Spectral Characterization of Stride-to-Stride Variability in Children Gait Motion

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Abstract—In this paper, we present a study of stride variations and their dependency on human physical parameters and dynamics. We concentrated on the stride to stride intervals on 50 different subjects. The effects of age, height, weight, length of legs and the speed of walking are researched and analyzed against the stride time variations for each subject. It can happen that a subject during the initial and end stages of walking, display some non-uniform stride movements. So, in order to achieve a stable data for analysis, the initial and final samples of stride are truncated. It is understood that the variations in stride at consecutive steps denote instability in walking, which is considered as abnormal in case in adults. In case of children these studies help in assessing the progress in the stability of stride movements as the age progresses. The result of this study can be applied to enhance progress in stride stability by providing adequate feedback to the individuals. For example, for a young person, the analysis of weight against his stride stability may be used to help him control his food or to automatically adjust treadmill speed in Gymnasium. For a child this analysis may be used to anticipate/predict his stride stability in future and provide proper training to improve the irregular patterns according to the feedback. The first and second harmonics of the stride variations are considered for the analysis. The mean and standard deviation of these harmonics are calculated in time domain as well as frequency domain and are used in presentation of parameters. The mean values are analyzed against the age, height, weight and speed of all the subjects. The information contained in the spectral components of stride cycle and their correspondence with the physical parameters, are demonstrated with the help of different plots and parameters.

Index Terms—Gait Signal, Harmonics, Stride length, Spectral Analysis, Stride variations, Fast Fourier Transform

I. INTRODUCTION

The potential of gait as a biometric was proved on different databases including many subjects with multiple samples. For this purpose, we have chosen children maturation

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II. BACKGROUND AND RELATED WORK

Study of correlations between stride cycles and the physical parameters like age, height, weight had been done by many researchers at times. The variations in stride at consecutive steps denote instability in walking, which is considered as abnormal in case in adults. Chiraz Ben Abdelkader et al researched on the view-invariant estimation of height and stride for gait recognition [1]. The work presents a parametric method to identify people in a low resolution video by estimating the stride parameters namely the cadence and the height. Stride length and cadence are taken as stride parameters. A work by Hausdorff et al demonstrates a good analysis of stride variations in children. It states that mature stride dynamics will not be completely developed even in 7-yr-old children and also the different aspects of stride
dynamics attain maturation at different ages. Statistical and
temporal measurements are used in the analysis [6]. In another
work by Rajagopalan et al, a higher order spectrum approach
based on stride length for detecting human motion is described
[7]. Here the human video images are being analyzed. Gait
analysis has been carried out in the work by Mario Manca and
team, where the repeatability of protocol is described for gait
analysis in adult subjects [8]. Another work by Ahmed
Mostayed et al describes the abnormal gait detection and
analysis using Discrete Fourier Transform (DFT). The work
concentrates on analysis of joint angle characteristics in
frequency domain and harmonic coefficient recognition [9].
And it is not dealing with stride cycle variations as such. The
research by Liang Zhang and team presented a novel
constraint-based method to adapt the captured gait motions to
new paths while preserving the original gait style [10]. In another
research work, Alberto Ferrari et al, does a quantitative
comparison of five current protocols in gait analysis. Here
they present a comparison study about five worldwide
representative protocols by analyzing kinematics and kinetics
of gait cycles [11]. An analysis of the video content of humans
walking towards a camera, revealed the nonlinear nature of
fronto-normal human gait consequently the use of nonlinear
theory for automatic identification of humans gait is motivated
[8]. In another interesting work by Hyun G. Kang, the events of
walking speed, strength and range of motion on gait stability
in healthy older adults are discussed [9]. The study concentrates
on how age and walking speed affect independently the
dynamic stability during walking. It is also investigated if the
dynamic stability in old adults is improved by walking slower,
and how leg strength affected the stability of walking. The
research also states that the walking stability in both younger
and older adults is improved by slow walking, in spite of
increased variability. This measure of instability during walk
is a good indicator of future risk of fall [9]. The research by
Toby Weilun Lao demonstrates an approach to implement
estimation and recognition of human motion from video
sequences [10]. Jeffrey M Hausdorff published a work on methods and modeling for measuring the gait variability
[11]. The paper describes the study of stride-to-stride
fluctuations in walking, and how it offers a complementary
way of quantifying locomotion and its changes with aging [12].
There is another research paper by Valery B. Kokshenev on
the dynamics of human walking at steady speeds [12]. And T.
Karnikb presented a work about using motion analysis data for
foot-floor contact detection [13]. The major purpose of this work is to obtain the stride data almost instantaneously, but the work doesn’t deal with how the measured data can be interpreted effectively.

