Somatosensory Dance Interaction System Based on Motion Evaluation Algorithm

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Abstract: Square dance is a way of physical exercise, entertainment and social interaction with high participation. In view of the characteristics of square dance activities and the problems of the actual implementation, this paper analyzed and improved the motion evaluation algorithm, and evaluated the human skeleton sequence which the Kinect captured in real time. This paper designed and integrated a motion sensing dance interaction system based on Kinect to serve the grass-roots public culture, to give full play to the effect of motion sensing interactive experience. Users can fully mobilize body subjective in the process of participation. It provides new activity way and convenience for grass-roots mass cultural activities.

1. Introduction

Square dance is a collective dance fitness activity, and it usually carries out in open spaces such as parks and squares. Participants are mostly middle-aged and elderly women. The square dance has the functions of fitness and entertainment, which can bring the people a pleasant experience both physically and mentally. [1] Square dance has become one of the main forms of entertainment for middle-aged and elderly people. It not only occupies the squares and parks of various cities in China, but even spreads abroad, such as Paris, France and Red Square in Moscow. Square dance combines the beauty brought by traditional dance with the physical exercise effect of sports, which not only reflects the aesthetic taste, but also has the fitness function. In a word it has multiple cultural values [2].

Human-computer interaction technology is constantly evolving, and people's demand for more natural interactions is becoming increasingly prominent. At the same time, the traditional way of interaction gradually shows some shortcomings. The motions of the human body have various forms of expression, including the body posture or motion process of the arms, head, face, limbs, etc. The motion of the human body belongs to the information interaction between the human and the environment, which can maximize the inner users' ideas. [3] Therefore, the use of human body motions for human-computer interaction has become a novel and natural way of interaction.

For the interaction of dance, traditional video teaching method is one-way information dissemination without feedback mechanism, and learners can't be aware of their learning status in real time. The somatosensory interaction is the closest mode to the natural motion of the person. It

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can intuitively reflect the human motion to the virtual world of computer games. It has a more realistic experience and can reduce the user's operation difficulty, so that the digital technology is more extensive in public. The different ages, especially the middle-aged and the elderly, they also experience the fun of digital technology and their entertainment and spiritual needs are met.

2. Current Status of Somatosensory Research

2.1 Research on Somatosensory Technology

Somatosensory technology usually uses sensors or depth cameras to sense the motion of the human body and recognize the motion trajectory of the human body, and transfer the acquired data to the computer for subsequent processing, which is a newer way of human-computer interaction. Since the last century, researchers have begun to study human motions. Among them, the famous psychologist Johansson has carried out a lot of experiments in the field of motion perception: only the highlights are attached to each joint point of the human, and the experimenter only counts the motion position changes of various joint points [4].

The experimental results show that the time series of light spots in the relevant motion process can be observed through the visual system to be aware of the sports patterns such as running and walking, and even the gender of the athletes. It shows that the joint information can contain most of the information of human motion, and the collection of joint motion information has great value for studying human motion.

In recent years, the price of motion capture facilities has declined in an environment where hardware is constantly being updated and costs are falling. Three-dimensional human motion capture with optical principle has quickly become the mainstream method to get motion data in the movie industry. At the same time, there have been some other motion capture systems and motion databases.[5-7] After the appearance of the depth camera, human-computer interaction and somatosensory games have applied it to motion capture [8]. Since information of 3D motion capture can greatly restore motion details and motion trajectories, and has the advantages of high precision and high quality, it has been widely favored in many industries such as virtual teaching, intelligent security, sports simulation and medical rehabilitation[9-11].

The Kinect somatosensory control system is currently a popular somatosensory experience device, as shown in Figure 1. Kinect has a high-resolution depth camera that provides depth data, infrared data, color data, etc. It recognizes the human skeleton and provides data such as exercise power, facial expressions, and muscle information. It has instant motion capture, microphone voice input, and speech image recognition, community interaction and other functions[12]. These functions make the human-computer interaction more natural, which greatly enhances the user's immersion. The data obtained by Kinect and the SDK provided by Microsoft provide great convenience for the development of somatosensory applications.

