

Retraction

Retracted: Optimization of Interactive Animation Capture System for Human Upper Limb Movement Based on XSENS Sensor

Journal of Sensors

Received 22 August 2023; Accepted 22 August 2023; Published 23 August 2023

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

- (1) Discrepancies in scope
- (2) Discrepancies in the description of the research reported
- (3) Discrepancies between the availability of data and the research described
- (4) Inappropriate citations
- (5) Incoherent, meaningless and/or irrelevant content included in the article
- (6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

- [1] C. Che, "Optimization of Interactive Animation Capture System for Human Upper Limb Movement Based on XSENS Sensor," *Journal of Sensors*, vol. 2021, Article ID 5246438, 10 pages, 2021.

Research Article

Optimization of Interactive Animation Capture System for Human Upper Limb Movement Based on XSENS Sensor

Chaochun Che 

College of Art and Design, Shanghai Institute of Technology, Shanghai 200235, China

Correspondence should be addressed to Chaochun Che; chechaochun@sit.edu.cn

Received 28 September 2021; Accepted 29 November 2021; Published 15 December 2021

Academic Editor: Guolong Shi

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This paper uses the XSENS sensor inertial motion capture device to collect the experimental data of the human body's typical motion and posture-upper limb movement, based on the angular acceleration kinematics parameters of the human body's upper limbs and upper limbs. We study the characteristics of human kinematics, statics, and dynamics and construct the upper limb movement model of the human body. Secondly, based on the principle of human anatomy, the human body is divided into 23 segments, with 18 upper limbs and 36 degrees of freedom; some anatomical terms are defined, and a unified coordinate system for the upper limb model of the human body is planned and established. In the process of experimental simulation, on the basis of analyzing and summarizing the laws and characteristics of the upper limb angles of the hip upper limbs, knee upper limbs, and ankle upper limbs during walking, a general function of the upper limb angles of the three upper limbs changing with time during walking was established. On the basis of analyzing 40 sets of upper limb movement data, with the three parameters of height, weight, and upper limb movement cycle as independent variables, the general function coefficient solving equation is given through function fitting. Finally, the production of interactive animation of upper limb movement is taken as an example. Based on the acceleration sensor and three-axis gyroscope, the limbs during the movement of the upper limb motion data are collected, preprocessed, and transmitted, and then, coordinate correction and data filtering are used to output quaternary parameters to give Maya an animated character model. The animation interactive demonstration is carried out in the way of web 3D, and the XSENS sensor is explored in the animation capture.

1. Introduction

With the maturity of XSENS motion capture technology, the display of realistic three-dimensional upper limb motion movement through inertial three-dimensional motion capture allows users to obtain a visual virtual animation interactive learning experience and realizes upper limb motion learning under digital media and Internet technology [1]. With the adjustment of market structure and the emergence of small enterprises, the scenes faced by animation objects are changing from structured scenes to unstructured scenes. This requires animation objects to have a certain degree of autonomy. Traditional industrial robots have relatively high security levels [2]. Therefore, to perform tasks in the fence, in unstructured scenes, it is necessary to liberate the animated objects from the fence and share the work space with collaborative humans and because small enterprises have the

characteristics of small batches and customization. The tasks performed by the animation objects are frequently adjusted [3]. For traditional industrial animation objects, hard-coding tasks into the animation objects are no longer applicable. Humans sharing operating space require human-computer collaboration. Humans and animated objects perform certain tasks together, or there are animated objects to help humans perform tasks. In the process of human-computer collaboration, the animated objects must first be able to correctly recognize the actions of the collaborator and can correctly understand the intention of the collaborator [4–6].

With the continuous development of animation capture systems, motion capture technology has become more and more widely used in digital sports program production, virtual sports animation, sports training, etc. It can not only help coaches observe and monitor athletes' technical indicators from multiple angles and obtain precise physiological

and biochemical parameters, and through the later modeling and processing of images and data, provide conditions for the digital and virtual teaching of sports [7–9]. In human motion capture, photoelectric capture and wearable devices are usually used. Photoelectric capture is prone to occlusion and requires the deployment of a large number of photoelectric devices, resulting in higher costs. Wearable devices can capture human movements more accurately. The XSENS sensor is used to capture the motion of the upper limbs of the human body and calculate the posture.

In response to the above problems, based on the research theory and data support required by parallel humanoid animation objects and based on the XSENS sensor inertial motion capture device, this paper selects the typical human movement-upper limb movement and initially explores the three independent variables of a natural person's height, weight, and upper limb movement cycle; the general function of the upper limb angle changes with time when the human upper limb moves. In the process of human-machine collaboration, it is necessary to capture the motion of the upper limbs of the human body. The devices for capturing the motion of the upper limbs usually include wearable devices and photoelectric devices. In the article, the XSENS sensor is used for human motion capture. The motion capture experiment is carried out in the article. From the experimental results, the method is effective, and the result is ideal. The XSENS inertial motion capture system is based on a unique miniature inertial motion transmission sensor and a wireless system, which avoids unnecessary data transmission lines or power lines to restrict the user's movement. It meets the requirements of sports biomechanics and can capture the inertial motion of the human body's degree of freedom in real time. At the same time, the data is transmitted to the computer through the wireless network, and the dynamic capture effect can be recorded and viewed in real time.

