

# DIRECTABLE AND STYLIZED HAIR SIMULATION

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**Abstract:** Creating natural looking hair motion is considered to be one of the most difficult and time consuming challenges in CG animation. A detailed physics-based model is essential in creating convincing hair animation. However, hair animation created using detailed hair dynamics might not always be the result desired by creators. For this reason, a hair simulation system that is both detailed *and* editable is required in contemporary Computer Graphics. In this paper we therefore, propose the use of External Force Field (EFF) to construct hair motion using a motion capture system. Furthermore, we have developed a system for editing the hair motion obtained using this process. First, the environment around a subject is captured using a motion capture system and the EFF is defined. Second, we apply our EFF-based hair motion editing system to produce creator-oriented hair animation. Consequently, our editing system enables creators to develop desired hair animation intuitively without physical discontinuity.

## 1 INTRODUCTION

Recently, virtual humans are being increasingly used in various CG applications and realistic hair design, modeling and animation are fundamental elements required in the creation of virtual humans. However, simulating natural-looking human hair has proven to be one of the most difficult and challenging tasks in CG animation as a result of its complicated motion characteristics, volume, and fineness. In entertainment applications, creators hope to not only achieve a natural-looking result but also to convey their taste, intentions, and imagination. Even when animation is correct from a physics-based perspective, results can be worthless if the animation fails to reflect the creators' artistic intentions. For these reasons, we have developed a motion capture-based hair animation system with interactive editing capabilities.

First, we design a hair simulation model for reed-shaped hair strands. This easy-to-use structure is commonly utilized in the entertainment industry. For example, in (FINAL FANTASY □, 2005) the characters' hairstyles were modeled using this type of structure. At that time, however, a feasible simulation model for hair structures had not yet been developed, so it was necessary to apply a clothing simulation to the hair model in order to create the desired effect. As a result of this need, we develop a

specialized hair simulation model for this hair structure. In this paper, this structure is referred to as the "Hair Object Model".

Secondly, we capture hair motion using a Motion Capture System, and then design an External Force Field (EFF) model based on the captured hair motion data. Generally, because of the limitations of captured data, creators need to obtain generous amounts of motion data by capturing each hair style when blown by winds from different directions. Using our method, however, the motion capture data becomes universal and, consequently, various hair styles can be animated once creators have captured the hair motion.

Finally, we develop a hair motion editing system based on EFF. There is a widespread need for not only realistic-looking but also artistically meaningful hair motion, especially in entertainment applications. To create such animation, creators currently have to modify almost every frame manually. We, therefore, develop a system that allows creators to easily modify hair motion by editing EFF. Consequently, our system enables creators to intuitively design the natural-looking hair motions they wish to create without physical discontinuity.

### 1.1 Related Work

This overview of related work is limited to previous work on hair dynamics, which focused on explicit

hair models. These models handle the shape and dynamics of each strand and are especially suitable for long hair. (Anjyo et al., 1992) used a simplified cantilever beam to model hair, and one-dimensional projective differential equations of angular momentum to animate strands. (Rosenblum et al., 1991) and (Daldegan et al., 1993) reduced computation time by using sparse representative hair samples. (Bertails et al., 2006) presented Kirchhoff's theory for elastic rods. The mechanical model for one individual hair strand, called Super-Helices, handles hair natural curliness. Although these advances have greatly improved hair animation in CG, CG creators still hope to create animation that exactly matches their artistic vision. Moreover, their hair simulation model is usually applied to a single hair. However the hair object used in commercial use is usually modeled as reed-shaped polygons. Therefore, we develop a specialized motion model for the hair model.

Although hair-hair interaction is not the subject of this paper, we would like to briefly touch upon innovative approaches to this issue. (Hadap and M.-Thalmann, 2001) proposed modeling dense dynamic hair as a continuum by using a fluid model for lateral hair movement. (Chang et al., 2002) modeled a single strand as a multi-body open chain expressed in generalized coordinates. Dynamic hair-to-hair collision is solved with the help of auxiliary triangle strips placed among nearby strands. (Bando et al., 2003) proposed a method in which they model unordered particles that have only loose connections to nearby control points. Considering hair-hair interaction is also making significant contribution to hair expression in computer graphics (Ward et al., 2007).