Even though there are many researches as described above
which propose and demonstrate methods to describe the
variations in stride cycle and its dependency on physical
parameters, we find there is still a scope for more study and
analysis to describe these dependencies systematically. Many
of the above researches do not concentrate on using the stride
intervals as a parameter for the study of gait motions; instead
do concentrate on other gait parameters. In some of them they

do work on the stride intervals, but that doesn’t describe in
detail the dependency on different physical parameters. We
present in this paper, some systematic study methods and
results regarding how the first and second harmonics of the
stride variations behave with respect to the age, weight, height
and velocity of the subjects.

III. METHOD FOR ANALYSIS

The stride to stride intervals of 50 subjects are taken from
children of ages between 3 years and 14 years. The time and
frequency contents are analyzed to get an overview about the
stride variations. We have used database available in
PhysioNet, an example of which is shown in the Table I [12].

<table>
<thead>
<tr>
<th>Subject-ID (1-50)</th>
<th>Age (months)</th>
<th>Gender</th>
<th>Height (Inches)</th>
<th>Weight (lbs)</th>
<th>Leg-length (Inches)</th>
<th>Speed (m/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
<td>M</td>
<td>40.5</td>
<td>43</td>
<td>23</td>
<td>1.04289</td>
</tr>
<tr>
<td>2</td>
<td>45</td>
<td>F</td>
<td>40</td>
<td>35</td>
<td>20</td>
<td>1.05322</td>
</tr>
<tr>
<td>3</td>
<td>47</td>
<td>F</td>
<td>39.5</td>
<td>35</td>
<td>21</td>
<td>0.98953</td>
</tr>
<tr>
<td>4</td>
<td>48</td>
<td>M</td>
<td>40</td>
<td>37</td>
<td>20</td>
<td>1.01551</td>
</tr>
<tr>
<td>5</td>
<td>49</td>
<td>M</td>
<td>39</td>
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</tr>
<tr>
<td>6</td>
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<td>F</td>
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<td>50</td>
<td>22</td>
<td>1.02284</td>
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<tr>
<td>8</td>
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<td>F</td>
<td>41</td>
<td>34</td>
<td>21</td>
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<td>F</td>
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<td>37</td>
<td>20</td>
<td>1.1377</td>
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<tr>
<td>10</td>
<td>54</td>
<td>M</td>
<td>44</td>
<td>41</td>
<td>22</td>
<td>1.05846</td>
</tr>
</tbody>
</table>

The time domain representation of a stride signal for a
subject of age 40 months and height 40.5 inches in which the
stride interval is given on y axis and the actual time of
occurrence of this stride on x axis is shown in Fig.1.
Similarly, the frequency spectrum of the same subject is plotted as shown in Fig.2, with the spectral amplitudes on y axis and the corresponding frequencies (rate of variations) on the x axis.

We customized the length of each subject to 400 samples in each subject, in order to ease our calculations. It can happen that a subject during the initial and end stages of walking, display some non-uniform stride movements. Some numbers of initial and final samples are truncated in the calculations, in order to avoid the possible unstable stride cycles during the start and end of walk.

In the next part of the analysis, the standard deviation of each subject in time domain is calculated. The measure of the standard deviation of stride intervals of each subject, with respect to its mean value gives good information about the stride variations.