2. Related Work

For the upper limb bionic theory, it is through research to obtain relevant data and theoretical support. Human motion is complex and diverse. From the initial simple observation to the capture of human motion by the camera, to the application of Adams, Ansys, and other software in human motion biomechanics, the human body is simulated and analyzed, and the human motion can be approximated. However, the development of wearable devices, human body capture technology, myoelectric measuring instrument, three-dimensional dynamic force measurement, and other technologies now provide the possibility to directly collect and analyze human motion data [10].

Ahmadi et al. [11] first studied the law of upper limb movement and developed a 7-degree-of-freedom orthosis, which measured the angular movement range, angular velocity, and angular acceleration of several upper limbs during daily activities. Subsequently, multirigid body dynamics was applied in the analysis of human motion, which provided a theoretical basis for the analysis of human motion. Shintemirov et al. [12] and others constructed a

rigid body model of the lower limb in a two-dimensional plane and simulated and analyzed the changes in the upper limb force and upper limb moment of the human body during standing long jump, high-down jump, and in situ high jump. Bleser et al. [13] constructed a human body system model from sitting to standing up. According to the obtained kinematic data, he analyzed the upper limb force and upper limb moment of the upper ankle, upper knee, and upper limb of the hip in the upright state. Marin et al. [14] used the method of analyzing motion images to analyze the motion of the upper limbs of the experimental subjects during the upper limb movements and obtained the relative rotation relationship of the upper limbs. Kim et al. [15] pioneered the application of accelerometer in human gait analysis, providing more advanced technical support and more accurate data information for human motion analysis.

Some scholars have used the human lower limb rigid body dynamics model to analyze the upper limb force and upper limb moment of the hip and upper knee and explored the changing trend and reasons of the gait characteristics of normal people affected by age. Some scholars did human gait experiments on treadmills, measured and studied the laws of human motion at asynchronous speeds, obtained upper limb angles and upper limb motion trajectory images of the lower limbs, and established an integrated finite element model of the mechanical virtual human skeletal muscle system. The finite element model of each upper limb was studied, the load set of muscle force was studied, and the finite element simulation analysis of the human body bending and carrying heavy objects [16–18]. Scholars use camera capture technology to collect the dynamic trajectory of human upper limb movements and build a complete human motion information detection and analysis system. This system overcomes the shortcomings of slow and complex data processing in the later stage of the camera capture technology. The researchers studied the gait of the lower limbs and established a positive dynamic model of the lower limb system of nerve-muscle-tendon, laying the foundation for studying the principle of human nervous system controlling upper limb movement coordination. Some teams collected the upper limb movement trajectory and upper limb angle changes of the experimental subjects in common road conditions and analyzed the changes of human gait characteristics and trajectory under different road conditions [19–21].

3. Construction of an Interactive Animation Capture System for Human Upper Limb Movements Based on XSENS Sensors

3.1. XSENS Sensor Node Distribution. The XSENS sensor is a tracking device fixed on a specific part of a moving object. It will provide the system with position information of the moving object. Generally, the number of trackers will be determined with the degree of detail of the capture to fix the two XSENS on the upper arm and the forearm, respectively. The fixed direction is shown in the coordinate system in the figure. The coordinate system r represents the base coordinate system, s represents the direction of the fixed

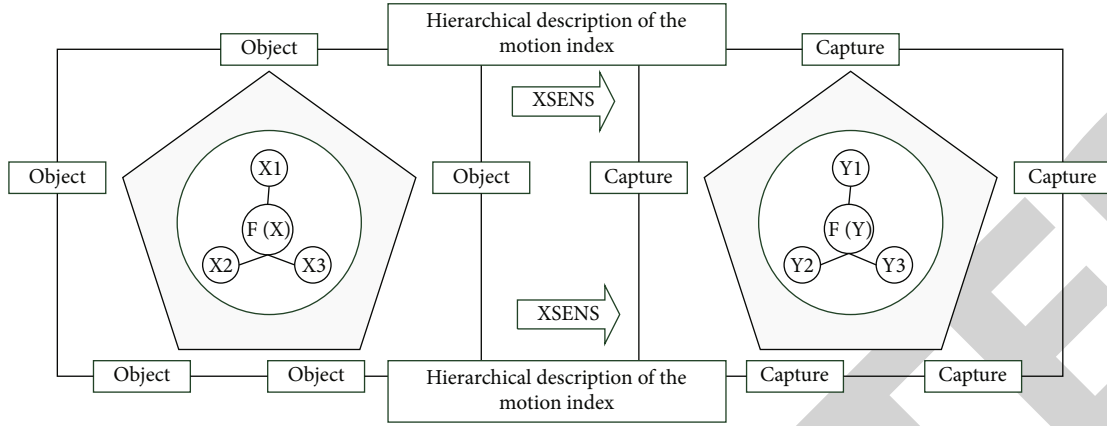


FIGURE 1: XSENS sensor network topology.

sensor on the upper arm, and t represents the direction of the fixed sensor on the forearm [22]. Figure 1 shows the XSENS sensor network topology.

