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Optimization of Animation Curve Generation Based on Hermite Spline Interpolation

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Abstract

Computer animation is the combination of computer graphics and art field. In computer animation design, the adjustment of route for the animation object movement is a time consuming work for the designers. It is not only related to the generation of motion path curve, but also related to the speed smoothness of key frames. Based on the methodology of Hermite spline interpolation, this paper proposes a method to adjust the curve tangent vector length by considering the parameter of key frame, and use this method to relieve the unevenness of animation speed. Experimental results demonstrate that this method can improve the movement effect of animation route design efficiently.

***Keywords**: Hermite spline; Spline interpolation; animation movement curve*

1. Introduction

On the basis of traditional animation, computer animation is gradually developed and matured with the development of modern computer technology, especially the development of graphics and multimedia. In particular, as the information network develops, a revolution occurred to animation field. Computer animation colligated the theories and methods of some fields, such as computer graphics, artificial intelligence, physics, art, *etc.* to promote animation to a new level and form a novel study field. At present, computer animation technology has been greatly improved. However, there is still a lot aspects to be improved, for example, pursuing faster and better design means, higher degree of automation, better visual effect, *etc.*, which means that there is still a lot of room for the relevant research on computer animation.

The motion generation and control technology in animation is the most important technology of computer animation. According to different motion control methods, computer animation can be classified into two categories, namely keyframe animation and algorithm animation. The former is a process of producing smooth animation by generating the animation sequence of in-between frames through interpolation algorithm based on the set of key frames given by animation designers. And it is usually suitable for two-dimensional (2D) animation, while the latter is generally applicable to three-dimensional (3D) animation, where an algorithm was used to realize the motion control of animated characters or simulate the motion control of a camera. Through presetting the properties of the required animation effect, it is only needed to prepare a set of key points and the values related to time for keyframe animation. And these key points are usually extracted from the key frames of animation sequence, while the values of the other time frames can be calculated by using these key values through specific interpolation method to achieve smooth animation effect. By setting the values of the main keyframe points generating animation, the animation of in-between frames is completed by computer automatically. So far, keyframe animation is one of the most fundamental and widely used methods in computer animation.

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2. Relevant Backgrounds

2.1 Key Frame Interpolation Technology

Key frame interpolation method is the most simple and direct motion control technique of animation designers. In general, there is no need for designers to have abundant theoretical knowledge about kinematics to set keyframe animation, while it depends on designers' experience and skills as well as continuous debugging to determine the key frame. And then computer interpolation technology is adopted to automatically generate in-between frames so as to produce relatively smooth animation. The keyframe interpolation method is most widely applied in computer motion animation design. The main processes are as follows: (1) to simulate the animation path and set key frames by animation designers; (2) to generate the motion path curve by using an interpolation method; (3) to debug and judge the animation quality subjectively, while if it is unsatisfactory, the values of key frames are adjusted until the animation is satisfactory. The generation of motion path relies on the interpolation method. Linear interpolation is the simplest one among all interpolation methods. According to the geometrical meaning, it means to draw a straight line through two points on the curve, which is utilized to approximately replace the curve. The animation looks stiff if the two points on the curve move linearly by using linear interpolation. Thus, it is usually expanded to quadratic polynomial interpolation or high-order polynomial interpolation method as required.

The polynomial interpolation method directly connects the keyframe parameters and frame frequency together, which is widely used. The common interpolations in animated graphics, including Lagrange interpolation and Newton interpolation, are solving methods with polynomial equations. Their advantages are as follows: sample data structure of key frames; controllable computation complexity and high speed. In addition, it is likely to be designed, controlled and interacted, and it is also suitable for 2D structures. However, the changes in animation pictures are apt to be relatively uniform, which looks mechanical and less expressive. Polynomial interpolation methods are often employed for the animation control with soft relative changes in speed curve.

