Abnormal Gait Detection Using Discrete Fourier Transform

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Abstract

Detection of gait characteristics has found considerable interest in field of biomechanics and rehabilitation sciences. In this paper an approach for abnormal gait detection employing Discrete Fourier Transform (DFT) analysis has been presented. The joint angle characteristics in frequency domain have been analyzed and using the harmonic coefficient recognition for abnormal gait has been performed. The experimental results and analysis represent that the proposed algorithm based on DFT can not only reduce the gait data dimensionality effectively, but also lighten the computation cost, with a satisfactory distinction. In order to make the algorithm more generic, a Mean Square Error (MSE) analysis is also presented. Future work will be the expansion of the detection introduced in this system to include abnormality detection instead of just an abnormal or normal detection that would prove to be a valuable addition for use in a variety of applications, including unobtrusive clinical gait analysis, automated surveillance in addition to a variety of others.

1. Introduction

Motion analysis or gait has been an emerging research field since the advent of the still camera in 1896 [1]. Since then a lot of researchers have analyzed human gait in terms of angle, position, force and moment etc. in order to give information about limb motion. From those research points of view a number of areas have gained interest from researchers which can be classified into two types that include clinical gait analysis and biometric gait analysis [2-5]. These are two main research fields for gait analysis. Although the two area deal with human gait but they are distinct to each other in terms of techniques and methods. Clinical gait analysis uses on collection of kinematic data in controlled environments using motion analysis systems and the data acquisition system is integrated with motion analysis system. Motion analysis data provides large amounts of data to describe motion such as walking speed and gait events, as well as joint angles, forces, and moments as functions of the percent of the gait cycle. Using those data joint kinetics, joint moments and joint powers have been used to for gait recognition [6-10] lately. On the other hand Biometric gait analysis concentrates on individual's gait recognition in a variety of different areas and scenarios. As a result of this, biometric gait analysis is based on visual data capture and analysis systems. Due to lack of information like motion analysis system biometric gait recognition uses computer vision method to describe motion that is exclusively being applied to identification tasks. However, gait can disclose more than identity. There should be a method that that can characterize human gait for determination of abnormalities and also would give us information for applications such as surveillance and rehabilitation etc. Although much progress have been observed in the field of computer vision for the human gait recognition , sufficient research has not been done in the area of global gait analysis for abnormal gait detection. Recently, principal component analysis (PCA) has become a popular method to try to describe gait pattern. PCA method is used to estimate bone forces, net moments and knee angles to show the deviation from 'normal' of individuals [11] by using methods describing deviations from the mean and interactions between curves. A similar recent study also has been done for flexor extensor power at the hip [12]. But some study reported that there have been complications about interpretations of PCA analysis [13]. Although some methods are available for gait detection but very few effective methods are found for abnormal gait detection. In this paper we describe a method based on Discrete Fourier transform (DFT) which allows us to investigate how far a person's gait deviates from normal. Here we have considered three joint angles: 'ankle-knee', 'knee-hip' and 'hip-ankle for abnormal gait detection. These angles are straightforward to measure and are quite consistent across different gait analysis systems [14] thus making it feasible to use the results reported here on new data. The method presented here is unique in the way that it can identify the abnormal gait as well as the individual gait for whether normal or abnormal. The assumption that human gait motion behaves as a damped harmonic oscillator that reacts in sum fundamental way to certain stimuli is exploited in a pattern recognition scheme used to classify the observed gait as normal or abnormal. Firstly the data is collected from 3d motion analysis system using eight markers from where we extracted the joint angles. In the data analysis section it is shown that our proposed method can accurately detect normal and abnormal gait when presented with a number of different walking subjects exhibiting a variety of abnormal gait motions as well as normal gait. From mathematical point of view, we have tried to obtain measure clear distinctions between normal and abnormal gait using wide spread data.

2. Method

2.1 Data Collection

9 children, 36 females and 34 males with age range between 10 and 69, were recruited to participate in the study. The purpose of the study was explained to each subject before they were taken part into the experiment. They practiced until they could reliably walk for both normal and with impair conditions. The impair condition were given in three types such as impair in knee, impair in ankle and impair in both ankle and knee. For marker system we have utilized Helen Hayes protocol [14]. All the trials were taken while the subjects were walking in the treadmill. Each subject was asked to perform four sets of walks that include normal walking and walking under three different impair conditions on a treadmill as mentioned before. The reason for performing the trials was to cover a range of walking for both abnormal and normal gait. The subjects were asked to repeat the walks in each one of the four conditions until at least three 'clean' trials were recorded. These data had been previously collected as part of routine clinical gait analysis at the Motion Analysis Laboratory at the Health Metrology Group, Korean Research Institute of Standards and Science. All these data are obtained using Optotrak Certus along with eight markers.

