Distribution of Slopes of Harmonics of Gait Power of Persons with and without Brain Damage

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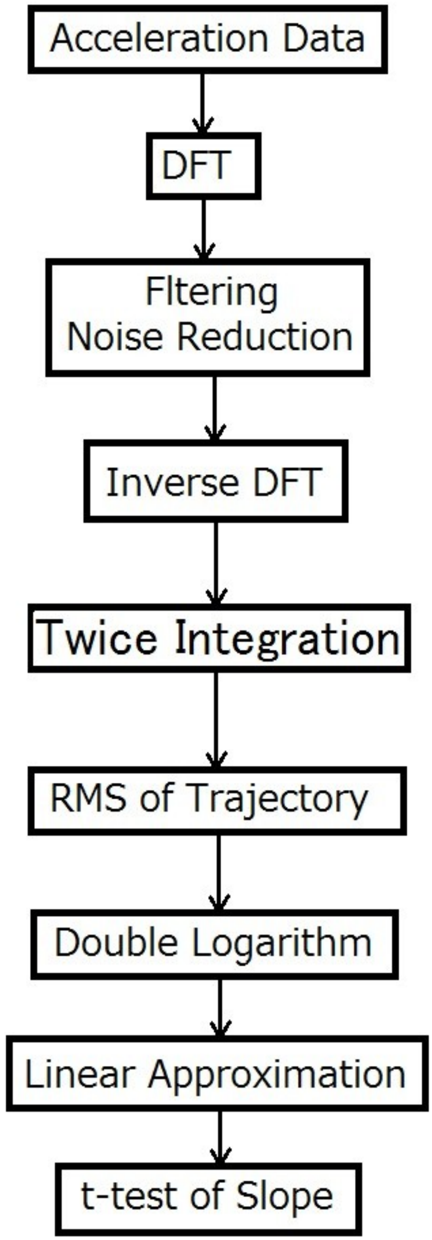

Abstract

A gait is one of indicators of health. We reported that the ratio of the step power per the stride power in Fourier transform harmonics of a gait shows a recovery from a damage of total hip replacement operation several years ago. Now we show that there are linear relations between power of harmonics of gait and the frequency in a double logarithmic chart. The slope values of the linear relations are different between groups with brain damage and without it in a double logarithmic chart. Coefficients of correlation were under -0.93. And its statistical significance level was 0.01(=1%).

1. Introduction

Most persons concern about health. Walking is one of barometer of health. Many researchers investigated about walks and gaits. B. Auvinet et al. [1] investigated the relation between accelerometer data and heel touch timing or else. M. Henriksen et al. [2] investigated relations between RMS (root mean square) of acceleration data and speeds of walks. T Herman et al. [3] investigated stability of walk of high-level gait disorder (HLGD) cases. S. A. England et al. [4] investigated relations between stability

Figure 1. Block Diagram

Figure 1 shows the block diagram of the proposed method. First the time sequences of acceleration data of a human body are acquired by an accelerometer. Next the time sequences are transformed to a frequency distributions by DFT (discrete Fourier transform). The noise in the frequency distributions are reduced by filtering. Then the frequency distributions are transformed to a time sequences of trajectories of a human body by inverse DFT. Trajectories are different by the harmonics upper limit h. The RMS (root mean square) of distances of trajectories of different h is calculated. The RMS values are plotted on to a double logarithm chart. The plotted results are almost straight lines and their correlation coefficients are under 0.93. The slope values of the lines of patients with brain disease are different from those of normal persons. A

2.1. Acceleration Data

Figure 2 shows a sample of time sequence of acceleration data $\boldsymbol{a}_i(t)$ measured by an accelerometer worn on a human waist .

