

Abnormal-Gait Based Auxiliary Diagnosis System for Parkinson's Disease



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Received 13 January 2019; Revised 5 March 2019; Accepted 12 March 2019

Abstract. Parkinson's disease as a neurological disease affects the patient's gait. It is very dangerous for the Parkinson's patient to have panic gait and freezing of gait (FOG). With the development of medical technology, Parkinson's disease can be well controlled, so that the early diagnosis of abnormal gait of patients has caused widespread concern. We design a auxiliary diagnosis system based on abnormal gait. Through the study of linear regression and wavelet transform, we finally successfully detect the patient's panic gait and freezing of gait (FOG). The average detection error of the step length is 3.17cm, the sensitivity of FOG detection is 90.2% and the specificity is 88.0%. The test results show that the abnormal-gait based auxiliary diagnosis system for Parkinson's disease can help doctors to diagnose the patient's symptoms and has a good application prospect.

Keywords: auxiliary diagnosis, FOG, linear regression, panic gait, wavelet transform

1 Introduction

Parkinson's disease is a common neurological disease [1], that the most people with are elderly people. The number of patients in China has reached more than 2 million, and the prevalence rate is increasing and tending to be young. The disease seriously affects the quality of life of patients and the abnormal gait is extremely harmful. The symptom of panic gait is that you will be faster and faster while walking, and it cannot be easily stopped. The other kind of abnormal gait is freezing of gait (FOG), which means that when walking, it is suddenly unable to move, and the feet seem to stick to the ground [2]. Abnormal gait is dangerous for the patient, so we need to find it as soon as possible. For this reason we design a auxiliary diagnosis system based on abnormal gait to detect the recovery of the patient and to assess the severity of Parkinson's disease patients.

Prior to this, people had done some work on Parkinson's abnormal gait detection. Marianna Amboni found that the step length of Parkinson's disease patients changed over the past three years [3], which provides a way for us to detect the panic gait. Marc Bächlin designed a wearable detection system for freezing of gait (FOG) [4]. In the paper three third-axis accelerometers are placed in shank (above the ankle), the thigh (above the knee) and the lower back of the patient. He used the PSD of the signal obtained by the FFT to detect FOG events. At the same time, he published his database DAPHNet [4]. This paper also uses the DAPHNet database for verification. In addition, many other wearable devices such as force sensitive insoles are designed to detect Parkinson's gait [5]. At present, most researchers only study FOG, and few researchers study panic gait. Therefore, we have proposed a method to detect panic gait, and we have got a good effect using wavelet transform to detect FOG.

In the first section, we mainly introduce the symptoms and related work for Parkinson's abnormal gait. In the second section, we introduce the composition of the auxiliary diagnosis system based on abnormal gait and the implementation of the system. In the third section, we analyze and summarize the system. The fourth section is our acknowledgement.

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2 Auxiliary Diagnosis System

The auxiliary diagnosis system consists of a detection board and a computer. In Fig. 1, the three-axis accelerometer transmits the original signal to the Bluetooth module, whose sampling frequency is 100 Hz. And then the Bluetooth module filters out the high frequency interference signal and transmits the processed data to the computer. In the end the computer processes the waveform in a 256-points sliding window, which in the window are detected whether a FOG event and a panic gait event.

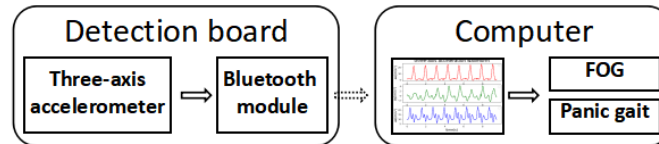


Fig. 1. Auxiliary diagnostic system

This paper will introduce the auxiliary diagnosis model of panic gait and FOG separately. The model of panic gait is based on linear regression [6], and the step length is fitted by the acceleration and step frequency. The gait of the patient is diagnosed according to the step length and the change of the step frequency. The auxiliary diagnosis model for FOG is based on wavelet transform to extract the characteristics of normal gait and FOG, and then analyzes the energy of wavelet coefficients at different scales to detect FOG events.

2.1 Detection Board for Parkinson's Abnormal Gait

The auxiliary diagnostic system consists of a detection board and a computer, wherein the detection board includes a three-axis accelerometer, a Bluetooth module, and a power supply. We placed the detection board on the shoe, as shown in Fig. 2. The direction the person facing is the positive direction of the X-axis.