2.2 Data Analysis

For our data analysis we will consider three joint angles: 'ankle-knee', 'knee-hip' and 'hip-ankle'. This angle data are available from motion analysis system. As we know human gait is cyclic and repeats itself, first we have to extract one full gait cycle for all angle data. Here the joint angle data are considered as complex data as for example
z (n)=ankle_angle(n)+j*knee_angle(n), where n is the sample number. Once the complex data is available we can take the FFT of z (n),

$$Z(k) = \sum_{n} z(n) \exp(-j2\pi kn / N) \qquad (1)$$

where N=101 and n=0, 1, …, N-1.

The discrete Fourier transform (DFT) is used as the most popular tool to obtain a spectral representation of a given physiological signal. The discrete Fourier transforms pair that can be applied to sampled signals can be expressed as:

$$Z(k) = \sum_n z(n) \exp(-j2\pi kn / N) \qquad (2)$$

and

$$z(n) = \frac{1}{N} \sum_k Z(k) \exp(j2\pi kn / N) \qquad (3)$$

for n=0,1,…, N−1; k=0,1,…, N−1.
where Z(k) represents the frequency domain function and z(n) the time domain function.

Utilizing these pair of formulas we can progress back and forth between a time representation of our complex joint angle signals (z(n)) and its frequency domain representation (Z(k)), that is, the DFT is invertible. Modification of the frequency spectrum is also possible to change the time representation. This procedure can be performed by either multiplication with a transfer function in the frequency domain or convolution with a filter kernel in the time domain [6]. In our analysis both Z(k) and z (n) are complex series. In the case of Z(k), each value of Z(k) contains information on the complex modulus, or magnitude, and the phase in its real (R (k)) and imaginary (I(k)) parts. These, the magnitude function (|Z (k)|) and phase (Φ(k)) can be expressed as:

$$|Z(k)| = \sqrt{(R^2(k) + I^2(k))} \qquad (4)$$

$$\phi(k) = \tan^{-1}\left(\frac{I(k)}{R(k)}\right) \qquad (5)$$

and the square of the magnitude function, the power spectral density (PSD) can be defined for periodic signals as:

$$P(k) = |Z(k)|^2 \qquad (6)$$

In fact, the DFT is implemented using the fast Fourier transform (FFT), an efficient algorithm that has advantages considerably over the computational time in terms of calculation for DFT [7]. Another widely used parameter to explain the frequency domain of physiological signals is the PSD which is defined in decibels and express the energy of each harmonic component (k) in the series, that correspond to samples of the continuous Fourier transform at values 0, Δk, 2Δk,…, (N−1) Δk, where Δk is a multiple of the fundamental frequency f_o and defined as

$$f_0 = \frac{1}{N\Delta t}$$

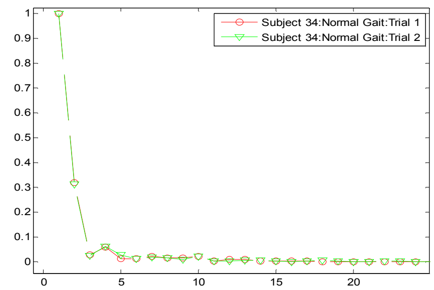
where Δt is the sampling interval of the sampled signal.

In our case the sample frequency is chosen as 30 Hz. We need only the magnitude spectrum. Moreover some normalization of scale is done by dividing the magnitude values of all Fourier coefficients by the magnitude of the second one (Z (1)). Not only that to eliminate any dissimilarity due to phase difference we had to discard the first coefficient (Z (0)). That means,

$$|Z| = \left[\frac{|Z(1)|}{|Z(1)|}, \frac{|Z(2)|}{|Z(1)|}, \cdots, \frac{|Z(N-1)|}{|Z(1)|}\right]^T \qquad (7)$$

where | Z | is the vector obtained from the magnitude of DFT of joint angle data z (n). The numbers in brackets indicate indices for DFT coefficients and T denotes transpose operation.

In case of experiment for each subject several trials were made on a trade mill and the marker data were recorded. The trials were taken at different sessions with at least a day between them. In all the simulation examples the trial data are chosen randomly without any bias. To normalize each of them to equal number of data points we interpolated those up to 101 data samples. For explanation purpose, data acquired from the experimental subject 34 (30years old male) is used. The high frequency components of Z (k) will give the variation between normal and abnormal gait as simulation results for subject 34 shows a clear distinction between normal and abnormal in the Fourier domain. The figures show for all subjects the normal gait has similar patterns and for abnormal gait the patterns differ significantly. We can repeat the same procedure for other joint angles and successfully distinguish normal and abnormal gait from the Fourier transform patterns.



