Research on Human Body Movement Posture Based on Inertial Sensor

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Abstract: *Human movement refers to the various actions completed by the human body with flexibility and diversity which cannot be found in actions completed by robots. This paper proposed to use inertial sensors to collect the information about body movements and apply the collected information to analyze and identify human movements. It was found through the experiment that the inertial sensor could well identify the human body movement postures, which provided theoretical basis for its application in the field of human motion posture recognition.*

Keywords: *Inertial sensor, Human motion recognition, Biomechanical characteristics.*

Introduction

Human movement refers to the various actions completed by the human body [8] and the collection of human body movement has a role in promoting bionic engineering, medical engineering and game animation. Scientists have put forward a number of different ideas for the analysis of human body movements. Thrasher et al. [11] recorded the actions of experimenters and obtained the posture data of the experimenters by calculating the posture of their heads, shoulders, torsos and hands. Swaisaenyakom et al. [10] used the human body motion model based on the electromagnetic simulation software XFdtd to perform motion capture on the 3D scanning surface of a real task in order to obtain the human motion data. Sardini et al. [9] designed a new wearable system to monitor the body's sitting position, in order to avoid musculoskeletal diseases caused by wrong sitting positions. However, these methods all share the shortcomings of high costs and poor portability. With the advantages of low costs and good portability, inertial sensors can be well applied to medical and animation fields [12]. In this paper, inertial sensor was applied to human body motion posture recognition and its validity was verified through an experiment.

Theory

Motion capture system

The motion capture system is mainly composed of hardware facilities and software. In order to carry out an effective analysis of human motion, we must acquire angular velocity and torso inclination data in biomechanics. The inertial sensor is a sensor that detects acceleration, tilt, shock, vibration, rotation and multi-angle motion [3, 4], which was used in this study. The ratio of angular displacement and time over a period of time is called the average angular velocity and the average angular velocity limit is instantaneous angular velocity [13]. During the movement of the human body, a gyroscope is used to measure the rotational motion of the joints of the human body to obtain an angular velocity value. As a vector, the direction of angular velocity is the same as the direction of the human body displacement. In the process of human movement, there is a torso inclination angle, which refers to the angle between the connecting line of the midpoints of the connecting line of the left and right shoulder and the connecting line of the left and right hip joint and the vertical direction [2, 14]. The position of each joint during the movement of the human body and the torso inclination angle are measured by a magnetometer. After collecting the human motion data, the data is transferred to the PC end for preprocessing, and then the motion posture is calculated.

Methods

Operation of the action capture system

In the process of data collection, the experimenters first fixed inertial sensors on the movement joints of the experimenters to obtain the accelerated velocity, angular velocity and torso inclination angle during movement. Then, through the wireless transmission protocol, these data were transmitted to the computer terminal. After preprocessing by the computer, the data were stored in the database. Before the experiment, each motion joints of the experimenters were installed with inertial sensors (including hands, feet and waists). The layout of different sensors can be carried out according to the actual situation. Besides, increasing the number of sensors can make data collection more accurate.

Algorithm design based on magnetometer and gyroscope

Initialization

Firstly, a coordinated system O_0 is set up with the direction of its X_0 axis the same with the progressing direction of the experimenter and its Z_0 axis in vertical direction. The coordinated axes of the coordinated system O_1 of the inertial sensor are all right hand axes, with the original point located in the center position of the sensor. The problem that magnetometer will be affected by the external magnetic field can be fixed by ellipse fitting method [1]. Before the experiment, the experimenter was standing still for 10 seconds, where the accelerated velocity could be ignored and its average is $m_{(0)}$. Then, by comparing it with the ideal gravity acceleration vector $-Z_0$, the initial attitude of the sensor can be calculated, denoted by a quaternion P_{ini}, as follows:

$$\varphi_{ini} = \cos^{-1}\left(m_{(0)} \bullet \left(-Z_0\right)\right), \tag{1}$$

$$V_{ini} = m_{(0)} \times \left(-Z_0\right), \tag{2}$$

$$P_{ini} = \left[\cos\frac{\varphi_{ini}}{2},\ \sin\left(\frac{\varphi_{ini}}{2}\right) \times \left[\frac{V_{ini}}{\left\|V_{ini}\right\|}\right]\right]. \tag{3}$$

In the equations, $\bullet$ and $\times$ are the inner product and the outer product of the vector; $-Z_0 = \left[0\ \ 0\ \ -1\right] \bullet \varphi_{ini}$ is the angle required for the rotation of O_1 around the V_{ini} axis to O_0. Then, P_{ini} is applied for the correction of the original data *gyro* and *i* of the sensor, as follows:

$$\begin{aligned} \overline{gyro} &= P_{ini}^{-1} \otimes gyro \\ \bar{i} &= P_{ini}^{-1} \otimes i \end{aligned}, \tag{4}$$

where $\otimes$ refers to quaternion multiplication; $\overline{gyro}$ and $\bar{i}$ are the angular velocity vector and

magnetic force vector based on O_0 after correction.
Magnetometer angle estimation
On the t time point during movement, the data obtained by the magnetometer can form a sensor matrix, denoted by $p(t)$, which can be transferred to an Euler angle to obtain the angle θ of the sensor on M/L, where $\bar{i}(0)$ refers to the average of the magnetometer in the quiescent phase.

