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ORIGINAL RESEARCH ARTICLE

A method of attitude measurement and level assessment for skiers based on wearable inertial measurement

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ABSTRACT

Quantitative analysis of sports is an important development direction of scientific skiing training, and the digital expression of human movement patterns during skiing is the basis for scientific quantitative analysis. A human motion capture and attitude reconstruction system based on a wearable BSBD inertial measurement unit was designed and built, combined with the human multi-rigid body motion model to realize the human body reconstruction during the skiing, and applied to the auxiliary training of slewing movements in alpine skiing. At the same time, for the indoor training scene based on the multi-degree-of-freedom simulated ski training platform, a digital evaluation method suitable for ski slalom is proposed. The method uses motion capture system and posture reconstruction system to extract five kinds of sliding characteristic data of skiers, and realizes the evaluation of skiers' technical parameters through similarity measurement and linear fitting with high-level athletes' motion parameters, so as to assist scientific training. Finally, experiments are carried out on the indoor Olymp simulated ski training bench to verify the effectiveness of the method.

Keywords: motion capture; micro-inertial measurement unit; wearable sensor; assisted training

1. Introduction

When skiing, the ability to control body posture is a special specialty ability, which has an important impact on skiing performance. A motion capture and reconstruction system suitable for ski training can not only capture the body posture of skiers in real time, but also help ski trainers find the gap between themselves and high-level athletes with digital evaluation methods, find their own lack of action, correct the error of force, while popularizing skiing, increase the public's enthusiasm for skiing. In addition, a reliable motion capture and scoring system provides a powerful tool for the scientific training of ski trainers.

After decades of development, motion capture technology is mainly divided into two categories: video device-based motion capture and sensor-based motion capture. The motion capture system based on video equipment has high cost, low portability, and is susceptible to interference[1]. With the lower and lower cost of inertial sensors, sensor-based motion capture systems are gradually developed. At present, some companies in foreign markets have launched relatively mature motion capture products: Such as the MVN products

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launched by the Dutch company Xsens[2], the 3DSuit products launched by the American company Innalabs[3] and the Vicon Motion System launched by the British company Vicon. There is also a certain development of motion capture in China. For example, Noitom, developed and designed by the Dai Ruoli team launched by Beijing company Noi Teng[4] and MMocap developed by Professor Wu coming from Research Center of Sensor Networks and Applications of Chinese Academy of Sciences[5,8].

At present, motion capture systems are widely used in the field of sports training. Ghasemzadeh et al. applied the wearable posture detection device to golf training, and collected the rotation angle of the wrist during the golf swing[9]. Sharma et al. applied the wearable posture detection device to tennis, and analyzed the action standard of each stage[10]. Samir et al. installed a wearable detection device on the athlete's arm to identify whether the athlete is throwing in baseball or hitting in volleyball[11]. Chan et al. applied wearable posture detection equipment to dance training, which is convenient for teachers to guide students to improve their skills[12]. However, at present, there are few motions capture and reconstruction systems suitable for skiing, and there is a lack of quantitative analysis of skiing, which is an important development direction for scientific skiing training. The digital representation of movement patterns during human skiing is a key step in scientific quantitative analysis.

In this paper, a wearable motion capture and reconstruction system based on inertial sensors is designed for alpine skiing, which captures and reconstructs the motion data of 11 nodes of the human body in real time. The device can be used both outdoors and indoors. The device can be used both outdoors and indoors. At the same time, combined with the multi-rigid body motion model of the human body, the human body reconstruction during the skiing process is realized. Finally, in view of the lack of quantitative analysis and evaluation research on skiing, a digital evaluation method for slalom in alpine skiing is proposed, which can be used for ski trainers to analyze sliding characteristics and assist training.

2. Wearable human posture detection device

This motion capture and reconstruction system is an independent research and development system, and its work flow chart is shown in **Figure 1**.

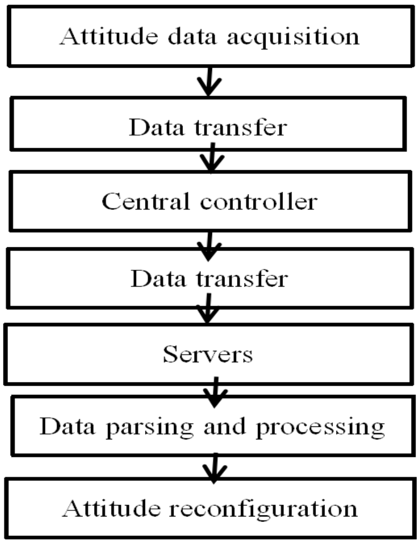

Figure 1. System flow chart.

