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Computation of Heel and Toe Strike Intervals using Computer Aided Techniques

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Abstract
Gait disturbances are the main symptoms for the patients suffering from neuro-degenerative diseases. This paper provides a brief description to the neuro-degenerative diseases and looks specifically at the gait changes typically seen in patients suffering from neuro-degenerative disease. This paper provides automatic Heel and Toe strike detection and interval computation for patients and healthy control. This report first reviews the study of the heel and toe strike properties of gait. In neuro-degenerative disease firstly heel and toe strike of healthy subjects and patients for each foot were detected and then heel to heel and toe to toe intervals were computed. After computing heel and toe strike intervals of each left and right foot, mean and Standard Deviation (SD) were calculated to obtain the Coefficient of variation (CV) and compared with healthy control. This CV of neuro-degenerative disease subjects and healthy control subjects is published in this paper.
Keywords: Neuro-degenerative diseases, Parkinson's disease, Amyotrophic Lateral Sclerosis (ALS), Huntington's disease, healthy control, Gait, Heel strike and Toe strike.

1. Introduction

Neuro-degenerative disease causes gait problems. Shuffling gait, shortened stride length, reduced speed, increased variability are the main symptoms of this disease. It can be characterized as hereditary and sporadic conditions. It includes diseases such as Alzheimer's disease, Epilepsy, Genetic Brain Disorders, Head and Brain Hydrocephalus, Parkinson's disease, Amyotrophic Lateral Sclerosis (ALS), Huntington's disease, and others [1].

In this paper, we mainly focus on three diseases: Parkinson's disease, Amyotrophic Lateral Sclerosis (ALS) and Huntington's disease. Neuro-degenerative diseases are caused by loss or death of neurons. These diseases are characterized by progressive nervous system dysfunction [2]. Strong depression of motor control and dysfunction of rhythm generation in basal ganglia causes movement disorder and abnormal gait. These include quick and short gait step and freezing gait. Most of the researchers considered 13 subjects for each PD, HD and ALS respectively and 13 healthy controls for classification [3].

We can differentiate between normal and abnormal gait through “heel to toe characteristics”. In normal gait, first the heel and then toe strike the ground that is called heel to toe walking whereas in disturbed gait, entire foot strikes the ground at the same time, that is called flat foot strike. In normal gait vertical Ground Reaction Force (GRF) has two steps: first when the foot strikes the ground and the second is caused by push-off force from the ground. In case of neuro-degenerative disease, ground reaction force is more like flatfoot strike. The plot of force from the sensor attached to the sole of the foot gives heel and toe strike pattern. This paper is identified manually. Subsequently, heel to heel and toe to toe strike intervals are computed. This process is highly tedious, time consuming and error-prone. Need was felt to automate this process [review].

This paper gives the methodology to compute heel to heel and toe to toe strike intervals automatically, using MATLAB software.

2. **Data source**

All data were downloaded from www.physionet.org. Through PhysioBank ATM using Gait in Neurodegenerative disease database (gaitndd) [5]. Data was downloaded in Microsoft excel form. One minute data was recorded for both left and right foot signals in standard form were considered. The data had 300 samples/sec sampling rate.

3. Methodology

13 subjects of Parkinson’s disease (PD), 13 subjects of Huntington’s disease (HD), 13 subjects of Amyotrophic lateral sclerosis (ALS) and 13 healthy control subjects were selected for analysis.

The aim here is to compute heel to heel and toe to toe strike intervals. The data of force sensor is available in text file format on physionet.org. This text file is exported to MATLAB for analysis. In order to compute heel to heel interval. It is necessary to first detect the exact moment at which the heel strikes the ground. It is taken as the first, maxima as shown in figure 1. Similarly toe strike is detected as second maxima, again shown in figure 1 . Detecting the heel strike means find the exact time when first maxima occurs .from two subsequent heel strike times, heel strike interval is calculated. Hence to compute heel strike interval, it is required that heel strike time is identified accurately. Similarly toe strike interval requires accurate identification of toe strike time.

