Indian Institute of Technology
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B. Tech Project I

Modeling and Simulation of Flying Birds

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Without the help all of these people, this project couldn't have been what it is today.

Abstract

In today's world, people are moving towards physics based animation to present phenomenon like a storm, ocean waves, etc. as physics-based simulation looks more real. Using physics, people have developed models of humans(biped), animals(quadruped) which can be directly placed in an environment.
In this report, I present you the work I have done in the development of physics based model of a flying bird and its simulation. I propose an intuitive user interface tool which can be used to generate a 3d model of bird directly using the 2d sketches of a bird.

Contents

Chapter 1

Introduction

With the increasing demand of Computer Graphics in Games, Cinema and Medical field, Computer Graphics researchers all across the world have proposed a lot of ways to model real life things. Computer animation research has produced a number of models for the natural motion of animals. Most of this research has focused on terrestrial animals, primarily humans.

Perhaps equally, if not more, intriguing is the motion of animals in flight. Birds and insects are both among the most frequently seen wildlife in our everyday life. The flight of birds is arguably the most graceful and expressive of all natural motions. However, modeling aerial motion is extremely challenging. First, any locomotion in air flows or other environments with high Reynolds numbers presents a significant simulation and control challenge. The interaction between a bird's wings and the air is very complex. The forces generated by this interaction are chaotic and hard to control. The simulations are often unstable because of high sensitivity: the slightest change of wing position during down-stroke can have significant effects in the result and the stability of the bird's flight. Furthermore, the specific musculoskeletal structure of the bird, and especially the elastic properties of the feathers, seem to greatly affect not only a bird's wingbeat pattern but also whether the bird can fly at all.

The modeling softwares available today are very generic in nature. So, it is very difficult to model a new element from scratch. If one has to make a large number of models having a similar structure for some experiment, he/she needs to do a lot of work to generate them. To deal with this, I have developed a tool to generate a 3d model of bird using its sketches. The tool generates a generic bird with a torso, tail and wings.

In this report, I discuss my attempt on development of physics-based model of a bird and its simulation. I also discuss the tool the I have developed to ease the process of development of bird model.

Chapter 2

Literature Survey

To get started with the physics-based animation, I started with the blog of Christopher Batty, a CS prof at the University of Waterloo. He writes about every physics-based animation paper published in Top tier CG conferences. His blog made me aware of past development in this field and the current importance of physics-based animation in CG World.

By going through the web, I have found a large number of researchers have tried modeling realistic human motion and a also some number of researchers tried modeling other animals. Birds have received somewhat limited attention within the computer graphics community.

Jia-chi Wu[1] described a physics-based method for synthesis of bird flight animations. Their method computes a realistic set of wing beats that enables a bird to follow the specified trajectory. He modeled the bird as an articulated skeleton with elastically deformable feathers. The bird motion was created by applying joint torques and aerodynamic forces over time in a forward dynamics simulation. The final model was able to us to produce flight motions of different birds performing a variety of maneuvers including taking off, cruising, rapidly descending, turning, and landing.

Yanyun Chen[2] presented techniques for realistic modeling and rendering of feathers and birds. He used L-system to describe the branching structure of feathers of the bird. The parametric L-system allowed the user to easily create feathers of different types and shapes by changing a few parameters. Their system also incorporated randomness in feather geometry. Based on this framework of feather modeling, they developed a system that can automatically generate appropriate feathers to cover different parts of a bird's body from a few "key feathers" supplied by the user, and produce realistic renderings of the bird.

Chapter 3

Bird Model

*This model is inspired from the model developed by Jia-chi Wu[1].

3.1 Overview

The input for the system is the bird model specifications. The bird model includes the skeletal structure, mass distribution, and wing feather specification. We group all degrees of freedom (DOFs) for the bird into a vector $\vec{q}$. This vector includes the bird's global rotation and translation, as well as all controllable joints of the bird's skeleton.

For each Wingbeat, a bird flaps its wing from a neutral position upward, then downward, and then upward to the neutral position again. The algorithm finds values for the wing beat parameters $\vec{u}$ that enable the bird to flap its wings in a most natural way. These parameters determine the desired state patterns $\vec{q}^*(\vec{u}; t)$ for the controllable DOFs during the wingbeat cycle. The bird's motion is controlled by a proportional-derivative (PD) controller that generates joint torques that bring each of the controllable DOFs $\vec{q}$ towards its desired state $\vec{q}^*$.