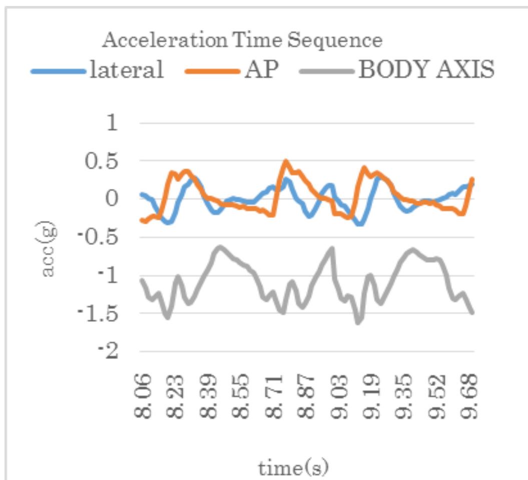

Figure 2. Acceleration Time Sequence

Data $\boldsymbol{a}_i(t)$ is a 3-D vector and changes along time t. The number i indicates the i-th person.

2.2. DFT

Data $\boldsymbol{a}_i(t)$ in Figure 2 are transformed to $\boldsymbol{b}_i(f)$ shown in Figure 3 by DFT. The value f indicates a frequency. Distribution is a series of 6-D vectors(3 complex numbers).

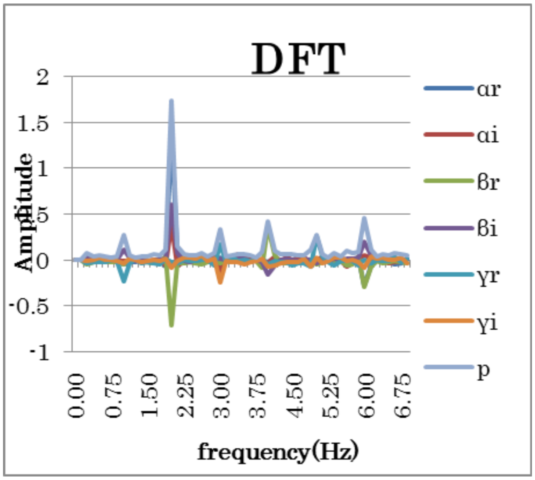

Figure 3. DFT

The value p in Figure 3 indicates the length of a 6-D vector. There are several peaks in Figure 3. The peak at about 0.88 Hz is the first one. The next peak at about 1.75 Hz is the second one. Then the third and the fourth peaks follow after them.

2.3. Filtering

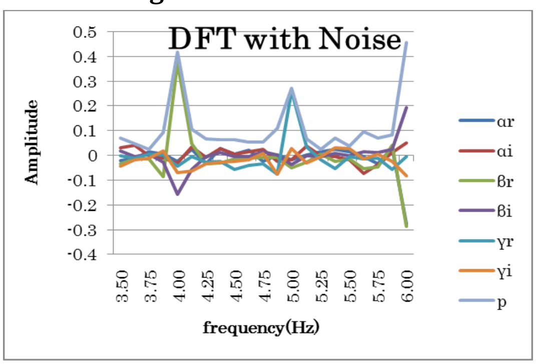

Figure 4. DFT with Noise

Figure 4 shows a distribution from the 4th peak to the 6th peak. There is noise between peaks. Band-pass filtering reduce the noises to 0 between peaks like Figure 5. Side bands aren't reduced.

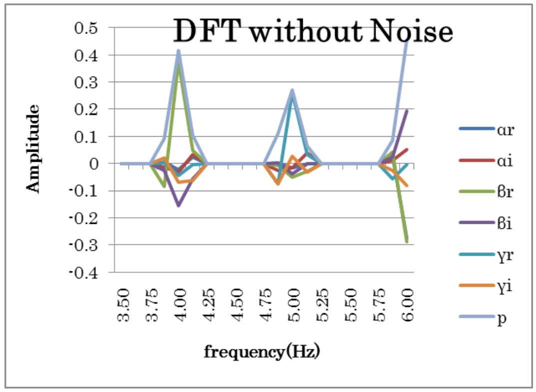

Figure 5. DFT without Noise

Figure 5 shows a distribution after filtering. Then peaks are segmented individually like Fogure 6.

