD, HD+PD+ALS versus control group. The classification showed that ALS can be more easily distinguished from PD with accuracy of 85.47%, HD with accuracy of 86.52% and the control group with accuracy of 93.96%. PD and HD can be distinguished from the healthy control with accuracy of 86.43% and 84.17%. The accuracy of PD versus HD was only 79.04%, because their gait pattern has similar characteristics and both diseases occur due to the impairment of basal ganglia [3].

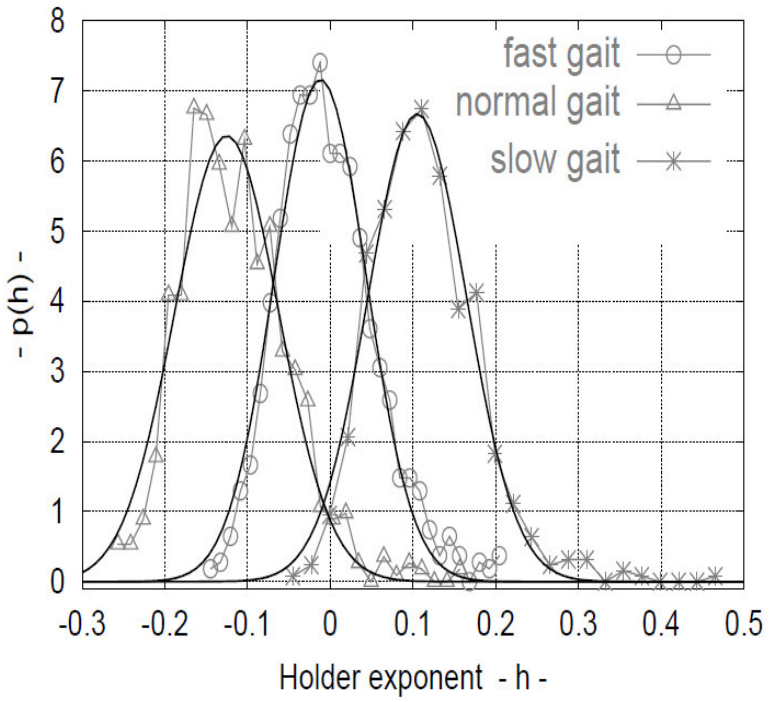

Figure 1: Histogram and probability density estimation of the Holder exponents

4. Parkinson's Disease

Parkinson's disease (PD) is a degenerative disorder of the central nervous system. It was first described in 1817 by James Parkinson, a British who published a paper on what he called "the shaking palsy." The main symptoms are trembling in the hands, arms, legs, jaw, and face, stiffness the limbs and trunk, slowed movement, and impaired balance and coordination. Symptoms of Parkinson's disease usually come on gradually and affect people over the age of 50, although there are rare forms that progress more quickly and strike at a younger age. Parkinson's disease is both chronic, meaning it persists over a long period of time, and progressive, meaning its symptoms grow worse over time. Parkinson's disease occurs when nerve cells, or neurons, in an area of the brain known as the substantia nigra die or become impaired. Normally, these neurons produce an important brain chemical known as dopamine. Dopamine is a chemical messenger responsible for transmitting signals between the substantia nigra and the next "relay station" of the brain. As the disease progresses, the shaking or tremor that affects the majority of Parkinson's

patients may begin to interfere with daily activities. Patients may not be able to hold utensils steady or they may find that the shaking makes reading a newspaper difficult.
Parkinson's disease does not affect everyone the same way, and the rate of progression differs among patients. Tremor is the major symptom for some patients, while for others; tremor is nonexistent or very minor. PD symptoms often begin on one side of the body. Y. Balash made a study of 230 patients with PD, 43% reported falling at least once in 12 months [4]. Jeffrey M. Hausdorff has done a research that consists of long range correlation properties of gait in PD. The stride length, Gait variability and Fractal scaling of gait are impaired in PD. In study of 230 patients with PD, 43% reported falling at least once in 12 months. Patients with PD are unable to generate sufficient stride length. The swing time series from a patient with PD and a control subject under usual walking conditions and when performing serial 7 subtractions were calculated. Coefficient of Variability (CV) is larger in patient with PD (CV=2.7%*)* compared to the control (CV=1.3%). Coefficient of variability increases during dual tasking (serial 7 subtractions) in the subject with PD CV=6.5% but not in the control CV=1.2%. It may be mentioned here that CV is the ratio of Standard Deviation (SD) to Mean. In serial 7 subtraction, the subject is asked to walk while subtracting 7 from 100 i.e. 100, 93, 86, 79, 72, 72…etc. If subject is emphatically asked not to memorize the series, but rather subtract number 7 from the previous number [5]. In recent years fluctuations of time series data is becoming more important. Detrended Fluctuation Analysis (DFA) is one of the methods for analyzing the fluctuation of the gait cycle. Leo ota *et.al* performed the DFA analysis of gait cycle in 200 meters walk of 17 PD patients and 12 healthy young people. It was found that the fractal exponent is lower for PD patients in compare to the healthy control [6]. Freezing of gait in PD patients using wearable sensor was detected by E. Jovanov *et.al*. Wireless headset was used to generate acoustic cues to unfreeze the gait [7].