3.2 Bird Dynamics

The bird is modeled as a hierarchy of articulated links. Each bird has 9 articulated links, 18 joint DOFs(12 local DOF, 6 global DOF to locate position and orientation

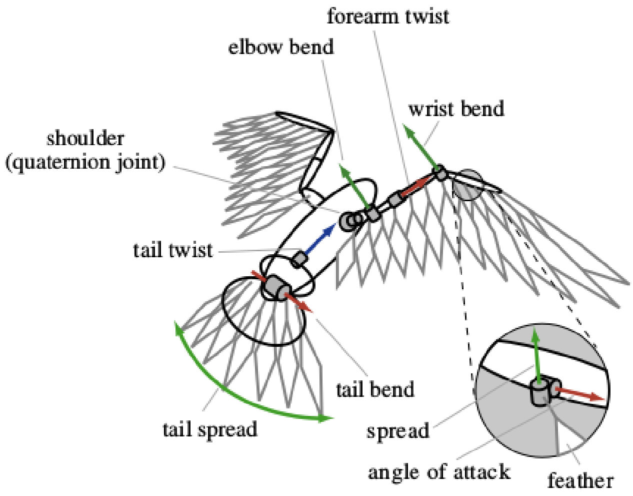

FIGURE 3.1: The bird skeleton from Jia-chi Wu[1] paper.

of bird), and additional DOFs for feathers. The skeletal structure and controllable DOFs are described in figure 3.1.
To model the wings, each of the flight feathers is attached to the wing by a Ball and Socket Joint whose joint angles are completely determined by the shoulder, elbow, and wrist joints in a way that resembles that of the flight feathers of real birds.

- Articulated Links
  - Torso
  - 2 x Shoulder
  - 2 x Forearm (Divided into two links to model both twist and bend movement)
  - 2 x Wrist
- Joints and Degrees of Freedom.
  - 2 x Shoulder Ball and socket joints. (3 DOF)
  - 2 x Elbow Bend (1 DOF)
  - 2 x Forearm Twist (1 DOF)
  - 2 x Wrist Bend (1 DOF)

Parameter	Description
$\vec{u}_1^d$, $\vec{u}_1^u$	arm dihedral angle
$\vec{u}_2^d$, $\vec{u}_2^u$	arm sweep angle
$\vec{u}_3^d$, $\vec{u}_3^u$	arm twist angles
$\vec{u}_4^d$, $\vec{u}_4^u$	forearm twist angles
$\vec{u}_5^d$, $\vec{u}_5^u$	wing spread extents
$\vec{u}_T$	duration of the wingbeat

Table 3.1: Wingbeat Parameter.

3.3 Wingbeat parameterization

In order to represent the desired DOF patterns for a wingbeat, set of wingbeat parameters $\vec{u}$ is used. The parameters are shown in Table 3.1. The superscripts u and d indicate upstroke and downstroke parameters. Most of these parameters are replicated for the left and right wings. The dihedral and sweep angles are defined in Figure 3.2. These parameters are used to determine the composite functions g_k which in turn determine $\vec{q}^*$:

$$\vec{q}_i^*(t) = \underline{\vec{q}}_i + (\overline{\vec{q}}_i - \underline{\vec{q}}_i) * g_k(\vec{u}^d_{\mu(i)}(i), \vec{u}^u_{\mu(i)}, \phi(t))$$

where $\overline{\vec{q}}_i$ and $\underline{\vec{q}}_i$ are the maximum and minimum allowed values for DOF i (i.e. the joint limits), and ϕ is the phase of the wingbeat cycle.
Each wingbeat starts with the downstroke, i.e. , $\phi = 0$ is the beginning of the downstroke and $\phi = 2^*\pi$ is the end of the upstroke. The function $\mu(i)$ determines the mapping between DOFs and wingbeat parameters. DOF i is determined by the parameters $\vec{u}^d_{\mu(i)}$ and $\vec{u}^u_{\mu(i)}$. The composite functions g_k are

$$\begin{aligned}
\mathrm{g}_1(\vec{u}^d_j, \vec{u}^u_j, \phi) &= (^u_j - \vec{u}^d_j)\frac{1+cos\phi}{2} + \vec{u}^d_j \\
\mathrm{g}_2(\vec{u}^d_j, \vec{u}^u_j, \phi) &= \left\{ \begin{array}{cc} ^d_j & 0 \le \phi < \pi \\ (^u_j - \vec{u}^d_j)\frac{1-cos(2\phi)}{2} + \vec{u}^d_j & \pi \le \phi < 2 * \pi \end{array} \right\}
\end{aligned}$$

Based on the observations made in the biomechanics literature, the authors of the paper use g_1 for upper arm dihedral and use g_2 for the arm sweep, arm and forearm twists.

