Editing method of virtual human motion path based on motion cycle step-length

Wenju Wang[1]*, Liujie Sun[1], Zhang Xuan[2]

[1]*University of Shanghai for Science and Technology, Shanghai 200093, China*

[2]*Shanghai Conservatory of Music, Shanghai 200031, China*

Abstract

An editing method of virtual human motion path based on movement cycle step-length is presented: it uses the Cardinal spline interpolation to extract the original path and equably sets the path editing control points; alters the positions of path editing control points to generate a new path and adjusts the position and orientation of the original motion sequence frame's root joint nodes on the new path; automatically judges any path curve segment that generates the problems of footstep disharmony after editing; for every incorrect curve segment, deletes the frames of general motion cycle step-length between the two path editing control points that contain incorrect curve segment based on the definition of motion cycle step-length and adjusts the spacing and moving direction of root nodes in every frame on the paths between the two control points; finally does constraint re-establish to all floor frames in the new path. The experimental results show that: the motion path editing method is simple and easy to operate. The generated virtual human motion is natural and smooth. It can effectively eliminate the footstep sliding phenomenon to improve the reusability of motion capture data.

Keywords: Motion path editing, Cardinal spline interpolation, Motion cycle step, Constraint reestablishment, Footskate cleanup

1 Introduction

Virtual human animation is to use a computer program or software to simulate the human motion. In the game and entertainment, simulation training and simulation tests based on virtual reality, such as virtual scene display, sophisticated skill training, virtual manufacturing and ergonomics analysis, it plays a more and more important role [1, 2, 3]. The motion capture technology means to use the data capture device to record some real human motion, and then map the recorded motion data to the virtual human in computer, to drive the virtual human moving [4, 5]. Because it has accurately recorded a wealth of detailed information and can efficiently draw realistic and delicate human motion, the technology has become the current study hotspot of virtual human animation. But it can only generate a particular human motion prior captured and the acquired data can only be applied in certain circumstances, which is not adaptable, of poor flexibility and with low reusability [1]. In the actual animation designs, human-body motion is rich and varied. If re-capturing the motions for every slightly differences of design actions, it will bring high costs. So, editing and addressing the existing captured motions to fit design requirement, to improve the reusability of captured data to reduce production costs is significant. The motion editing is an effective way of editing that changes other actions of virtual human as little as possible, and edits motion paths to fit animation design

requirements of different trajectories under different situations.

But in the motion path editing process, it often generates the footstep slip phenomenon. Despite adopting many effective measures and methods, it is not well resolved. For example, Michael Gleicher had proposed a path transformation method. He used the arc length parameter to map the virtual human location to the new motion path. Then, he used the method of geometric constraints to define the double-foot position or relative position. But the resulted effect was not realistic [5]. In 2002, Michael Gleicher proposed a way to automatically recognize previous foot location constraints and manually edit and generate new foot position by users. This process did not introduce artifacts, but increased the labour input editors [6]. Noah Lock used an improved deformation technology approximating to rigid body to modify the motion paths, and time bending technology to allow users to concentrate on meaningful space path editing. Meanwhile, it automatically improved the motions, to regularly maintain a biomechanical relationship between the path shape and speed. But time bending technology has strict rules on speed, which makes its applicable scope limited [7].

Lu Xaojun used the joint interpolation method to generate each frame's joint parameter from the original captured data. It got the animations of different motion paths by interpolating values to the positions of motion locus of human body basis points. The process contained no foot position constraint and was prone to appear foot

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* *Corresponding author* e-mail: wangwenju666@163.com

sliding phenomenon, making the generated animation on poor quality [8]. Liu Shuang proposed an improved motion path editing method: evaluating the foot position of original motion data for each frame to use as the initial constraints. Then, it automatically generated new constraint position of supporting point according to the motion direction changes. Following this, it would use the real-time inverse kinematics algorithm according to frame editing to solve constraint conditions [9]. In the motion path editing process, Luo Zhixiang established the appropriate objective function by defining a set of space-time constraint conditions and used inverse kinematic and numerical optimization method to solve the motion posture meeting the constraint conditions [10]. Chen Zhihua introduced the motion auto simplification technology into the conventional space-time optimization method and introduced the physical constraints into the conventional path transformation method, to guarantee the rapid convergence of the optimization process and the physical authenticity of the resulting motion [11]. However, in the above-described algorithm, it added the physical constraints containing velocity and acceleration. They were both non-linear functions. This would greatly increase the complexity of time-space optimization solution, and the overall solving speed is slower.

SAFONOV A [12] and some others put forward a search model based on the motion diagram that means to connect different motions by the way of diagram. Thus, it changes the motion path editing problem to the problem of finding optimal path according to the motion diagram. However, the effect of splicing and fusing the motion fragments is not satisfying and the mode needs to spend more time on fusing motions.

