Gait Analysis and Classification of Restricted Knee Based on Electrostatic Sensing

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ABSTRACT

This paper presents a technique of restricted knee gait analysis and classification based on electrostatic sensing, which can be applied in home nursing of patients with exercise rehabilitation. The technique is used to monitor the electrostatic signals generated during the movement of the human body, extract the gait features under restricted knee conditions, and classify the limited angles of the knee joint to evaluate the condition of rehabilitation of the knee in family environment. This may provide a theoretical basis for the treatment of diseases of the knee rehabilitation. This paper is helpful to establish a new technique to evaluate the rehabilitation degree of knee joint disease. It has the advantages of small size, easy to use and suitable for family promotion. It has a good application prospect in family wisdom medical field.

Keywords: gait analysis, human body static, knee rehabilitation, wisdom medical

1 INTRODUCTION

Human gait affected by the body's joint damage, deformity, nervous system diseases, mental state and other factors. In the field of rehabilitation medicine by monitoring the gait activity, gait analysis and gait behavior of the comparative study, the knee can be rehabilitated to assess the situation. At present, the access to human gait information is divided into the following three categories: based on computer vision, based on plantar pressure and based on surface electromyography. The most widely used method based on computer vision. By shooting 31 patients with knee osteoarthritis and 31 members of the control group gait, Baliunas analysis showed that patients have imaging of knee osteoarthritis performance, the control group without this clinical manifestations. Bauckhage C, and Giakas et al. Demonstrated the differences in the gait characteristics of healthy and knee patients in combination with time domain and frequency domain analysis after verifying the stability and symmetry of ground reaction in walking. In 2008, Wu Jianfeng, Zhejiang University [6] used the wavelet analysis method to establish the mapping relationship between the eigenvalues of surface EMG signals and the type of lower limb movements.

Although these three methods can be measured the angle of the lower limb joints when the human body walking, but that can not be used in the family environment because it need for special equipment. In this paper, a knee joint gait analysis and classification based on electrostatic detection is proposed, which can be used in home care of patients with sport rehabilitation. The technique is used to monitor the electrostatics signals generated by the footsteps of human movement, to extract the gait characteristics under the restricted knee condition, to classify the knee joint angle, and to evaluate the knee rehabilitation in the home environment.

2 ANALYSIS AND SIMULATION OF ELECTROSTATIC CHARACTERISTICS OF HUMAN GAIT

The human body in the daily activities of the inevitable contact with the various objects and separation, resulting in the body charged. The charged body can disturb the space electric field during the movement, and can obtain the movement information of the human body by measuring the disturbance of the space electric field.

2.1 Electrostatic Charging Mechanism and Electrostatic Characteristics of Gait

The human body itself is an electrostatic conductor, and the human body by the clothing, footwear and other insulating materials wrapped, the body and the earth can be seen as two capacitors plate. As shown in Figure 1, when the human body be in walking (or running), the feet alternately lift off the ground, the capacitance between the lift feet and the earth, the equivalent of the capacitor in series with a parallel plate capacitors which an area of S_S, feet off the ground height distance for the h (t), and the medium is air (dielectric constant ε_a). Its value is:

$$C'_f = \frac{C_f C_s(t)}{C_f + 2C_s(t)} \tag{1}$$

Among them, C_f is capacitance of the feet to the ground.

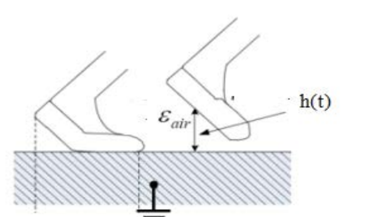

Figure1: the capacitance diagram between the foot and the ground when the human body walking

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The total capacitance of the body to ground can be obtained :

$$C_B(t)=C'_f+C_r+\frac{C_f}{2}=\frac{C_fC_s(t)}{C_f+2C_s(t)}+C_r+\frac{C_f}{2} \tag{2}$$

C_r is the capacitance of other parts of the body and the surrounding environment.