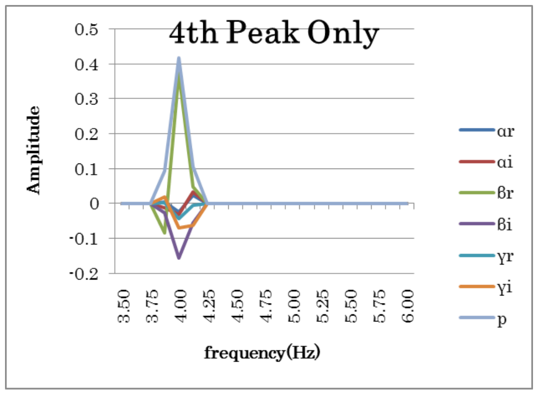

Figure 6. Indivitualy Segmented DFT

Figure 6 shows d $\boldsymbol{c}_i(h,f)$. The integer value h indicates the h-th peak. Summation from $\boldsymbol{c}_i(1,f)$ to $\boldsymbol{c}_i(h,f)$ is $\boldsymbol{d}_i(h,f)$.

2.4. Inverse DFT and Twice Integration

Figure 7 shows the coronal (frontal) trajectory view of a human waist trajectory $\boldsymbol{e}_i(6,t)$ during walking after transform (inverse DFT) and twice integration from $\boldsymbol{d}_i(6,f)$..

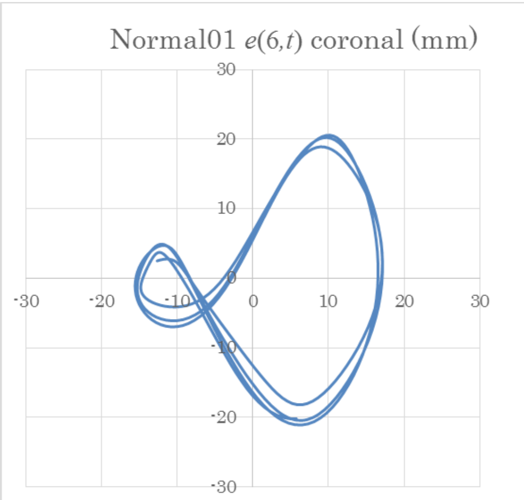

Figure 7. Trajectory $\boldsymbol{e}_i(6,t)$

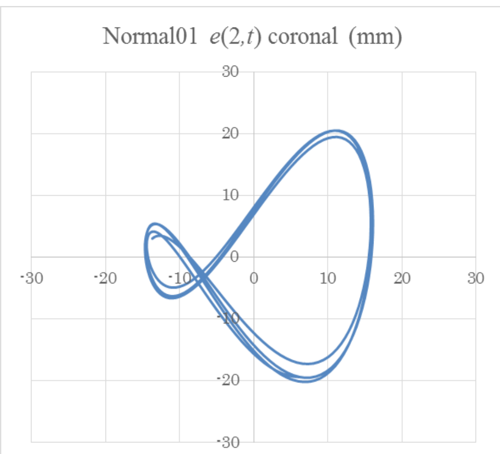

Figure 8. Trajectory $\boldsymbol{e}_i(2,t)$

Figure 8 shows the $\boldsymbol{e}_i(2,t)$. The $\boldsymbol{e}_i(7,t)$ is almost the same to the $\boldsymbol{e}_i(6,t)$. Then we ignore $\boldsymbol{e}_i(h,t)$ $(h \geqq 7)$.

2.5. RMS of Trajectory

Figure 7 and Figure 8 are slightly different from each other. The difference is caused by the sum of the powers from $\boldsymbol{c}_i(3,f)$ to $\boldsymbol{c}_i(6,f)$. We defined the difference from $\boldsymbol{e}_i(h,t)$ to $\boldsymbol{e}_i(6,t)$ as $\boldsymbol{g}_i(h,t)$. And we calculated RMS of $\boldsymbol{g}_i(h,t)$ in a stride cycle.