To solve these problems, here proposes a motion path editing method based on motion cycle step-length. It can effectively eliminate the footstep sliding phenomenon to improve the reusability of motion capture data.

The section 2 describes related work of the motion path editing algorithm; the section 3 describes some preliminaries as the theoretical basis of the algorithm; the section 4 gives a virtual human motion path editing algorithm based on motion cycle step-length; the section 5 is experimental results and analysis of our algorithm; the section 6 gives the conclusion.

2 Preliminary knowledge

2.1 FORMAT OF MOTION CAPTURE DATA

The file format of motion capture data mainly contains BVH, HTR, ASF / AMC. (In which, the BVH format developed by the Biovision is more common. This paper will take data on this file format as the input object of motion path editing.)

Analysing these human motion capture data, the content is mainly divided into two parts [13]: 1. data being used to describe the structure and the initial position of human skeleton; 2. recording a set of specific

data for each frame including displacement of each root node in every frame under the global coordinate system and motion data information between adjacent joints as Euler angle and so on.

The hierarchical skeleton model is usually used to describe the human skeletal structure of the virtual human (as in Figure 1). The skeletal system is represented as a set of interdependent joint chains in the hierarchical skeleton model, and can be described as a tree structure (as in Figure 2). The root node of the tree is Root. Other nodes correspond to each joint of the human body model. The whole human motion can be seen as being composed by translation and rotation, that it is achieved by the translation of the root node and the rotation of the rest nodes relative to their parent nods on the tree. Wherein, the translation of the root node determines the motion trajectory of human, and the rotation determines the motion direction of human. Except the root node, the rotation of the rest nodes is done in the local coordinate systems which take their parent nodes as coordinate origin. So, in each frame of the motion sequence, the position of each joint node p_{n+1} in human model can be solved in the world coordinate system by the following formula:

$$p_{n+1}^{world} = \prod_{i=Root}^{p_n} T_i R_i p_{n+1}^{local} \qquad (1)$$
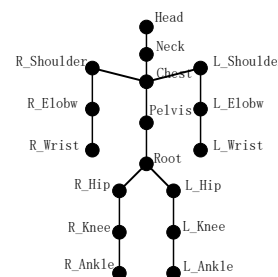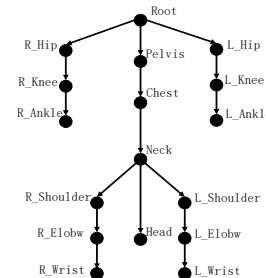

FIGURE 1 Structure diagram of human skeleton

FIGURE 2 Hierarchical skeleton model of human

In the equation (1), p_{n+1}^{world} is the world coordinate of joint node p_{n+1}, p_{n+1}^{local} is the coordinate of joint node under the local coordinate system using p_{n+1} as origin and $T_i, R_i (i = Root, p_1, ...p_n)$ is the offset and rotation matrix of the child node relative to the parent node.

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3 A motion path editing algorithm based on motion cycle step-length

In the motion path editing, it often appears a footstep slip phenomenon because of the original path changing. There are two main reasons for this phenomenon: 1. the location and motion direction of the virtual human are not timely adjusting. The total frame amount does not change, but the path length becoming relatively short after editing, that is, the relative distance between root nodes of motion sequence frames becoming smaller (what we called frame aggregation is too high). Their relative movement rate increases. But the step exercise frequency and step-length remain unchanged. These result the phenomenon of "out of step". 2. in the original motion sequence, a supporting point (i.e. a foot) is at the same position in space on two or more continuous moments. However, after motion path editing, the position of the supporting point has changed on the corresponding moments. If still using the original motion frame sequence to draw, it will produce footstep slip and appear motion disharmony.

To solve the footstep slip phenomenon, the new motion path editing method is proposed from these two areas. The algorithm steps are described as follows:

(1) Here takes global offset of each frame's root joint node in accordance with the Cardinal spline interpolation to extract the original motion paths and save, and calculates the slope of the spline interpolation curve of each frame's root node as a motion orientation.

(2) Evenly setting the path editing control points on the original motion path and taking two adjacent path editing control points as the starting terminal and ending terminal of a curve segment, by this it divides the original motion path curve into a number of curve segments. For each curve segment, along with the direction of human motion and with each path editing control point as starting point, it will find starting frames of each general motion cycle step-length in turn.

(3) It changes the location coordinates of the path editing control point, then rebuilds a new motion path by Cardinal interpolation, and adjusts the position and motion orientation of each frame on the new path.

(4) On the newborn motion path, here determines the curve segments with footstep disharmony phenomenon to construct the corresponding curve segment collection. If the curve segment collection is empty, namely no curve segment with footstep problem, then it directly turns to step (8).