The generated animation curve by the technology completely dependent on key frames is likely to be perfect, but it is extremely prone to be not smooth in motion, especially in the non-uniformity of speed. It takes a lot of time and energy of animation designers to debug the attribute values of key frames to obtain an ideal effect. It is mainly because that interpolation technique, as a method based on graphics, influences the spatial factors of motion objects rather than the time factors of frames. It is difficult to achieve a favorable effect by adjusting manually. The path curve of motion object was appropriately changed through adding relevant parameters of frames to Hermite spline interpolation method to effectively improve the fluency of motion animation of key frame on time. Meanwhile, the redundancy for adjusting key frames by animation designer was increased to greatly reduce their work for adjusting the key frames.

2.2 Hermite Spline

In theory, it is more likely that the speed of animation motion is non-uniform by using polynomial keyframe interpolation method if there are a few of sampling frames. The cubic spline interpolation proposed by Hermite, a French mathematician, is suitable for motion control of keyframe animation. Hermite spline curve is a segmental cubic polynomial, which includes a given tangent line at each control point. The advantage of Hermite spline is local adjustment owing to each curve segment only depends on end-point constraint. Compared with polynomial interpolation method, the complexity of Hermite spline interpolation method is little improved, but the uniformity is preferable. The more intensive the nodes, the better the effect. Then the required accuracy can be achieved, at the same time, the convergence can be guaranteed, which is enough for the animation architecture acquiring not very high accuracy. However, there are great defects in animation application of the mode for generating curve by the polynomial interpolation based on graphics or spline interpolation. The non-uniformity of speed is not considered by the shape of interpolation curve, if the curve is generated without inputting the slope value of curve or the other geometrical information but calculating the derivative of parameter by the coordinate position of control point. Thereby, it is significant to research that how to flexibly restrain the shape of interpolation curve to meet the demand for generating animation motion path if the interpolation conditions are fixed.

The curve construction of Hermite spline is simple and concise. Besides, the shape is apt to control with the favorable continuity and local controllability of spline curves. The shape of Hermite spline curve is modified by adjusting the length and direction of tangent vector at the connection endpoint of curve segments to adjust the shape of curve and ensure the continuity of spline curve at the same time. Whereas, the deficiency of Hermite spline is that the adjustment method of endpoint vector is not intuitive. In other words, the tangent of the endpoint of curve segment influences both the shape of curve segment itself and the shape of the adjacent curve segment of spline curve, as well as the corresponding geometric continuity and the overall fairness of curve shape. Owing to the lack of editing means, the editing modification of the geometrical shape of Hermite spline curve is less widely available than Bezier curve in animation design. However, a mode is needed to be designed to meet the requirements of the speed of animation motion object. The mode can change the shapes of several segments of curves and also generate curves by interpolation as long as the position of input point is given. In addition, it is able to adjust the shape of curve by changing the length and size of the endpoint tangent of curve segment. Theoretically, it is convenient to adjust the shape of Hermite spline curve or Bezier spline curve, *etc.* by directly adjusting the vector of the points on curve. Nevertheless, Hermite spline curve is superior in the conciseness of shape adjustment, for example, the endpoint tangent of Hermite spline curve is much closer to the curve than that of Bezier spline curve. Therefore, it is a favorable way to adopt the input point of Hermite spline curve interpolation for design curves through column generation during designing animation motion path.

3 Parameterization of Hermite Spline Curve

3.1 Cubic Hermite Spline Function

If two points on the plane, namely P_i and P_{i+1},as well as the corresponding tangent vector, V_i and V_{i+1} are given, the construction of interpolation bases of Lagrange interpolation method can be utilized to establish the Hermite interpolation basic function. At first, the linear interpolation is established as follows:

$$P(u) = (1-u)\,(P_i + uV_i) + u((1-u)P_i + uP_{i+1}) \tag{1}$$

It is apt to be verified that $P(0)=P_i$, $P(1)=P_{i+1}$, $P'(0)=V_i$.

Similarly, the quadratic curve function is established as follows:

$$P(u) = (1-u)\,((1-u)P_i + uP_i) + u((P_{i+1} + (u-1)v_{i+1}) \tag{2}$$

It is easy to validate that $P(0)=P_i$, $P(1)=P_i+1$, $P'(1)=V_{i+1}$.

