Study on Gait Symmetry Based on Human Body Electric Field

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Abstract. Walking is the most common movement in people's daily life, and symmetry is an important feature of gait. Hemiplegia gait can significantly change the symmetry of gait. Studying the symmetry of gait has important research significance for the diagnosis and rehabilitation evaluation of hemiplegia. This article uses a new non-contact electrostatic measurement method combined with the plantar pressure system to obtain human gait signals. Determining the left and right single-foot support period in the electrostatic gait signal by the plantar pressure gait signal, and the algorithm is designed to extract the corresponding time parameters. Using the left and right single-foot support period asymmetry coefficient algorithm proposed in this paper, calculating the asymmetry coefficient of 20 hemiplegic patients and 20 control subjects, the average values of hemiplegic patients and control are \( \text{GA}_{\text{STP}} = 21.07 \pm 1.45 \), \( \text{GA}_{\text{STP}} = 5.56 \pm 0.86 \) respectively, the significance test results of the two groups of data were \( p < 0.05 \), and there was a significant difference between the two. The results show that the left and right single-foot support period asymmetry of the electrostatic gait signal proposed in this paper can be used as a feature to distinguish between hemiplegic gait and normal gait.

Introduction

According to statistics, stroke has become the leading cause of death among Chinese nationals [1]. About 1.5 to 2 million new stroke patients occur each year in China, and 116 to 219 people per 100,000 people [2]. Although the medical conditions in China has gradually improved, the incidence, disability and mortality of stroke are still on the rise [3]. Hemiplegia is a sequela caused by a brain-related neurodeficiency disease that causes damage to the brain and causes a decline in motor function. Its main manifestation is motor dysfunction of the upper and lower limbs of the affected side [4]. Hemiplegia makes patients lose their self-care ability and labor ability, which brings a huge burden to families and society [5].

Human body gait carries a wealth of body characteristics and health information, and studying key parameters in gait signals is of great significance for mastering human health [6]. Symmetry is an important feature of gait [7]. The human motor or central nervous system is damaged, resulting in a disordered balance of muscles, and the symmetry of the gait is destroyed. Compared with traditional gait assessment features, such as step size, pace, gait cycle, etc. The symmetry feature of gait can map the intrinsic ability of controlling gait and provide guidance for clinical diagnosis and rehabilitation.

Clinically, the gait ability of patients with hemiplegia is judged mainly by two methods. One is a high-precision three-dimensional pressure system and an optical tracking system [8], such as a pressure force plate and a VICON system [9], which acquire motion information of important joint parts of the body. Then through a large computer for data analysis, accurate quantitative analysis of hemiplegic symmetry. These devices are usually only placed in professional sports labs in high-level hospitals. The other is a doctor who has extensive clinical experience to score the scale according to the patient's gait condition [10], to qualitative analysis of patient gait symmetry. Although the first measurement method can accurately quantify the symmetry of the hemiplegia gait in a short time, the measurement requires an expensive instrument, maintenance, and dedicated personnel to perform the test operation. The second method is inexpensive and does not require any equipment, but the gait analysis results are qualitative and subjective judgments of the clinician. Based on the above reasons,
the development of a miniaturized device that takes into account the advantages of the above two measurement methods, accurate, low-cost, long-term monitoring of gait signals and analysis of gait symmetry is still an urgent problem to be solved. At present, the inertial system has the above advantages, and measures information such as the angle, acceleration, and speed of the joint during walking [11]. But this inertial system needs to be worn and needs to be transmitted over the air for wireless transmission. On the one hand, it affects the tester's normal gait; on the other hand, wireless transmission requires power supply, which prevents the gait from being monitored for a long time.

Therefore, a non-contact, gait system capable of monitoring gait for a long time and accurately acquiring gait symmetry features has important research significance. The electrostatic detection method has gradually become a research hotspot in the field of gait measurement because of above advantages.

The main purpose of this paper is to study the gait asymmetry characteristics of the gait signals of patients with hemiplegia and control, and to select the gait single-foot support period time parameters to quantify the asymmetry. The rest of this article is organized as follows: In section 2 introduces the principle of electrostatic gait signal acquisition, insole type foot pressure-electrostatic gait comparison measurement system, gait symmetry quantization algorithm based on single foot support period. In section 3 analyzes the single-foot support period in the electrostatic gait signal by the known plantar pressure gait signal. In section 4 is result, compares and analyzes the asymmetry of single foot support period in patients with hemiplegia and control. Finally, is the conclusion and discussion.

Materials and Methods

Principle of Electrostatic Gait Signal Acquisition

Electrostatic phenomenon is a ubiquitous physical phenomenon. The human body will be charged with static electricity during the process of rubbing with clothes [12]. When the human body is walking, the friction and contact separation between the foot and the ground will cause the human body to carry a certain amount of electric charge [13]. This charging phenomenon causes the electric field around the human body to change with the movement of the foot during walking [14]. In the previous study, we established an equivalent model of the human body and the surrounding environment based on the principle of electrostatic field [15].

