A Realistic Automatic 3D Hair Visual Effect Modeling Method

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Abstract. We present an automatic 3D hair modeling approach that makes use of geometric information from a given 3D virtual head model to obtain the initial envelope shape-points that cover the whole head using a series of geometric methods that simulate the hair growth process. Considering that natural hair has uneven thickness and irregular shape char5acteristics, we further refine the envelope shape-points and define the hair density and expansion with hair-clusters as the basic unit. The B-Spline function is then used to fit the curve cluster, finally obtaining the virtual hair 3D data by mapping the texture picture with transparency. The experimental results show that this method can obtain realistic 3-dimensional hair using very few manual operations.

Keywords: envelope shape-points, B-Spline function, random parameter range, irregular hair, 3-dimensional hair

1 Introduction

In three-dimensional computer animation, creating vivid realistic characters involves building models, texture mapping, ray tracing, attitude description, motion analysis and many other aspects [1]. Building the model's head is the key factor [2]. Hair is the most important decoration in addition to the facial features on the human head, which reflect the personality characteristics of the human model [3]. The same person can express different attitudes and motions using different hairstyles.

Modeling human hair is very challenging work because real hair presents complex geometric structures composed of hundreds of thousands of single hairs. Each single hair can be viewed as a curve in 3D space. Its diameter is usually between 0.05mm and 0.2mm, less than the common display pixel size, making it difficult to accurately display. Completely constructing a hair mass requires describing each single hair curve. This would produce a huge amount of data and require extremely complex manual operations. Therefore, a simple intuitive method for building three-dimensional virtual hair with realistic visual effects at low manual operation cost is needed. The current most widely used 3D modeling software such as Maya, 3DsMax and Poser etc. can produce virtual 3D hair however these softwares are expensive and require large numbers of manual operations. A long time is required to skillfully master these modeling programs.

In view of the currently existing virtual 3D hair modeling approaches with complex manual operations consuming a great amount of time, we present an automatic virtual 3D hair modeling method. This method makes full use of the geometric information from a given model head. Only a small number of manual operations are necessary to obtain virtual 3D hair with realistic visual effects.

2 Related Research

In modeling virtual three dimensional hairs, the geometric and physical characteristics [4] must be fully considered. Both domestic and overseas researchers have made fruitful research into hair characteristics. Bai [5] established the NURBS curve for hair on the head surface and then extended the hair piece along the curve. Particle dynamics were applied to produce a three-dimensional hair model. Feng [6] obtained the hair cluster section by generating a closed B-spline curve and then adjusting the key hairs and the cluster section using the local B-spline properties. In order to simulate the thickness of realistic hair Kim [7] designed a hair surface fitting the scalp and then expanded the hair as a thin shell volume along the normal vector direction of the local surface. The outer surface of the thin shell volume is described to make it show the hair shape. Chai [8] presented a hair modeling method using surface grid control to express the basic hair appearance using additional shape grids. The hair trajectory is then generated out of the grids to obtain the hair-style for the fitting shape. Zhan [9] used the cluster simulation approach to model hair. His method first specified rectangle grids over the scalp where hair grows and then the random hair distribution points were set for each grid. The growth curve for the hair cluster is finally adjusted to obtain 3D data.

Huan [10] used the Delaunay algorithm for triangle meshes on the scalp surface and extended the curve outward from each sub triangle center to simulate hair growth using manual operations. A simple cloning was finally performed in each sub triangle to cover the scalp with hair by increasing the hair density. Li [11] presented methods for generating photo-realistic 3D human head models from a geometric model and recovered the 3D positions of hair contour points extracted from multiple view color images. The growth root, direction and length of every hair were then grown until the entire scalp is covered. A Coons-patch is finally constructed to approximate the hair surface from four closed 3D contour curves. Yang [12] described a human short hair modeling method. A hair style model is first derived interactively from a scalp model. The hair model is then derived from the hair style and scalp models. Texture mapping is applied to the hair model for a better visual effect.

Although these methods can obtain 3D hair data, they require a lot of manual operations to construct the scalp surface grids or to assign the hair growth direction.

3 Automatic 3D Hair Shape-Points Envelope Generation

In reality human hair has shape characteristics from attachment to the scalp, i.e., uneven surface thickness and irregular details distribution. We present an automatic modeling method that simulates the hair growth process producing realistic human hair. The hair shape-points envelope attached to the scalp is generated first. The shape-points envelope mesh is then sub-divided. Through a series of geometric constraints virtual 3D hairs with different thicknesses, densities and growth directions are generated randomly onto the head model.