It can be seen that the capacitance of the walking body to the earth will be ever-changing, which will lead to the corresponding changes in the electrostatic field around the body. So we can use the non-contact detection plate to obtain the body movement generated by the electrostatic induction signal, and extract the corresponding human motion characteristics.

2.2 Electrostatic characteristics of human body gait

When electrostatic signal of human body gait to be detected, the electrostatic induction current which generated in the non-contact detection plate by the human walking body by can be expressed by the literature [7]:

$$i(t)=\frac{\varepsilon_a S}{\sqrt{x(t)^2+y(t)^2}}I(t) \tag{3}$$

among them: $I(t)=i_1(t)+i_2(t)$

$$i_1(t)\propto\begin{cases}\dfrac{\pi f_a x_0\sin 2\pi f_a t}{S_0}, nT\le t\le nT+\beta T\\ \dfrac{2\pi x' f_s\sin(2\pi f_s t+\pi)}{S_0(1-\cos 2\pi f_s t)+2\Delta s}-\\ \dfrac{2\pi x' f_s(1-\cos(2\pi f_s t+\pi))\sin(2\pi f_s t)}{(S_0(1-\cos 2\pi f_s t)+2\Delta s)^2},\\ nT+\beta T\le t\le(n+1)T\end{cases} \tag{4}$$

In equation (4), $i_1(t)$ and $i_2(t)$ are the electrostatic induction current generated by the two-leg movement on the non-contact detection plate. Δt is the time difference between the two feet alternating movement. β is the ratio of the swing period of the lower limbs to the gait cycle during walking. f_a and f_s are the movement frequencies of the lower limbs during the swing and support periods, respectively, which is inversely proportional to the ratio of the gait cycle.

The electrostatic signal of the human gait are simulated according to the formula (4), among which the parameter value are： $\beta=0.4$, $f_a=2.5Hz$, $f_b=1.66Hz$, $S_0=150cm^2$, $\Delta t=0.5s$, $\Delta s=15cm^2$, $x_0=20cm$, $x'=2cm$, $y(t)=1m$. We can get the simulation waveform shown in Figure 2.

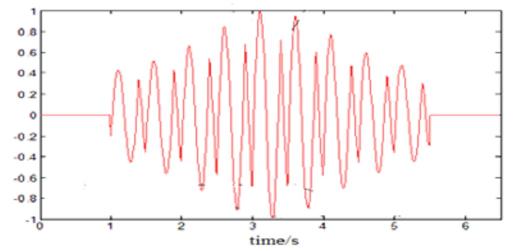


Figure 2: Simulation waveform of walking human gait electrostatic signal

It can be seen from the simulation results that the electrostatic induced current waveform generated on the non-contact detection electrode when walking the human body is followed by a lower peak of the amplitude after the main peak with higher amplitude. This is due to the characteristics of the human footsteps with bipedal support. During this period, the feet are in the fall of the soles and the heel of the movement state, so the lower limb movement generated by the electrostatic induction signal superposition effect makes the non-contact electrostatic detection system to obtain the signal appears sub-peak waveform.

3 HUMAN GAIT ELECTROSTATIC SIGNAL ACQUISITION

In order to obtain the electrostatic signals when the human body is walking for human gait analysis, an electrostatic detection sensor is designed to measure the rate of change of electric field intensity. Electrostatic detection sensor block diagram is as follows：

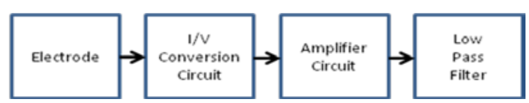


Figure 3: Block diagram of electrostatic signal detection sensor

In the experiment, the knee joint angle controller was given to the normal person and the activity angle of the knee joint was controlled, which indicated that the degree of rehabilitation of the patient with knee disease was normal gait, restricted gait and semi-restricted step state.