The parameters of this motion capture and reconstruction system are shown in **Table 1**.

Table 1. Motion capture device parameters

Parameter Type	Parameter
number of nodes	11
Power supply	Wired connection / power bank
Supply voltage/V	3.3～5
Current/mA	<25
Size/cm	2.4×2.4×1
Output angle range/ (°)	±180
Attitude measurement stability/(°)	0.01
Data output frequency/Hz	120
Data transmission method	Wireless transmission

The 11 attitude acquisition modules are respectively worn on the 11 main nodes of the human body, and the wearing positions are shown in **Figure 2**. The hip also wears a central controller, which is responsible for receiving the posture data of 11 nodes and sending it to the server.

3. Human body modeling and pose reproduction

Human motion modeling based on inertial sensors is divided into skeleton model establishment and human kinematics model establishment. Due to the complex structure of the human body, the following modeling assumptions are made for the human body model:

Figure 2. Posture detection module wearing position.

(1) Ignore the influence of skin deformation on human movement. (2) The human skeleton is abstracted as a rigid body, and each joint defines the joint axis. (3) The joint coordinate system, the sensor coordinates system and the bone coordinate system are regarded as the same coordinate system.

Build a skeleton model containing 11 nodes and 5 parent-child inheritance relationship lines. The 5 parent-child relationship lines are:

(1) Pelvis—Chest cavity—Head. (2) Pelvis—Chest cavity—Left upper arm—Left forearm. (3) Pelvis—Chest cavity—Right upper arm—Right forearm. (4) Pelvis—Left thigh—Left calf. (5) Pelvis—Right thigh—Right calf.

The skeleton model is shown in **Figure 3**.

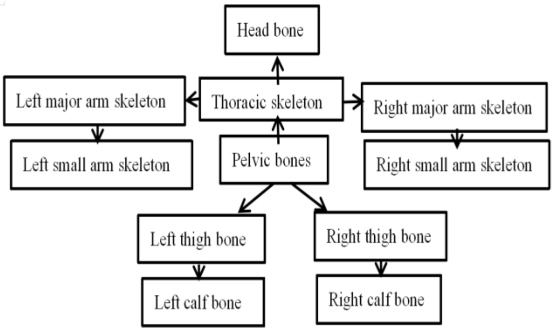

Figure 3. Skeletal model diagram.

Two coordinate systems are defined, namely the world coordinate system and the sensor coordinate system. In the world coordinate system, the X axis is the horizontal direction, the Y axis is the vertical direction, and the Z axis is vertical to the XY plane. For the Y axis, counterclockwise is positive and clockwise is negative.

After the initial posture of the human body is calibrated, the solution of the posture is mainly composed of the rotation matrix and the position matrix. The rotation matrix is expressed as:

$$R_x = \begin{bmatrix} cos\,\alpha & sin\,\alpha & 0 \\ -sin\,\alpha & cos\,\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (1)$$

$$R_y = \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\,\beta & sin\,\beta \\ 0 & -sin\,\beta & cos\,\beta \end{bmatrix} \quad (2)$$

$$R_z = \begin{bmatrix} cos\,\gamma & sin\,\gamma & 0 \\ -sin\,\gamma & cos\,\gamma & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (3)$$

Among them, α, β, γ are respectively the rotation angles of the three-dimensional vector around the *X*, *Y*, and *Z* axes; R_x, R_y, and R_z are the rotation matrices obtained by rotating the three-dimensional vector around the *X*, *Y*, and *Z* axes, respectively. The total rotation matrix is expressed as:

$$R = R_x R_y R_z \quad (4)$$

The total rotation matrix is obtained from equations (1)–(4).

$$R=\begin{bmatrix}\cos\alpha\cos\gamma-\cos\beta\sin\alpha\sin\gamma & \sin\alpha\cos\gamma+\cos\beta\cos\alpha\sin\gamma & \sin\beta\sin\gamma\\ -\cos\alpha\sin\gamma-\cos\beta\sin\alpha\cos\gamma & -\sin\alpha\sin\gamma+\cos\beta\cos\alpha\cos\gamma & \sin\beta\cos\gamma\\ \sin\beta\sin\alpha & -\sin\beta\cos\alpha & \cos\beta\end{bmatrix} \tag{5}$$

When the attitude is translated, the position matrix P is expressed as:

$$P=[P_x \quad P_y \quad P_z]^T \tag{6}$$

Among them, P_x, P_y, P_z are the translations of the three-dimensional vector in the X, Y, and Z axes, respectively.