(5) Here selects a curve segment with the phenomenon of footstep disharmony from curve segment collection. And it judges whether there is a general motion cycle step-length within the curve segment, if no, reading the next curve segment, Otherwise, starting to count the number of the to-be-deleted general motion cycle step-length on the curve segment. It assumes the curve segment on the original motion path which uses two adjacent control points as terminals AB, and the

curve segment after path editing as AB'. The number of to-be-deleted general motion cycle step-length is calculated by equation (2), where λ is the general motion cycle step-length.

$$N' = \left\lceil \left| \frac{\left| AB - AB' \right|}{\lambda} \right| \right\rceil \quad (2)$$

(6) According to the number of to-be-deleted general motion cycle step-length in the curve segment, it will delete the frames of general motion cycle step-length between the frame sequences where the two control points are.

(7) It finds the nearest two editing path control points in the newborn path. The curve segment taking the two control points as terminals should contain the curve segment with the phenomenon of footstep disharmony. Between the two control points, it adjusts the frames that has deleted the general motion cycle step length. Checking if all the curve segments with the phenomenon of footstep disharmony have been treated in the curve segment collection, if still existing untreated curve segment, it turns to step (5), otherwise to step (8).

(8) It constrainedly reestablishes all the foot landing frames in the newborn path.

3.1 PATH EXTRACTION METHOD BASED ON CARDINAL SPLINE

To edit the motion path of virtual human, it has to extract its motion path from a section of known motion capture data. The new motion path extraction method based on Cardinal spline interpolation is as follows:

(1) On the equal time interval frame in the original motion sequence, it takes the global offset of root joint node as the position of Cardinal spline curve control point.

(2) For the translation trajectory of human root node, it carries out Cardinal spline interpolation to its horizontal axis component and longitudinal axis component (in the BVH files, because the world coordinate system is defined as the right-handed coordinate system and takes the positive direction of y axis direction as the positive direction of vertical axis, it takes the x axis component, z axis component as horizontal axis component, longitudinal axis component) conducting curve fitting to generate the original motion path.

In the process of extracting the original motion path, here selects the Cardinal spline interpolation because the slope of control points can be obtained from the coordinates of two adjacent control points and easy to implement. It assumes that $p(u)$ is the parameter cubic function between the two control points p_k and p_{k+1}. The four control points between p_{k-1} to p_{k+1} are used to

establish the boundary conditions of Cardinal spline segment [14], see equation (3):

$$p(0) = p_k$$
$$p(1) = p_{k+1}$$
$$p'(0) = \frac{1}{2}(1-t)(p_{k+1} - p_{k-1}) \cdot \qquad (3)$$
$$p'(1) = \frac{1}{2}(1-t)(p_{k+2} - p_k)$$

Then, the curve passing the two control points p_{k-1}, p_k can be noted as equation (4).

$$\begin{cases} p(u) = (-su^3 + 2su^2 - su)p_{k-1} + [(2-s)u^3 \\ \qquad + (s-3)u^2 + 1]p_k + [(s-2)u^3 \\ \qquad + (3-2s)u^2 + su)p_{k+1} + (su^3 - su^2)p_{k+2} \\ s = \dfrac{(1-t)}{2} \end{cases} \qquad (4)$$

According to equation (4), similarly the curve segment can be calculated passing p_k, p_{k+1} and the one passing p_{k+1}, p_{k+2}. Analysing this equation can get a certain interpolation curve of the curve segment that requires the coordinate values of four control points $p_{k-1}, p_k, p_{k+1}, p_{k+2}$ to obtain, so the original path is generated by combining groups of interpolation curves taking 4 control points as a unit, as in equation (4). In this formula, $u \in [0,1]$ and there is a variable t to control the tangent tensor of the being calculated spline, where t values zero.

3.2 SET OF PATH EDITING CONTROL POINT AND DEFINITION OF MOTION CYCLE STEPLENGTH

The step of evenly setting editing path control points on the original motion path is:

1. The number of user-defined path editing control points is N, $N \geq 4$, using the starting point and end point of the original motion path as the first and the last path editing control points, and it determines the time interval $\Delta t = frame\ time$ between frames of the original path (reading from BVH file).

2. It calculates to determine the frame n_i where the i-th path editing control point located, in order to achieve an even set of the path editing control points. Wherein, $n_i = (i-1) \times \left\lceil \dfrac{n}{N-1} \right\rceil, i = 2 \cdots N-1$, n is the total frame number of the original motion sequence.