The human body gait electrostatic signal detection sensor placed on the 1m high tripod, the selection of six healthy, nervous system and exercise system were normal healthy people as the test personnel to the normal walking speed around the detection sensor to walk. During this process, the distance between the test subject and the detection electrode is maintained at 1.5 m. Using the oscilloscope to get the human body step static signal. The experimental scenario is shown in Figure 4.

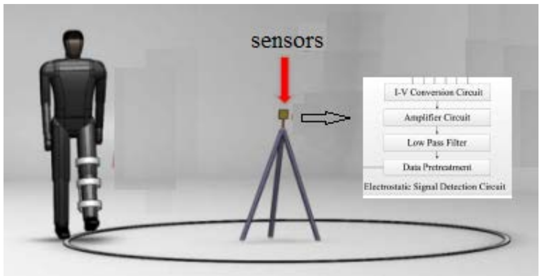


Figure 4: Experimental scene of human gait electrostatic signal acquisition

The six testees' legs were put on the knee angle controller and allowed to walk in three knee joints. The three cases shown in Figure 5 control the knee joint movement angle of 150 degrees (normal gait), 0 degrees (limited gait) and 30 degrees (semi-restricted gait). Experiments were conducted by the test personnel around the electrostatic detection sensor to keep a circular route uniform speed, where the circular route radius of 1.5m. Each experiment requires the subject to walk five laps.

a normal gait b limited gait c semi-restricted gait

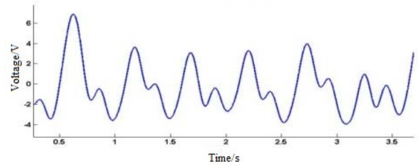
Figure 5: The three cases of control the knee joint movement angle

4 FEATURE EXTRACTION AND CLASSIFICATION RECOGNITION OF HUMAN BODY GAIT ELECTROSTATIC SIGNAL

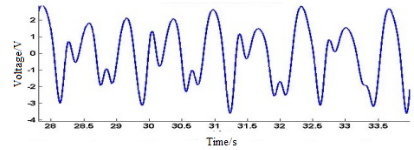
The data collected by the experiment are filtered and FFT preprocessed, then the characteristic parameters are extracted by PCA, and the three gait types are identified by K nearest neighbor method

4.1 Human body gait electrostatic signal data preprocessing

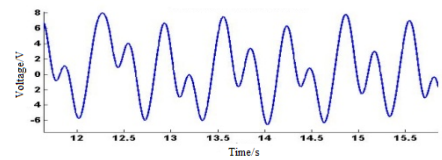
Because of the existence of external noise, it has some difficulties in signal recognition. Therefore, this paper designs FIR digital filter to remove noise interference. After the signal filtering processing three gait electrostatic signals shown in Figure 6.



a Filtering the human normal gait electrostatic signal



b Filtering human restricted gait electrostatic signals

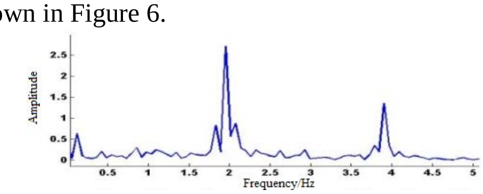


c Filtering human semi - restricted gait electrostatic signals

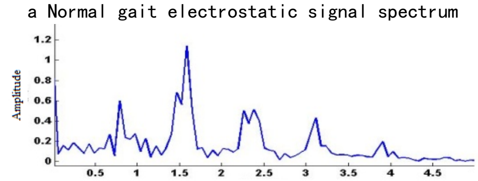
Figure 6: Three kinds of electrostatic signals of human gait after filtering

It can be seen from the figure in the restricted gait electrostatic signal waveform, there have been sub-peak and no secondary peaks of the waveform alternately generated phenomenon. In the waveform of the semi-restricted gait electrostatic signal, although the sub-peak appears in each waveform, the sub-peak is not obvious enough to quantify the data compared with the normal gait signal. In this paper, the spectral characteristics of human gait electrostatic signals are further analyzed from the frequency domain.

