Physically-Based Virtual Glove Puppet

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Abstract: Glove puppetry in Taiwan is a popular performing art. In this paper, we present a physically-based virtual glove puppet system which simulates the dynamics of glove puppet and allows user to observe and manipulate the motion of the virtual puppet interactively. With physics simulation techniques, we can generate realistic motion of the virtual puppet with high-level inputs. In our system, the puppet is modeled as a multi-body object with many degrees of freedom among parts. The physical simulation of the puppet clothes is controlled by a mesh, which is used to define a set of particles and limitations among them. Furthermore, we apply texture and normal maps to clothes to enrich the appearance. We demonstrate the effectiveness of our system by showing a plausible running motion of the virtual glove puppet and various styles of puppet costume in our system.

1. Introduction

Glove puppet show is an important performing art in Taiwan. It combines essential of music, story-singing, sculpture, painting, embroidery and architecture. A successful puppet show requires the art of manipulations by puppet master to control the puppet with fine and precise hand motions. It takes many years of learning to master the manipulation of glove puppet. It is even a more difficult task to generate puppet motions as an animation in a computer, because it consists of secondary motions in many parts that are not directly controlled by the performer. In other words, it is an interesting challenge to simulate the dynamics of glove puppet in computer animation, especially the cloth dynamics. If we can build a virtual puppet system with appropriate physics, we will be able to archive the cultural heritage by recording the script, music and performance of the glove puppet in digital way. The convenience of digital technologies has facilitated the teaching of glove puppet and promoted the tradition art as shown in the work of Lin et al. (2009).

The motion simulation of digitalized puppet is most related to the research in the field of computer animation. There are three mainstream methods in computer animation including *keyframe* animation, *data-driven* animation and *procedural* animation. First, in the approach of keyframe animation, software packages are commonly used to specify key frames and generate the in-between frames automatically by interpolation techniques (Lasseter, 1987). Nevertheless, it is still a labor-intensive task to assign keyframes in order to produce realistic motion. Second, data-driven animation is based on the motion data from motion capture devices to produce the desired motion. Therefore, it is a quick and direct way to generate realistic animations compared to the keyframe-based method. However, it is difficult to edit and modify the motion for a new environment. Third, procedural animation uses a set of algorithmic rules to produce the desired motions. The difficulties of this approach come from the background knowledge needed for the generation of appropriate rules for complex models. Several studies have tried to combine the advantages of different approaches. For example, Chen et al. (2010) proposed a procedural character animation method taking data from motion capture devices and using them as the parameters in an animation procedure. Besides the above methods, physical simulation is another common technique to generate realistic motions with relatively high computation cost. Fortunately, modeling and simulating the physical property of an animated object are becoming prevailing due to the fast development of physics engines and hardware devices such as GPU (Graphics Process Unit).

The objective of this paper is to design a physics simulation system capable of showing realistic motions of a glove puppet. It can reproduce the puppet shows in the virtual world by adopting an appropriate dynamics model close to the real world. Figure 1 shows the architecture of the proposed system. First, we use 3ds Max to build the cloth mesh of the puppet, and UVW mapping is built to attach the texture map and normal map for appearance according to the Boardman's tutorial (2010). The texture and normal maps were dealt with by using an image editing software to design the color and surface variation of the puppet's cloth. Then we can export the geometry and texture information of our model. Second, we use PhysX (Nvidia, 2008) as the physics simulation engine in our system. Our system contains three main components under PhysX dynamics including *rigid body*, *joint* and *cloth*. Rigid bodies are used to construct the body of puppet while joints are used to restrict the degrees of freedom between rigid bodies. With the system, a user can manipulate the puppet and observe the generated motions in various parts of the model, including body and cloth.