The signal capture device is responsible for capturing and identifying the signal from the sensor and is responsible for quickly and accurately transmitting the motion data from the signal capturing device to the computer system. This type of equipment will vary depending on the type of system. For mechanical systems, it is a circuit board that captures electrical signals, and for optical systems, it is a high-resolution infrared camera.

$$\begin{cases} X(i) \cap X(j) = \emptyset, \\ A \cup X(i, j) = A(i, j), \end{cases} \quad (1)$$

$$\min_{u \in \mathbb{Z}} \text{TV}(u) - \text{s.t.} \|f - u(i, j)\|_t^2 = \sigma^2. \quad (2)$$

Data transmission equipment, especially systems that require real-time effects, needs to quickly and accurately transmit a large amount of motion data from the signal capture equipment to the computer system for processing, and the data transmission equipment is used to complete this work.

$$p(x, t) + \nabla \times \left(\frac{\nabla u(x, t)^k}{|\nabla u(x, t)^k|} \right) = 0. \quad (3)$$

After the central node is powered on and initialized, it enters this state. In this state, the central node only does one thing: monitor the channel to determine whether there is broadcast information from the base station, and enter the networking state if it receives the start control command from the base station.

$$\begin{aligned} P(S(i), S(j), \dots, S(k) | T(t)) \\ = P(S(i) | T(t))P(S(j), \dots, S(k) | T(t)), \end{aligned} \quad (4)$$

$$P(B | A) = \sum_{i=1}^N P(B | A(i)) \times P(A(i)). \quad (5)$$

If no data or synchronization response is received from a certain node that has already entered the network in several communication cycles, it means that the node has gone out of the network and no longer needs time slots. The central node will release its time slot resources and resynchronize the time. The slot is allocated, and this information is updated when the slot allocation packet is sent next time.

$$\int f(x)p(x | t)dx - \frac{1}{n} \times \int f(x)p(t | x)p(x)dx = 0. \quad (6)$$

The data captured by the system needs to be corrected, processed, and then combined with a three-dimensional model to complete the computer animation production. This requires the use of data processing software or hardware to complete this work and the computer's high-speed computing power for the data to complete the data processing, make the three-dimensional model truly and naturally move, and correct and process the data, and combine it with the three-dimensional character model [23].

3.2. The Composition of the Upper Limbs of the Human Body. The upper limb of the human body is a relatively complicated open chain with seven degrees of freedom. There are three origins in the upper limbs of the shoulders and upper limbs. There are two origins in the upper limbs of the elbow and the upper limbs in different directions. In the human upper limb right arm upper limb model, in order to facilitate the establishment of the base coordinate system, u is the length of the upper arm, f is the length of the forearm, and h is the distance from the upper limb to the palm. The upper limb movement usually rotates around the movement axis, and its basic movement form is clockwise or counterclockwise rotation around 3 mutually perpendicular axes, so there are 3 major and 6 minor movements. The shape of the upper limb surface determines the form of movement of the upper limb but also depends on the area difference between the two upper limb surfaces, the thickness and tightness of the joint capsule, the number of upper limb ligaments, and the surrounding muscles. The origins of the three upper limbs of a human arm should be coincident.

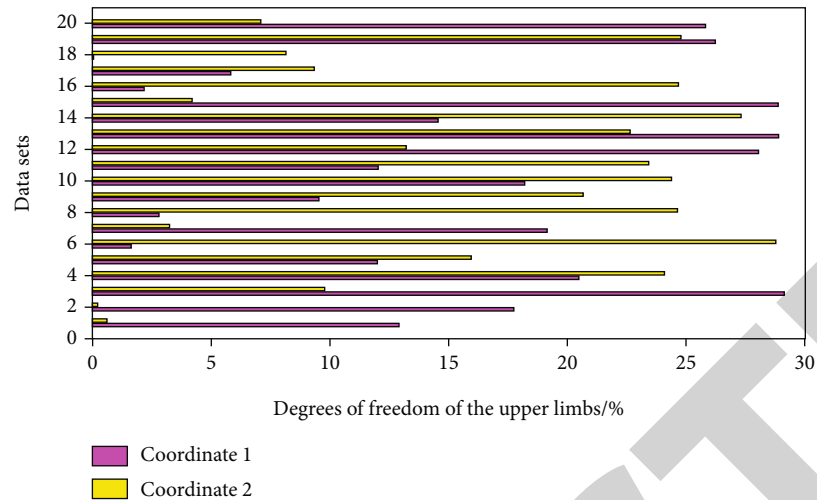


FIGURE 2: The distribution of degrees of freedom of the upper limbs of the human body.

In order to better show the coordinate system relationship of the three upper limbs, they are separated. Similarly, the upper elbow and the upper wrist are also separated, S3 and S4 represent the two upper limbs of the upper limb of the elbow, S5 and S6 represent the two upper limbs of the upper limb of the wrist, and S7 represents the state of the end. Figure 2 shows the distribution of degrees of freedom of the upper limbs of the human body.