Following everything mentioned above the final model generated is shown in figures 3.3, Figure 3.4, Figure 3.5.

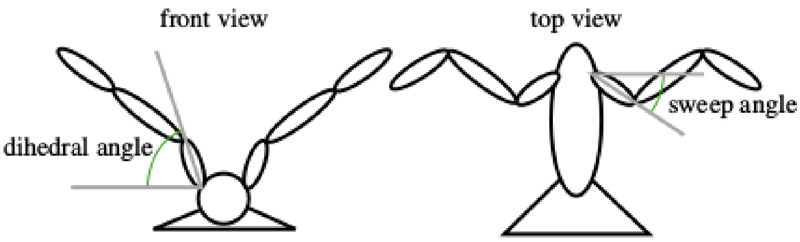

FIGURE 3.2: Arm dihedral and sweep angle from Jia-chi Wu[1] paper.

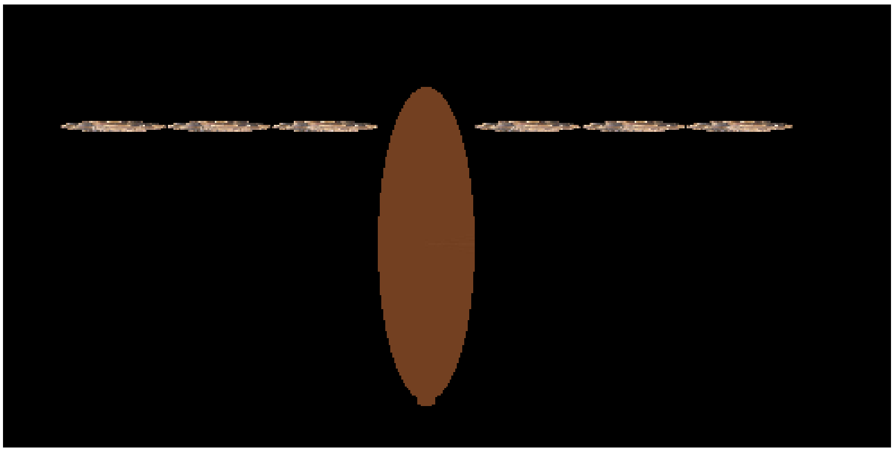

FIGURE 3.3: Bird Skeleton

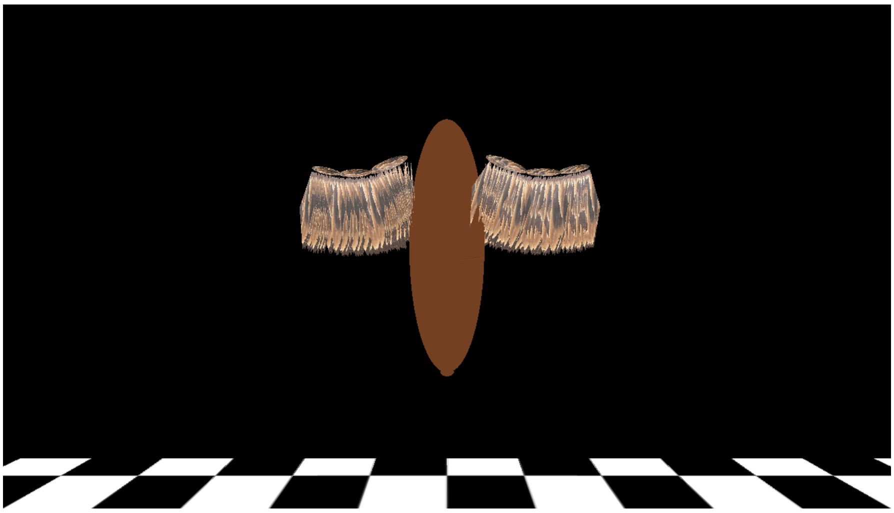

FIGURE 3.4: Bird with feathers rolled in

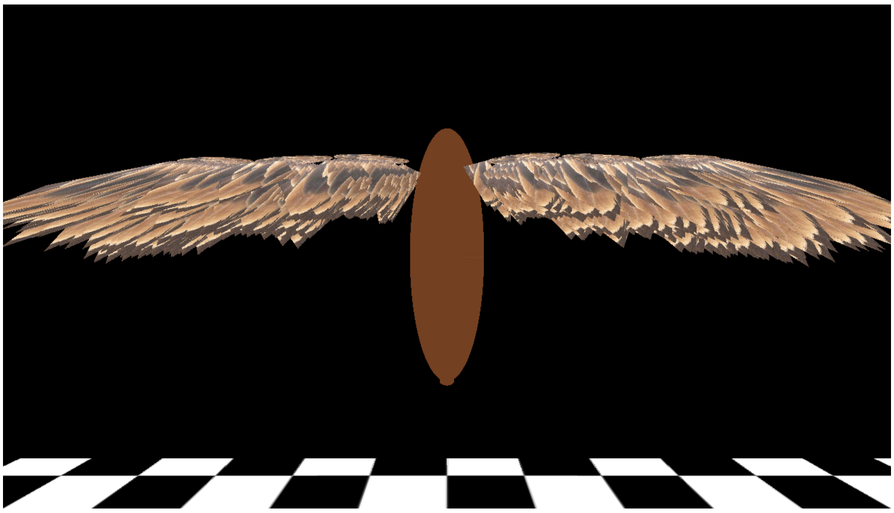

Figure 3.5: Bird with feathers rolled out

Chapter 4

Modeling Tool

It is often cumbersome to generate a model of any object from scratch. To ease this process, I have developed a tool to generate a 3d graphical model of bird using the 2d sketches of the bird.

The model I have used for the bird is very generic right now. The bird has a torso and wings. Using the tool and a top of view of a bird, user can locate the major points on the image. I have used Bezier curves for making the sketch, hence by adjusting the control points, the user can fit the final curve on the image. The tool is assuming that the bird is symmetric which makes generatin of model even easier. Figure 4.1 - 4.4 shows the tool in action.