According to the actual motion of the posture, the transformation of the posture and position of the limb segment j in the joint j-1 coordinate system is represented by a homogeneous transformation matrix ${}^{j-1}_{j}\boldsymbol{T}$:

$${}^{j-1}_{j}T=\begin{bmatrix}{}^{j-1}_{j}R & {}^{j-1}_{j}P\\ 0 & 1\end{bmatrix} \tag{7}$$

Among them, ${}^{j-1}_{j}\boldsymbol{T}$ is the rotation matrix of the limb segment j in the parent joint j-1 coordinate system; ${}^{j-1}_{j}\boldsymbol{T}$ is the position matrix of the limb segment j in the parent joint j-1 coordinate system.

Through the above analysis, it can be obtained that the homogeneous transformation matrix of joint system j in joint system i is:

$${}^{i}_{j}T={}^{j-1}_{j}T\,{}^{j-2}_{j-1}T\cdots{}^{i}_{i-1}T \tag{8}$$

According to equation (8), the expression and conversion of the attitude in the specified coordinate system is completed.

In the specific implementation of human body motion 3D display, Unity 3D is selected as the development tool, and the motion reconstruction diagram based on inertial data is shown in **Figure 4**.

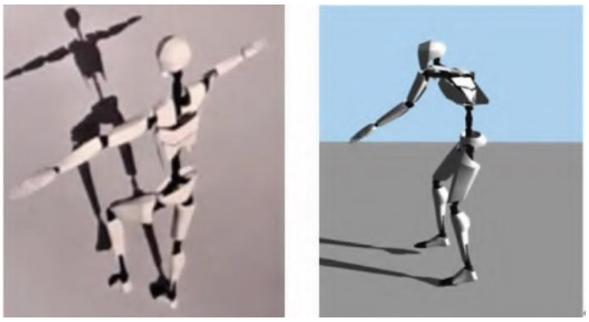

Figure 4. Motion reconstruction images based on internal data.

4. Ski aid training

The motion capture system described in this paper can be used not only in outdoor skiing environment, but also in indoor simulated ski training platform, providing skiers with analysis of key skiing techniques, and with digital scoring methods. The method can be used for the analysis of sliding characteristics and auxiliary training of ski trainers.

Taking an indoor simulated ski training platform as an example, this paper provides a digital ski level scoring method based on a motion capture system and suitable for slewing motion. The Olympic simulation ski training platform of SkyTech-Sport Company is used for the experiment, and its appearance is shown in **Figure 5**.

Figure 5. Top view of simulated ski training platform.

The trainer wears the motion capture system to perform rotary motion on the simulated ski training platform, and the motion capture system captures the trainer's posture and will be displayed in real time.

4.1. Analysis of key skiing technologies

In this paper, the process of the skier from the middle position of the simulated training platform to the leftmost end to the middle position to the rightmost end and then to the middle position is defined as a slewing movement, and the slewing speed is defined as:

$$v = \frac{R_1 + R_r}{t} \tag{9}$$

Among them, R_1 is the distance from the middle position of the simulated training platform to the leftmost position of the skier in a slewing movement; R_r is the distance from the middle position of the simulated training platform to the rightmost position of the skier in a slewing movement; t is the time required for the trainer to complete a slewing movement.

The three datum planes of the human body are sagittal plane, frontal plane and horizontal plane, as shown in **Figure 6**.