In order to describe the kinematics and dynamics of the human body more accurately with numbers, it is necessary to establish the body upper limb model coordinate system. The body upper limb model coordinate system is divided into three types, namely, the fixed coordinate system, the whole body coordinate system, and the local coordinate system. (1) The fixed coordinate system, also called the world coordinate system, is to create a fixed coordinate system on the ground to describe the relative motion of the human body. (2) For the whole body coordinate system, a coordinate system is established at the root node of the human body (perineum point) to describe the relative positional relationship of various parts of the human body and organs relative to the root node of the human body. (3) The local coordinate system is to create a respective coordinate system at each upper limb of the body to illustrate the relative relationship between each upper limb and body segment. When the human body is doing activities such as walking, jumping, and running, the spine maintains the stability and balance of the body by adjusting the trunk.

The intervertebral discs also have similar functions to protect the trunk and brain during intense or large-scale exercise. It forms the thoracic cavity, the sternum forms the thoracic cavity, and the hip bones form the pelvis, which wraps the important internal organs of the human body and plays a protective role. In addition to the role above the spine, it can also perform sensitive exercises. It can complete large-scale movements by accumulating movement between multiple vertebrae and can perform flexion and extension, lateral flexion, rotation, and circular rotation.

3.3. Implementation of Action Interaction Algorithm. XSENS inertial motion capture system is a low-cost, high-precision three-dimensional motion measurement equipment; it records six-dimensional information, that is, not only can get the spatial position but also the direction information, and secondly, the speed is fast, and the real-time performance is good. During motion capture, the character model in the animation system can react at the same time, which is convenient for adjustment and modification, and supports the control and navigation of sports motion capture in small scenes. The content includes human body inertial sensing, cameraless character animation, VR training and simulation, etc. By binding sensors on the key upper limbs of human movement, following the performer's movements in the electromagnetic field, it communicates with data wirelessly. The processing units are connected to perform measurement and transmission of data such as speed, acceleration, reaction time, distance, and torque, but there are restrictions on the performer's actions.

Figure 3 shows the framework of the action interaction algorithm. After completing a data collection, the node will store this data in FLASH for backup and push it into the sending buffer to wait for transmission. Unlike timer 1, the configuration of timer 2 for data transmission services will dynamically change with the time slot allocated by the central node. For example, the time slot allocated by the central node for a node starts at t_0 and has a length of t_1 . As a result, each MLCP router always guarantees the fairness of all passing data flows based on local network congestion information. The timer 2 initialization timing length is t_0 , enters the interrupt at t_0 , and then reinitializes the timer timing length to t_1 ; during this period of time, the node will continuously read data from the sending buffer and send it for the central node; when the timer enters the interruption time again, the timer 2 is immediately stopped, waiting for the central node to allocate a time slot to the node again and so on. For motion capture process, first, we prepare for work, put on the data suit. According to the height and weight of the taekwondo performer, we tie 17 inertial