It can be obtained from the literature [15] that the person alternately leaves the ground while walking, and the induced current I placed on the sensing plate at a distance from the tester is shown in Equation 1:

\[
I = \frac{dQ_B}{dt} = C \frac{dU_B}{dt} \propto \frac{1}{S} \frac{d}{dt} (h(t)) - \frac{h(t)}{S} \frac{dS}{dt}
\]

Where \(U_B\) is the induced potential generated during walking of the human body, \(h(t)\) is the height function of the foot from the ground when walking, and \(S\) is the effective bottom area from the ground height \(h(t)\). This paper assumes that the human body is a good conductor. The first term in equation(1) represents the current generated by the movement of the foot before the foot is off the ground, and \(\frac{h(t)}{S} \frac{dS}{dt}\) represents the current caused by the movement of the foot and leg after the foot is completely off the ground. Therefore, when the tester moves near the electrostatic measuring electrode, the static induction current caused by the movement of the human body under non-contact conditions can be obtained.

Insole Type Foot Pressure - Electrostatic Gait Measurement System

Insole type foot pressure-static comparison measurement system mainly includes: power module, electrostatic sensor module, plantar pressure sensor module, data acquisition and processing module, wireless communication module. The data acquisition and processing module and the wireless
communication module are modules shared by the foot pressure-electrostatic system. The overall structure of the comparison measurement system is shown in Figure 1.

The plantar pressure sensor module mainly includes a piezoresistive sensor, a channel selection circuit, and a signal conditioning circuit. This article uses 16 pressure sensors, each sensor controls the gating operation through a 6×4 bus. The gate of the sensor bus is controlled by the analog switch CD4051B chip. In this paper, each sensing unit is scanned and accessed by scanning. The amplifying circuit of the plantar pressure signal is shown in Figure 2. The working system of the plantar pressure sensor is shown in Figure 3.

The electrostatic sensor module includes an induction electrode, I/V conversion circuit, and signal conditioning circuit. A variable induced current is generated on the sensing electrode, and is converted into a voltage signal by an I/V conversion circuit to perform signal conditioning such as amplification and filtering, and converts the weak induced charge amount into a voltage signal that can be processed.

Figure 1. Comparison of the overall structure of the measurement system.

Figure 2. Foot pressure sensor classic amplifier circuit.

Figure 3. Foot pressure sensor working system diagram.
The analog signal obtained by the electrostatic sensor module and the plantar pressure module is then received by the acquisition computer and the real-time transmission module to receive the gait waveform signal in real time through the upper computer.

**Subjects**

In this experiment, there were 20 patients with hemiplegia and 20 controls and participated in data collection. The control group were all patients with no neurological damage (12 males and 8 females). Their average height was 1.73m (height range: 1.58~1.81m) and the average weight was 61.7kg (45~78kg). The average age is 28 years (age range: 24-33 years old). Hemiplegia patients are all 2017 cooperative hospital patients (12 males and 8 females). Their average height was 1.68m (height range: 1.58~1.76m), and the average weight was 68.7kg (56~78kg). The average age is 46 years (age range: 31 ~ 60 years), patients with hemiplegia can stand for more than 1 minute independently.

In the experiment, the static electricity detecting device was placed at a height of 1 m from the ground to the position of the experimenter using a tripod. The foot pressure system was installed in the ordinary rubber sole shoes worn by the control personnel. The experimenters wore ordinary rubber sole shoes and were in electrostatic induction. The stepper movement was performed 1 meter in front of the plate, and the tester was asked to use his most natural speed to step at least 10 seconds, and 5 experiments per person. In order to avoid the influence of temperature and humidity on human body charge, all data are collected in an ambient temperature range of 20 to 25° C and a humidity range of 50% to 60%.

**Asymmetry Coefficient of Left and Right Single Foot Support Period**

The gait cycle can be divided into a support period and a swing period. The support period includes a bipedal support period and a single-foot support period. The support period and the swing period of the normal gait account for 60% and 40% of the gait cycle, respectively. When the human brain is damaged, the balance of gait will be destroyed, and the abnormal gait will maintain the balance of the body by increasing the support time of the lower limbs. Therefore, calculating the single-foot support period asymmetry coefficient of the electrostatic gait signal is of great significance for the diagnosis and treatment of hemiplegia patients. The asymmetry coefficient of the single-foot support period of the gait defined in this paper is:

\[
G_{A_{STP}} = 100 \times |\ln(SSTP / LSTP)|
\]  

(2)

Among them, \(G_{A_{STP}}\) represents the asymmetry coefficient of the single-foot support period of the gait, SSTP and LSTP represent the smaller and larger values of the average left foot and the right foot during the walking process, respectively. The formula for SSTP and LSTP is:

\[
\bar{LSTP} = \frac{1}{N} \sum_{i=1}^{N} LSTP_i, \bar{RSTP} = \frac{1}{N} \sum_{i=1}^{N} RSTP_i
\]

(3)

\[
SSTP = \min \{LSTP, RSTP\}, LSTP = \max \{LSTP, RSTP\}
\]

(4)

LSTP and RSTP respectively indicate the single-foot support period of the left and right feet. \(\bar{LSTP}\) and \(\bar{RSTP}\) respectively represent the average of the left foot support period of all left and right feet in the tester's time series of an electrostatic gait cycle.