5. **Huntington's disease**

It is a neurodegenerative genetic disorder that affects muscle coordination and leads to cognitive decline and psychiatric problems. Huntington's disease is a progressive, degenerative brain disorder that produces physical, mental and emotional changes. The disease was named after George Huntington, who first described it in 1872 [8]. The people affected by disease are not able to think, talk and move properly. It destroys the cells in the basal ganglia, the part of the brain that controls these capacities. It is also a hereditary problem. Every child has a 50% chance of inheriting the abnormal gene. Because Huntington's disease affects the mind, body, and emotions, symptoms often mimic other conditions. The general symptoms in early stages can include poor memory; difficulty in making decisions; mood changes such as depression, anger or irritability; a growing lack of coordination, twitching or other uncontrolled movements; difficulty in walking, speaking or swallowing. Scientist Grimbergen YA *et.al* analyzed fall and gait disturbances. Falls were recorded in 45 patients suffering from early to mid stage Huntington's disease. Falls rate were measured using Unified Huntington's Disease Rating Scale (UHDRS) and quantitative measures of balance (using angular velocity Sensors) and gait (using a pressure-sensitive walkway). Comparison between healthy control and patients suffering from Huntington's disease was done. They found that the Huntington's patients had decreased stride length and decreased gait velocity as compare to control subjects. Because both characteristics were found in fallers so he concluded that falls are the common symptom of Huntington's disease [9].

6. **Amyotrophic Lateral Sclerosis** (**ALS**)

This disorder is referred to as motor neuron disease. It is also related to muscles problem. The disease is characterized by progressive weakness, difficulty in speaking, swallowing, breathing, muscle twitching (involuntary muscle contraction and relaxation), muscle stiffness etc. When motor neurons get damaged in any part of body, that part is affected by Amyotrophic Lateral Sclerosis disease. It does not affect the sensory nerves and involuntary nervous system. It means most of the patient will maintain touch, hearing, smell, sight, and taste. Yunfeng Wu *et.al* downloaded the data via physionet.org. The least-squares support vector machine (LS-SVM) was used to distinguish the stride patterns between the ALS patients and healthy controls with an accuracy of 82.8% [10]. Hausdorff *et.al* proposed an algorithm to detect stride interval for both left and right. They compared the gait rhythm of patients suffering from ALS with normal controls and with subjects suffering from Parkinson's disease (PD) and Huntington's disease (HD). They recorded stride to stride fluctuation using an ankle-worn recorder. Ankle-worn recorder recorded the 5 minutes movement of the subjects walked at their usual pace. The gait pattern of the patients with ALS was found more disorganized and less steady. Some common and some distinct characteristics were found when comparison was made among ALS, HD and PD patients [11]. Lakshmi Sugavaneswaran *et.al* proposed ML (Machine learning) based TF kernels to obtain one-step discrimination between different non-stationary patterns. An accuracy of 93.1% was obtained for neurological gait data base from the signals (16 controls and 13 Amyotrophic

lateral sclerosis subjects). Comparison was made between ALS and healthy control by placing force sensitive insole under the subject's foot. Subjects were asked to walk at their comfortable walking speed. Stride to stride measurements were recorded [12].