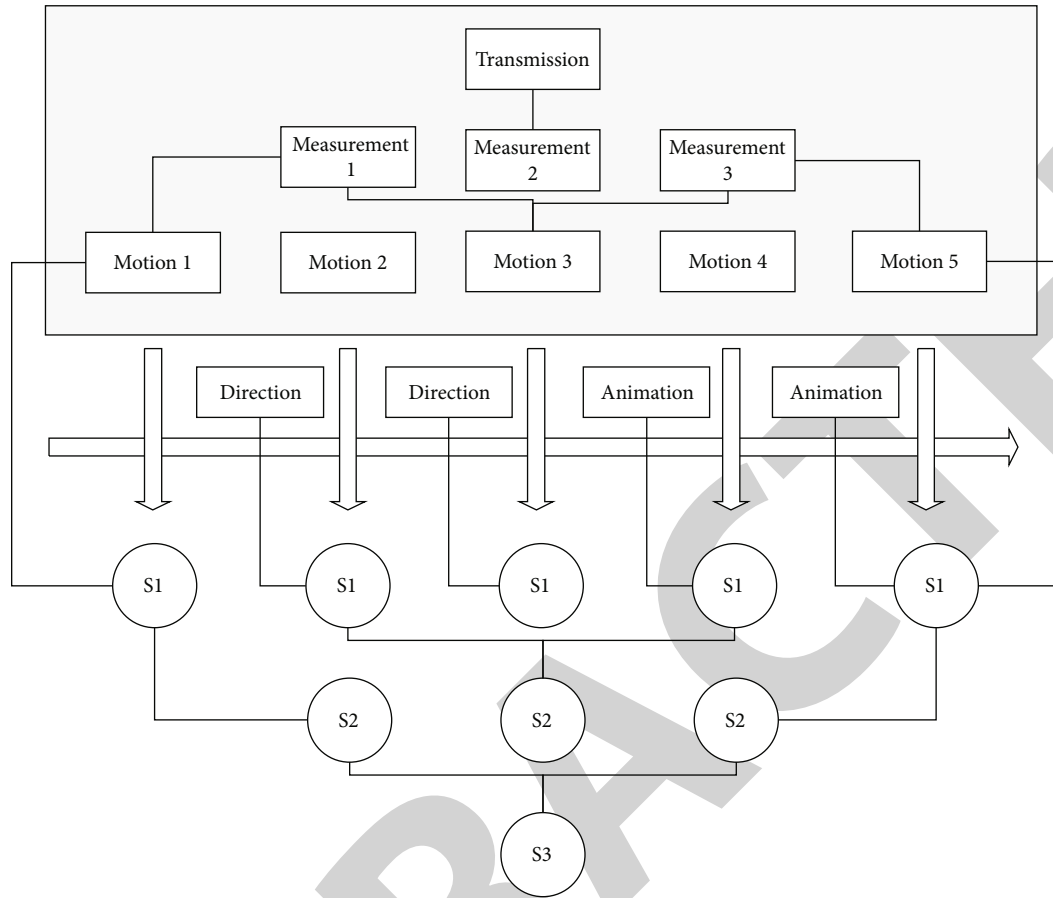


FIGURE 3: Action interaction algorithm framework.

sensors to the body with fixed straps and mark the boxing according to the designated positions.

3.4. Analysis of Animation Capture System. Motion capture technology involves dimension measurement, physical space positioning, etc. It is a system used to accurately measure the movement of moving objects in three-dimensional space. It is based on the principle of computer graphics. It records the motion status of moving objects in the form of images through several video capture devices arranged in space and then obtains three-dimensional space coordinate data after computer processing. Data such as acceleration, acceleration, etc. are quantified, thereby greatly improving the analysis methods of XSENS sensors, which can be used in animation production, gait analysis, sports simulation, and other fields. Data capture, that is, data collection, refers to the process of collecting data from the external environment through related equipment and transmitting it to the inside of the equipment. The data acquisition device used in the experiment is the inertial motion capture device XSENS sensor. Figure 4 shows the XSENS sensor data collection index.

According to the working principle, motion capture is divided into six main types: mechanical motion capture, acoustic motion capture, electromagnetic motion capture, optical motion capture, video-based motion capture, and

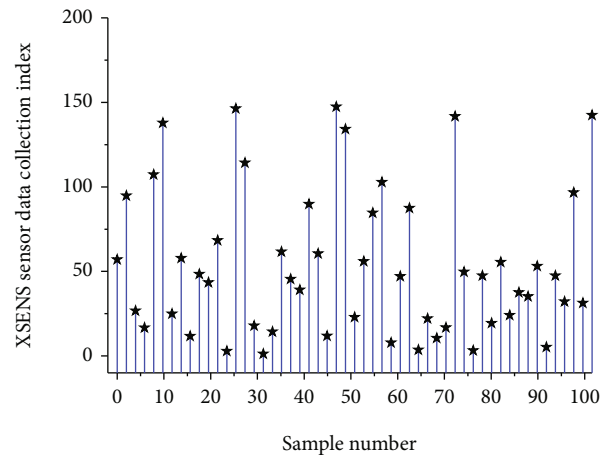


FIGURE 4: XSENS sensor data collection index.

inertial motion capture. According to the hierarchical characteristics of upper extremity point movement, the upper extremity point is divided into 5 layers, and the dynamic clustering algorithm based on the nearest neighbor rule is used to classify the motion database and construct a hierarchical description of the motion index tree. The tree is actually a hierarchical classifier. Each nonleaf node on the tree contains a motion subset of the motion database, and each leaf node contains a retrieval subset. During retrieval, the

TABLE 1: Sports data library subset clustering.

Subset number	Node number	Motion index	Clustering ratio
1	12	2.70	0.97
2	22	2.20	0.83
3	17	1.90	0.88
4	21	2.50	0.91
5	19	2.30	0.93
6	22	2.10	0.79

tree is searched from the root node to the leaf nodes to obtain a subset of motion similar to the input example. Table 1 shows the clustering of a subset of the exercise database.

When the user enters a search example, the system first generates a minimum enclosing rectangle with the same process and then calculates the distance between the minimum enclosing rectangle and the smallest enclosing rectangle of all candidate samples in the motion index through a defined function.

Before the realization of upper limb movement interactive animation design, it is necessary to accurately capture upper limb movement data and use 3D modeling technology to realize 3D upper limb movements. Motion demonstration animation, using XSENS based on miniature MEMS inertial sensing technology, can realize upper limb movement sports direction and position measurement.

4. Application and Analysis of Interactive Animation Capture System for Human Upper Limb Movements Based on XSENS Sensor

4.1. XSENS Sensor Data Collection. In order to facilitate the posture calculation, the base coordinate system with the same orientation as the sensor is selected in this article. Therefore, the rotation transformation relationship between the initial position of the sensor and the base coordinate system is an identity matrix. The XSENS sensor is used in the human motion capture experiment. The sensor integrates a gyroscope, accelerometer, and magnetometer. The system uses a gyroscope to detect the current angular position of the sensor and maps it to the upper limbs of the human body through a posture calculation algorithm. For shoulder upper limbs and elbow upper limbs, the system detects the upper limb rotation information of the shoulder upper limbs, and the upper elbow limbs are given. The browser client layer integrates all the content of interaction with the user and is controlled by the application (software interface) and the toolkit Java Script.