When the calculated asymmetry coefficient \(G_{A_{STP}}=0\), it means that the left and right feet are completely symmetrical; when the calculated step symmetry coefficient \(G_{A_{STP}}\) is closer to 0, it means that the left and right feet are highly symmetrical.

**Gait Signal Analysis**
The obtained electrostatic gait signals of the hemiplegia patients and the control personnel are shown in Figure 4.

![Figure 4. Electrostatic gait signals from hemiplegic patients and controls obtained with an electrostatic measurement system. (a) Electrostatic gait signals from patients with hemiplegia (b) Electrostatic gait signals from controls.](image)

The experiment used the plantar-electrostatic ratio measurement system to obtain the control personnel's plantar pressure-electrostatic gait signal as shown in Figure 5.

![Figure 5. Foot pressure of the control person - electrostatic gait signal.](image)

There are 16 foot pressure signals for each of the left and right feet. For clearly researching the changes of foot pressure, we analyze a typical natural stepping foot pressure gait cycle signal curve. The curve of the left foot sole pressure gait cycle signal in a step cycle is shown in Fig. 6.

In a typical natural stepping foot pressure gait cycle signal curve, data1, data2, data3, and data4 represent the pressure curves collected by the four foot pressure sensors at the heel, data13, data14, data15, and data16 represent the pressure curves collected by the four foot pressure sensors from the toes. During the stepping process, the pressure transitions from the toes to the arch and then to the heel. The 13th to 16th collection points are located at the toe position. During the stepping process, the toes have an impact force on the ground, and the pressure curve of the toe area rises rapidly, and then the peak point of the pressure is reached. After then the heel begins to touch the ground, the pressure curve at the heel position begins to rise. When the heel is completely in contact with the ground, it is the single-foot support period, and the force-bearing area of the foot reaches the maximum, so the force of the sensor will decrease slightly, but the tendency to decrease at the heel position is not obvious. And then the foot is ready to leave the ground, the pressure on the heel begins to decrease rapidly until the toe is off the ground.

A detailed analysis of the foot pressure revealed that the entire foot pressure curve exhibited an M-shaped change during the stepping process. The $F_1$ to $F_2$ period can be determined as the
single-foot support period, which can be seemed as the single-foot support period between the peak points of the foot pressure.

![Figure 6. Left foot plantar pressure gait cycle signal curve.](image)

The characteristics of the foot pressure gait signal versus the single-foot support period of the electrostatic gait signal are shown in Fig. 7. From Figure 7, the single-foot support period of the electrostatic gait signal measurement can be determined according to the single-foot support period of the plantar pressure. The starting point of the single-foot support period of the electrostatic gait signal is a peak point of the electrostatic gait signal. The end point is the point at which the electrostatic gait signal appears to fall rapidly after the small peak fluctuation. And we discovered that the correspondence between the foot pressure gait signal and the electrostatic gait signal occurs in each gait cycle.

The schematic diagram of the algorithm for automatically extracting the single-foot support period of the electrostatic gait signal designed in this paper is shown in Figure 8. The asymmetry of the gait is calculated by the single-foot support period of the left and right feet. The algorithm steps are designed as follows:

1. Deriving the preconditioned electrostatic gait signal.
2. Get the extremum of the derivative, find the first zero crossing on the right side of the maximum extreme point, and the first zero crossing on the left of the minimum extreme point.
3. The derivative zero point between the peak points of the electrostatic gait signal is the single-foot support phase of the electrostatic gait.

![Figure 7. Characteristics of pressure gait signal versus single-foot support period of electrostatic gait signal.](image)
Results

The single-foot support period of the hemiplegia patients and the control personnel was extracted using the algorithm for extracting the single-foot support period of the electrostatic gait signal described above. Five groups of data were collected from each tester, each group consists of 5 complete cycles. 100 GA_{STP} were obtained from the patients with hemiplegia and control by the calculation of the biped support period and asymmetry. The statistical results of the single-foot support period symmetry evaluation index of all testers in this paper are shown in Fig. 9. The average asymmetry of all patients with hemiplegia was GA_{STP}=21.07±1.45, the average asymmetry of all controls was GA_{STP}=5.56±0.86.

Conclusions & Discussion

This paper designs the plantar pressure-electrostatic gait comparison test system to obtain both the foot pressure gait signal and the electrostatic gait signal. The single-foot support period in the electrostatic gait signal is determined by the plantar pressure gait signal. The automatic extraction algorithm of the single foot support period of the electrostatic gait signal is designed, and calculated the asymmetry of the left foot support period of the static gait signal of the experimental hemiplegia patient and the control. The average asymmetry of all patients with hemiplegia was GA_{STP}=21.07±1.45, the average asymmetry of all controls was GA_{STP}=5.56±0.86. The significance
test results of the two groups of data $p<0.05$, the two have significant differences. Therefore, our experiments show that the asymmetry of the left and right foot single support period of the electrostatic gait signal can be stabilized as a feature distinguishing the ectopic gait signal and the normal gait signal.

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