Then Formulas 1 and 2 are interpolated linearly again to obtain the cubic interpolation function of smooth curve, namely,

$$P(u) = (1-u)\,((1-u)P_i + uV_i) + u(((1-u)P_i + uP_{i+1})$$

$$+ u((1-u)\,((1-u)P_i + uP_{i+1}) + u(P_{i+1} + (u-1)V_{i+1})$$

After summing up, it can be obtained that:

$$P(u) = P_i(2u^3 - 3u^2 + 1) + P_{i+1}(-2u^3 + 3u^2) + V_i(u^3 - 2u^2 + u) + V_{i+1}(u^3 - u^2) \quad (3)$$

From Formula 3, it can be known that solving Hermite spline curve is actually to solve the values of tangent vector VI and V_{I+1}.

Setting the fixed-point coordinates as P_0,P_1,and P_2… P_n, segmental cubic Hermite interpolation is established, where V_I is the tangent vector at Point P_i, then it can be obtained that:

The tangent vector of intermediate point can be expressed as:

$$V_i = a_i(P_i - P_{i-1}) + (1 - a_i)(P_{i+1} - P_i) \quad (i=2, 3, 4\ldots n-1) \quad (4)$$

Where ai is the tangent vector parameter to control spline curve. In practical application, different parameter designs can produce various curve shapes during generating cubic Hermite spline curve by interpolation. Figure 1 shows a simple example for interpolating the same three points, where u= [1, 2, 3], and y=[0, 2, 0], to obtain the quadratic parameter curve through these three points. The left one in Figure 1 presents the curve of the parameters of the three points of -1, 10 and 1 respectively from left to right, while the right one is the curve for the parameters of -1, -10, and 1. It can be seen that the curve shapes greatly change due to the different tangent vector parameters.

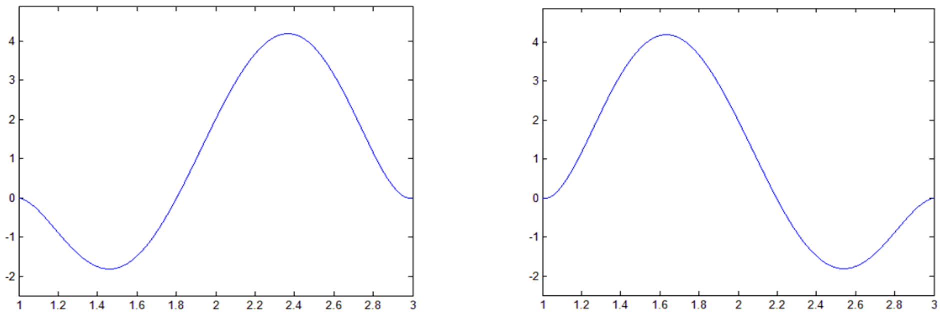

Figure 1. The Curve Shapes for Different Tangent Vecto

The common parameter design methods include: uniform parameter method, cumulative chord length method, centripetal parameter method, *etc.* In order to guarantee the consistency of animation motion, the centripetal parameter method mainly based on convex arc is often utilized during animation design. The parameter design of ai by centripetal parameter method is as follows:

$$a_i = \frac{|P_{i+1} - P_i|}{|P_{i+1} - P_i| + |P_i - P_{i-1}|} \quad (5)$$

The motion path curve generated by Formulas 3-5 is with favorable fairness, but the curve produced on the basis of computer graphics does not take the time factor of animation frame into account. It is extremely apt to appear non-uniformity of the speed of motion objects for the motion animation produced in this way. Thus, it is necessary to improve it with consideration of the time factor of motion animation.