And this control mechanism leads to low link bandwidth utilization and unfairness between long and short data flows in a multibottleneck network. The browser and the server run in different environments. The application development is implemented by HTML and XML documents embedded in Java Script and loaded in the browser, providing users with all functions operate. Web 3D provides the functions of transmission of 3D animation data from the data server

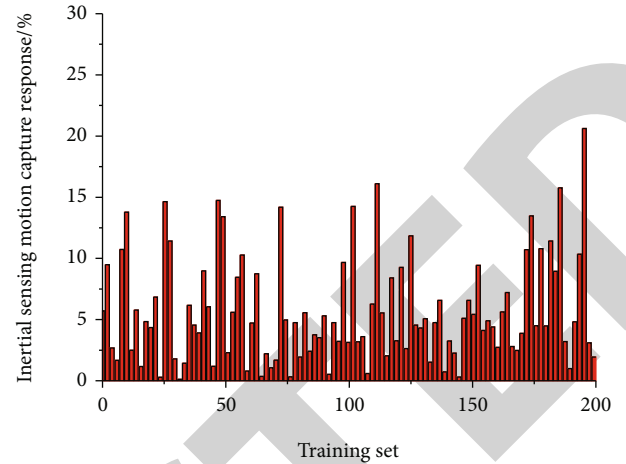


FIGURE 5: Inertial sensor motion capture response histogram.

to the browser client, 3D interaction of mouse and keyboard; the data server layer stores the animation data, scene data, pictures, sounds, and text required by the system for information and runs a database system that manages user data at the same time.

Figure 5 shows the histogram of the inertial sensing motion capture response. In this article, there are 10 subjects participating in the experiment, including 5 men and 5 women. Each subject moves 100 meters of upper limbs each time. We take the average value of each step of the experiment for statistical analysis. A total of 40 sets of walking data were studied. Then, we turn on the wireless sensor to test whether the working point is normal. After the sensor responds, we open the MSENS Studio software to start the initial coordinate position calibration. We set the height and weight of the upper limb movement performer, and the system for the upper limb model is automatically matched to the response.

After the initial coordinates are calibrated, the system starts to capture the upper limb movements. The performer is always within the range of the video captured by the camera. The upper limb movement performance starts, and the system records the movement data to the end of the actor's performance. After the motion capture is over, you need to reopen MSENS Studio to reconstruct the data and perform the performance. The upper limb model of the patient is matched, and the data is simply processed for export. The inertial sensing motion capture device records a sequence of preset points and then responds to the restored discrete points of motion and establishes a topological connection that matches the human upper limb template.

4.2. Realization of Action Interaction Simulation. According to the above theory and sensor fixation method, the following experiments are done, using ROS to detect sensor data, using python for posture calculation algorithm, and sending the calculated data to MATLAB to display the current state of human upper limbs in real time. The XSENS sensor inertial motion capture device used in the experiment is based on the unique and most advanced miniature inertial sensor, biomechanical model, and sensor fusion algorithm. Through

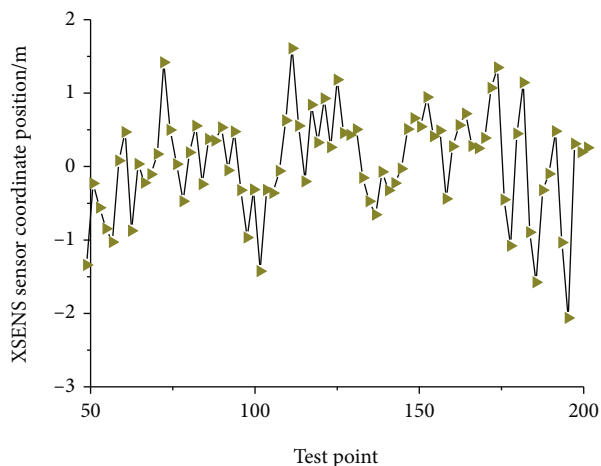


FIGURE 6: XSENS sensor coordinate position broken line diagram.

the signal acquisition device, the acquired position and orientation of each upper limb and upper limb segment are transmitted to the computer through wireless Bluetooth technology or wired means to achieve data acquisition. In order to make humanoid animation objects realistically imitate the movement of natural people, it is necessary to study the basic motion laws of the human body, describe the human motion laws by mathematical methods, and extract the required human motion posture functions. The bvh file mainly outputs the offset and rotation angle of the upper limbs. What is imported into MATLAB is a series of discrete point data. This series of discrete point data changes with time and needs to be described by curve fitting and related functional relationships. Therefore, the research idea of the human body motion posture law is as follows: firstly, we extract the upper limb or upper limb data that needs to be studied in the bvh file, and save it in a reasonable way. Secondly, we separate the coordinate position information and the related human body motion process according to the research needs.

