Pisco Med Publishing

Original Research Article

Design of Gait Detection System Based on FCM Algorithm

Xiaochen Guo[1,3], Chao Yang[2], Xuanling Chen[1], Tongle Xu Corresponding Author3

1.The University of Manchester, Manchester, M13 9PL, UK

2.Shanghai Marine Equipment Research Institute, Shanghai, 200031 ,China

3.Shandong University of Technology , Zibo 255000 , Shandong China

Abstract: Gait detection technology is widely used in medical and military fields. The key of gait detection technology is low cost, high accuracy and portable detection equipment and real-time detection algorithm. This paper introduces a real-time gait detection system, this kind of gait detection system using machine learning algorithm based on FCM clustering analysis and calibration of the sensor data filter algorithm based on rules, the kinematic data is divided into five different gait events, namely the heel strike , foot flat, heel off , toe off and initial swing phase . Compared with 3D posture capture experiment equipment, the accuracy of gait event detection of the proposed gait detection system is verified to be highly reliable.

Keywords: FCM Algorithm ; Real-time Gait Detection ; Internal Measurement Unit (IMU) ; Machine Learning

1. Introduction

Gait detection is an effective method to detect human foot gait changes and is meaningful for rehabilitation training and daily life assistance [1] . The purpose of gait detection is to find and extract the characteristics of changes between individuals from the behavior of moving human beings to realize automatic behavior recognition [2] . It has been well used in many fields such as intelligent monitoring, rehabilitation therapy, intelligent prosthetic design, and identification.

Wearable sensors are considered to be an efficient and low-cost way to record kinematic data, and various gait detectors can be developed by combining different sensors with gait algorithms . Commonly used sensors include weighing modules, foot switches , gyroscopes, etc. [3] . However, most of the above sensors are installed separately around the human body to measure separately . To meet the demand for a portable kinematic data collection system , this system developed a gait detection technique that fuses multi-sensor data[4].

This paper introduces a real-time gait detection system , which realizes the real-time detection of gait phase through multi-sensor fusion data calculation and FCM clustering algorithm processing. This gait detection system uses four force-sensitive resistors to collect the pressure data of the sole of the foot and the triaxial attitude angle , triaxial angular velocity and triaxial acceleration data obtained by the inertial measurement unit (IMU) to realize data acquisition and gait detection. Through the three-dimensional attitude capture device VICON, it is verified that the accuracy rate of the gait phase detection system in this paper and the acquisition rate at different speeds have high reliability, and the recognition rate of gait detection events is over 90% .

2. Related technologies

2.1 Hardware system

2.1.1 FSR pressure sensor

FSR is a sensor made of a thick polymer polymer film, which increases the active surface force as the resistance decreases. The resistance value of the FSR decreases with the non-linearly applied force. FSR can be used together with Arduino to jointly detect the change of pressure value between the smart insole and the sole of the foot [5] .

2.1.2 Inertial Measurement Unit (IMU)

This project applies MPU6050 inertial measurement unit (IMU) , which can provide accurate azimuth, level, position, speed and acceleration signals. In the process of gait detection, the inertial measurement unit will be offset. The accelerometer and electronic compass with superior static performance are used to correct the error in the attitude calculation process of the inertial measurement unit (IMU).

GND , SCL and SDA need to be applied in the gait recognition detection system, and the data is sent to the Arduino through the I_2C bus.

2.1.3 Arduino development board

Arduino UNO R3 is the model of the development board used in this project. It is a micro-controller based on ATmega328. The Arduino UNO development version consists of 14 digital input/output pins and 6 analog input pins. This development board The matching USB interface can provide the function of converting the serial port, and the data is directly displayed in the serial port mon-

doi: 10.18282/l-e.v10i8.3061

itor of the Arduino IDE.The workflow of the detection system is shown in figure1.

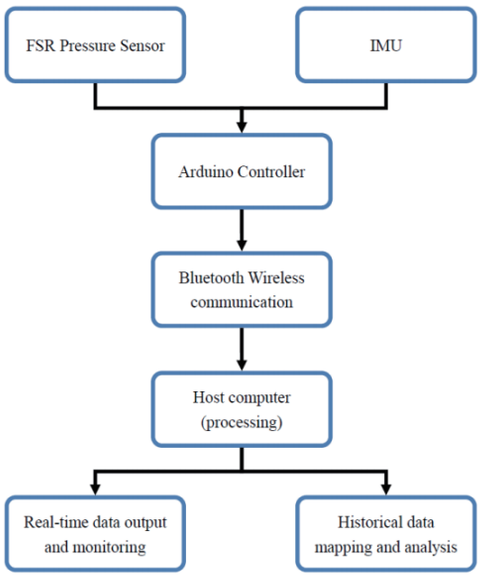

Fig.1 Equipment workflow

2.2 Data acquisition

The device obtains data through FSR pressure sensor and MPU6050. Gyro instruments provide signals such as bearing, level, position, velocity, and acceleration. FSR and Arduino are used together to detect the change of the pressure value between the smart insole and the sole of the foot [6]. When the lab subjects are walking, the resistance value of the FSR is constantly changing, and the Arduino reads the voltage value across the FSR resistance, through the Arduino serial port and the Processing host computer program Specific data can be obtained.