In the method above, it is about to remove part of the frames, to reduce the relative velocity between the root nodes of the frames. But if optionally removing a certain frame, it may cause incoherence of the motion action. We find that in most of the motion capture data there exists walking, running, small stride jumping and other actions. And actually, these actions are simple cyclical motion,

such as walking that the action that left foot moves a step and then the right foot moves another step which can be regarded as a motion cycle. In order to keep the drawn motion action still smooth and continuous, after removing several sequence frames, we can take the motion cycle as a unit for deletion treatment to reduce the problem of motion actions excessively concentrating.

It defines the motion cycle step-length as follows: Any frame in which the left foot begins to lift is recognized as the beginning of a motion cycle. Through the left foot landing, and the right foot lifting and landing, the frame in which the right foot begins to land is defined as the final of the motion cycle. The spacing (in the plane of x, z) between the root nodes of the beginning frame and the final frame in the motion cycle is called the motion cycle step-length λ, as in Figure 3. Based on the definition of the cycle step-length we can also define the half-cycle step-length: Between the first frame any foot begins to lift and the first frame this foot lands and the other foot prepares to lift, the spacing (in the plane of x, z) between their root points is called the half-step-length of motion cycle, noted as $\lambda/2$.

Of course, it should be noticed that in a motion cycle step it may exist two cases as following. In Figure 3, if at the landing points p_{i1}, p_{i2} of the left and right foot, respectively comparing with the first frame the left or right foot lifting in the half-step-length containing these points, the human motion direction does not change to be a linear type or changes a small angle (≤ 60 degrees), it's called the general motion cycle step-length; If at the landing points p_{i1}, p_{i2} of the left and right foot, the human motion direction changes greatly(> 60 degrees), it's called special motion cycle step-length. To keep the important details of motion after editing, we will take the general motion cycle step-length as deletion objects.
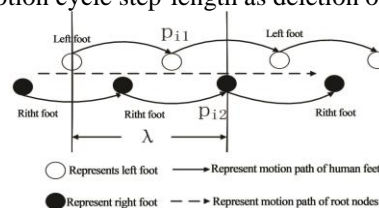

FIGURE 3 Motion cycle steplength

3.3 EDITING OF MOTION PATH AND FRAME ADJUSTMENT

In this paper, the path editing is realized by changing the position coordinates of the horizontal axis component and longitudinal axis component of path editing control points. In that, it does not change the vertical axis component to avoid artificially causing the phenomenon of feet suspending, feet into the ground and other issues. Therefore, it can only generate new motion path by carrying out Cardinal interpolation on the adjusted path

editing control point coordinates in the plane of horizontal axis and longitudinal axis.

It still needs to determine the position and motion orientation of each frame on the new path. The location treating process is as follow: the known number of original motion sequence frames is n, the number of path editing control points is N, and then it can calculate the incremental step length $step = \dfrac{(N-1)}{n}$ of u. Due to equation (4), in the curve segments $p_{k-1}p_k$, $p_k p_{k+1}$ and $p_{k+1}p_{k+2}$, every time u adding *step* getting a point, separately calculating the horizontal axis and longitudinal axis coordinate components of the points, that is the location information of a certain frame root node in the new motion obtained by editing motion path.

About the adjustment of the human motion direction, it is known that in the motion path the motion direction of human at a certain moment is related to the slope of its position in the curve segment at that time. To this end, we will use the slope of each frame's root node position in the curve segment as the orientation of virtual human at this moment. So after editing the motion path, the position of the root node at time t also needs to be adjusted by changing of curve slope.

3.4 JUDGEMENT OF PATH CURVE SEGMENT ARISING FOOTSTEP DISHARMONY PHENOMENON

In the process of motion path editing, if the path change results in the moving velocity increasing of the root node (i.e. the curve segment length of the edited human motion path which passes the two control points is shorter than the length before editing) and the number of footsteps remains unchanged, it will cause footstep disharmony phenomenon, as in Figure 4. A, B are two adjacent edit path control points. L is the curve segment length of original motion path which passes these two points. L1 is the curve segment length of edited motion path which passes these two points. If $L_1 < L$, and because the number of frames between A, B is a fixed value, the moving velocity increasing of root node will surely cause the footstep disharmony phenomenon.
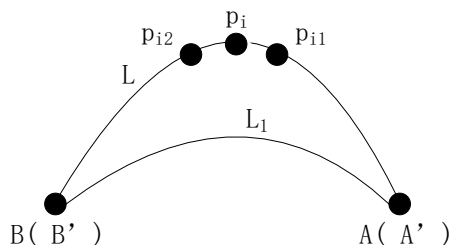

FIGURE 4 Variation diagrams of motion path before and after editing

Method of judging the specific curve segment arising footstep disharmony phenomenon in the motion path curve:

(1) It finds the root node collection $\{p_1, p_2, \cdots\cdots, p_n\}$ in the original path with the slope $k = 0$, and selects root node p_i from the collection in turn.