Therefore, we modify the MLCP protocol's control mechanism for each data flow. The rotation angle information is converted to the relevant coordinate system through the transformation matrix, and then with the help of MATLAB, the discrete point map of the human body-related upper limb data is drawn, including the position trajectory and the angle trajectory, and then, the continuous motion trajectory of the human body-related upper limb points is fitted through the curve. Finally, the continuous motion trajectory with an appropriate function is to obtain the human body motion posture function. Figure 6 shows the broken line graph of the XSENS sensor coordinate position.

During the experiment, we used 4 miniature sensors to capture and reproduce the motion of the lower body of the human body to place a sensor node on each of the right thigh and right calf of the subject. The node on the calf is fixed on the outer side above the ankle 10 cm, the node on the thigh is fixed on the outer side 10 cm above the knee, and two sensor nodes are placed on the torso. The sampling frequency of the node is 50 Hz. Each sensor node collects the movement information of the corresponding limb, such as

the thigh sensor collects the movement information of the thigh, and the calf sensor collects the movement information of the calf. Through Maya, we convert the FBX file exported by MSENS Studio, that is, the upper limb movement data into bone animation, so as to drive the character model in Maya. The production of the model should meet the following requirements: when the human body is in a relaxed state, the arms are naturally drooping; when the arms are raised horizontally in a "T" shape, the shoulders are in a tightened and raised state, and the upper limbs of the elbows should be in a straight state, and the upper limbs of the ankle should be straight.

After importing Maya from the FBX file, we select the role to match the upper limb point and use the upper limb point (including movement information) to drive the role to generate skeletal animation. According to the definition of the upper limb movement cycle, we analyze the change of the upper limb displacement over time. Because people are not moving at an absolute uniform speed when walking, the kinematic parameters cannot be exactly the same in each movement cycle. Therefore, these data should be averaged to obtain the kinematic parameters.

4.3. Case Application and Analysis. The data collection process of XSENS sensor inertial motion capture equipment is the process of using sensor to capture the movement offset and rotation angle of each upper limb and upper limb segment during human movement, and the process of transmitting the obtained information to the computer. The XSENS sensor inertial motion capture device uses 17 sensors to obtain the linear displacement, angular displacement, linear velocity, angular velocity, linear acceleration, and angular acceleration data information of each upper limb and upper limb segment during human movement and transmits it through wireless Bluetooth technology or USB wired interface to the computer to display the motion pictures of the upper limbs of the human body in real time. From the relationship between Y-axis displacement and time, it can be seen that at the moment when the Y-axis displacement is the smallest, at 2.1 s, 3.4 s, 4.6 s, 5.8 s, and 7 s, the soles of the feet touch the ground, and the upper ankle is closest to the ground at this time. The maximum displacement on the Y-axis is at 2.8 s, 4.05 s, 5.3 s, and 6.5 s, and the foot lift is the highest at this time. The Y-axis displacement of the left foot is the smallest at 2.75 s, 4 s, 5.2 s, and 6.4 s; the left heel just touches the ground, and the Y-axis displacement of the left foot is the largest at 2.2 s, 3.4 s, 4.7 s, 5.9 s, and 7.1 s.

Obviously, the main movements of the three upper limbs are on the sagittal plane, and the three upper limbs mainly do periodic flexion and extension exercises. Therefore, Fourier functions can be used to fit the upper limbs. The smallest is the upper ankle, let us fit their motion trajectories separately. Figure 7 shows the statistical distribution of the flexion amplitude of the upper limbs of the human body.

Studying the relationship between the knee upper limb angle and the image shows that there is basically no stretching movement of the upper knee limb. According to the relationship between the joint angle and the time in the figure below, the flexion amplitude of the knee upper limb is the

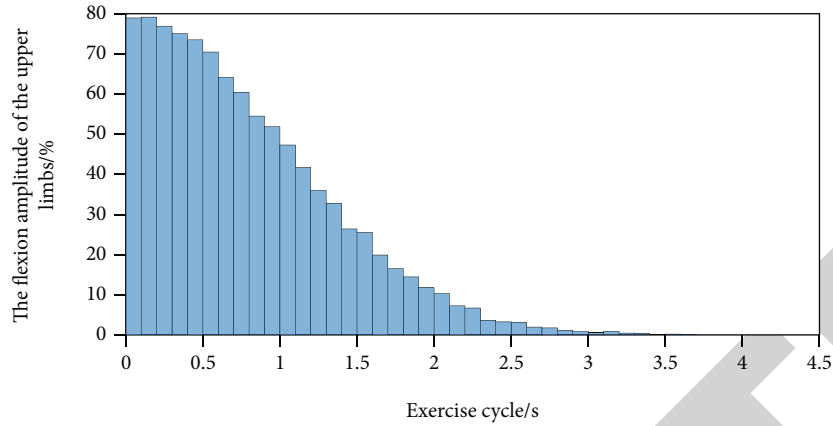


FIGURE 7: Statistical distribution of flexion amplitude of human upper limbs.