The automatic 3D hair shape-points envelope generation needs to make full use of the geometric information from the given head model. The geometric center of the head model is set as the original point O for constructing the 3D right-handed Cartesian-coordinate $OXYZ$. The Y axis coordinate of the lowest point is then set as $Y_{\min}$, which is the projection in the Y axis of the lowest grown hair. Finally, two points are set in the opportune position in front of the scalp as the separate hair boundary, which is recorded as $A\left(A_x, A_y, A_z\right), G\left(G_x, G_y, G_z\right)$.

The shape-points envelopes are generated as follows:

1). The points A and G are connected with the original point O to obtain vectors $\overline{OA}$ and $\overline{OG}$ separately. The arc $\widehat{AG}$ is divided into 6 segments using the vector linear interpolation method. We obtain the points set:

$$\Psi = \begin{Bmatrix} A\left(A_x, A_y, A_z\right) \\ B\left(B_x, B_y, B_z\right) \\ \cdots \\ G\left(G_x, G_y, G_z\right) \end{Bmatrix} \quad (1)$$

2). The growth process for a single key hair can be simplified as a particle starting from the hair follicle on the scale and then making a parabola along a certain direction. The particle trajectory is defined using the initial velocity unit vector $\vec{v}\left(v_x, v_y, v_z\right)$, the gravity g acceleration, the movement time t and the scalp surface shape. The forehead hair should not cover the facial features needs to be specified using two points near the edge of the eyebrows as the growth direction for the initial key hair, which is recorded as $L\left(L_x, L_y, L_z\right), R\left(R_x, R_y, R_z\right)$.

3). The key hair growth is taken from point $A\left(A_x, A_y, A_z\right)$ as an example, set the end point of the hair as $Q\left(Q_x, Q_y, Q_z\right)$, and the length ratio as $\alpha\left(0<\alpha<1\right)$, so we can obtain $Q_y = A_y - \left(A_y - Y_{\min}\right)\cdot\alpha$. The direction of the initial velocity vector $\vec{v}\left(v_x, v_y, v_z\right)$ is from point A to point L. We have $t = t_0$ when the hair grows to the finish point. The coordinate of point P is $P\left(A_x + v_x\cdot t_0, A_y - \frac{gt_0^2}{2}, A_z + v_z\cdot t_0\right)$. Simultaneous equations as follows:

$$\begin{cases} \frac{gt_0^2}{2} = \left(A_y - Y_{\min}\right)\cdot\alpha = A_y - Q_y \\ v_x = \frac{L_x - A_x}{\sqrt{\left(L_x - A_x\right)^2 + \left(L_z - A_z\right)^2}} = \frac{Q_x - A_x}{t_0} \\ v_z = \frac{L_z - A_z}{\sqrt{\left(L_x - A_x\right)^2 + \left(L_z - A_z\right)^2}} = \frac{Q_z - A_z}{t_0} \end{cases} \quad \textbf{(2)}$$

Solution to the coordinate of point Q:

$$Q\begin{pmatrix} A_x + v_x\cdot\sqrt{\frac{2\alpha\cdot\left(A_y - Y_{\min}\right)}{g}} \\ A_y - \left(A_y - Y_{\min}\right)\cdot\alpha \\ A_z + v_z\cdot\sqrt{\frac{2\alpha\cdot\left(A_y - Y_{\min}\right)}{g}} \end{pmatrix} \quad \textbf{(3)}$$

Using cosine theorem formula to calculate the angle between vector $\overrightarrow{OA}$ and vector, denoted as β, then we have:

$$\beta = \arccos\left(\frac{\overrightarrow{OA}\cdot\overrightarrow{OQ}}{\left\|\overrightarrow{OA}\right\|\cdot\left\|\overrightarrow{OQ}\right\|}\right) \quad \textbf{(4)}$$

Among them, "." is inner product, "‖ ‖" calculates length. Set 7 shape-points containing the initial point A on the parabola, which is $A_k\ \left(k = 0,1,2...6\right)$, so we can obtain A_k by the algorithm as follows:

```
k=1
for t=0:0.05:t0
  Getting the position of the point P at moment t
  If (the angle between OP and OA is (k/6)·β)
     A_k = P
     Scaling the vector along OA_k until it intersects at point T on the
     head model.
     A_k = 1.04×T
   endif
 endfor
```