(2) It selects two frames which are $\pm m (5 \leq m \leq 10)$ frame away from the frame where p_i is. It calculates the slope k_{i1}, k_{i2} of root nodes p_{i1}, p_{i2} of these two frames in the original motion path curve and the slope k'_{i1}, k'_{i2} in the edited motion path curve. If one of k'_{i1}, k'_{i2} is positive and the other is negative and $k_{i1} \neq k'_{i1}, k_{i2} \neq k'_{i2}$, it executes (3), else it goes to (5).

(3) In the original path, that takes p_i as center to determine the two nearest control points A, B in the curve segment which passes the three points p_i, p_{i1}, p_{i2}.

(4) It calculates the curve segment lengths AB, AB' on the original and the edited path between the two control points A, B and the difference of the two lengths. If $AB - AB' > 0$, the curve segment in the edited path will arise footstep slip.

(5) Returning to (1), until finishing traversing the root node collection with the slope $k = 0$, the judging method ends.

3.5 ADJUSTMENT OF FRAMES AFTER REMOVING CYCLE STEPLENGTHS

In the newborn path, the specific method of adjusting two adjacent editing path control nodes after removing general cycle step-length can be illustrated by the following example. It assumes A, B are two adjacent editing path control points in the curve segment, which has been determined existing footstep slip phenomenon and noted as A', B' in the edited path. E, F is starting frame and ending frame of the N' to-be-deleted motion cycle step-lengths. $C(C'), D(D')$ are the editing path control points nearest to $A(A'), B(B')$, as in Figure 5.

(1) It separately calculates the number n_{EF} of to-be-deleted frames in curve segment EF. In the curve segment $C'E$ there contains $n_{C'E}$ frames. In the curve segment FD' there contains $n_{FD'}$ frames.
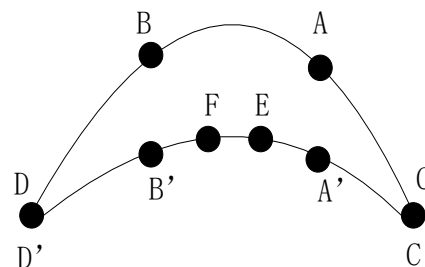

FIGURE 5 Removing Step-length

(2) It calculates the time T_{EF} that the frame sequence contained in curve segment EF spends for broadcasting, the time $T_{C'E}$ that the frame sequence contained in curve segment $C'E$ spends for broadcasting, and the time $T_{FD'}$ that the frame sequence contained in curve segment FD' spends for broadcasting.

(3) After removing the cycle step length in EF, it adjusts the interval length of the frames in $C'E$, FD' by equation (5) (6) to make it smooth and continuous.

$$j_i = \left\lfloor i \times \frac{T_{C'E} + \frac{1}{2}T_{EF}}{n_{C'E} \times \Delta t} \right\rfloor \quad i = 1,2,3\cdots\cdots n_{C'E} , \tag{5}$$

$$l_k = \left\lfloor (k+1) \times \frac{T_{FD'} + \frac{1}{2}T_{EF}}{n_{FD'} \times \Delta t} \right\rfloor + j_{n_{C'E}} . \tag{6}$$

$$k = 0,1,2,\cdots\cdots n_{FD'}$$

The equation (5) represents: after removing cycle step length, it determines the frame number j_i how far the to-be-adjusted frame, which is i-th frame apart from C' in the curve segment $C'E$, will be apart from C' in the newborn motion path after editing. The equation (6) represents: after removing cycle step-length, it determines the frame number j_i how far the to-be-adjusted frame, which is the k-th frame apart from F in the curve segment FD', will be apart from C' in the newborn motion path after editing.

(4) It takes the position information and motion direction information of the root node on frame j_i or l_k, to be the position information and motion direction information of the root node on the i-th or k-th frame after removing general cycle step-length, and takes equation (1) to calculate the position information of each joint node in the frame.

3.6 CONSTRAINT REESTABLISHMENT OF THE FLOOR FRAME

In the original motion sequence, the positions of the end effecters (feet) at two or more continuous moments are at the same landing position in space. However, after treated by path editing, it will make the human feet in different positions at these few moments appearing the footstep slip phenomenon. In order to ensure the quality of motion actions unchanged before and after motion path editing, in the newborn path that has deleted the cycle step-length, and it needs to constrainedly re-establish the foot landing frames (floor frame) inside the half-cycle step-length in the original path.

The judgment of human foot landing is distance, to check if the vertical distance between foot and ground is close to zero. The determining formula is equation (7).

$$\left| \vec{d} \cdot \vec{n} \right| \le H . \tag{7}$$

In equation (7), $\vec{d}$ represents distance vector from end effecter (foot) to the ground, $\vec{n}$ represents vertical unit vector and H represents the set threshold of landing detection. After landing detection, it will get the serial numbers of those frames at the foot landing moment. This allows the frame of the original motion sequence to classify, taking half-cycle step-length as unit to establish a collection S_L of frames of left foot landing moments and collection S_R of frames of right foot landing moments as landing constraint frames.