Fig. 1 overall picture of Kinect

Compared with the desktop-based two-dimensional interface mode, the somatosensory interaction in the three-dimensional space is not only the increase of the operation motion and display dimension, but also a better experience closed to the true environment because the relationship between people and environment and the change in the motion join the interaction process. So that users can get a more intense "immersive" feeling. For game design, the design that is free from pure desktop interaction and can promote people's physical motion and benefit the body and mind is already a future development direction [13]. Most of the game operations currently are basically to participate in the game by controlling the virtual agent in the game, which makes the player leave the game situation and lack the feeling of immersion and experience. By utilizing the characteristics of the somatosensory device, players can interact with the game elements in the virtual scene in a natural interaction manner in the three-dimensional space, thereby improving the player's feeling of experience and immersion in the game, and putting exercising in entertainment. It can satisfy player’s needs of entertainment, at the same time, it can minimize the harm to body by the traditional video games.

Therefore, we use the somatosensory game as a way to express square dance, and give full play to the advantage of somatosensory, and fully consider the unity of the collectivity and the individuality, the unity of entertainment and organization. Square dance with the form of somatosensory interaction can fully meet the needs of the masses and provide a novel experience.

2.2 Research on the Current Situation of Somatosensory Dance Games.

The game industry has experienced rapid development in the world in recent years. With the blossoming of the game industry, players’ demands for the sense of gaming experience, operation and substitution are increasingly. Somatosensory games don't require additional controllers, and limb control is popular with many players. [14] One of the most representative products, XBOX game machine, promotes somatosensory games to home users, allowing players to get a double experience of games and sports without leaving home. Dance is a long-standing activity. For a long time, people used dance to express joy, strength, and victory. There are many types of dance games, but as an activity that mobilizes the whole body, somatosensory game is undoubtedly the best way.

Dance mats and dance machines appeared at the end of the last century, first appeared in Japan, and later spread to Taiwan. The biggest difference between this kind of rhythm type game and traditional video game is the operation mode. The traditional video game uses the remote control lever or the four-button handle, and the dance machine uses the player's feet to complete the game. This way of using body parts to control the interaction of the game is more advance than traditional mouse and keyboard, handles and the like. The dance mat and the dance machine are very simple to play. The upper, lower, left and right arrows will appear continuously in the game screen. The player will step on the corresponding pedal with the foot, as long as the arrow moves to the position that coincides with the top arrow frame. But the play of the dance mat weakens the aesthetic needs of the dance itself, and the main strength training is concentrated in the legs, which is not conducive to the coordination of the whole body. The dance machines are mainly distributed in entertainment venues such as the game hall. The players are mainly young people.

With the development of natural human-computer interaction, there was a somatosensory game using a handheld simulator, such as 《Happy Group Dance》 using a Nintendo Wii simulator. The player holds and waves the handle according to the motion of the character in the picture to imitate the character motion in the game. This game way does not completely liberate the hands, and the motion prompts in the game make the player's motions more rigid. Until the appearance of the depth camera, a dance game that mobilizes the whole body is derived called somatosensory interaction. The typical representative is the 《just dance》and 《Dance Central》in the XBOX. The XBOX is a video game console with functional maturation and rich video game .It use Kinect as peripheral equipment to get depth image information and capture the motion of players in three dimensions. Dance games in XBOX are more vivid and natural than traditional video teaching. Its content focuses on physical exercise or leisure and entertainment, and some have a storyline, mainly providing family entertainment. There are obvious deficiencies in the purposeful study of dance and group entertainment in public places. For this situation, we integrate all-in-one machine with square dance game is mainly dedicated to serving public culture. The content of square dance is aimed at China's unique square culture. It can be used as a tool to learn square dance and provide the public with a new and interesting game entertainment experience [15].

3. Key Technology Research

3.1 Beat Control.

Music is a very important part of the dance game. It plays an important role in the overall style definition of the game, rhythm control, and system structure in the game development process. For example, in the game menu control section, the player switching option needs to switch the current background music in real time so that the player can have a preview of the song; at the beginning of the game, the standard dance motion, recording and evaluating of the player's motion in real time, the game special effects, UI rhythm control, etc. are all controlled by beats.