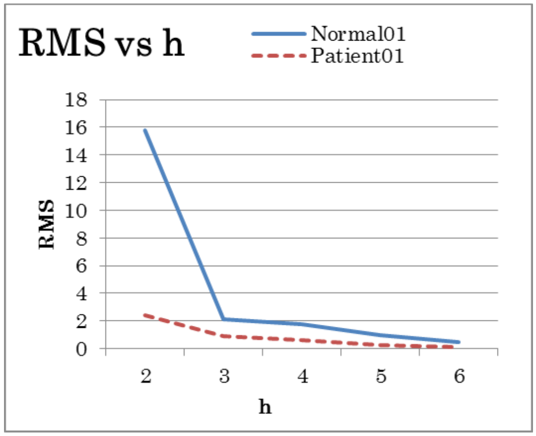

Figure 9. RMS of $\boldsymbol{g}_i(h,t)$

Figure 9 shows RMS of $\boldsymbol{g}_i(h,t)$ of a normal person and a person with disease. The results are not linear.

2.6. Double Logarithm and Linear Approximation

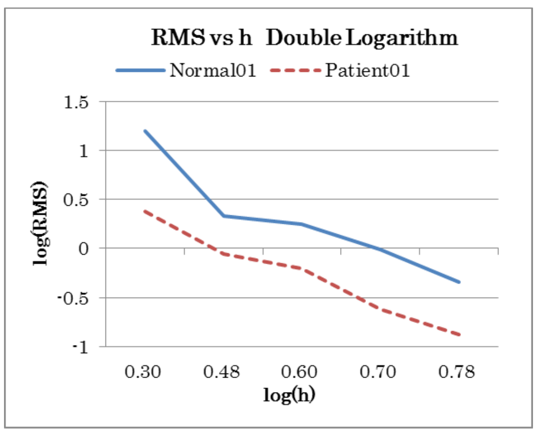

Figure 10. Double Logarithm of RMS

Figure 10 shows the double logarithm chart of RMS vs h. The plots seam as lines. We approximated them to lines as shown in Figure 11. And we calculated their correlation coefficients.

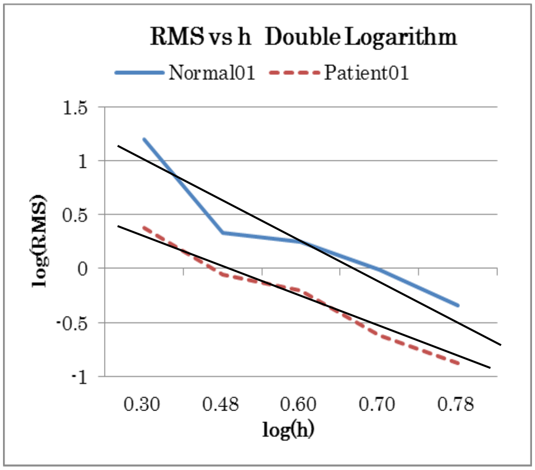

Figure 11. Line Approximation

2.8. Distribution of Slope of Approximated Line

We calculated the slope values of approximated lines in Figure 11. We compared the slope values of person with brain disease and ones of normal persons.

3. Experimental Result

We gathered 10 walking acceleration data of normal persons and 10 walking acceleration data of persons with brain disease.

3.1. Correlation Coefficient

The correlation coefficients of both groups are very near to -1.