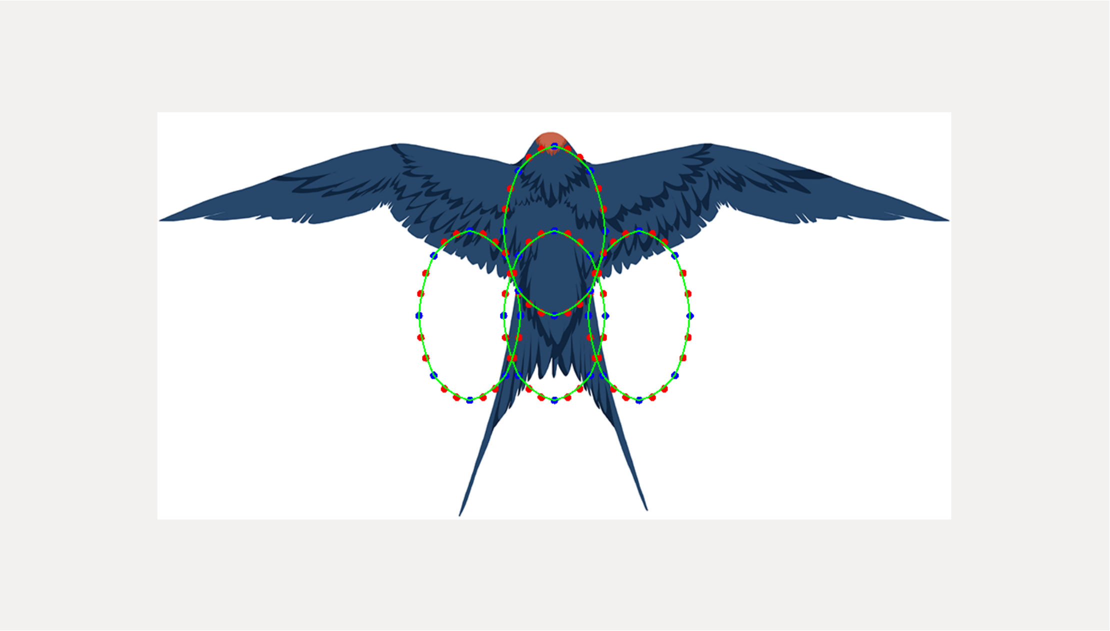

FIGURE 4.1: Loading of Image

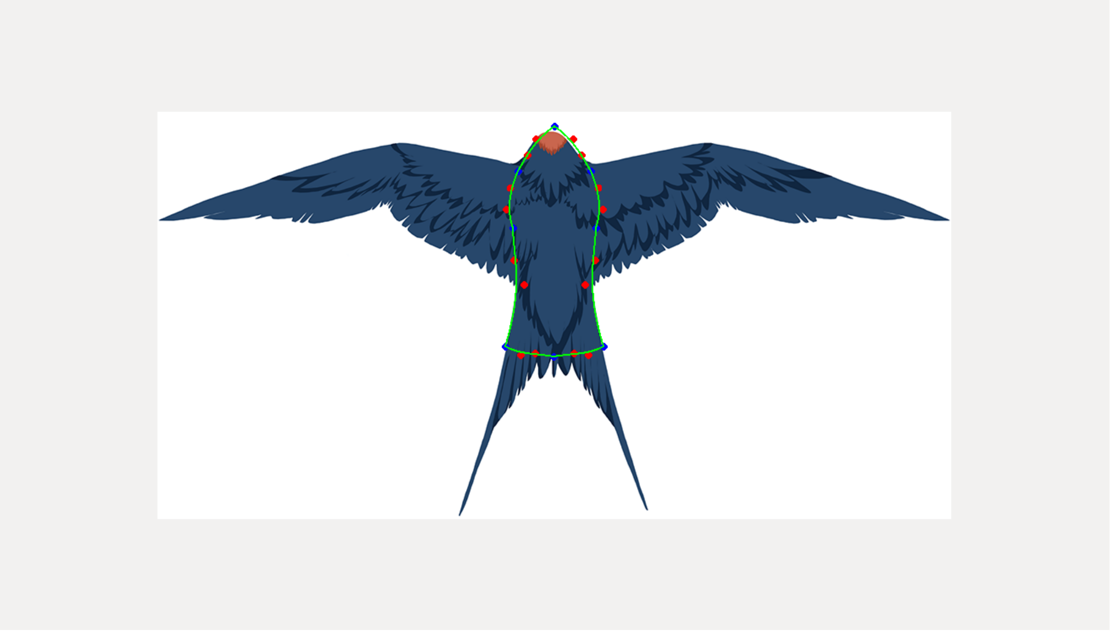

FIGURE 4.2: Sketching of Torso

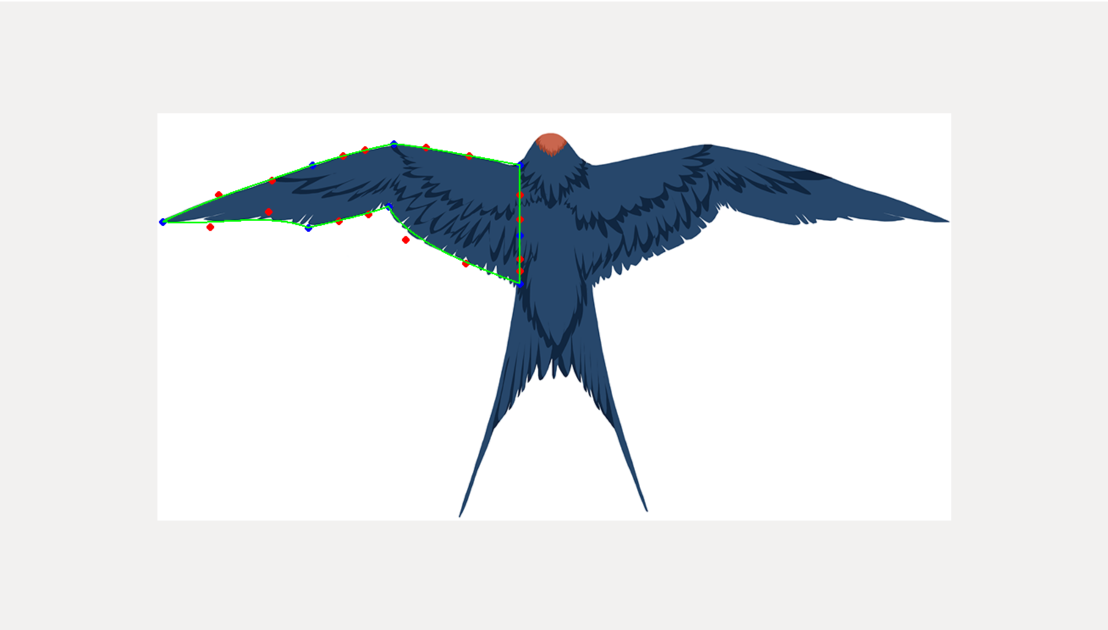

FIGURE 4.3: Sketching of Wing

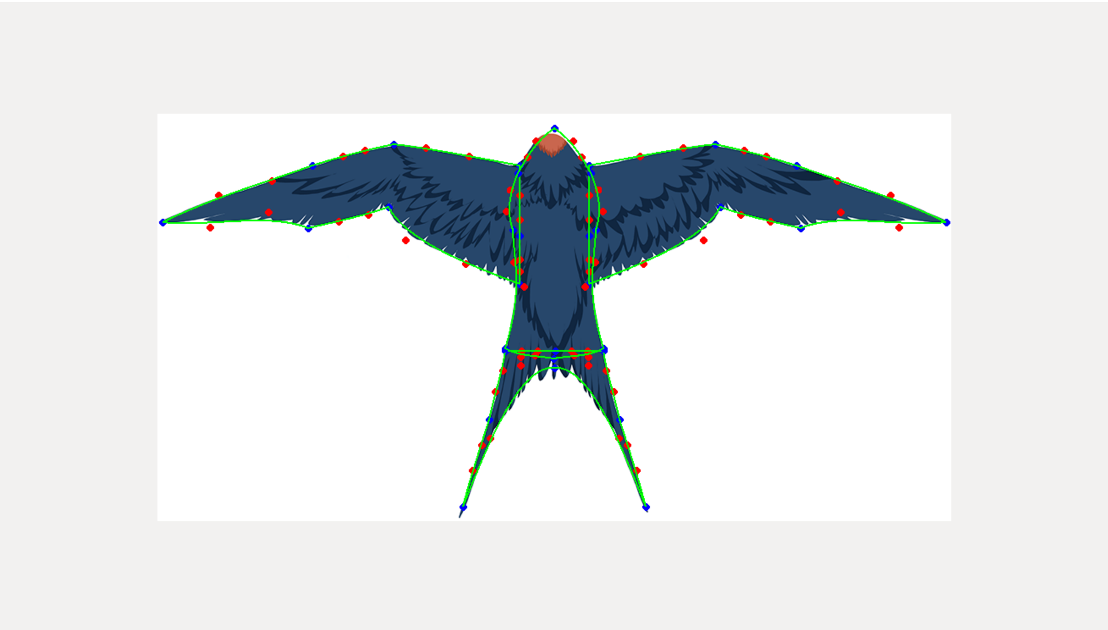

FIGURE 4.4: Final Sketch

Chapter 5

Future Work

My next step is to simulate the bird in an actual environment. Right now, I have implemented only the flapping of wings. There exist no external forces on the bird now, the model uses only the internal forces. The external forces will bring quite big challenges to the simulation. One of the biggest challenges in physics-based systems is the stability. The model often becomes unstable because of even slightest change in the parameters. One major challenge will also be to prevent the toppling of the bird about its center of mass. This will require an enormous amount of calibration and computation of forces at each feather/point. This will also require a good study of aerodynamic forces.

I will also try to improve the modeling tool. The tool currently takes only the top view of the bird and generate the 3d model using some heuristics. I wish to incorporate all 3 views (top view, side view and front view) to generate better bird models.

Bibliography

[1] Jia-chi Wu and Zoran Popović. Realistic modeling of bird flight animations. *ACM Transactions on Graphics (TOG)*, 22(3):888–895, 2003.

[2] Yanyun Chen, Yingqing Xu, Baining Guo, and Heung-Yeung Shum. Modeling and rendering of realistic feathers. In *ACM Transactions on Graphics (TOG)*, volume 21, pages 630–636. ACM, 2002.