3.2 Hermite Spline Parameters Combining Key Frames

If the point coordinates are set as P0, P1, P2, …, Pn, then the frame values of each fixed-point are f0, f1, f2, …, fn, where fn > fn-1, …, > f0. On the basis of Hermite spline, the tangent vector parameter of key frame, Si is set to change the size of tangent vector by combining key frames, that is to say:

The tangent vector of intermediate point is:

$$s_i = \frac{\sqrt{|P_{i+1} - P_i| * (f_{i+1} - f_i)}}{\sqrt{|P_{i+1} - P_i| * (f_{i+1} - f_i)} + \sqrt{|P_i - P_{i-1}| * (f_i - f_{i-1})}} \quad \text{(i=1, 3, 4… n-1)} \qquad (6)$$

The tangent vector of boundary point is: S0 = 0, Sn =0.

According to Formulas 4 and 6, it can be obtained the value of the tangent vector of new intermediate point:

$$T_i = S_i(P_i - P_{i-1}) + (1 - S_i)(P_{i+1} - P_i) \qquad (7)$$

Establishing the cubic Hermite spline with key frames, its cubic interpolation formula can be converted as:

$$P_i(u) = P_i(2u^3 - 3u^2 + 1) + P_{i+1}(-2u^3 + 3u^2) + T_i(u^3 - 2u^2 + u) + T_{i+1}(u^3 - u^2) \qquad (8)$$

The formulas above took the design parameter of the curve shape of data point, ai into consideration. Meanwhile, the frame parameter of data point Si was also involved. These two parameters changed the length of tangent vector and shape curve to make the moving track of the adjacent keyframe points more reasonable. The tightness of animation curve considered both spatial factors and time factors so that the animation designers could adjust the keyframe values to influence the tightness of animation curve based on specific requirements. At the same time, owing to the parameter Si was greater than or equal to 0, the continuity of Hermite spline curve was not influenced.

The angle of the tangent vector was obtained by using Hermite spline. When the distance between the two endpoints was fixed, the length of tangent vector at both ends was influenced by changing the keyframe values to change the animation curve to some extent. The examples indicated that when the angle of the tangent vector and the distance between two endpoints was fixed, the length of the tangent vector at both ends was changed by parameter Si. Then the changing length of tangent vector directly affected the curve shape of motion animation. Besides, the smoothness of the animation curve was reduced, but the non-uniformity of the speed of the endpoint of could be improved to some degree.

3.3 Experimental Verification

The key points of motion animation and the corresponding keyframe values were set, where the coordinate vectors of key points were x = [1:1:6], y =[1, 1, 2, 2, 3, 3], and the keyframe value was F = [1:1:6]. Then the different curve fitting effects were compared respectively. Figure 2 shows the motion trajectory produced by cubic polynomial spline interpolation; while Figure 3 illustrates the motion trajectory of shape-preserving Hermite interpolation. Besides, Figure 4 presents the motion trajectory produced by Hermite interpolation with Formula 5 as tangent vector parameter. In addition, in combination with key frames, the motion trajectory generated by Hermite interpolation by using Formula 6 as tangent vector parameter is indicated in Figure 5.