$$\varphi(t)=\cos^{-1}\frac{\bar{i}(t)\bullet\bar{i}(0)}{\|\bar{i}(t)\|\,\|\bar{i}(0)\|},\qquad V(t)=\bar{i}(t)\times\bar{i}(0),\tag{5}$$

$$p(t)=[a,\ x,\ y,\ b]=\left[\cos\frac{\varphi(t)}{2},\ \sin\left(\frac{\varphi(t)}{2}\right)\times\left[\frac{V(t)}{\|V(t)\|}\right]\right],\tag{6}$$

$$\theta_i=\tan^{-1}\frac{2(ax+yb)}{\left(1-2\left(x^2+y^2\right)\right)}.\tag{7}$$

Estimation of the angle of the gyroscope
Through the calculation of the data obtained by the gyroscope, the following can be obtained:

$$\underline{gyro}(t)=p(t)\otimes\overline{gyro}(t),\qquad \underline{gyro}_{xt}=\frac{\underline{gyro}_x(t-1)+\underline{gyro}_x(t)}{2},\tag{8}$$

where $\underline{gyro}(t)$ refers to the sensing data at T point, $\underline{gyro}_{xt}$ refers to the average value of the data on the gyroscope on M/L from t – 1 point to t point. The estimated value of the gyro sensing data needs to integrate the angular velocity information. The data estimates of the two sensors are calculated using the Kalman filter [5]. $X(t)$ is obtained by combining the final value θ and error $l\theta$ of t. The state space model is as follows:

$$\begin{pmatrix}\theta\\ l\theta\end{pmatrix}_t=\begin{pmatrix}1 & -T\\ 0 & 1\end{pmatrix}\begin{pmatrix}\theta\\ l\theta\end{pmatrix}_{t-1}+\begin{pmatrix}T\\ 0\end{pmatrix}\underline{gyro}_{xt}\Leftrightarrow X(t)=AX(t-1)+BU(t)\tag{9}$$

$$[\theta_i]=[1\ \ 0]\begin{pmatrix}\theta\\ l\theta\end{pmatrix}\Leftrightarrow Z(t)=HX(t)\ ,\tag{10}$$

where T refers to the sampling time and the vector $Z(t)$ is the data content of the magnetometer sensor.

Definition of human actions and establishment of database
In defining the human action, the human body can be divided into three parts, namely the upper limbs, the trunk and the lower limbs. The detailed information is shown in Table 1.

Table 1. Definition of human actions

Action number	Action	Category	Definition
1	Walking	Walking forward	Move forward by putting one foot in front of the other in a regular way, with hands swaying
2		Walking backward	
3		Side walking	
4		Cross step	
5		March on the spot	
6	Jumping	Jumping up	Bend one's knees, push against the ground with one's feet, and move quickly upward into the air or forward
7		Jumping forward	
8	Turning around	Side turn	Change body direction
9		Backward turn	
10	Twisting waist Kicking leg	Twisting waist	Left and right rotation of the waist; move one's legs with very quick, small, and forceful movements
11		Kicking leg	
12	Waving	Waving arm	Up and down swinging of arms

After being installed on the human motion joints, the sensors collect the motion information and send it to the computer end to be recorded and stored, preparing for action identification and analysis, as shown in Fig. 1.