4). Set $M = 6$, N is the number of shape-points envelope sets, the point envelope on the left side of point A is $A_k\left(k = 0,1,2,...,M\right)$, and the corresponding point envelope on the right side of the point A is $A_k^{'}\left(k = 0,1,2,...,M\right)$. The angle between A_k and X axis is set as θ_1, the angle between $A_k^{'}$ and X

axis is θ_2, we have $\Delta\theta = \frac{\pi + \theta_1 - \theta_2}{N-1}$. When other points involved in Ψ generate the data envelope the corresponding θ must be updated to $\theta + n \cdot \Delta\theta \left(n = 0,1,2,...,N-1\right)$. In order to make the shape-points envelopes look more natural, we add a tiny random variable for each single shape-point.

We designed a simple hairstyle by synthesizing the above methods. The following pictures of the shape-points envelopes for the key hairs are observed from different angles.

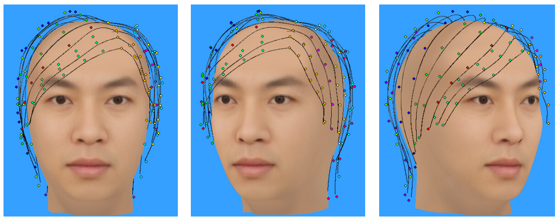

Fig. 1. Pictures of the shape-points envelopes of the key hair observed from different angles

4 Random Hair Cluster Covers and Texture Mapping

In this section the hair shape-points envelope is processed further based on the last section. The final 3D virtual hair is obtained using random hair cluster construction achieving a more realistic visual effect.

Using the two shape-points $A_k \left(k = 0,1,2,...,M\right)$ and $B_k \left(k = 0,1,2,...,M\right)$ for the key hair as an example, the vector interpolation points d between A_k and B_k, are defined as well as the density ρ of the hair clusters and the degree of expansion Δr. The first $m\left(1 \le m \le d+2\right)$ key point is $S\left(S_x, S_y, S_z\right)$, we have:

$$S = A_k + \frac{\left(B_k - A_k\right)}{d+1} \cdot m \quad \textbf{(5)}$$

Set point $S\left(S_x, S_y, S_z\right)$ is used as the center using the spherical coordinate formula generated around the ball point set to simulate the hair clusters. Set $r = \|S\| = \sqrt{S_x^2 + S_y^2 + S_z^2}$ as the distance between point S and the head model, as well as two direction angels named θ' and φ'. We can then adopt the algorithm as follows to calculate the point set $S_k' \left(k = 1,2,3,...,\rho\right)$:

for k=1: ρ

$\theta' = rand()\%\pi$

$\varphi' = rand()\%\left(2\pi\right)$

$S_{k,x}' = \left(r + \Delta r\right) \cdot \cos\left(\theta'\right) \cdot \cos\left(\varphi'\right)$

$S_{k,y}' = \left(r + \Delta r\right) \cdot \sin\left(\theta'\right)$

$S_{k,z}' = \left(r + \Delta r\right) \cdot \cos\left(\theta'\right) \cdot \sin\left(\varphi'\right)$

End for

Put all of the key hair shape-points into the same process. Using the relevant B-spline theory [13][14][15] functions along the hair cluster growth directions to obtain virtual 3D hair. The figures below show 3D hairs with different dividing lines and initial growth directions:

Fig. 2. 3D hairs of different dividing lines and initial growth directions

From fig.2 we can see that different virtual 3D hairs can be generated by specifying different dividing lines and initial growth directions.

Table 1. The comparison between suggested method and references in manual operation.

	Manual Operation Steps
Paper[6]	Adjust every single hair shape-point
Paper[7]	Draw hairstyle outline, automatic generation of the thin shell volume
Paper[8]	Draw the hair roots outline and specify the growth direction of the hair
Paper[9]	Draw the key hair and adjust the shape-points
Paper[10]	Specify the area constructed by multi triangles meshes on the scalp surface
Paper[12]	Draw hairstyle outline, generate short hair randomly
Suggested method	Specify 2 dividing points of hairstyle Specify 2 growth directions of the initial key hair Specify length ratio for each key hair in the form of one dimensional array（about 20 numbers）

Table 1 lists a comparison between the suggested method and manual operation references. The suggested method avoids drawing a hairstyle outline, specifying the grown direction of all key hairs and adjusting a large number of shape-points, which simplifies the manual operation to a great extent.