Setting the position of foot in the first landing constraint frame inside every motion half-cycle step-length on the new path as the position of foot in all the landing constraint frames inside this half-cycle step-length, it uses per-frame Inverse kinematics (inverse kinematics edited according to frame) [15] to calculate the rotation changes of other joints nodes to meet the position requirement.

4 Experimental results and analysis

In this paper, it verifies the proposed virtual human motion path editing method based on the motion cycle step-length by experiment. Experimental environment: Operating system: Microsoft Windows XP; CPU: IntelQuadQ9550 2.8GHz; Memory: 3GB; Program compiler environment: Microsoft Visual Studio 2008. The Human body motion capture data is collected by the OptiTrack whole body motion capture system with 12 cameras by the frame rate of 60 frames/Sec, and is stored by BVH file format.

In reality, the human motion is often complex but not single cycle motion as walking, running, etc.. To illustrate the generality and the effectiveness of the proposed method, we take a motion capture sequence (as in Figure 6) with 740 frames mixed with walking and jumping by the right leg for verification. In 1- 660 frames, it records the walking action starting with left foot, In 661-710 frames, it records the jumping action by the right leg, and in 711-740 frames, and it records the action of left foot walking a step after right foot landing. In this hybrid action sequence, walking is general cycle action.

During the process of building original motion path, the root nodes of each frame are as control points of Cardinal spline curve. For the motion capture data is the BVH file format, it does Cardinal spline interpolation to the positions of root nodes in the plane xoz to obtain the original motion path, indicated by the solid line in Figure 7. Before editing the path, it selects 4 control points to be path editing control points from the original motion path which is a Cardinal spline interpolation curve. According

to the setting method of path control point in this paper: two control points are the starting terminal C (root node position of frame 1) and ending terminal D (root node position, frame 740) of Cardinal spline interpolation curve, while the other two control points A, B are the root node positions of 247-th and 494-th frames. Now, it edits the path by changing the positions of path editing control points: in the x axial direction, the point C moves 35 units down, the point A moves 140 units down, and point B moves 100 units down; in the z axial direction, point C moves 5 units to the left. The new motion path curve is generated by carrying out Cardinal spline interpolation to these four control points, indicated by dotted line in Figure 7. As shown in Figure 7, the two motion path curves are smooth, and the transition between action sequences of right leg jumping and walking frames is natural, indicating the effectiveness of the Cardinal spline interpolation for virtual human motion editing path.
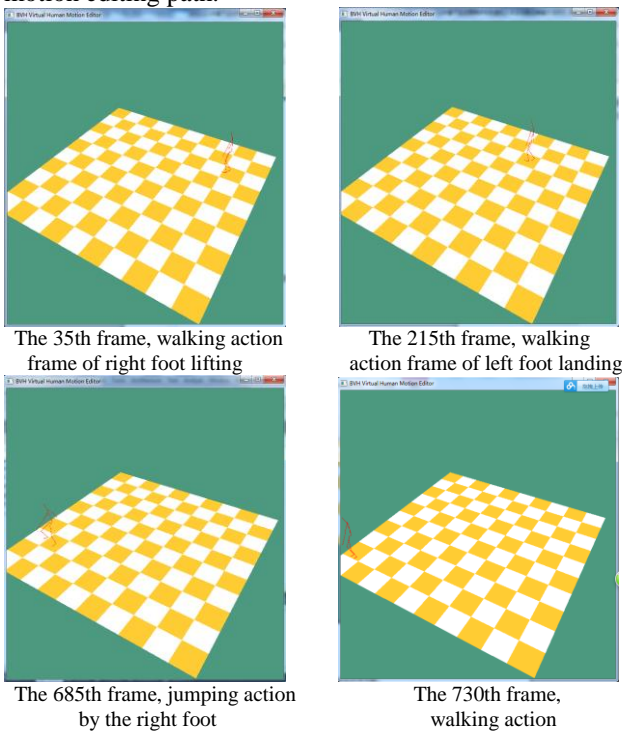

The 35th frame, walking action frame of right foot lifting
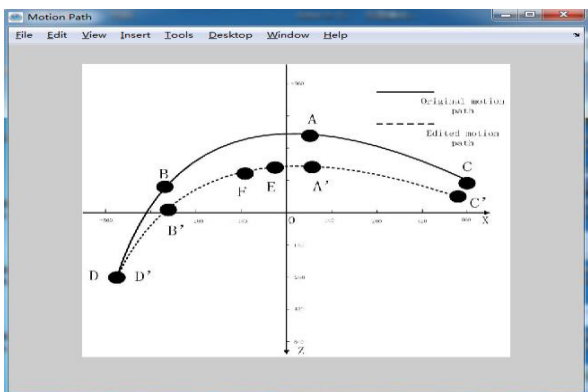
The 215th frame, walking action frame of left foot landing