## 2 HAIR MODEL

In this section, we introduce our Hair Object Model and explain why we have attempted to handle this model. Additionally, we describe how our method controls hair strand motion.

### 2.1 Hair Object Model

One of the common models used to create realistic hair is by mapping textures onto reed-shaped polygons to represent each hair strand. (Figure 1). This model has already been used to realistically create the hair of human characters in movies and games. Our hair structure is also based on this model. The term "hair strand" usually refers to a single thin



Figure 1: Hair Object Model.

hair. In this paper, however, we use the term to refer to hair of the structure depicted in right image of Figure 1. Here, we call whole hair strands "Hair Object Model". We describe the simulation model for this Hair Object Model in the following subsection.

### 2.2 Hair Simulation Model

We construct a specific hair motion structure for the Hair Object Model (Figure 2). This motion structure is modeled as chains of rigid stick and springs connected by control points. Each rigid body has 2 degrees of freedom (angles of spherical coordinate) and the motion of rigid body is represented by the following equation (Sugisaki et al., 2006).

$$I_{1,i,j} \ddot{\Phi}_{i,j} + I_{2,i,j} \dot{\Phi}_{i,j} + \tau(\Phi_{i,j} - \Phi_{0,i,j}) = H(i,j) \quad (1)$$

$$\Phi_{i,j} = (r_{i,j}, \theta_{i,j}, \phi_{i,j})$$

Where  $i$  is the number of hair strands,  $j$  is the joint number from the hair root,  $I_{1,i,j}$  is the moment of inertia,  $I_{2,i,j}$  is the air resistance, and  $\tau$  denotes the strength of the hair's own force. This force is an important factor in creating natural-looking hair motion. Where  $\Phi_{0,i,j}$  is the initial angle of joints, and  $r_{i,j}$  is the length of the rigid body. We explain the external force to hair strands  $H(i, j)$  in section 2.2.1.

### 2.3 External Forces

The external force to hair  $H(i, j)$  has five components. The first component is gravity. Gravity,  $g$ , is a static force. The second component  $\Omega(t)$  must be the force of wind. To achieve a natural-looking hair simulation model,  $\Omega(t)$  can be the key component of our hair simulation model. We explain how to model the wind force  $\Omega(t)$  in Section 3. The third component is the force generated by the head and body moving. The fourth  $S(i, j)$  is a spring

force The last component  $\Psi(j)$  is the force caused by the collision between the hair object and body.

$$\begin{aligned}
 H(i, j) &= g + \Omega(t) + \Xi(X) + S(i, j) + \Psi(j) \\
 S(i, j) &= -k(L_{0,i,j} - L(i, j)) \\
 \Xi(X, R) &= -X * E(\Phi_{i,j}) \\
 \Psi(j) &= \kappa \exp\left(\frac{l^2}{(j-l)^2}\right) \\
 E(\Phi_{i,j}) &= \begin{bmatrix} \cos(\phi) & 0 & 0 \\ \sin(\phi) & \sin(\theta) & 0 \\ 0 & \cos(\theta) & 0 \end{bmatrix}
 \end{aligned} \tag{2}$$

Where  $X$  is the distance in movement of the head,  $L_{i,j}$  is the current state of the spring,  $L_{0,i,j}$  is the initial state of the spring,  $L_{i,j}$  is the current state of the spring, and  $l$  is the joint number that is detected by the collision.

### 3 EXTERNAL FORCE FIELD

Wind streams around the head and body are difficult to simulate. Consequently, defining the force of wind on hair strands is considered to be one of the most challenging tasks in hair simulation. Therefore, we define a vector field that represents the wind stream, which we call the ‘‘External Force Field’’ (EFF).