7. Conclusion and Future directions

Neuro-degenerative disease includes Parkinson's disease, Huntington's disease and Amyotrophic lateral sclerosis. Electroencephalogram (EEG) is commonly used physiological parameter for detection of Epilepsy [13]. In addition to epilepsy, PD and HD can also be detected using EEG [14]. Interestingly analysis of human gait can also be used for detection of PD, HD, and ALS. This is done based on the fact that People suffering from neuro-degenerative diseases face gait problem. Freezing of gait, shuffling gait, taking small steps etc. are the most disabling and distressing symptoms of these diseases. Researchers have done some research related to significance of gait. Foot pressure was measured by placing ultrathin force sensitive switches inside each subject's shoe. All the readings were taken manually and the left and right stride interval calculated from this data, mean, median, Coefficient of Variability (CV) of Parkinson's disease patient, Huntington's disease and Amyotrophic lateral sclerosis were compared with healthy control. The process of manually calculating stride interval is very time consuming and error prone task. It is therefore proposed that Automatic detection of heel and toe strikes and calculation of heel and toe strike interval be done using computational technique. After detecting heel and toe strikes for neuro-degenerative disease patients, the strike time shall be compared with healthy control. Additional features like coefficient of variation, mean, standard deviation etc. will also be derived automatically for patients suffering from neuro-degenerative diseases and healthy control. A suitable classifier also needs to be designed using these computed features for diagnosis of neuro-degenerative diseases.

8. References:

[1] Nicola Scafetta, Damiano Marchi and Bruce J. West, "Understanding the complexity of human gait dynamics", *Chaos*, vol.19, 026108, 2009.

[2] Bruce J. West and Nicola Scafetta, "Nonlinear dynamical model of human gait", DOI: 10.1103/PhysRevE.67.051917, 2003.

[3] Mingjing Yang , Huiru Zheng, Haiying Wang, Sally McClean, "Feature Selection and Construction for the Discrimination of Neurodegenerative Diseases Based on Gait Analysis", International Conference on Digital Object Identifier, 10.4108, Page(s): 1 - 7, 2009.

[4] Jeffrey M. Hausdorff, "Gait dynamics in Parkinson's disease: Common and distinct behavior among stride length, gait variability, and fractal-like scaling", Chaos, 19, 026113 2009.

[5] Y. Balash, C. Peretz, G. Leibovich, T. Herman, J. M. Hausdorff, and N.
Giladi, "Falls in outpatients with Parkinson's disease: Frequency, impact and identifying factors", J. Neurol. 252, 1310 , 2005.

[6] Leo Ota, Hirotaka Uchitomi, Kazuki Suzuki, Michael J. Hove, Satoshi Orimo and Yoshihiro Miyake, "Relationship between Fractal Property of Gait Cycle and Severity of
Parkinson's Disease", IEEE/SICE International symposium on Digital Object Identifier: 10.1109/SII.2011.6147452 , Page(s): 236 – 239, 2011.

[7] E. Jovanov, E. Wang, L. Verhagen, M. Fredrickson, R. Fratangelo, "deFOG – a Real Time System for detection and unfreezing of Gait of Parkinson's Patients", *Annual International Conference of the IEEE* , Page(s): 5151 – 5154, 2009.

[8] Hausdorff JM, Mitchell SL, Firtion R, Peng CK, Cudkowicz ME, Wei JY, Goldberger AL, "Altered fractal dynamics of gait: reduced stride-interval correlations with aging and Huntington's disease". *J Applied Physiology*; 82:262-269, 1997.

[9] Grimbergen YA, Knol MJ, Bloem BR, Kremer BP, Roos RA, Munneke M., "Falls and gait disturbances in Huntington's disease", *Mov disord*, 23(7), DOI: 10.1002/mds.22003, 2008

[10] Yunfeng Wu and Sin Chun Ng, "A PDF-Based Classification of Gait Cadence Patterns in Patients with Amyotrophic Lateral Sclerosis", *Annual International Conference of the IEEE EMBS Buenos Aires, Argentina*, Page(s): 1304 – 1307, 2010

[11] Hausdorff JM, Lertratanakul A, Cudkowicz ME, Peterson AL, Kaliton D, Goldberger AL, "Dynamic markers of altered gait rhythm in amyotrophic lateral sclerosis". *J Applied Physiology*, *Mov Disord* , 23(2)**:**S423-425. 88:2045-2053, 2008.

[12] Lakshmi Sugavaneswaran, Karthikeyan Umapathy and Sridhar Krishnan, "Discriminative Time-Frequency Kernels for Gait Analysis for Amyotrophic Lateral Sclerosis", *Annual International conference of IEEE*, 10.1109, Page(s): 2683 – 2686, 2011.

[13] Mandeep Singh, Sunpreet Kaur, "Epilepsy detection using EEG an overview", *International Journal of Information Technology and Knowledge Management*, Volume 6, No. 1, pp. 3-5, December, 2012

[14] Mandeep Singh, Sunpreet Kaur, "Feature selection for Epilepsy detection using EEG", *International Journal of Information Technology and Knowledge Management*, Volume 6, No. 1, pp. 7-9, December, 2012.