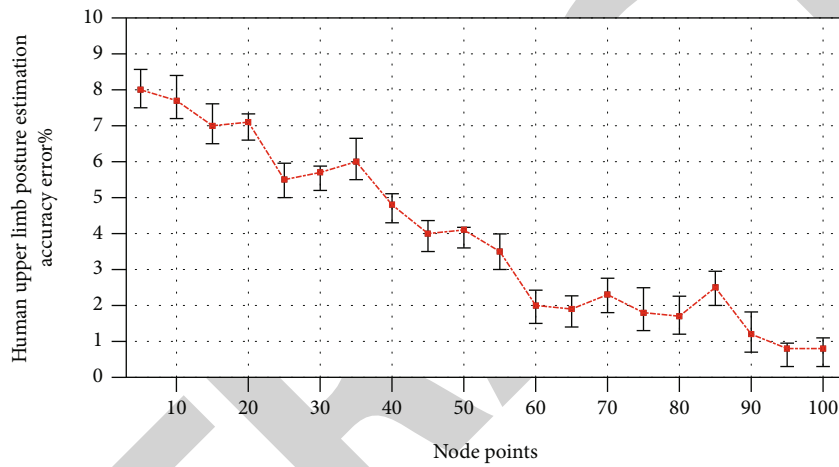


FIGURE 8: Error analysis of estimation accuracy of human upper limb posture.

largest at 2.85 s, 4.1 s, 5.3 s, and 6.5 s; from 1.9 to 2.4 s, the upper knee is basically in a state of extension; from 2.4 to 2.85 s, the flexion of the upper knee increases, and the flexion is the largest at 2.85 s, which is 73.3%, which is about 80.8% of the upper limb movement cycle, from 2.8 to 3.1 s.

It can be seen from the correlation coefficient that there is a significant linear positive correlation between the early or late dual support phase and the upper limb movement cycle. When the upper limb movement cycle becomes larger, the proportion of the early or late dual support phase will gradually increase, because the early or late dual support is equal to the support phase minus half of the swing phase difference, so the support phase fits the function. The fitting function of the early or late dual support phase can be obtained. The correlation coefficient between the maximum extension of the hip and upper extremity and the movement cycle of the upper limb is 0.50.

In the iMLCP protocol, each iMLCP sender only updates its congestion window based on the load index calculated by the smallest bandwidth link of its data packet on the path. It can be seen that there is a significant linear positive correlation between the maximum extension of the hip and the upper extremity and the movement cycle of the upper limb. When the walking period gradually becomes larger, the pro-

portion of the maximum extension of the hip and upper limbs is roughly gradually increased, but it is not suitable for linear fitting, and the custom equation method is used to fit the function.

The previous analysis shows that it is more accurate to estimate the attitude of the measured object by acceleration and magnetometer when it is stationary or moving at a low speed; while the measured object mainly uses a gyroscope to estimate its attitude when it is moving. Figure 8 shows the error analysis of the estimation accuracy of the human upper limb posture.

For the continuous long-term motion of the measured object, the attitude estimation mainly relies on the integration of the output value of the gyroscope. If the system cannot get the acceleration and magnetometer attitude correction over time, the deviation and drift of the gyro will make the attitude estimation accuracy. When the measured object is continuously moving, we separately analyze the attitude output of the gyroscope, and the error of its Euler angle is as described in the text. Comparing the animation of the human body model with the captured video, it is found that the animation of the human body model can track the movement of the real human body well. The experimental results show that the human body model driven by microsensor data can

accurately reproduce real human motion in real time. The host computer of the system runs in real time at a speed of 25 fps, and the delay of the entire system caused by wireless transmission, data processing, and routing protocol is 0.89 s.

5. Conclusion

In view of the spherical motion properties of the upper limbs of the human body, the working space is simplified into a part of the spherical surface, and the spherical surface enveloped by the trajectory of the upper limb output mark (limit) is divided into the joint flexible working space, and the measured data of the upper limb flexible working space is collected and analyzed the characteristics of flexible working space of upper limbs from two description forms of spherical coordinates and Euler angles. A dynamic model of the three-branched human body is established, and the statics of the lower limbs and the movement dynamics of the upper limbs are analyzed and solved. According to the animation capture principle, the balance equation of the space force system considering the inertial force and the moment of inertia is obtained and solved; with the support of the balance equation of the space force system and the experimental data, the static characteristics of the lower limbs when the human body is standing and the hip and upper limbs when the human is walking are analyzed. Knee upper limbs, upper ankle upper limbs upper limb force, and upper limb torque change images and their upper and lower limits and range of change are given. Taking the spherical parallel bionic ankle upper limb of a humanoid animation object as an example, the human body motion trajectory function is used as the output to perform kinematic inverse solution, and the result is compared with the result obtained by the Adams simulation software. The generality of the general function is set to take the actual measured human upper limb force and upper limb moment as a reference; through the calculation of the dynamics of the upper limb mechanism, the driving force is obtained, and the appropriate human upper limb movement interaction model is selected, which reflects the basicity of the results of the actual measurement and analysis.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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