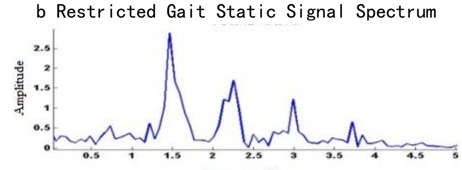
The human body gait electrostatic signals were obtained by FFT of the three kinds of knees in the experimental case, as shown in Figure 6.



a Normal gait electrostatic signal spectrum



b Restricted Gait Static Signal Spectrum



c Semi - restricted gait electrostatic signal spectrum

Figure 7: Three kinds of human gait electrostatic signal spectrum

It can be seen from the figure 7 that the peak frequency of the normal signal is mainly about 1.9Hz and 3.9Hz, and the peak frequency of the limited signal appears at 0.7Hz, 1.6Hz, 2.4Hz and 3.3Hz, Semi - restricted peaks appear at 1.5Hz, 2.3Hz and 3Hz. For the two types of restricted gait, the knees are subject to varying degrees of restraint, resulting in human walking time cycle time increases, and the limited foot in the gait cycle support period is shortened, swing period extended, while normal The support period of the foot in the gait cycle is prolonged and the swing period is shortened. So there is a limited foot swing frequency slowed down and support the frequency to speed up the normal foot swing frequency to speed up and support the frequency of slow down the phenomenon. From the above analysis, we can get the body frequency of the human body step by step static signal to determine the human body when walking knee limited circumstances.

4.2 Realization of Algorithm Based on Principal Component Analysis and k Nearest Neighbor Classification

First, the principal component analysis method is used to extract the characteristics of three knee joint fixes, and then the k nearest neighbor classification algorithm is used to classify the unknown samples. The specific algorithm steps are as follows:

①The frequency domain information of the human gait electrostatic signal is selected from the experimental data. The feature matrix is extracted by the principal component analysis method, and the characteristic matrix which reflects the distribution of the three frequency domains is obtained. Feature matrix, and then these three training feature matrix as k nearest neighbor classification algorithm training set；

②Through the experiment and data preprocessing, the data of the data to be tested is obtained, and the same data dimension reduction and feature extraction are done. The characteristic matrix of the test data is called the test feature matrix and the test set as the classification algorithm；

③The distance calculation method of k nearest neighbor classification algorithm is selected to calculate the distance between the test feature matrix and the three training feature matrices；

④Find the k sample points closest to the test feature matrix, calculate the weight of the three training feature matrices in the k sample points, and classify the test set as the highest weight。

Using the above steps to process the experimental data, we can get that when the k value is 2, the recognition rate is 84.75%, which proves the feasibility of the principal component analysis and k nearest neighbor classification algorithm in this study.

5 CONLUSION

In this paper, the electrostatic generation mechanism of the bipedal movement is analyzed, and the detection equation of the static equation of the human body is established, and a gait electrostatic signal acquisition system is built. The gait simulation experiment of knee joint disease patients was designed to obtain the gait electrostatic signals in the normal, restricted and semi - restricted cases of knee joint respectively. The fast Fourier transform of the gait electrostatic signal is obtained, and the frequency domain information of the signal is obtained. PCA is used to reduce the dimension information in the frequency domain, and the characteristic parameters are obtained. The k nearest neighbor algorithm is classified and identified, and the highest recognition rate is 84.75%. The results show that the frequency domain information of human body static signal can better reflect the activity of human knee joint, which can provide theoretical basis for the rehabilitation of knee joint disease. This article is helpful to establish a new technical means to evaluate the rehabilitation of knee joint disease. It has the advantages of small size of monitoring equipment, convenient use and convenient family promotion, and has good application prospect in family wisdom medical field.

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