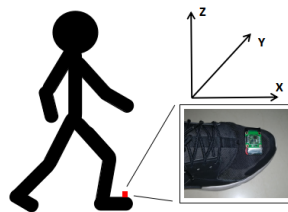


Fig. 2. The position of detection board and the direction of the third-axis acceleration

2.2 Auxiliary Diagnostic Model for Panic Gait

Experimental data and methods. The symptoms of panic gait are getting faster and faster, and the step length is getting smaller and smaller. Therefore, this paper proposes the model to detect the step frequency and the step length of the wearer. We used this system to collect 60 sets of gait data from 60 experimenters. Each experimenter kept the step as evenly as possible and walked 40m in a straight line. We record the number of steps and the data of the filtered three-axis accelerometer. Fig. 3 is a waveform from three-axis accelerometer while an experimenter is walking. The two maximums indicate that the wearer has taken a step (the experimenter took one foot to take the foot again). We exclude the two samples, where the waveform distortion may be caused by the looseness of the sensor, and then divide the samples into training sets and test sets. The remaining 58 sets of data are divided into training sets and test sets. The number of samples in the training sets is 44 and the number of samples in the test sets is 14.

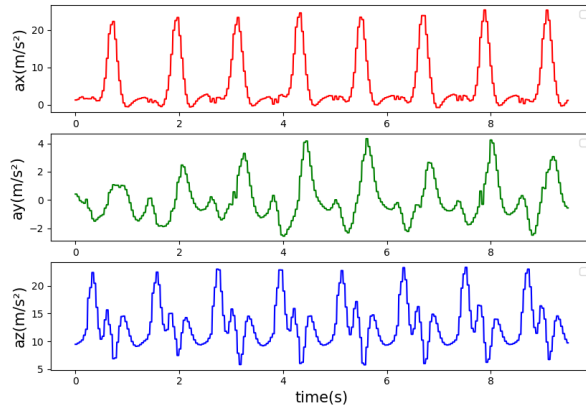


Fig. 3. The waveform from three-axis accelerometer

Step length and step frequency model. The walking frequency of a person is usually 0.5-5 Hz. The system sets a sliding window with 256-points and a step size of 64-points and then analyze the acceleration waveform in the window. Combine the acceleration in the x-axis, y-axis, and z-axis:

$$a(k) = \sqrt{a_x(k)^2 + a_y(k)^2 + a_z(k)^2} \quad (1)$$

Fig. 4 is a waveform from acceleration synthesized by Fig. 3. $a(k)$ has a maximum value in one period. The waveform between the two maximums indicates one step.

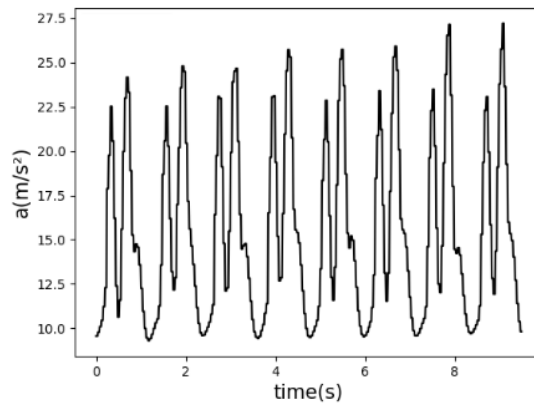


Fig. 4. The combined waveform from three-axis accelerometer

It can be seen that there are other extreme point in one period, so maximum detection is required. Judge whether $a(k)$ satisfies:

$$\begin{aligned} a(k-1) - a(k) &< 0 \\ a(k+1) - a(k) &< 0 \\ a(k-5) - a(k) &< 0 \\ a(k+1) - a(k) &< 0 \end{aligned} \quad (2)$$

The qualified $a(k)$ is the extreme point, and the extreme points due to noise is excluded. Sort all extreme points in time, placing $a(k)$ and the corresponding time t into $a[]$ and $t[]$ and then find the maximum $a_{\max}=a[i]$ and calculate the period N :

$$N = t[i] - t[i-2] \text{ or } N = t[i+2] - t[i] \quad (3)$$

The step frequency F :

$$F = 1/N/f = f/N \quad (4)$$

And the length of size L:

$$L = S/n \quad (5)$$

Assume that the model is:

$$L = \theta_1 * F + \theta_2 * a_max + \beta \quad (6)$$

The 44 sets of training sets L, F, and a_max are fitted to the model, and the model is obtained as follows:

$$L = -20.05 * F + 3.82 * a_max + 78.84 \quad (7)$$

The remaining 14 sets of sample were put into the model for testing. The test results are shown in Fig. 5. The average error of the test data is 3.17 cm. The step frequency can be directly obtained from the accelerometer waveform, and the error can be neglected.