Since there are several game objects in the game that need to rely on music beats for updating, a separate music beat component is needed to send events to other modules at the right time. The module has a "one-to-many" feature, and the "multiple" end is easy to change, so use the "observer mode" for design[16], as shown in Figure 2. The observer mode separates the observer from the observed object, and uses the motion evaluation module, the UI module, the prompt module, and the background control module as observers, the music beat is taken as the observed object, and the observer can process according to the observed data. In this way, each module can be clearly divided to improve the overall reusability and maintainability of the system. In the game design and development process, we set up a special beat control module, using the observer mode, to control the overall game rhythm.

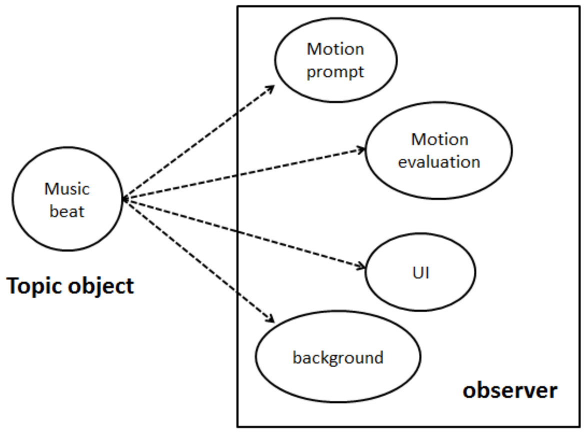

Fig. 2 Observer mode for music beat control

3.2 Motion Evaluation Algorithm.

The traditional methods of dance learning include video teaching, on-the-spot teaching, etc. For people who have no or only a small amount of dancing experience, Video teaching method lacks comparison materials and has no standard evaluation of whether the motion is standard, which leads to low learning effect and large deviation of motion. On the other hand, on-the-spot teaching can achieve better learning results, but it consumes a lot of manpower and cannot be studied at any time.

Therefore, we put motion evaluation algorithm in the game process to feedback the player's motions in real time to achieve a good learning effect.

The main job of motion similarity evaluation is to let the computer automatically perceive where the person is and determine what the person is doing. The first step in the evaluation of motion similarity requires posture estimation. The posture evaluation mainly refers to identifying the posture parameters of each part of the human body in each frame based on the specific image sequence. For example, the position and orientation of each parts of the body in the entire three-dimensional space is a set of posture parameters, which is usually done by the motion capture device. The motion similarity evaluation is based on the posture estimation. The feature is extracted from the motion frame and by calculating the distance between the feature vector of reference motion sequence and the feature vector of the comparison motion sequence, the similarity between the two motion sequences is obtained. Since the motion similarity evaluation algorithm relies heavily on the results of posture estimation, the accuracy of posture estimation has an impact on the accuracy of motion similarity evaluation. Therefore, we need to perform some preprocessing work on motion data, such as data noise reduction.

We have studied several popular motion similarity evaluation methods, including static matching method, motion similarity evaluation algorithm based on DTW (Dynamic Time Warping), and DTW motion similarity evaluation algorithm based on adaptive joint weight, motion similarity evaluation algorithm based on interpolation wavelet key frame extraction, and so on. The evaluation of motion similarity has certain difficulty, because each motion has multi-dimensionality, and the motion data will be accompanied with a lot of noise when collecting, and the difference of performance of different individuals is also high, and the real-time requirements, etc., all of these factors add to the difficulty of motion evaluation [17].

The DTW motion similarity evaluation method of adaptive joint weight is to improve the motion characteristic based on the structural characteristics of the skeleton, and the motion similarity evaluation method based on the interpolation wavelet key frame extraction is to improve the timing characteristics of the motion. The two methods improve the motion features in different dimensions. Therefore, we merge these two methods, we use the interpolation wavelet to extract the key frames of the motion sequence, and then match the comparison motion sequence and the reference motion sequence through DTW method. In the matching, the method of adaptive joint weight is used to calculate the distance between two motion frames, and finally the average distance between the matched key frames is normalized and scored as the motion similarity result. [18]

The specific implementation process of the algorithm is as follows:

(1) Data noise reduction

Firstly, the Faber-Schauder interpolation wavelet and the mean filtering method are combined to reduce the noise of the collected motion data. In the background of low noise, some motion details in strenuous motions are easily regarded as noise, and it is suitable to use interpolation wavelet; in the background of high noise, combined with mean filtering can obtain better noise reduction effect.