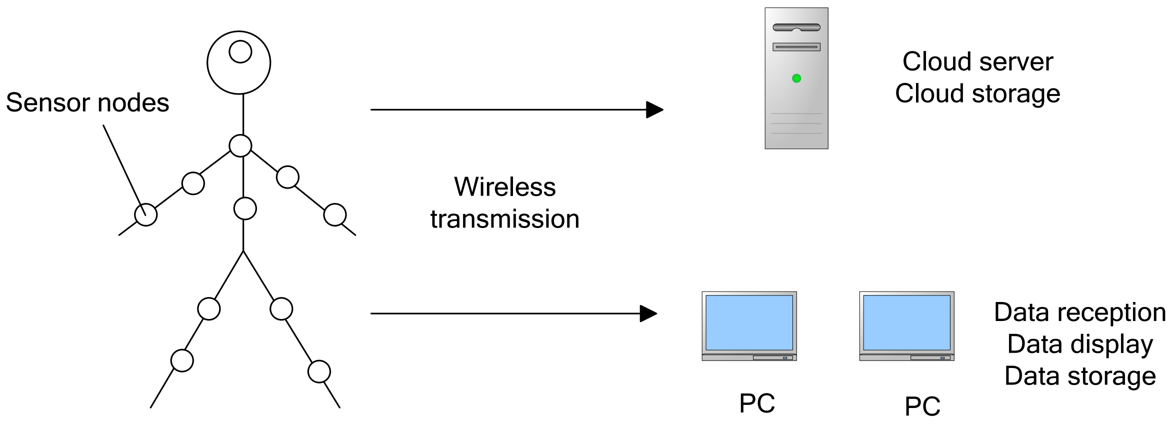

Fig. 1 Human motion capture system database

Movement posture test

Twenty healthy testers from the Physical Education College of Zhoukou Normal University in Henan province (without limb injury occurred within six months to ensure the consistency of the experiment) were included and did the following actions after wearing the sensors: squat, kick, bend over, sit, walk forward, walk backward, turn side, turn around, cross the steps, go up steps and go down steps and sideslip. Every subject did these actions for five times according to the standard and the data were then collected and recorded in the database.

The experiment was approved by the Sports Committee of Physical Education College of Zhoukou Normal University in Henan Province. Each tester signed the informed consents and was willing to cooperate with the experiment.

Statistical analysis

The data were statistically analyzed using SPSS ver. 22.0. Measurement data were expressed as mean ± standard deviation (SD). Independent variable and dependent variable were put into software box to output corresponding statistics. Then it entered the box of post-hoc test. The average values were compared between groups using t test, and the results were output. The output results contained values of corresponding descriptive statistics; the result of analysis of variance (ANOVA) was the output result. Difference was considered as statistically significant if $p < 0.05$.

System test results and analysis

After the inertial sensor system was designed, it was tested with LibSVM, which could effectively solve various problems and be applied to problem classification. All function declarations and definitions for LibSVM need to be included in the LibSVM.h file. When testing, the file should be included and connected to the corresponding database. The training samples and testing samples need to have the same format, and each one is a vector. The first value is the label of the category and the others are eigenvalues, which need to be separated. The specific format is as follows:

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1 -21 13 32 23 -35 24 34 13 -34 16 31 27 -2 4 8 9...
2 -24 14 63 24 -23 14 52 23 -43 13 24 36 -1 3 3 13...
3 -32 23 44 23 0 0 32 24 2 3 21 26 37 -3 12 13...
4 -21 23 72 23 -51 22 64 23 -13 24 34 31 -4 10 12...
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Before classification, SVM needs to be mobilized for function training to generate and preserve an SVM classification file. After getting the classification model, we use SVM to predict the function. This makes it possible to use this classification model to determine the class of input data. Then, the testers' action data in the database were extracted (a total of 100 samples). Subsequently, the preprocessing and feature extraction were performed sequentially, and finally the recognition of these actions was performed. The following table shows the recognition rate of the motions.

As shown in Table 2, the recognition rate of all actions was above 90% and the average recognition rate reached 92.8%, which suggested that the system could meet the requirements of recognizing human motion postures. Also, it was found that the recognition rate of kick, bend over and sit was high and the difference between these actions and other actions was significant ($p < 0.05$), which was because these actions were simple to imitate by the sensor.

Human body posture can be applied to a variety of fields. There are many new devices developed on the market to capture human body posture such as mobile monitor, MVN BIOMECH inertial detection system and so on. This paper studies the use of inertial sensors in human posture detection. Inertial sensors can capture and reconstruct the motion attitude of the human body, measure the motion information of the moving object in three-dimensional space, process the information and construct motion models in the computer. With the development of computers, the application of inertial sensors in the capture of the human body movement gesture is becoming more and more popular, with great research values. Ni et al. [7] applied the multi-node inertial sensor to the human pose test, and proved the feasibility of the sensor through experiments. Lee [6] put the inertial sensor on the top of the elbow of 10 elite athletes to carry out an experiment and found that inertial sensors were suitable for testing gait, step and posture durations, which provided an opportunity to measure gait outside traditional labs.

Table 2. Recognition rate of the motions

	Recognition rate	**Standard deviation**
Squat	92.2%	1.1217
Kick	95.2%*	1.0564
Bend over	94.5%#	0.8986
Sit	95.1%※	0.9475
Walk forward	92.5%	1.3491
Walk backward	91.3%	0.9476
Turn side	93.1%	1.1246
Turn around	91.1%	1.5246
Cross the steps	92.5%	0.7648
Go up steps	93.1%	0.9488
Go down steps	92.3%	1.2245
Sideslip	91.0%	1.3143

Note: * means $p < 0.05$ in the comparison between kick and all the other actions except bend over and sit; # means $p < 0.05$ in the comparison between bend over and all the other actions except kick and sit; ※ means $p < 0.05$ in the comparison between sit and all the other actions except kick and bend over.

Conclusion

In summary, inertial sensors can play an important role in the study of human movement posture. In this paper, inertial sensors were applied to collect human motion posture data and establish a database. It was found through the LibSVM system that the average motion recognition rate was 90.8%. Therefore, inertial sensors have practical significance in human body posture recognition.

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