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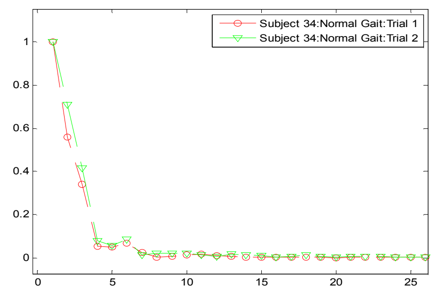

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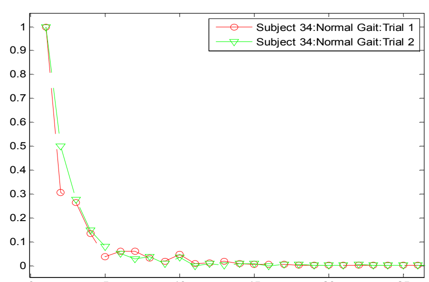
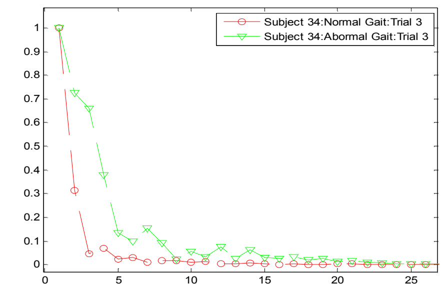


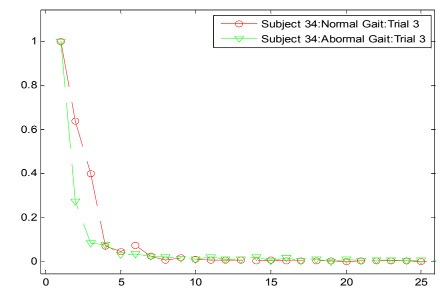
(c)

Figure 1. Comparison between two different trials of normal gait for subject 34. (a) Ankle-knee angle (b) Knee-Hip angle (c) Hip- Ankle angle

We are considering three joint angles for analysis as mentioned before. Figure 1 shows the first 25 coefficients of | Z | for the subject 34 at normal gait condition. The higher coefficients do not contain any significant information hence not shown in figures. In this case the normal gait is compared between trial 1 and trial 2. It is evident that the two curves are very close to each other especially for ankle-knee data. We also have done same analysis for the subject 17 and got similar results. Both figures suggest a specific pattern for normal human gait. This same pattern is obtained for all the subjects under examination. Figure 2 shows a comparison between normal and abnormal gait pattern for the subject 34. For both types of gait 'trial 3' is chosen where subject were given impair condition both in ankle and knee. The deviation in pattern is obvious from figures. The shapes obtained for these trials are a general scenario for all the subjects we have investigated. To make our point stronger we also presented similar figures for the subject 34 for trials other than in figure 2 in figure 3. All figures related to the subject 34 are similar and abnormal gait is easily distinguishable from the patterns.



(a)



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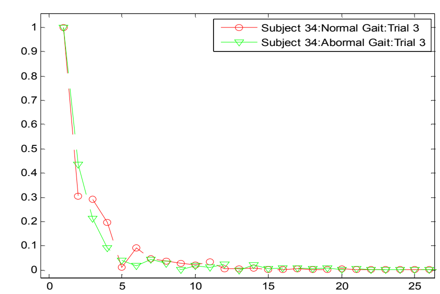
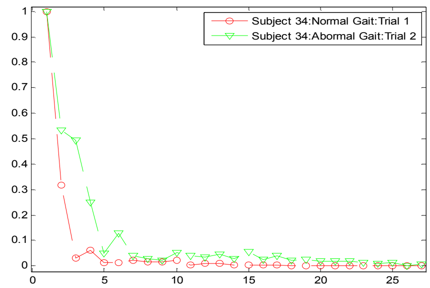
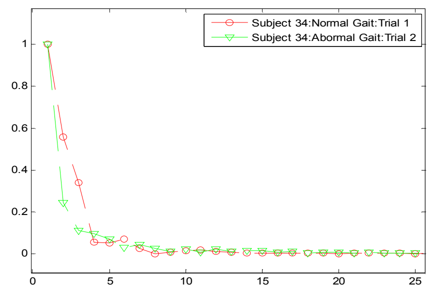


(c)

Figure 2. Comparison between normal and abnormal gait for subject 34. (a) Ankle-knee angle (b) Knee-Hip angle (c) Hip- Ankle angle



(a)