The 685th frame, jumping action by the right foot

The 730th frame, walking action

FIGURE 6 Frame sequence of original motion

FIGURE 7 Diagram of original path and motion path after editing

The 375th Frame, left foot lifting

The 405th frame, left foot landing

The 420frame, right foot lift

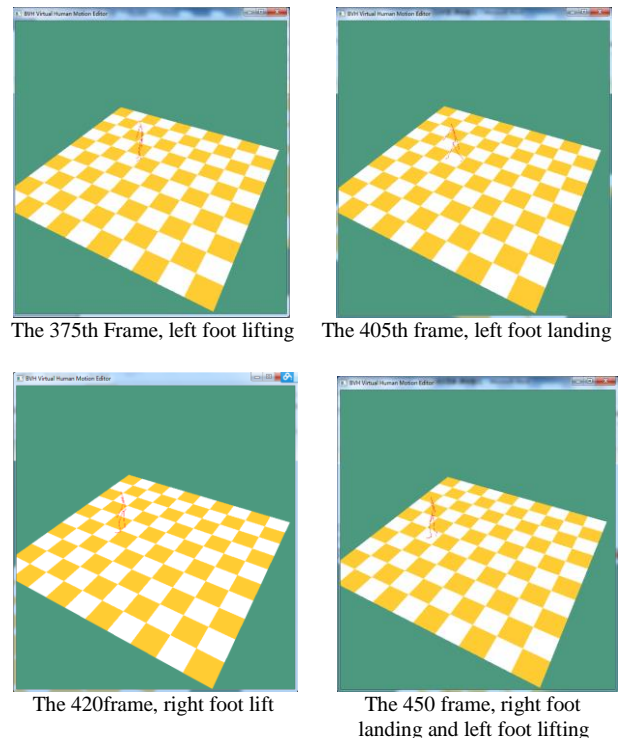The 450 frame, right foot landing and left foot lifting

FIGURE 8 Frame sequence of footstep disharmony phenomenon

That is shown in Figure 8 is a motion frame sequence generated after editing the path. In which, it is found that there happens significant footstep disharmony phenomenon from the 375-th frame to the 450-th frame and human action is not natural and smooth. The reason is because after adjusting the editing path control points neither root nodes position or root nodes orientation of each frame are adjusted, and the shortening of curve length between the two points causes the frame aggregation to be too high. So, firstly, after adjusting the editing path control points, the root nodes position and orientation of each frame must be adjusted. Secondly, the problem of frame aggregation being too high should be solved by cutting the general motion cycle step-length. According to the judging method of path curves existing footstep disharmony phenomenon mentioned in section4.4, it can automatically determine the footstep disharmony phenomenon occurs in the curve segment with the path edit control points A, B as endpoints. It's determined by: the length of the curve segment with the endpoints A, B is 531cm, and after path editing its length is 510cm, the curve length becoming shorter; while the slope of the 280-th frame is 0, and the slopes of the 275-th frame and the 285-th frame which are 5 frames away from that point at its both sides are one positive and one negative. The 280-th frame is just in the curve segment with the two paths editing control points as starting and ending. This illustrates that the proposed method in this paper can achieve the automatic determination of path curve segment existing footstep disharmony phenomenon.

In the path curve segment AB, there exists general cycle step-length, and the starting frame and ending frame of

the first general cycle step-length are the 300-th frame and 360-th frame in which the root nodes identified by points E, F are. According to equation (2), it can get the difference between the lengths of the curve segment with the two path control points as terminals before and after the path editing. The ratio that the difference is divided by the general motion cycle step-length λ (here sets λ to be 100 cm, and it can be adjusted according to the different motion human subjects) is 0.21. So, it should delete a cycle step-length that is the motion frame between the two points E, F . Then, according to equation (5) and (6) to adjust the position and orientation of the frames between the curve segments EC, FD , the result is shown in Figure 9. It can be seen from this that although this method deletes the general motion cycle step-length, it does not affect the animation effects of right leg jumping, and this hybrid motion remains consistent and smooth.

In addition, in Figure 9, we find no footstep slip phenomenon occurs after path editing. This is because it uses the equation (7) to find each floor frame, and using inverse kinematics to constrainedly re-establish, to make the foot in the frames of these types at the status of landing before and after path editing.