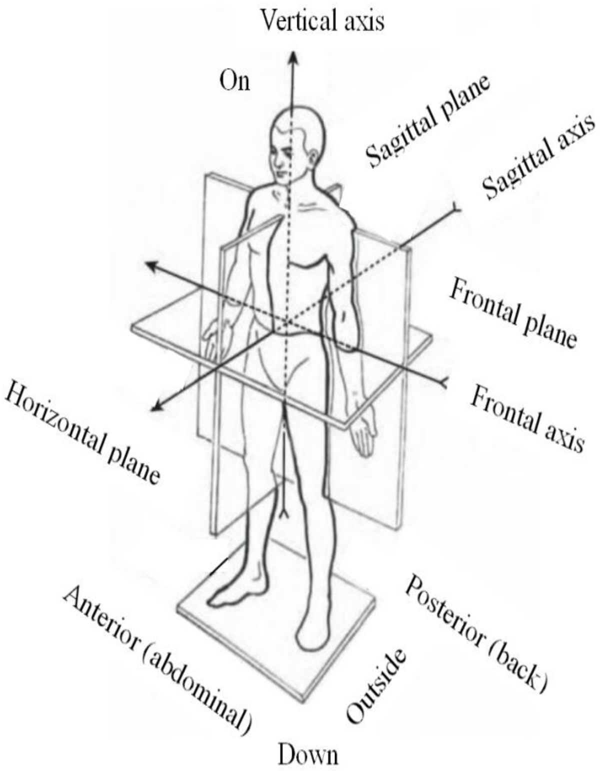

Figure 6. Human datum level.

In the experiment, the posture data of skiers with three levels of skiing, including ski instructors, intermediate skiers, and inexperienced skiers, were collected on the training platform, and the average speed of each slewing exercise was recorded.

Five characteristics that can reflect the physical fitness and skiing ability of skiers are extracted, as shown in **Table 2**.

Table 2. Table of ski features parameters

Number	Characteristic parameters	Corresponding physical fitness
1	Swing speed	Whole body coordination[13]
		Lower body Explosiveness[13]
		Knee extension[13]
2	Maximum inclination angle of the left swivel slide plate (vertical edge angle)	Lower body strength[14]
		Whole body coordination[14]
3	Maximum inclination angle of the right swivel slide plate (vertical edge angle)	Lower body strength[14]
		Whole body coordination[14]
4	Average angle between the back and the vertical axis in the sagittal plane	Upper body stability[15]
		Core power[15]
5	Maximum angle between the back and the vertical axis in the frontal plane	Upper body strength[16]
		Core power[16]

Among them, the angle between the back of the sagittal plane and the vertical axis is shown in **Figure 7.**

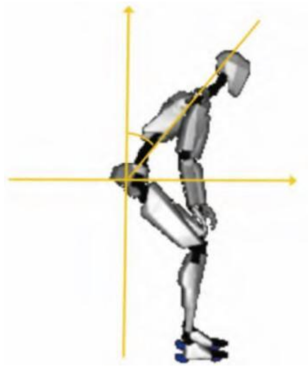

Figure 7. Angle between dorsal and vertical axis in sagittal plan.

The angle between the back of the frontal plane and the vertical axis is shown in **Figure 8.**

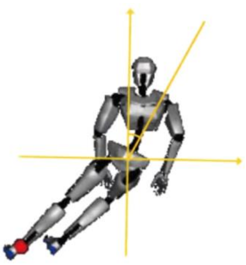

Figure 8. Angle between dorsal and vertical axis of coronal plane.

The maximum inclination angle of the skateboard, the angle between the back and the vertical axis on the sagittal plane, and the angle between the back and the vertical axis on the frontal plane are shown in **Figure 9.**

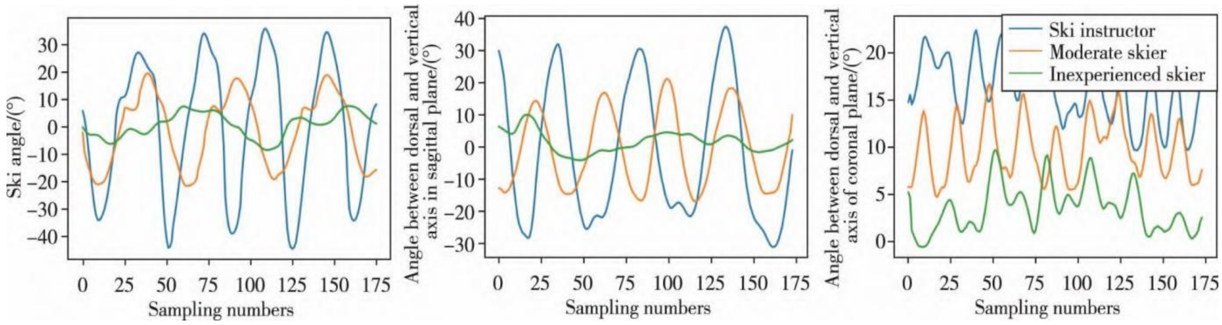

Figure 9. Skiing features of skiers at different levels.