(2) Evaluation method of adaptive joint weight

Starting from the motion characteristics, the motion sequence is divided into multiple sub-segments, and the cascaded joint direction data is used as the feature. The joint weights of the motions are calculated and compared, and the distance between any two frames can be calculated.

(3) Determine the motion sequence mapping relationship

The unique mapping relationship between the reference motion sequence P and the contrast motion sequence Q is determined using a DTW motion sequence matching algorithm. Then we record the set of matching relationships between the two.

The DTW-based motion sequence matching algorithm is described as follows:

a) Starting from the first node, the path distance is calculated cyclically. Based on the inter-frame distance measurement formula and the three conditions of DTW regularization, the smallest one of the matches is selected, and the minimum distance of the path is obtained by adding the current distance;

b) Repeat the previous step until you get the complete regular path;

c) Create an array MapFrame to record the unique mapping relationship of all frames in the reference motion sequence P in the comparison motion sequence Q. Traverse the regular path and store its mapping relationship in the MapFrame.

(4) Extract multi-dimensional motion sequence key frames

The key frame extraction method based on multi-scale Faber-Schauder interpolation wavelet and interval-interpolation wavelet based on central affine transformation is used to extract the key frame of P, and then we obtain the key frame set Kpr(r=1,...R), and R is the number of the key frame in the motion sequence. Combined with the set of matching relations obtained in step (3), the key frame Kqr' (r=1, . . . R) of Q is obtained, where r is the number of key frames of the motion sequence.

(5) Perform similarity evaluation

The multi-dimensional motion features obtained in the previous step are similarly evaluated for P and Q, that is, the distances of all key frames in the two sequences are calculated and averaged.

$$DIST(\mathbf{P},\mathbf{Q}) = \frac{\sum_{r=1}^{R} dist(\mathbf{kp}_r, \mathbf{kq}_{r'})}{R}$$

The similarity was evaluated after normalization. The higher the score, the higher the similarity.

$$SIMILARITY(\mathbf{P},\mathbf{Q}) = \frac{1}{DIST(\mathbf{P},\mathbf{Q})+1}$$

Most of the square dance enthusiasts are middle-aged and older, so they are more dependent on the coach when learning a new dance. Using the somatic device to collect the motion and using the motion similarity evaluation algorithm to evaluate the score, the problem can be solved to a certain extent. In the real-time evaluation system of motion, the subject data of the somatosensory sports teaching needs to have high follow-up and real-time, so an accurate evaluation system is the technical guarantee for promoting the application of rural public culture.

4. Game Design

4.1 Design Principles and Strategies

As an expression form of Chinese characteristic culture, square dance is mainly aimed at middle-aged and elderly people. They spontaneously gather at squares, parks, playgrounds and other open spaces at specific times of the day. The leader of the dancers needs to carry sound equipment. And the activity last for one to two hours every day. We found that there are some problems in the process of square dance organization. For example, beginners cannot learn and practice at any time and organizers need to carry music players, so resource sharing is difficult, and dance resources are not updated in time. According to the above situation, we designed the game with the following principles and strategies:

1) Considering the user's ability to accept new things, in order to make the game serve the masses more widely, the game process and menu design is as simple and easy as possible.

2) There should be real-time feedback on the player's performance, so that the players can know their performance in time to adjust their motion and the evaluation can increase the joy of game and give players encourage.

3) Evaluating player's motion in real time, and giving remark in the game process, such as "great", "make persistent efforts ", etc., and finally giving the overall evaluation.

4) Different songs correspond to different motions and different difficulty. This design can satisfy the needs of all age group, such as the young and the aged.