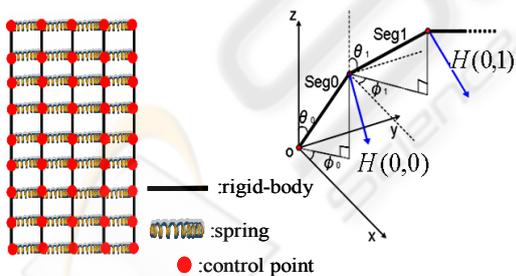


Figure 2: Hair motion structure.



Figure 3: Reproduction from the motion capture data.

In this section, we introduce a novel approach for hair motion capture and explain how we construct the EFF.

First, we capture hair motion using Vicon’s Motion Capture System. Secondly, we apply a wind force to the hair motion structure, based on the motion capture data. Finally, we define the EFF based on actual captured data by the wind force. We can therefore create animation of the wind blowing the hair.

### 3.1 Hair Motion Capture

#### 3.1.1 Setting for Capturing

We obtain 3D hair motion data using an Optical Motion Capture System. We prepare a wig to be used during the motion capture by attaching small reflective markers to 27 hair strands. The dimensions of the reflective markers were 1.5mm wide by 3.0mm long. The capture area is approximately 4000mm wide by 5000mm long by 3000mm high, and a mannequin wearing the wig with the 27 hair strands is placed in the center of the capture area.

#### 3.1.2 Capturing Hair Motion

In this section, we detail how we prepare the hair strands for the motion capture.

To prevent miscalculations prior to the experiment in the captured 3D data, we determine to use as few hair strands as possible. We therefore select 27 hair strands to represent the overall hair motion. We lightly attach 4-10 reflective markers onto each of the hair strands, depending on its length. In addition, 8 normalized markers are attached to the forehead, nose, both cheeks, and the jaw and neck of the person wearing the experimental wig. Secondly, we attach the 27 representative hair strands to the wig, arranging them based on the *layer model*, a model hair stylists generally use to design human hair styles.

Figure 3 shows an example of real hair strands blown by the wind (right image) and the reproduced hair animation using captured data from the same wind (left image). As Figure 3 shows, our method can reproduce hair motion similar to the reference animation.

### 3.2 Applying Wind Force

We apply a wind force based on the motion capture data obtained from the hair motion structure.

Where  $X_{i,j}$  is the position of a motion capture marker,  $s$  is the frame number of the motion capture data.

### 3.3 External Force Field

In this subsection, we introduce the concept of EFF: one of the advantages of this paper. The EFF is grid cubes resembling a voxel around the head (Figure 4). Each cube has a direction and power of a wind force. The range of the EFF is 60 cm because the lengths of most hair styles fall within this range. The EFF is applied to the control points on our hair motion structure. When a control point moves into a grid cube, the force effects a change in the motions of the control point.

$$\Omega(i, j) = \frac{2(X_{i,j}(s) - X_{i,j}(0))}{s^2} E(\Phi_{i,j}) \quad (3)$$

Next, we explain how we define the direction and power of each grid cube. Firstly, we define the force existing outside of the grid cubes. Even though the range of the EFF has been designed, there is still the possibility that a hair strand may move outside of the grid cubes. Therefore, we define the direction of the force from a point where the wind is generated towards the head. Secondly, we allocate the wind forces from the motion capture data in grid cubes based on the difference between hair motion capture data at a certain time step (arrow 1 in Figure 4). When motion capture markers do not exist at the time step in a grid cube, the wind force on the grid cube is defined by interpolating around the wind force. There are two methods of interpolation. In the first, the grid cubes are linearly interpolated by the nearest two cubes (arrow 2 in Figure 4). In this case, the subject grid cube is nearer to the head or body than the grid cube with the defined wind force. The second case is where grid cubes are interpolated by the nearest cube and the force existing outside of the EFF (arrow 3 in Figure 4). This process is implemented by linear interpolation. Through these processes, the external force is defined (Figure 4). Repeating these processes, we are able to design richer EFF that can achieve more impressive hair animation.