From the data analysis, it can be seen that skiers with higher levels have better body coordination, greater explosive power of lower limbs, and greater range of motion of lower limbs, The higher the skier's level, the more stable the upper body is, the upper body leans forward and the center of gravity is pressed down, and the average angle between the back and the vertical axis on the sagittal plane is larger; The higher the skier's level, the greater the core strength of the body, the greater the left and right shaking of the upper body, and the greater the angle between the back and the vertical axis on the frontal surface.

4.2. Technologies ski level rating

This paper proposes a digital ski level scoring method suitable for slalom movements in alpine skiing.

Extract the five standard sliding features of ski instructors, and record them as y_1, y_2, y_3, y_4, and y_5 in the order of **Table 2**, and extract the sliding characteristics of any skier, and record them as x_1, x_2, x_3, x_4, x_5, the Euclidean distance method is

$$\boldsymbol{d}(\boldsymbol{X},\boldsymbol{Y}) = \left(\sum_{i=1}^{5}(\boldsymbol{x}_i - \boldsymbol{y}_i)^2\right)^{\frac{1}{2}} \qquad (10)$$

According to the above similarity measurement results, the characteristics of the collected skiers are linearly fitted, in which the high-level coaches are scored 100 points, the intermediate-level skiers are 80 points, and the inexperienced skiers are 40 points. According to the fitting results, the final comprehensive scoring equation is obtained.

Taking the data collected in this experiment as an example, the fitting equation obtained according to the above evaluation method is:

$$S = -1.2d + 100 \qquad (11)$$

Among them, S is the comprehensive score; d is the similarity measurement result.

According to this scoring method, every time the skier performs a slalom on the training platform, the system will give a real-time evaluation of the slalom. The higher the score, the closer the action is to the ski instructor.

In order to verify the feasibility of the scoring method, the experiment called 9 people to slide on the simulated training platform. Among them, 3 people were ski instructors, 3 people were intermediate level skiers, and 3 people were inexperienced skiers. Before skiing, 9 people were given subjective evaluations according to their skiing experience and level. The objective score is given by the scoring system when taxiing, as shown in **Table 3.**

It can be seen from **Table 3** that the system scoring results are all within the subjective scoring range, and the scoring method is feasible.

Table 3. Table of skiers' scores

Skater	Ski level	Subjective scoring	System Score
1	high level coach	90 ~100	96
2	high level coach	90 ~100	94
3	high level coach	90 ~100	96
4	Intermediate skiers	75~ 90	83
5	Intermediate skiers	75~ 90	80
6	Intermediate skiers	75~ 90	79
7	inexperienced skier	30~ 60	48
8	inexperienced skier	30~ 60	44
9	inexperienced skier	30~ 60	56

4.3. Ski training advice

For alpine ski trainers, this article makes the following recommendations: (1) For skiers with a slow average turning speed, strengthen knee extension exercises and lower body explosive power exercises. (2) For skiers with a small inclination angle and poor upper body stability, strengthening the muscle group strength training of the core (waist-pelvis-hip joint) can improve body stability and control through suspension training and Swiss ball training. (3) For skiers with a small range of upper limb movements during slewing, strengthen the strength exercises of the upper limbs and the waist and abdomen, and enhance the ability of the upper limbs to drive the movement of the lower limbs through exercises such as pull-ups and push-ups.

5. Conclusions

This paper designs and builds a motion capture and reconstruction system for alpine skiing. The main contributions and significance are as follows:

(1) Design and build a human motion capture and attitude reconstruction system based on wearable MEMS inertial measurement unit, and combining the multi-rigid body motion model of the human body, the human body reconstruction in the skiing process is realized, which provides a data basis for the in-depth analysis of the performance of alpine skiing. (2) Innovatively propose a quantitative extraction algorithm of key technical indicators for the analysis of the slewing action level in alpine skiing and a digital evaluation method based on key technical indicators to provide data support for scientific analysis of sports level and auxiliary guidance of sports training. In the future, on the basis of the motion capture system, data collection and processing technology can be further studied to deepen the refined training guidance of high-level players. (3) According to the different characteristics of ski trainers, put forward targeted training suggestions to help trainers improve their special abilities.

Conflict of interest

The authors declare no conflict of interest.

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