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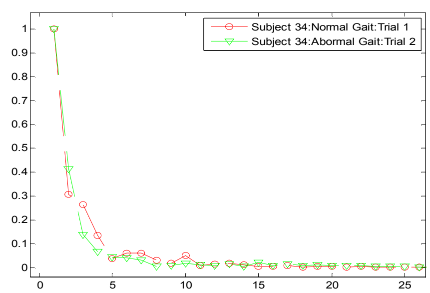

(c)

Figure 3. Comparison between normal and abnormal gait for subject 34 with different trials from figure 2. (a) Ankle-knee angle (b) Knee-Hip angle (c) Hip- Ankle angle

3. Discussion

The Discrete Fourier transform (DFT) constitute the most widely used operation in exploring the frequency domain of physiological signals. In the present paper we have intended to apply DFT to illustrate its application to the study of the frequency domain of joint angle data. Our Proposed method can be easily understood from the figure 4.

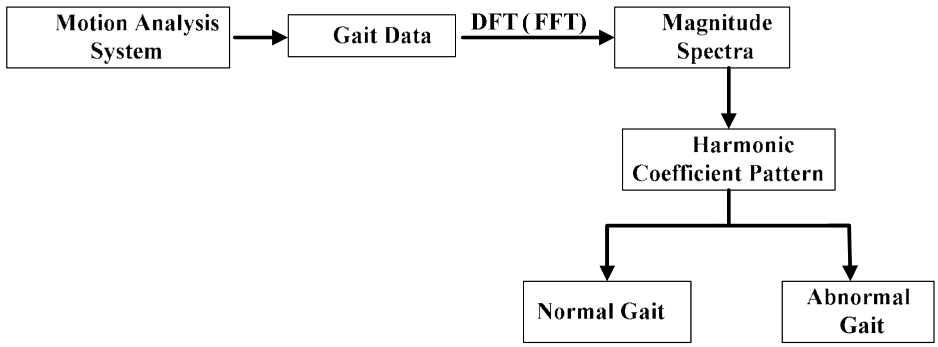

Figure 4. Block diagram for proposed method for gait detection

While taking the data we have used a sample frequency of 30 Hz. Analyses in the frequency domain (Fig. 1-3) using the FFT revealed that the lower frequency content of the joint angle data provides sufficient information about the normality or abnormality of human gait. Our inspection is based on the magnitude spectra of the data. However, the phase information is yet to be investigated and they may also give some additional information. As shown in figure 1 the normal pattern (lower frequency content) of gait is similar and irrespective of trials. The second frequency coefficient in the figures is a deterministic factor to identify gait patterns coming from same person although the next few are also effective but it is a dominant harmonic among them. Figure 2 and 3 all the way show the differences in pattern between normal and abnormal gait. The discriminating features are more prominent for the joint ankle-knee data and can be used as raw data for such recognition process. More likely the normal gait the abnormal gait exhibits certain patterns for joint angle except for hip-ankle data. In addition to the simulation results the Mean Square Error between trails values for all three figures are given in table 1.

Table 1. Mean Squared Error between trials for all three joint angles from figure 1 to 3

	M.S.E.		
	Ankle-Knee	Knee-Hip	Hip-Ankle
Figure 1	3.027E-4	8.564E-4	6.885E-4
Figure 2	0.0147	0.0262	0.028
Figure 3	0.0058	0.0215	0.0084

The M.S.E. can be viewed as an additional measure of similarity. As seen in Table 1 the M.S.E. values between trials give us idea about deviations for the abnormal gait from the normal one. Moreover very small values for figure 1 suggest the similarity between normal gait patterns for the subject 34. Nevertheless, spectral analyses using DFT provides a visual and precise methodology to recognize normal and abnormal gait and easier to implement compared to other methods involving gait recognition. A combination of some quantitative measures would greatly increase the reliability of this method. Such methods may involve Coefficient of Multiple Correlation (CMC) analysis and Wavelet Distance Measure (WDIST). We intend to investigate the performance based on more complicated and decisive CMC or WDIST in a future work.

4. Conclusion

In this paper an approach for abnormal gait detection employing DFT analysis has been presented. The results indicate that the joint angle combination in the frequency domain can be used to characterize abnormal gait. In order to make the algorithm more generic, a MSE analysis is also presented. An important question is the capability of detecting gait abnormality at higher harmonics. However, a more in-depth classification like indexing would provide a more valuable addition to any number of applications in the area of gait analysis. Future work will be the expansion of the detection introduced in this system to include abnormality detection instead of just an abnormal or normal detection that would prove to be a valuable addition for use in a variety of applications, including unobtrusive clinical gait analysis, automated surveillance in addition to a variety of others.

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