## 4 MOTION EDITING SYSTEM

In this section, we introduce our hair motion editing system based on our hair simulation model and EFF

for natural-looking hair motion described in sections.

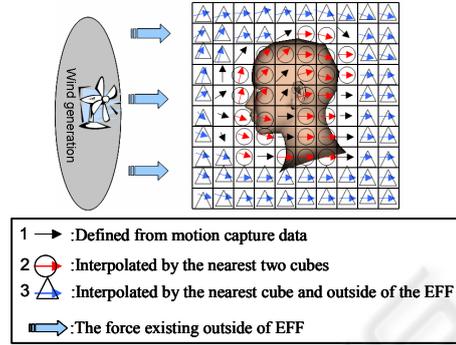


Figure 4: External Force Field.

2 and 3. First, we describe the hair motion editing process before moving on our editing system's motion modification process.

As mentioned previously, hair animation in entertainment applications, movies and games is intended to reflect the creators' intentions and imagination. This means that hair animation should be either more stylized depending on the effect desired by the individual animator. In movies, especially, animation often contradicts the laws of physics despite appearing natural. For example, hair motion tends to be more inordinate in movies than in the real world.

To create hair animation is a time-consuming and task requiring great skill, because CG creators manually control each hair strand in each individual frame. For this reason, we develop a hair motion editing system to solve such problems.

### 4.1 Editing Process

The direction and force of wind is determined by creators in Sections 2 and 3, so that the hair animation can be created. As mentioned previously, however, creators might not be satisfied with the resulting hair animation. For these cases, our system provides creators with the option of editing hair motion intuitively. An overview of the editing process is shown in Table 1. To achieve an interactive operation, our system allows creators to set key frames manually. In other words, when using our system, it is necessary to set the first key frame and to choose a target hair strand. Creators are then required to set the second key frame using a mouse. This process is repeated until creators are satisfied with the final result. After setting key frames, hair motion is automatically re-simulated. We describe how this automatic process is achieved in the next sub-section.

### 4.2 Dynamics for Editing

The extra force based on the operation in section 4.1 adds to a wind force  $\Omega(t)$  in EFF. As a result, the target hair strand moves toward the second key frame without physical discontinuity. The extra force  $a(i, j)$  is provided by the following equation:

rendered 120-hair strand–simulation runs between 15fps and 20fps on an Intel Core Duo 2.66Hz, platform with NVIDIA Quadro FX4500.

$$\alpha(i, j) = \frac{2(\Phi_{i,j} - \Phi_{0,i,j})}{s_i^2} \exp\left(\frac{l^2}{(l-p)^2}\right) \quad (4)$$

Figure 6 shows an example of hair motion applied to a CG character.

Figure 7 shows the animation in Figure 6 after being modified with our editing system. Both animations in Figure 6 and 7 are created using the standard Maya rendering pipeline.

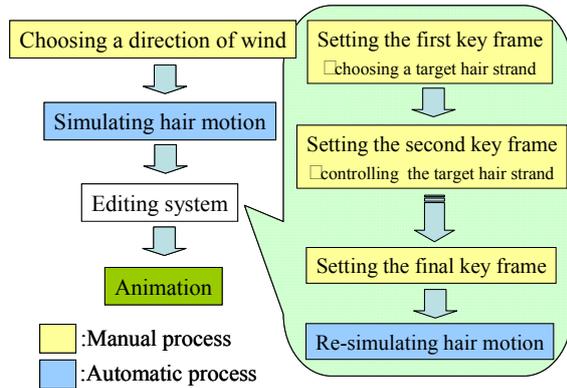


Figure 5: Edited EFF.