5) Teaching motions and player motions are mirror images to improve the player's immersion.

6) Combining somatosensory interaction and traditional interaction, menu selection does not use somatosensory control, to avoid misuse and lower the threshold for use.

We designed and developed this game to provide convenience to the masses who enjoy the fun of square dance. It is not only a dance game using somatosensory technology, but also a platform for guiding, teaching and organizing square dance. We take into account the needs of the vast majority of players to choose dance music covering different age groups, such as passionate youth dance music, popular pop music, and slower-paced activity for the elderly. In addition, considering the different gender needs, there are shadowboxing for middle-aged and elderly male users.

4.2 System Architecture.

The square dance somatosensory game software adopts a three-layer system design method, which include data layer, control layer and presentation layer.

The data layer is mainly responsible for reading the song configuration file and evaluation standard configuration file, and using the iterator as an intermediate abstraction layer to provide a convenient data access interface for the control layer and the presentation layer. The song configuration file stores songs' beat information, such as the beat type, the number of beats, the beat interval of the motion similarity evaluation, and the beat interval of the motion prompt picture display; and the evaluation standard file stores the corresponding relation between the motion similarity score and its rank.

The control layer includes music beat control, motion sequence preprocessing, motion similarity evaluation, and dance flow control system. We use the interpolating wavelet to perform noise reduction processing on the collected motion sequence in the motion sequence preprocessing module. The motion similarity evaluation module scores the user motions in real time. The beat control module passes the strong and weak beat message to the motion evaluation module and the part of presentation layer module based on the song configuration and the time manager of the Unity3d engine. The dance flow control module is responsible for overall process control, including keeping music and dance animation synchronous, pauses function, and dance end determination.

The presentation layer includes visual elements in the three-dimensional scene, user interface, etc., for receiving data input by the user and displaying data, and providing the user with a virtual interactive scene. The user integration module is used to accumulate the points of each motion evaluation and display; the motion prompt module is used to display the prompt maps of the previous, current and next motions; the scene interaction module controls the three-dimensional model in the scene to synchronize with the motions of the user. The evaluation display module is used for real-time display evaluation of the user's dance motion, wherein the data is derived from the logic layer's motion evaluation module; the completion degree display module is used to let the user know the schedule of the current song; the animation control module implements the prior motion the standard dance motions captured by the capture system are played on the 3D model. The system structure diagram is shown in Figure 4.

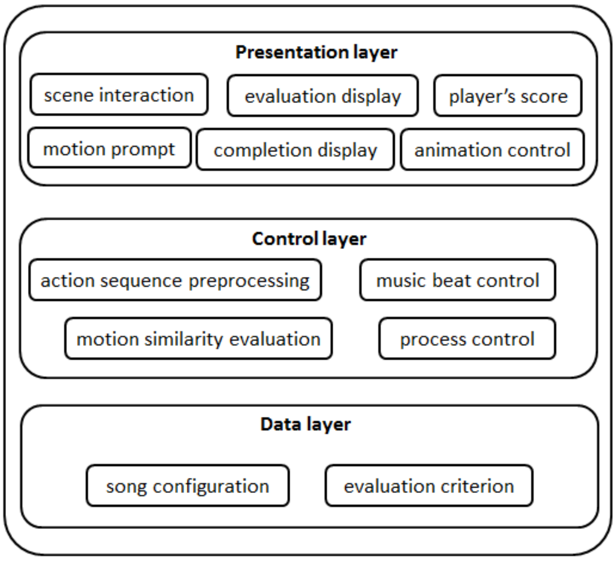

Fig. 3 Game system structure

4.2.1 Data Configuration.

The beat type, the number of beats, the beat interval of the motion similarity evaluation, and the beat interval displayed by the motion prompt picture are different for different songs, so independent data is configured for each set of dance songs, and the configuration file is read in the main scene of the system. Songs, motion evaluations, and motion prompts need to satisfy the following hierarchical relationships: The system contains a number of songs, each of which contains several bars, motion evaluations, special effects, and motion prompts, so the data can be described in XML format.