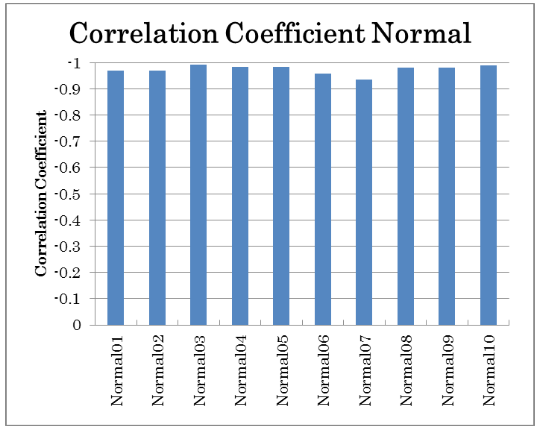

Figure 12. Correlation Coefficient Normal

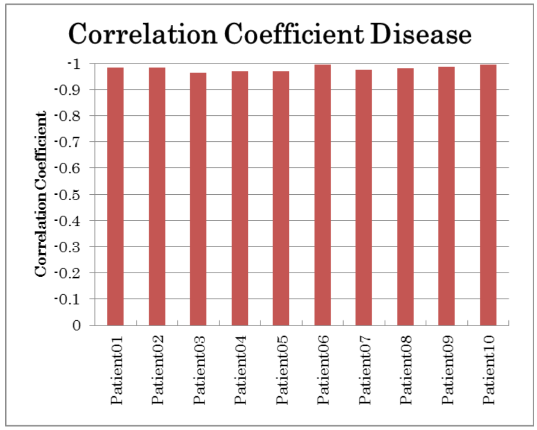

Figure 13. Correlation Coefficient Disease

Figure 12 and 13 shows correlation coefficients of double logarithm plots of normal group and disease group respectively. Both of them are very near to -1. they are almost under -0.962 and over - 0.993. Only a coefficient of Normal07 was -0.932.

3.2. Slope

Figure 14 shows the distribution of slope values of two groups. The left half of the graph is a normal group. The right half is a disease group. Almost values of normal group were under -2.8 but 1 value was over -2.8. Almost values of disease group were over -2.8 but 2 values were under -2.8. So if we use -2.8 as a threshold value there are 3 errors in 20 samples.

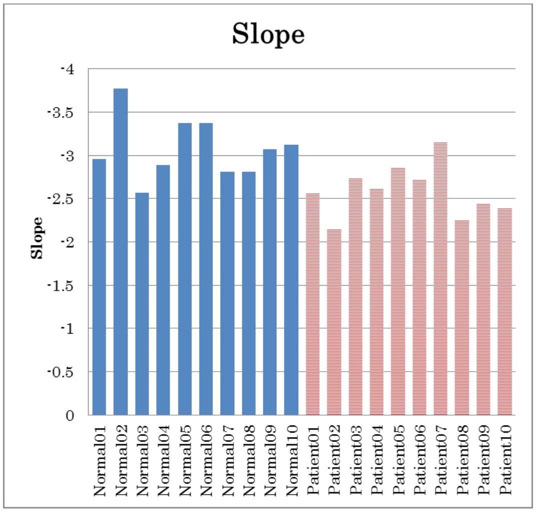

Figure 14. Slope values

3.3. T-test of slope distribution

We calculated t value of the result of two groups in Figure 14 for t-test. The t value was 3.35. The inverse t function value (both side) of (0.02, 18) was 2.55. 3.35 > 2.55. 0.02 / 2 = 0.01 = 1%. Then the two groups are different with significance level 1%.

4. Consideration

If the powers of peaks of acceleration in a frequency distribution (Figure 1) are the same, the powers are divided by ω^2. ω is an angular speed and is proportionate to frequency f and also to the peak number h. So the power of $\boldsymbol{g}_i(h,t)$ is proportionate to $1/\omega^2$. Then the slope value is -2. The value of slope of Patient02 is near -2. We assume that the peak values of Patient02 in frequency distribution are the same to others. If the peak values reduces along to $1/h^2$ the power of $\boldsymbol{g}_i(h,t)$ is proportionate to $1/h^4$. The slope value of Normal02 in Figure 14 is near -4 then we think that the acceleration peak values of Normal02 in frequency distribution reduces along $1/h^2$.

But we cannot explain the reason of linearity of the double logarithm chart in Figure 10 and the result of Figure 12 and Figure 13.

We could gather data of 20 persons. But they are few. We could not take out the effect of difference of age, body size, sex and other parameters.

It is uncertain that the results are unique about normal and brain disease. We must investigate cases of other disease.

Threshold value of slope is not so accurate. A combination with other values may allow us to discriminate a normal group and a brain disease group.

5. Conclusion

We found a linear relation between harmonic number h and the power of recovered motion from acceleration data of human walk. Also the difference of slope values of the lines have statistical significance between a normal group vs a brain disease group. In future we will investigate more data including other disease groups.

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