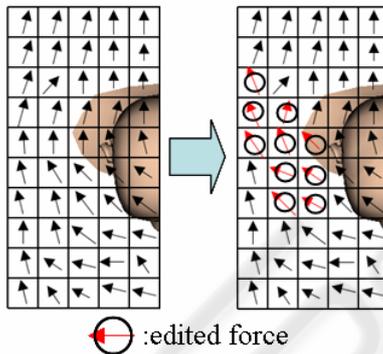


Table 1: Editing process.

Where  $\Phi_{0,i,j}$  is the position of the controlled target hair strand in the second key frame,  $t$  is the number of the key frame,  $l$  is the distance between the target strand and the edited grid cube,  $p$  is the distance from the position of the grid cube to the center of the edited grid cube.

Thus, the extra force required to change the wind force is applied to the chosen hair strand from the first to the last key frame (Figure 5).

### 5 RESULTS

In this section, we present the results of two animations created using our approach. The pre-

### 6 CONCLUSIONS

This paper has outlined three advantages of our approach to hair animation. First, we introduced the hair simulation model specialized for the Hair Object Model. Since the Hair Object Model is adjusted for commercial use, it is not so complicated to control. Therefore, creators can easily preview animation almost in real-time. The second advantage of our system is that it enables users to define EFF from hair motion capture. Since the captured data is from an actual motion, the result can be closer to the real hair motion. Thus, our EFF is created from captured data, enabling more realistic animation. The final advantage of our system is that it provides a way of editing hair motion interactively. This advantage is associated with the first advantage. Previewing the animation in real time, our hair motion model enables creators to edit hair motion intuitively. Consequently, creators can create hair animation depending on their taste, intentions, and imagination. The results produced with our system highlight our method’s accessibility, convenience and usability.

As can be seen in Figure 6, our system produces realistic results which are sufficiently complete for immediate use. However, by using our editing system, creators can re-create the resulting hair animation according to their individual preferences (Figure 7). This proves our motion editing system can be used commercially.

### 7 DISCUSSION AND FUTURE WORK

Here we discuss the advantages and limitations of our approach and mention future work. We have four issues to discuss.

First, in this research, the Hair Object Model that

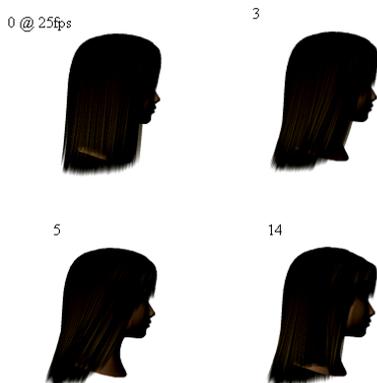


Figure 6: Sample hair motion.

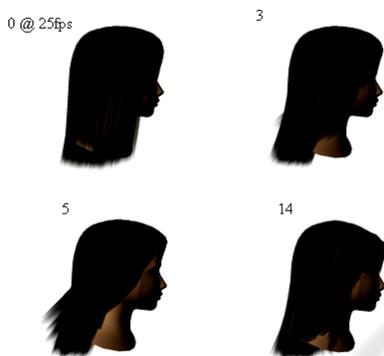


Figure 7: Edited hair motion.

we adopted is one of the most generic polygon structures used in the creation of CG characters. As shown in Section 5, our hair simulation model works successfully, however we have not tried to apply the hair simulation model to others yet. Therefore we need to modify our existing system, or develop a hair simulation model that can be applied to various hair structures, such as generic hair strands.

Secondly, we have successfully defined EFF handling of separate winds moving from various directions, depending on the hair motion capture.

As future work, we plan to capture hair motion generated by natural wind blowing from several directions at the same time. Furthermore, if a motion capture marker is attached to material that is more lightweight than hair, we will be able to capture wind streams more precisely and, consequently, create richer hair animation.

Finally, our hair motion editing system's GUI was designed using OpenGL and OpenCV. However, CG creators often have their own preferences regarding which 3DCG software they use. We

therefore, need to develop plug-ins for 3DCG software, such as Maya, 3DMax and so on.

## ACKNOWLEDGEMENTS

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