The configuration file format is as follows, the contents of the square brackets represent the attributes, the bullets and the indentation represent the hierarchical structure of the XML. For a song, the specific description is as follows:

Song 1[song name, song name in program, scene id, role id, beat number per minute]
  section division
    several identical sections[beat type, beat number]
  motion evaluation
    single evaluation[interval beat number, joint weight(six at all)]
  special effects
    single special effect[effect id, section position, duration, Whether to set the initial position, position coordinates]
  motion prompt
    single prompt[waiting beat number, text content]

The system data layer is responsible for storing the configuration file and parsing the configuration file. The storage configuration file module stores the song configuration data of the runtime as an XML file according to a predefined rule, and we set up a special parsing configuration file module to parse the XML and write the data in the data structure of the runtime. Such a data configuration method can keep the data in the configuration file consistent with the actual dance motion beat. The accuracy of the system motion evaluation and the overall dance experience have been greatly improved.

4.2.2 Game Flow.

In order to reduce the threshold of use, we do not choose to use the somatosensory motion for menu selection. Instead, we use the touch screen on the all-in-one device that installs the square dance game, and the player selects the song by touching screen. After the song is selected, the system unifies all module time and then players will enter the main dance screen.

The game flow control section controls the motion sequence preprocessing, the motion similarity evaluation, and the dance flow, etc. The motion similarity evaluation module is the core component of the application system. Firstly, the dance motion is divided into segments according to the song configuration file, and the user motion is collected in real time and divided into the same length with the above, and then the motion data is de-noised and the system score player's motions in real time. The beat control module dynamically generates strong and weak beats based on the song configuration and the time manager of the Unity3d engine, and passes the beat message to the motion evaluation module. The flow of motion evaluation is shown in Figure 3.

The entire evaluation process is not visible to the player, but the system will give comments such as "Continue to Work" and "Perfect" to motivate the player to continue the game. After the song is over, the system displays the overall score and gets the star rating, then returns to the main interface.

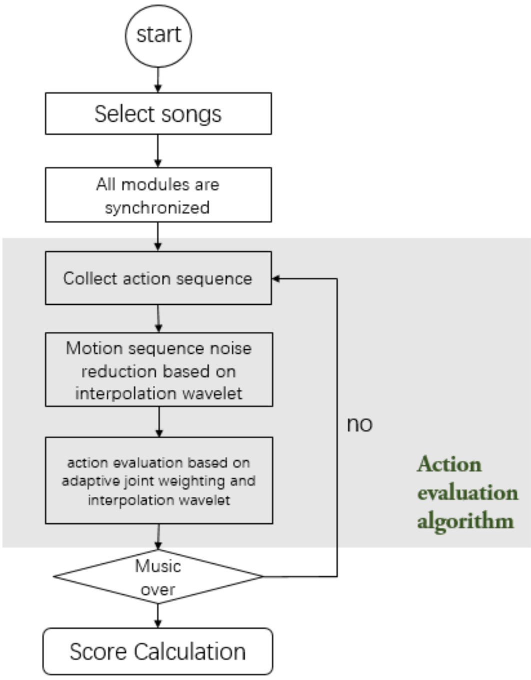

Fig. 4 Motion evaluation flow chart

5. Game Implementation

5.1 Hardware Integration.

Community public cultural service terminals need to have both community public cultural service functions and modern high-tech interactive digital entertainment fitness functions [19]. In order to adapt to all levels of the community, especially the elderly and children, some factors should be considered in the design. For example, digital entertainment facilities should have the advantages of somatosensory interaction; the product adopts a large touch LCD screen to provide a super visual experience; the operation is quick and simple. In addition, considering the experience mode and the experience location, the equipment needs to be safe, stable and reliable, and has basic design requirements such as windproof, rainproof, dustproof, anti-theft, and electric shock prevention. It requires beautiful appearance and easy movement in the shape design. And it need to be convenient to transport for long distance. The overall equipment is shown in Figure 6.