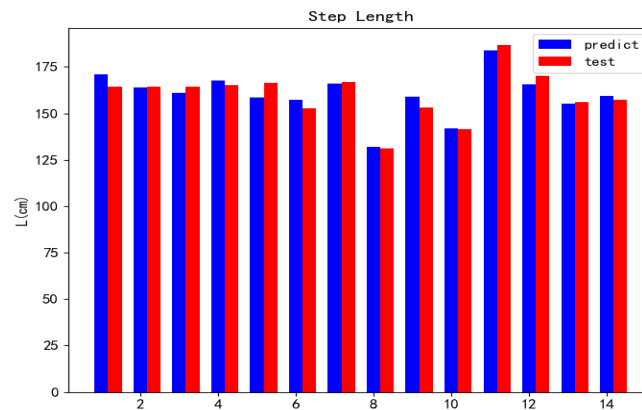


Fig. 5. The result of test set

2.2 Auxiliary Diagnostic Model for FOG

Experimental data. This experiment used the DAPHNet database, which was collected by the gait and neurodynamics laboratory of the Neurology Department at Tel Aviv Sourasky Medical Center. There were a total of 10 FOG data for PD patients. Three third-axis accelerometers are placed in shank (above the ankle), the thigh (above the knee) and the lower back of the patient. The data of the nine channels was recorded, which also gives the label of FOG and the normal gait. Fig. 6 is the data for a channel accelerometer for Parkinson's patient, the label is below the waveform. Our auxiliary diagnostic model selects the experimental data of channel 3 for verification.

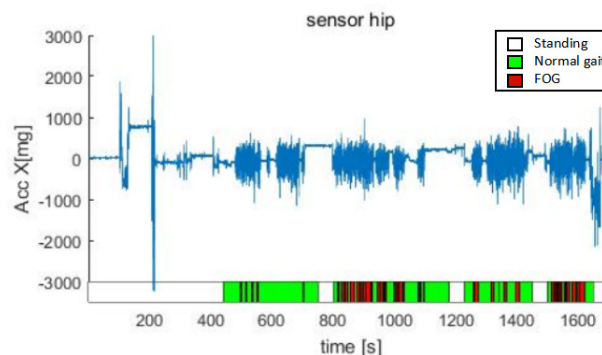


Fig. 6. The waveform of channel 3 for Parkinson's patient

Wavelet transform. Wavelet transform (WT) is a new transform analysis method. It inherits and develops the idea of localization of short-time Fourier transform. At the same time, it overcomes the shortcomings of window size and frequency variation, and can provide a change with frequency. The "Time-Frequency" window is an ideal tool for signal time-frequency analysis and processing. Its main

feature is that it can fully highlight some aspects of the problem through transformation, and can localize the time (space) frequency, and finally achieve time subdivision at high frequency and frequency subdivision at low frequency. The wavelet transform can automatically adapt to the requirements of time-frequency signal analysis, so that it can focus on any detail of the signal and solve the difficult problem of Fourier transform [7]. Wavelet transform has been widely used in the analysis of discrete random signals, such as muscle electrical signals [8].

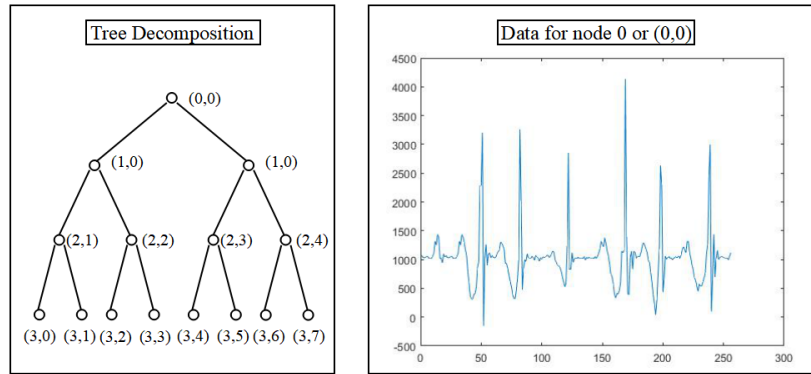


Fig. 7. Wavelet packet tree decomposition

Model. Set a 256-points sliding window with the step size of 64-points, and use the label of the last point in the window as the label of the window. The wavelet transform is used to extract the gait characteristics of the current window. Select db3 as the wavelet packet base, the number of wavelet packet decomposition layers is 3, the original waveform is decomposed into 8 nodes, and then obtain the coefficients of 8 nodes, which determines the frequency domain information. The left node in the wavelet packet tree is the low-pass filtering of the previous node, and the right node is the high-pass filtering of the previous node. Fig. 7 shows the waveform tree decomposition form and the waveform of (0,0) (original waveform).