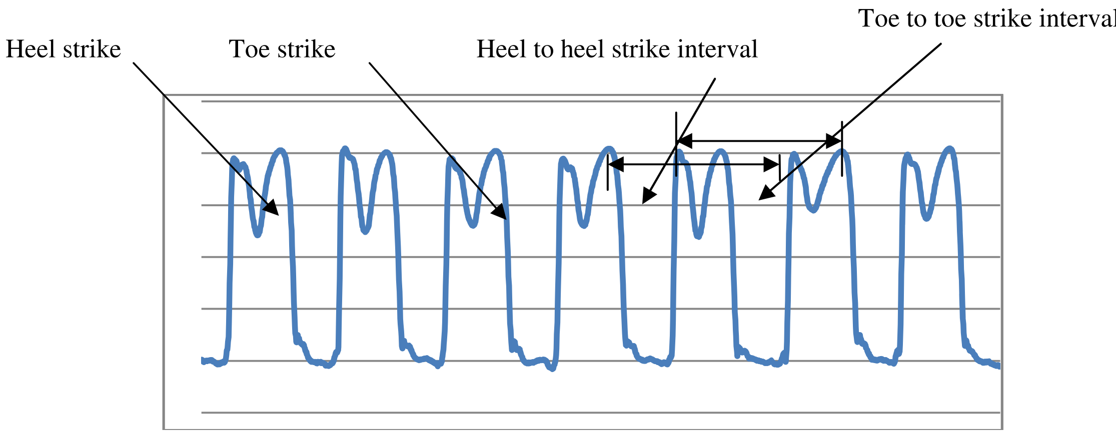

Figure 1: Signal taken from Huntington's left foot

The MATLAB program is based on the algorithm which identifies heel strike time and toe strike time. This algorithm was developed by the authors operates in the following sequences:

1. The average of the downloaded signals is taken.
2. The average is subtracted from each sample.
3. The minimum value of the entire set is computed.
4. 40% of this minimum value is added to the signal so as to elevate the signal appropriately.
5. When the waveform cuts the zero axis and move towards positive axis that is called rise point.
6. When the waveform crosses the zero axis from positive value towards negative, called fall point.
7. Moving towards right from the rise point, the first maxima are taken as heel strike point.
8. Similarly, Moving towards left from the fall point, the first maxima is taken as toe strike point.
9. The corresponding time, where the heel strike occurs, is recorded as heel strike time.
10. Similarly, where the toe strike occurs, is recorded as toe strike time.
11. Heel strike interval is taken by subtracting two subsequent heel strike times.
12. Toe strike interval is taken by subtracting two subsequent toe strike times.
13. The heel strike intervals and toe strike intervals are presented.
14. Mean of all heel to heel intervals is taken.
15. Standard deviation for all heel to heel point intervals is also calculated.
16. The values above and below the range "mean ± 2 *(standard deviation)" are rejected.
17. Step 14 and 15 are repeatedly performed until all the values lie within "mean ± 2 *(standard deviation)".
18. Mean of all toe to toe intervals is taken.
19. Standard deviation for all toe to toe point intervals is also calculated.
20. Step 17 and 18 are repeatedly performed until all the values lie within "mean ± 2 *(standard deviation)".
21. Coefficient of variation (CV) for heel strike and toe strike interval is calculated using the formula "C_V = Standard deviation / Mean".
22. CV for both heel strike and toe strike interval is presented.