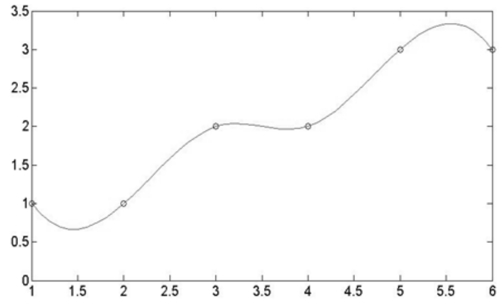

Figure 2. Cubic Polynomial Spline Interpolation

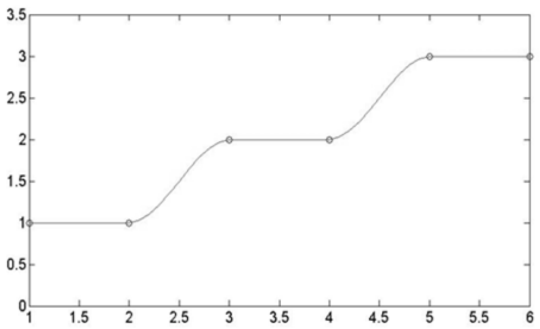

Figure 3. Shape-Preserving Hermite Interpolation

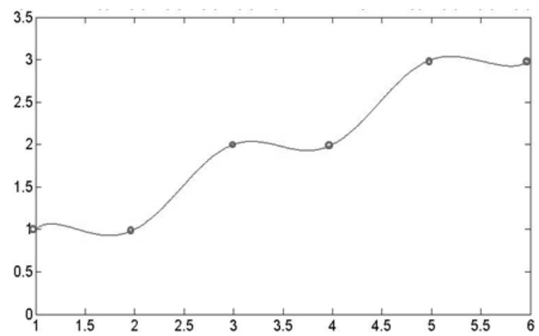

Figure 4. Centripetal Parameters Hermite Interpolation

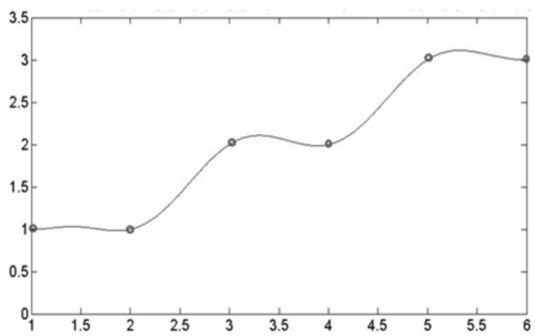

Figure 5. Key Frames Hermite Interpolation

From Figures 2-5, it can be seen that the curve in Figure 2 was with the best fairness, but its uniformity of motion direction was the worst, while the fairness of the curve in Figure 3 was the worst. In addition, the motion speed, especially the direction uniformity of the curve in Figures was favorable, but the velocity uniformity was the worst. As for Figure 4, the curve was with favorable fairness but not good uniformity of motion direction. The curve in Figure 5 was with acceptable fairness for animation, fine uniformity of motion direction and velocity uniformity. Apparently, the effect of the curve in Figure 5 was more ideal than that of the others in animation motion control.

Table 1. The motion Trajectory of the Curves in Each Figure

Curve figures	Fairness of curves	Velocity uniformity	Direction uniformity
Figure 2	Good	Medium	Poor
Figure 3	Poor	Poor	Good
Figure 4	Good	Medium	Better

Figure 5	Better	Medium	Good

As indicated in Table 1, the fluency of velocity of the motion curve obtained by Hermite spline interpolation combining with key frames was more favorable than that of the general Hermite spline interpolation. Moreover, the fluency could provide an improving effect to preferably match the distance between the frame values of key points and moving points so as to improve the non-uniformity of motion.

4. Results and Discussion

Compared with the general Hermite spline, the advantage of the method in this research is that the local tightness of curve can be adjusted for each segment by using the tension parameters in combination with key frames. When there is a deviation between the interval of control points and keyframe value, the tightness of curve is controlled by parameters to moderately improve the non-uniformity of motion velocity, but it slightly impacts the fairness of curve. The most critical factors affecting the motion quality of animation is always the matching relation between the selected distance of keyframe points and keyframe values. The main factor to promote animation effect is always to reasonably set the key point for both uniform motion and accelerated motion. When a reasonable key point is preset, the method proposed in this paper can be utilized to construct animation curve. When the deviation between the set frame value and motion distance is small, the influence on the fairness of the established curve is very little, but the uniformity of speed can be greatly improved.

It is a very time-consuming work to improve the motion curve and speed non-uniformity by adjusting key points during animation design. On the basis of Hermite spline interpolation, the length of tangent vector was changed by tensor parameters to improve the non-uniformity of motion in this research. Furthermore, it has obtained a certain effect to improve the work efficiency. As long as the deviation between the frame value and motion distance is small, the speed uniformity can be improved. Meanwhile, the effect of curve fairness is able to meet the requirement of animation design as well. Thus, there is no obvious difference visually.

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