And in the next step, frequency analysis is carried out. Frequency spectrum analysis is the standard method adopted for analyzing the dynamics of a stride pattern. For calculating the Fourier spectrum coefficients using FFT algorithms, we took the stride to stride interval as the time varying parameter. So a spectral representation of this data will imply how frequently the stride parameters are varying with respect to time. A non-overlapped window of length 64 is adopted to split the time sequence in to different blocks. This produces the number of analysis frames,

Number of Frames = Signal Length/Window Length

FFT algorithm is run for all the different frames one by one. The number of components in the FFT is calculated by measuring the next power of 2 from the Window Length. The DC Fourier component in the frequency spectrum is large compared to the fundamental and higher harmonics, thus it is not considered for study here. We firstly investigate the role of the fundamental and higher harmonic of order 2, taken for each frame.

Here we split up the analysis into multiple stages. In the first stage, we plotted the standard deviation of first and second harmonics of all the subjects. And the same is repeated for all the 50 subjects so that we get a list of the mean and standard deviation values for all the subjects. In the second stage, the spectral amplitudes of the first and second harmonics for all the subjects are studied. In the next stage, we studied the stride harmonics against the age groups, to see the dependencies of stride variation with respect to age of a subject. The next stage studies about the subject height and the harmonics and in further steps, about the subject weight, leg length and the velocity of movement of the subjects. In all the cases, the amplitudes of both the first and second harmonics are compared. At last the ratio of subject height to weight is studied against the harmonics and later the ratio of leg length to weight also. We use a database of the physical description about all the subjects for the above studies. This includes the age, height, weight, velocity information about all the subjects.

IV. RESULTS

The above methods are implemented in MATLAB using the datasets corresponding to 50 subjects, which are taken from children of ages between 3 and 14 years old. After applying the algorithms for statistical representation and spectral decomposition of stride data, we obtained a set of results which help in describing the dependencies of stride parameters with physical features like age, height etc.

We analyzed the mean value of stride variations for all the subjects as shown in Fig.3. In a detailed look at this plot, it is found that the mean value shows almost a gradual increase as the age progresses. For example, a 3 year old child shows an average stride interval of 0.9, whereas a 14 year old child shows an average value of nearly 1.2. If we look at these mean values in a different angle, we can also identify three different groups with close mean values; one group between 3 years and 5 years, a second group between 6.5 years and 8 years and a third group of ages between 11 and 14 years. In an overall viewpoint we can say that for this range of ages (children), we have roughly the same mean value.

Fig.4 shows a plot of standard deviation of the stride data in time domain with respect to each subject. The figure implies that more that 80% of the deviations are found within the value of 0.05 and there are only few random variations in case of some subjects. The subject numbers are selected and also plotted in the increasing order of ages.

Fig.2 Frequency Spectrum with Normalized Frequency
As seen in Fig. 5, children of ages till 8 years show a higher variation in stride cycle in comparison with the ages from 8 to 14 years. So we can state that, as the age increases we find a better stability in the stride variations of subjects.

Fig. 3. Mean Value of Stride Periods for Different Ages

We can see that the standard deviation of first harmonics components of the stride variations dominate in amplitude in comparison with second harmonics. This is the case for most of the subjects. This implies that more than 90% of the subjects exhibit a high amount of variations in stride to stride period at lower harmonics. Similar to the previous case, the subject numbers are selected and plotted in the increasing order of ages. So the plot also implies that, as the age increases, the first and second harmonics of stride variations show a better stability, since the deviations are lesser for the higher values of x axis.

Fig. 4. Standard Deviation of Subjects in Time Domain

Fig. 6 shows the result of applying the standard deviation in spectral domain. Standard deviation of the first and second harmonics of all the subjects is plotted by taking different window frames of each subject’s stride data. In the figure, the x axis represents the subject number and the y axis, the standard deviation of the spectral components corresponding to first and second harmonics. The blue color represents the first harmonics and red color represents second harmonics.

Fig. 5. Standard Deviation of Subjects in Time Domain with Respect to Age

Fig. 6. Standard Deviation of Spectral Components

As the next stage, we plotted the spectral amplitudes of the first and second harmonics directly against the subject numbers. In comparison with the previous step, we did not go...
for measuring the standard deviation. The response is as shown in Fig.7. We can see a similar result with increased stability in stride variations at the higher subject numbers.