The coefficients of each node are squared and then summed to find the energy $E[i]$ of each node. Normalize the energy of each node and find the total energy E_{total} :

$$E_{total} = \sqrt{E[1]^2 + E[2]^2 + E[3]^2 + E[4]^2 + E[5]^2 + E[6]^2 + E[7]^2 + E[8]^2} \tag{8}$$

Find each node $Er[i]$:

$$Er[i] = E[i]/E_{total} \tag{9}$$

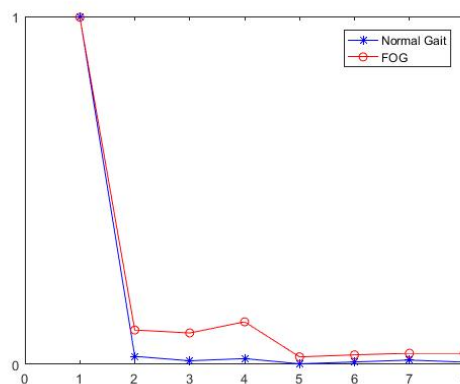


Fig. 8. Er of FOG

Fig. 8 shows the Er of the window. $Er[5]$ is 0.0074194 in the example of FOG, and $Er[5]$ is 0.0015463 in the example of normal gait. It was found that when FOG event occurs, $Er[5]$ will be bigger than in the normal gait. Through experiments, we found that it is efficient to set the threshold 0.002 to distinguish

between FOG and normal gait on the database. We predict whether each window is a FOG event, if it is a FOG event, mark the event as 1, if not mark the even as 0. All gait events of a patient are measured , which can count The sensitivity and specificity of a patient. Fig. 9 shows the test for patients No. 5 and No. 7, “label” is the calibrated data and “test” is the result of the test. The test sensitivity of patient 5 is 91.0% and the specificity is 87.0%. The test sensitivity of patient 7 is 88.0% and the specificity is 93.0%. The system Everyone in life has different walking patterns, so in order to obtain higher specificity and sensitivity. We can fine tune the threshold of the wavelet packet energy or select the Er of other nodes.

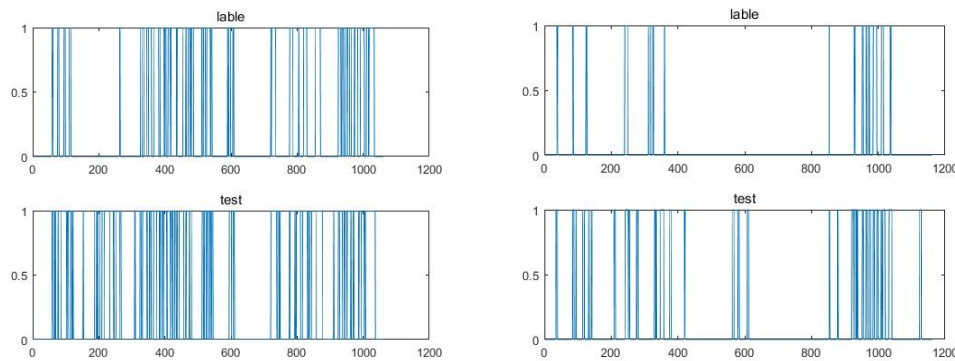


Fig. 9. Test for patients No. 5 and No. 7

3 Conclusion

Abnormal-gait based auxiliary diagnosis System for Parkinson’s Disease can detect both the panic gait and the FOG. In the Auxiliary diagnostic model for panic gait, the step frequency can be directly obtained from the accelerometer waveform, whose error can be neglected, and the average error of the model in the step length detection is 3.17cm. In the auxiliary diagnostic model for FOG, the average sensitivity is 90.2%, and the specificity is 88.0%. In addition, the use of the system is very easy. The detection board is fixed on the shoe, and the data of the collected three-axis accelerometer is sent to the computer automatically by Bluetooth, and the computer determines whether it is a Parkinson’s abnormal gait. The innovation of this paper is that we have proposed two abnormal gait detection methods. What’s more we use wavelet transform in the detection of FOG, it is very simple to detect FOG, and the accuracy can reach 90.0%. The system can assist doctors to diagnose Parkinson’s disease and has a good application prospect.

In the next stage, we will go to the hospital to test the effect of the system in Parkinson’s patients, and use this system to collect the three-axis accelerometer data of Parkinson’s patients to test the FOG detection model. In addition, there are many models of Parkinson’s gait detection. After collecting more data samples, consider using deep learning to fit the step length and detect FOG.

Acknowledgements

The work was supported in part by National Natural Science Foundation of China (Grant number 61871339, 61971365), the Key Laboratory of Digital Fujian on IOT Communication, Architecture and Security Technology (No. 2010499), and Xiamen Science and Technology Plan Project (No. 3502Z20183008).

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