The sensor placement positions are respectively located in the main high pressure areas of the plantar pressure: below the heel in the hind-foot, the first metatarsal, the fourth metatarsal and the big toe in the forefoot.

2.3 Data processing

It is transmitted to the background processor after quaternion algorithm and Kalman filtering .

When the MPU6050 receives the sensor signal , the data of the accelerometer and the geomagnetic-meter are converted into a geographic coordinate system, and the error is calculated with the corresponding reference gravity vector and geomagnetic vector to correct the output of the gyroscope, using the gyroscope data Do a quaternion update, then convert to Euler angles.

The core idea of the Kalman algorithm is to correct the state estimate by comparing the measured actual value with the measured predicted value. The data processed by Arduino is transmitted to the background processing terminal through the HC-06 Bluetooth module for further processing.

2.4 Gait event detection of FCM clustering algorithm

Cluster analysis is an unsupervised learning method in machine learning to study data ensemble classification problems . According to the principle of fuzzy clustering algorithm, the gait data set is divided into several clusters, so that under a specific similarity measurement method, the samples in the same class have high similarity, and the correlation between elements in different classes is weak . According to the different requirements for performance, efficiency, generalization ability, data form, data dimension and other aspects, various high-efficiency and special-purpose algorithms are derived. In practical applications, it is necessary to select an appropriate algorithm according to the research object and application conditions.

We found that the FCM algorithm is suitable for gait detection [7] . In particular, the fuzzy C-means clustering algorithm is also one of the most widely used classification algorithms at present , and the data processing flow is determined according to the algorithm as shown in Figure 2 .

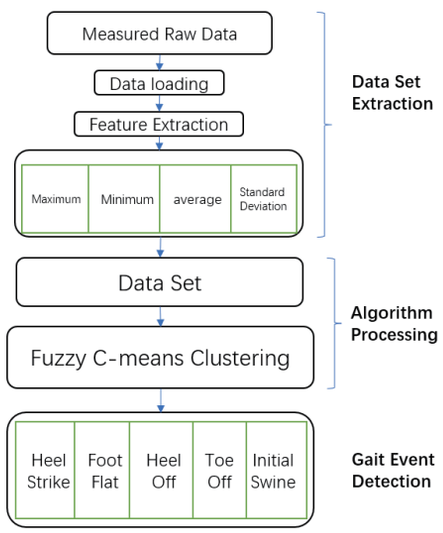

Fig2 Data processing flow chart by FCM

First determine the data set and collect data through the measurement system, thereby determining the number of classifications N. Then the center corresponding to the N classes is n_i, and the membership degree of each sample M_j belonging to a certain class N_i is set as C_{ij}, and C_{ij} satisfies the following conditions:

$$\begin{cases} \sum_{j=1}^{m} C_{ij} > 1, \forall i \\ C_{ij} \in [0,1], \forall i,j \\ \sum_{i=1}^{n} C_{ij} = 1, \forall j \end{cases} \begin{cases} \sum_{j=1}^{m} C_{ij} > 1, \forall i \\ C_{ij} \in [0,1], \forall i,j \\ \sum_{i=1}^{n} C_{ij} = 1, \forall j \end{cases} \quad (1)$$

Constructing the final objective function:

$$minFm(C,N) = \sum_{j=1}^{m} \sum_{i=1}^{n} C_{ij}^{a} \left\| x_j - n_i \right\|^2$$

$$minFm(C,N) = \sum_{j=1}^{m} \sum_{i=1}^{n} C_{ij}^{a} \left\| x_j - n_i \right\|^2 \quad (2)$$

In the formula, m is the number of sample data sets, n is the number of centers of the cluster, a is the fuzzy weight, $\left\| x_j - n_i \right\|$ $\left\| x_j - n_i \right\|$ and is the Euclidean distance between the sample points and the center, the formula is as follows:

$$n_i = \frac{\sum_{j=1}^{m} {c_{ij}}^{a} n_j}{\sum_{j=1}^{m} {c_{ij}}^{a}} n_i = \frac{\sum_{j=1}^{m} {c_{ij}}^{a} n_j}{\sum_{j=1}^{m} {c_{ij}}^{a}} \quad (3)$$

$$C_{ij} = [\sum_{k=1}^{n} \left(\frac{\left\| x_j - n_i \right\|}{\left\| x_j - n_k \right\|} \right)^{2/(a-1)}]^{-1}$$

$$C_{ij} = [\sum_{k=1}^{n} \left(\frac{\left\| x_j - n_i \right\|}{\left\| x_j - n_k \right\|} \right)^{2/(a-1)}]^{-1} \quad (4)$$

3. Experiment verification and result analysis

Experiments were conducted in a laboratory equipped with the VICON motion capture system. Subjects wore the gait detec-

tion system on the treadmill for testing. The 3D trajectory captured by the VICON camera was used as a reference, and the gait collected by the gait detection system was used as a reference. data for comparison.