![Graph showing Harmonics Amplitude Vs Subjects](image)

The difference in spectral amplitudes between the first and second harmonics is plotted as in Fig.8. It is visible from the figure that the difference in spectral amplitudes in majority is in positive direction. This indicates that the first harmonics of stride variations dominate in most of the cases in comparison with the second harmonics.

![Graph showing Difference in Harmonics Vs Subjects](image)

The next step gave us a result as shown in Fig.10. The plot represents different age groups along x axis and the harmonics of stride variation along y axis. There is a clear display of high variations in the spectral amplitudes between the age groups of 4 years and 8 years. And as seen before, as the age reached 10 years and above, there is a comparatively stable display of spectral amplitudes.

![Graph showing Harmonics Amplitude Vs Age Groups](image)

The figure we can see only few cases where the height of the $H(1)/H(2)$ axis going below the value 1.

![Graph showing Ratio of Harmonics $H(1)/H(2)$ Vs Subjects](image)

We used the height information of each subject in the next stage of analysis, to have a study with respect to the harmonics. We plotted the height of subjects in inches along x axis and the harmonics amplitudes along y axis, as shown in
Fig. 11. We noticed that there is a dependency for the stride variations on the height of subjects. As the height increases, the variations in stride interval get reduced. It is also noticed that the first harmonics of stride variations in almost all cases have higher amplitudes in comparison with the second harmonics.

In another step where the harmonics along y axis are plotted against the length of legs along the x axis, we got similar results as compared to the plot against heights of subjects. The leg lengths on the range 28 to 38 inches show a comparatively stable stride variation, in comparison with values less than 26 inches. In lower values, we get more variations, which is a sign of higher instability. As before, the first harmonics are again prominent as compared to the second harmonics. The same is visible in the plot Fig. 13.

In a similar study taking into account the subject velocities, we plotted the velocities along x axis against the harmonics as in Fig. 14. As seen in figure, we could not clearly conclude the dependencies due to some higher peaks even at higher velocities; but we see a higher concentration of peaks in the lower side of velocity axis. This implies that there is a possibility that, when the subject walks slowly, the probability of randomness in the stride duration is more. This may result in an unstable stride to stride interval at lower velocities.

In the next analysis, the ratio of height to weight of each subject is calculated. This ratio along the x axis is plotted against the signal harmonics along the y axis as shown in Fig. 15. As before the first harmonics are found higher compared to the second harmonics components. The important observation here is that, at lower values of height to weight ratio, we find a stable and lower spectral amplitudes. And at higher ratios, the stride spectral components are found unstable. In the lower ratio region, for example around the value 0.7, for the same values of height weight ratio, we find only slight variations in the stride spectral amplitudes. This variation is found less than 0.01. Whereas in the higher ratio region for example around 1.1, for the same values of the height weight ratio, the variations are more than 0.02.
The study of the spectral components of stride distance with respect to the ratio of leg length to weight is carried out as shown in the Fig.16. The response is found almost similar to that of the previous step using height to weight ratio. Around values of the ratio, for example 0.35, we find lesser spectral amplitudes in comparison with the higher values of the ratio for example around 0.53. This gives an indication that, if the leg length increases in a higher proportion with respect to the subject weight or, if the weight does not increase in a proper way proportion with respect to the leg length, the stride variations are found to be more. This indicates instability in walking.

V. CONCLUSION

From the above experiments and results, we conclude that, the dependency of stride to stride intervals on the physical parameters of the subject like age, height and weight, can be effectively represented using spectral methods. The spectral decomposition of the stride data helps in analyzing this systematically. The information gathered from this study can be properly used in a feedback system to improve the physical growth of the subject. For example, in case of a child this information can be used in assessing in the stride stability as the age progresses and possibly anticipate/predict his stride stability in future and provide proper training to improve the irregular patterns according to the feedback. A young person may be informed about his body weight control, whereby the food style can be optimized in order to achieve a better stride stability. This information can also be used to automatically adjust treadmill speed in Gymnasium. Developing some optimized algorithms for meeting these needs, shall be some possible future research works in the area.

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