Of course, the algorithm can also be applied to other virtual human motion path editing which contains cycle motion such as running, jumping, walking and other complex motion. It can effectively remove footstep slip phenomenon to obtain satisfying human motion animation effect.

5 Conclusion

To improve the reusability of motion capture data, here presents an editing method of motion path: the Cardinal spline interpolation is used to extract the original path and set the editing path control points; it alters the positions of path editing control points to generate a new path, and adjusts the original motion sequence frame on the new path; it aims at the human foot disharmony phenomenon caused by the shortening of the motion path curve segment after editing path, based on motion cycle step-length, proposing the way of deleting the frame of general motion cycle frames and adjusting the root nodes of every frame which contains that curve segment and between the two nearest editing path control points in the motion path to remove it; finally it does constraint reestablishment to all floor frames with cycle step-length, to reduce footstep slip phenomenon. The experiment results show that: the motion path editing method is simple, with less calculation, and easy to operate. The generated virtual human motion is natural and smooth. It can effectively eliminate the footstep sliding phenomenon.

However, this method does not consider that in the motion process, with the dramatic changes of path curvature, the centre of gravity of virtual human will be shifting to cause the human body tilt phenomenon; and

also does not consider the dynamic approach of human motion path when it meets obstacles. These two areas are the place that in the future we should work hard in.
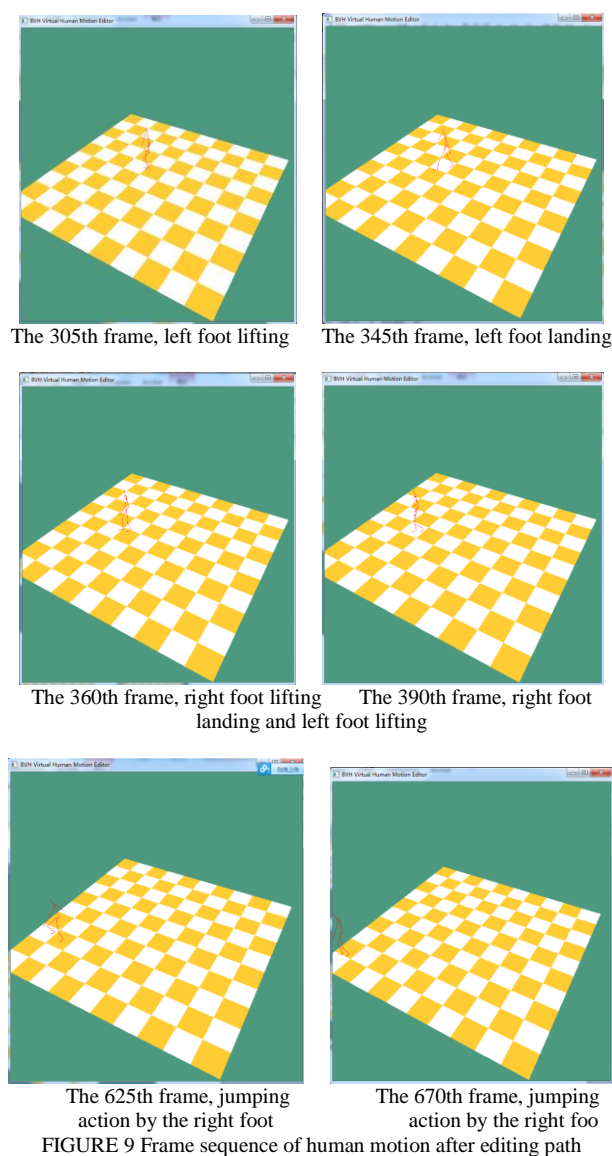

The 305th frame, left foot lifting   The 345th frame, left foot landing

The 360th frame, right foot lifting   The 390th frame, right foot landing and left foot lifting

The 625th frame, jumping action by the right foot   The 670th frame, jumping action by the right foo

FIGURE 9 Frame sequence of human motion after editing path

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Authors

Wenju Wang, born on March 27, 1979, China

Current position, grades: lecturer at University of Shanghai for Science and Technology and research fellow of Shanghai research institute of publishing and media, China.
University studies: PHD degree in computer application technology from Tongji University, China, in 2012.
Scientific interests: virtual reality, computer animation and computer graphics.

Liujie Sun, born on August 15, 1965, China

Current position, grades: professor at University of Shanghai for Science and Technology, China.
University studies: Ph.D. degree in Optical engineering from University of Shanghai for Science and Technology, China in 2008.
Scientific interests: information security and image processing.

Zhang Xuan, born on April 28, 1982, China

Current position, grades: lecturer in the Musicology Department, Shanghai Conservatory of Music.
University studies: Zhang Xuan received her Master's Degree in music composition from National Academy of Chinese Theatre Arts, China, in 2007.
Scientific interests: Chinese traditional music and digital music.