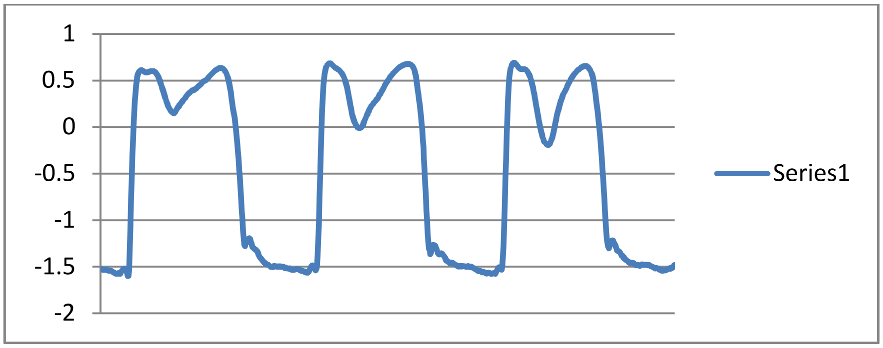

Figure 2 (a): Original Signal taken from Huntington's left foot

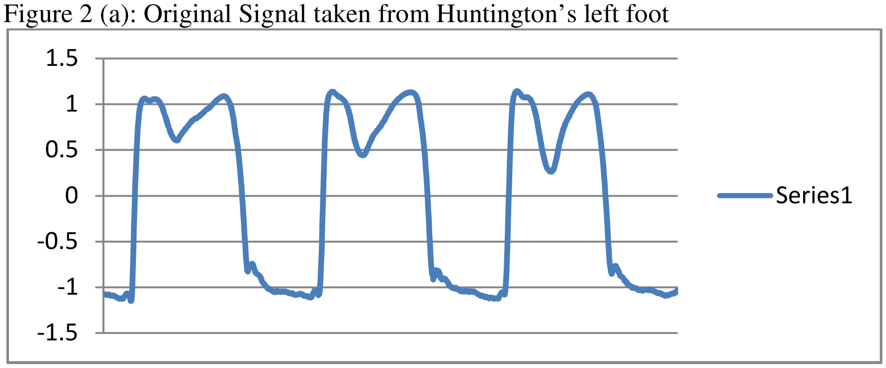

Figure 2 (b): Signal after subtracting mean value

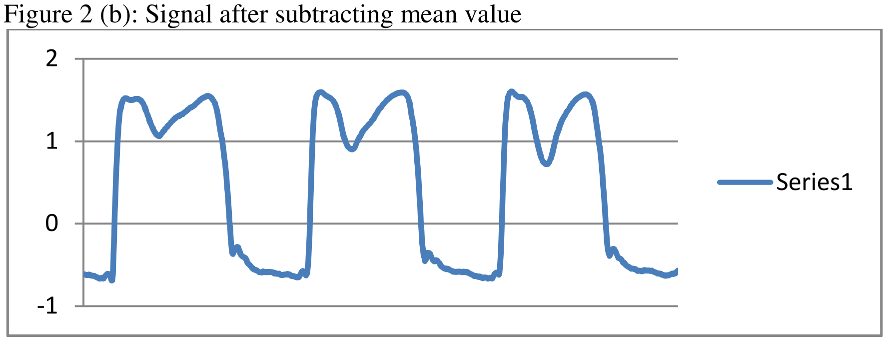

Figure 2 (c): Signal after adding 40% of minimum value

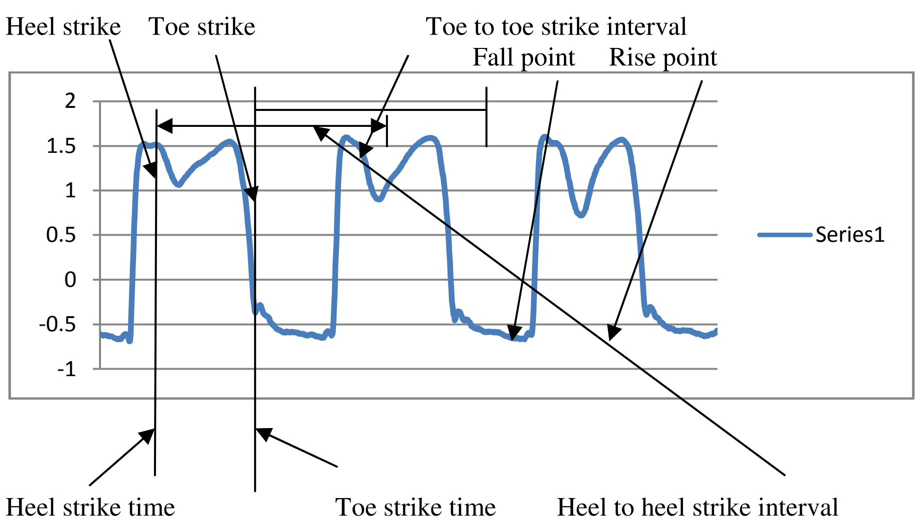

Figure 2 (d): Signal showing identified parameters

4. Results

To cross check the detection efficiency of MATLAB program, signals from the subject 1 of Huntington's disease, left foot was analyzed manually, wherein 60 heel strikes and 60 toe strikes were detected. The MATLAB program for this signal gives 61 heel and 61 toe strikes. Of these 61 strikes, 60 strikes are correctly detected; none of the strike is missed while one falsely detected strike is reported. If we compute accuracy of the algorithm for this signal comes out to be 98.33 %, which is highly satisfied. The accuracy can be calculated by the formula: "(Actual detection - Missed strikes - False detection) / (Actual detection)".

Table: 1 Confusion Matrix (Comparison of manual gait detection with computational gait)

Output / Desired	Manually detected h	Computationally
Computationally detected heel strikes	60	0
Manually detected heel strikes	1	60

Table 2, 3, 4, 5 concisely describe the Covariance of heel and toe strike interval for both left and right foot.
There are total 52 subjects:
(1)13 Healthy control (2) 13 ALS (3) 13 HD (4) 13 PD

Table 2: CV of 13 PD Subjects

Subjects	Left foot Heel strike	Left foot Toe strike	Right foot Heel strike	Right foot Toe strike
PARK1	0.070038	0.021344	0.029018	0.020928
PARK2	0.028801	0.031787	0.067669	0.026697
PARK3	0.063144	0.042653	0.035256	0.055042
PARK4	0.039457	0.027222	0.066766	0.021524
PARK5	0.301106	0.286624	0.051424	0.032498
PARK6	0.050278	0.039707	0.029469	0.03905
PARK7	0.09698	0.070059	0.119646	0.076914
PARK8	0.032059	0.030173	0.027168	0.038014
PARK9	0.053582	0.025893	0.367292	0.653307
PARK10	0.525637	0.472776	0.156842	0.156678
PARK11	0.083261	0.03026	0.028745	0.028342
PARK12	0.022464	0.087684	0.031348	0.027095
PARK13	0.029632	0.027679	0.033973	0.024128

Table 3: CV of HD Subjects

Subjects	Left foot Heel strike	Left foot Toe strike	Right foot Heel strike	Right foot Toe strike
HUNT1	0.05734	0.064892	0.07091	0.068975
HUNT2	0.098702	0.096021	0.098139	0.081684
HUNT3	0.094299	0.086311	0.104165	0.047279
HUNT4	0.064626	0.026839	0.037289	0.026319
HUNT5	0.040179	0.029596	0.065191	0.030287
HUNT6	0.107463	0.030763	0.049152	0.043331
HUNT7	0.039318	0.018978	0.039248	0.013578
HUNT8	0.041295	0.038312	0.052663	0.041429
HUNT9	0.036932	0.074962	0.033188	0.030259
HUNT10	0.073204	0.035551	0.261508	0.045279
HUNT11	0.072295	0.15502	0.074925	0.058226
HUNT12	0.035164	0.023276	0.034978	0.115548
HUNT13	0.039534	0.036478	0.058417	0.04118