Fig. 5 Somatosensory integrated equipment diagram

Fig. 6 Menu selection interface

The all-in-one device integrates computer host, Kinect camera, audio device, large-screen touch display and the like. The computer host requires the operating system to be win8 and above, the USB 3.0 or higher interface, the memory above 4G, and the hard disk above 125G. In addition, a GPU compatible with the interactive content needs to be configured, and a service information module and a network content-based interactive content experience management system are built to realize remote content update and daily maintenance.

5.2 Game Introduction.

This square dance game is designed and developed using the Unity3D game engine. It uses Microsoft's Kinect 2.0 as a somatosensory information acquisition device to acquire depth data and color data. The depth data has an image resolution of 640*480 and a refresh rate of 30Hz. Breaking through the graphics engine's somatosensory data-driven key technology, transforming the motion data captured by the somatosensory device into smooth bone motion data, and formulating matching bone nodes for the virtual character of the game according to human bone characteristics, we realizing three-dimensional somatosensory motion and bones in the three-dimensional game engine motion mapping configuration to achieve motion control with the virtual world. We designed and integrated the somatosensory device to facilitate the experience of the game content.

The song selection scene shows a list of songs in the current system, and the song information is displayed on the left side of the interface. As shown in Figure 7.

Fig. 7 Main scene of the game

Fig. 8 Game settlement scene

The main scene of the dance motion real-time evaluation system is shown in Figure 8. According to the song selected by the selection interface, enter the game core interface. According to the selected songs, different game scenes are randomly selected as the square dance background. In this scene, the system displays the standard dance motion recorded by the motion capture device in the form of three-dimensional animation, real-time mapping the user motion to another three-dimensional model in the scene through the somatosensory camera, and dividing the song segment according to the song configuration file to evaluate player’s dance motion.

Different songs match different character models to keep the player fresh in the process of multiple experiences. In the middle of the screen is the dance area, the virtual character shows the standard dance steps, and the player imitates the dance motion in front of the somatosensory camera. The virtual character motion is a mirrored version that the player can imitate directly. At the bottom right of the screen is the motion prompt area, which prompts the motion in real time according to each section of the music. Players can use the motion prompts to prepare the next bar motion. After a number of beats are completed, the game scores a percentage of the player's motions and displays the results of the evaluation around the virtual character. The evaluation criteria from high to low are: "super perfect", "great", "keep trying" and no evaluation. The game accumulates the score and displays the current score in the upper left corner of the screen. The lower left corner is the beat progress reminder and the music amplitude display. The music amplitude shows the sound amplitude of the current song, which enhances the player's game immersion. The player can pause the game at any time during the game.

When a set of dance motions is over, the system will jump to the end interface of Figure 8, System segments the collected user motions according to the song configuration file, and use the pre-processing method and evaluation method described the above to evaluate the user motion in real time, the scene displays the total score of the user and its overall rating star rating.

6. Discussion

The article describes our integrated somatosensory device and square dance somatosensory game. The system consists of motion capture system, real-time somatosensory motion evaluation system and data configuration tool. The optical motion capture system is used to collect dance motions, and combining appropriate post-processing we obtain standard dance motions. The real-time somatosensory motion evaluation system uses Unity3d three-dimensional graphics engine to build a virtual experience environment, with Kinect somatosensory camera as motion acquisition device, based on motion similarity evaluation algorithm evaluates user motions; the data configuration tool provides developers with a fast and accurate workflow for making dance song profiles. As one of the popular human-computer interaction methods in the 21st century, somatosensory technology has greatly promoted the development of natural human-computer interaction after the mouse and multi-touch technology. The organic combination of square dance in China's urban and rural residents and the somatosensory technology just provides an interactive and content-rich platform for the square dance [20-21].

7. Conclusion

We have built a set of somatosensory interactive application system for rural grassroots public cultural services with the square dances that the grassroots enjoy as the experience content. The somatosensory interaction technology and the motion similarity evaluation algorithm are applied to the rural grassroots square cultural service in three-dimensional visualization. In the process of integrating interaction technology with rural public cultural services, the digital content of rural public culture has been expanded. In the following research, we will continue to pay attention to the needs of the public culture field, and use advanced interactive methods to provide grassroots people with convenient and content-rich digital entertainment platforms.

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