The VICON system consists of Nexus host computer software and 6 V5 cameras. There are three cameras on both sides of the ceiling to track and measure the three-dimensional trajectory of the subject. The laboratory scale is 10m×5m , and the coverage area of the VICON system is about 5m. ×4m.

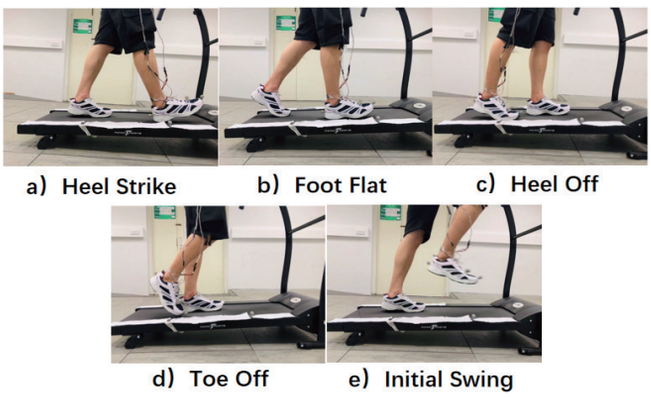

Fig3 Five gait events

Table 1 Detection accuracy of different test objects

Test subject	Age	Weight(kg)	Total data	Correct data	Failure data	Correct rate
Sean	26	75	681	644	37	94.57%
David	47	87.5	685	625	60	91.24%
Victor	35	66	651	604	47	92.78%
Chen	23	52	619	587	32	94.83%
Average	33	70	659	615	44	93.36%

Table 2 Detection accuracy of different gait events

Gait events	Heel Strike	Foot Flat	Heel Off	Toe Off	Initial Swing	Correct rate	Average
Correct rate	96.42%	91.76%	97.84%	86.04%	94.67%	92.58%	92.58%

After experimental tests, the gait detection rate of the system can reach more than 90%. The main error exists in the structure of some people's feet and walking habits[8]. For example , some errors exist in the experimenter's shoes that do not fit well, and the pressure fluctuations caused during the detection process.

4. Conclusion

(1) This paper proposes a gait detection method, which uses a single IMU combined with FSR to achieve high-precision detection of five gaits. The gait detection system can adapt to the changes of different individuals and different walking speeds. Gait events are identified through the fusion signal of a single IMU and FSR , reducing the burden on users, and processed by the FCM clustering algorithm to ensure the accuracy of feature data extraction. Table 4 shows the comparison of our gait detection method with other state-of-the-art methods in the field of gait detection.

Table 3 Comparison with other methods

author	Number of sensors	Featureextraction method	Accuracy
Our method	4FSR+1IMU	automatic	92.97%
young et al. 2014 [7]	3IMU+1FAR	manual	93.90%
liu et al. 2015 [8]	4FSR	manual	90.38%
Liu Xiyang et al.2016 [9]	unknown	automatic	85.30%
Yan et al. 2021 [5]	4FSR	automatically	87.00%

(2) The verification test of the gait detection method in this paper shows the advantages of high reliability and low cost on a flat road , which provides more reference for subsequent tests on complex road conditions such as uneven roads or climbing steps .

References:

[1] Lin Huiqing, He Jianmin, Chen Shumin, Chen Xianghua, Liang Wanchan, Zhong Lixia, Chen Xiaozheng. Nursing application of plantar pressure measurement in the prevention of high-risk groups of diabetic foot [J]. Chinese Community Physician, 2020, 36(18): 151-152.

[2] S. Borel, P. Schneider, and C. Newman, "Video analysis software increases the interrater reliability of video gait assessments in children with cerebral palsy," Gait & Posture, vol. 33, no. 4, pp. 727 –729, 2011. View at: Publisher Site | Google Scholar

[3] W. Dickens and M. Smith, "Validation of a visual gait assessment scale for children with hemiplegic cerebral palsy," Gait & Posture, vol. 23, no. 1, pp. 78–82, 2006. View at: Publisher Site | Google Scholar

[4] S. Liu, Q. Wang, and Y. Luo, "A review of applications of visual inspection technology based on image Processing in the railway industry," Transportation Safety and Environment, vol. 1, no. 3, pp. 185–204, 2020. View at: Google Scholar

[5] Liu Xiyang, Feng Siling, Chen Xianmei, Liu Jinrong. Recognition of Plantar Pressure Distribution Pattern Based on Fuzzy Theory [J]. Journal of Natural Science of Xiangtan University, 2016, 38(01): 93-96.

[6] Qu Binjie, Sun Shaoyuan, Samah A.F. Manssor, Zhao Guoshun. Multi-view gait recognition method based on perspective conversion [J]. Computer Engineering, 2021, 47(06): 210-216.7

[7] Young, AJ; Simon, AM; Hargrove, LJ A training method for locomotion mode prediction using powered lower limb prostheses. IEEE Trans. Neural Syst. Rehabil. Eng. 2014, 22, 671–677.

[8] Liu Z, Lin W, Geng Y, et al. Intent pattern recognition of lower-limb motion based on mechanical sensors[J]. IEEE/CAA Journal of AutomaticaSinica, 2017, 4(4): 651-660.