Table 4: CV of ALS Subjects

Subjects	Left foot Heel strike	Left foot Toe strike	Right foot Heel strike	Right foot Toe strike
ALS1	0.041411	0.027762	0.019919	0.02065
ALS2	0.049444	0.048	0.042323	0.046682
ALS3	0.057971	0.127942	0.153325	0.182501
ALS4	0.024044	0.033852	0.030648	0.05982
ALS5	0.060014	0.03748	0.205247	0.04527
ALS6	0.095806	0.082461	0.10109	0.177373
ALS7	0.013444	0.017996	0.01858	0.012898
ALS8	0.026808	0.015716	0.020486	0.023926
ALS9	0.014237	0.019693	0.018981	0.024232
ALS10	0.012002	0.015795	0.023072	0.012501
ALS11	0.034199	0.024395	0.120072	0.024292
ALS12	0.024762	0.026151	0.045355	0.028665
ALS13	0.051535	0.047871	0.049669	0.043397

Table 5: CV of Control subjects

Subjects	Left foot Heel strike	Left foot Toe strike	Right foot Heel strike	Right foot Toe strike
CONT 1	0.01767	0.030575	0.019203	0.03
CONT 2	0.014032	0.010834	0.009675	0.011616
CONT 3	0.027747	0.022474	0.045674	0.014173
CONT 4	0.021618	0.01644	0.020489	0.017795
CONT 5	0.022141	0.022345	0.02474	0.024528
CONT 6	0.044641	0.018917	0.02082	0.014187
CONT 7	0.016078	0.019513	0.011888	0.017431
CONT 8	0.147627	0.024434	0.038703	0.018457
CONT 9	0.019699	0.016929	0.020913	0.023932
CONT 10	0.012468	0.031141	0.067067	0.031865
CONT 11	0.102323	0.020768	0.092558	0.027716
CONT 12	0.033761	0.036911	0.06901	0.037517
CONT 13	0.027179	0.024912	0.019366	0.018328

As we can see from table 1, 2, 3, 4, the CV of patients suffering from neuro-degenerative diseases is higher than control subjects.

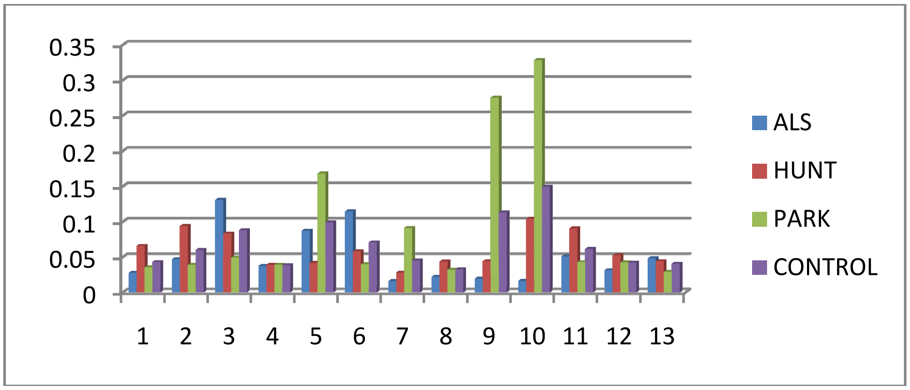

Figure 3: Average CV of heel and toe strike interval for both feet

5. Conclusion and Future Scope

Table 1, 2, 3 and 4 indicate that none of the four features namely CV of left foot heel strike, CV of the left foot toe strike, similarly CV of the right foot heel strike and CV of the right foot toe strike interval can be used in isolation for classification based on threshold method. It is required to build intelligent classifier to:

1. Classify normal and neuro-degenerative disease subjects.
2. Classify neuro-degenerative diseases into Parkinson's disease and Non-Parkinson's disease.
3. Classify neuro-degenerative diseases into Huntington's disease and ALS disease.

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