5 Conclusion

We presented an automatic three-dimensional virtual hair modeling method that uses random hair clusters. The experimental results show that this method can obtain virtual three-dimensional hair with realistic visual effects using a small number of manual operations.

The main steps are as follows:

1). Input four key-points in the property position of the given head model, with two of them are located near the eyebrows. The length ratio is then set for each key hair (about 20, in a one-dimensional array form).

2). Particle parabolic motion and vector expansion methods are used to simulate hair growth, which uses the initial hair data points envelope attached to the scalp.

3). Vector linear interpolation is used to obtain the key points set. The random hair clusters are simulated using expansion processing in spherical coordinates.

4). The relevant B-spline functions are used to obtain the 3D hair data. The virtual 3D hair is obtained with realistic visual effects using transparency texture mapping.

By specifying only four initial points the proposed method has limitations in terms of style diversity, currently suitable only for long separate hairstyle modeling. We will continue to improve this method in future research.

References

[1] R.A.A. Rahman, A. Bade, "Geometric modeling in 3D computer graphics and visualization," in Proceedings of Annual International Conference on Computer Games and Allied Technology 08 (CGAT 08), pp. 103-108, 2008.

[2] Y. Bando, B.-Y. Chen, N. Tomoyuki, "Animation hair with loosely connected particles," *Computer Graphics Forum*, Vol. 22, No. 3, 411-418, 2003.

[3] N. Ducheneaut et al., "Body and mind: a study on avatar personalization in three virtual worlds," in *Proceedings of the 27th International Conference on Human Factors in Computing Systems*, ACM Press, pp. 1151-1160, 2009.

[4] K. Ward et al., "A survey on hair modeling: Styling, simulation and rendering," *IEEE Transactions on Visualization and Computer Graphics*, Vol. 13, No. 2, pp. 213-233, 2007.

[5] X.D. Bai, Y.M. Jiang, Y.T. Luo, "Modeling and animating cartoon hair with NURBS surface in 3D," *Microelectronics & Computer*, Vol. 23, No. 4, pp. 107-109, 2006. (in Chinese)

[6] C.F. Feng, Y.M. Jiang, C. Deng, "The modeling of real hair based on B-spline," *Microelectronics & Computer*, Vol. 25, No. 5, 161-164, 2008. (in Chinese)

[7] T.Y. Kim, U. Neumann, "A thin shell volume for modeling human hair," in *Proceedings of Computer Animation 2000 Conference*, pp. 104-111, 2000.

[8] M.L. Chai, Y.M. Weng, Q.M. Hou, Z. Ren, "Surface mesh controlled fast modeling," *Journal of Computer-Aided Design & Computer Graphics*, Vol. 24, No. 8, pp. 975-983, 2012. (in Chinese)

[9] X. Zhan, D.Y. Xue, "V-HairStudio: An interactive tool for hair design," *IEEE Computer Graphics and Applications*, Vol. 21, No. 3, pp. 36-43, 2001.

[10] N.V. Huan, D.N. Toan, "Morphing and repairing a 3D scalp geometry in building hair models and simulation," in *Proceedings of the 2009 2nd International Congress on Image and Signal Processing (CISP'09*), pp. 305-311, 2009.

[11] X.L. Li, H.B. Zha, "Realistic human head modeling with hairstyle reconstruction," *Journal of Computer-Aided Design & Computer Graphics*, Vol. 18, No. 8, pp. 1117-1122, 2006. (in Chinese)

[12] G. Yang, Z.Y. Huang, "A method of human short hair modeling and real time animation," in *Proceedings of 10th Pacific Conference on Computer Graphics and Applications*, pp. 435-438, 2002.

[13] F.Z. Shi, *Computer Aided Geometric Design and Non-Uniform Rational B-spline*, Beijing: Higher Education Press, 2001.

[14] F.-H. Tseng, H.-H. Cho, L.-D. Chou, H.-C. Chao, "Efficient power conservation mechanism in spline function defined WSN terrain," *IEEE Sensors Journal*, Vol. 14, No. 3, pp. 853-864, 2014.

[15] A. Sakatoku, T. Osada, G. Kitagata, N. Shiratori, T. Kinoshita, "3D symbiotic environment for agent-aided collaborative work," *Journal of Internet Technology*, Vol. 13 No. 1, pp. 127-136, 2012.