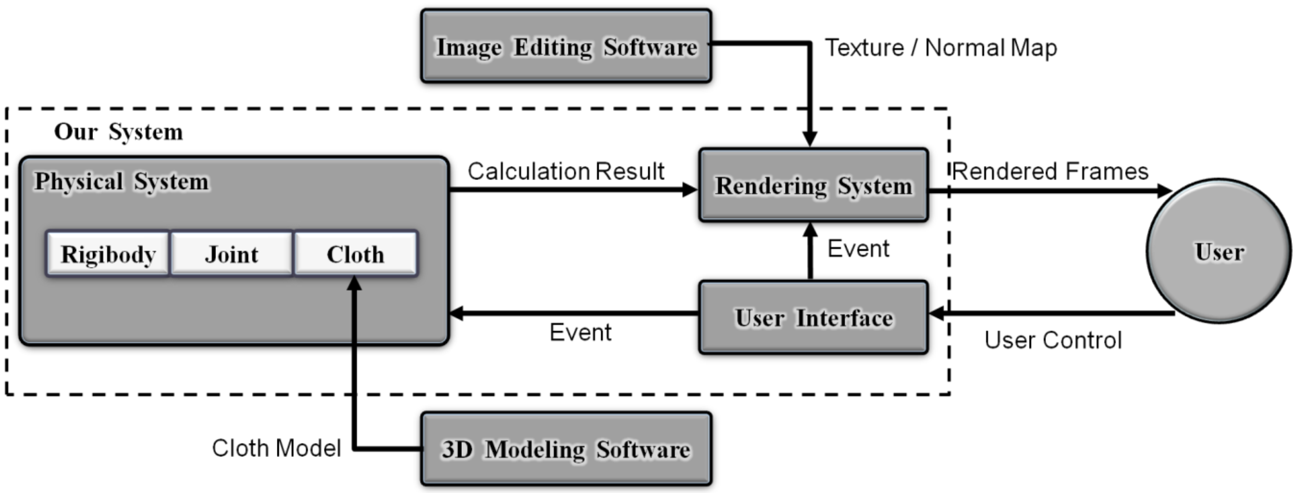


Figure 1. The architecture of our system.

2. Physics System

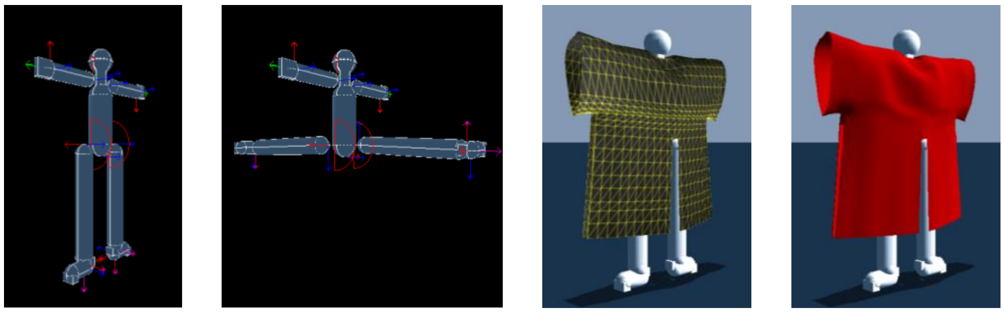
The basic structure of a real glove puppet includes the body and the cloth. The body is composed with a hollow head, cloth body, cloth legs, woody palms and shoes. The puppet master manipulates the motion of a glove puppet by applying global hand movement and using fingers to control the head and upper limbs to generate expressive motions.

In our system, we treat the head, upper limbs, legs and shoes as the basic components in rigid-body dynamics (see Figure 2a). The relative motion of connected parts is regulated by joints to restrict the rotation angle and translational distance. Through physics simulation, the motion of a virtual puppet can be generate to respect the physical law in the real world.

2.1. Rigid body and joints

The ideal rigid body is a solid geometry in which deformation can be ignored. The external force will not change the distance between any two points inside the rigid body. The shape and physical properties of an object are two basic elements for the construction of rigid-body dynamics. Two ways are commonly used to build a rigid body: from geometry primitives: box, sphere and capsule or from convex and triangle meshes. The model of the virtual glove puppet in our system is a complex rigid body system composed of multiple rigid-body parts as shown Figure 2 (a).

Each rigid body requires the modeling of several physical attributes to simulate the dynamics of the system. When two rigid bodies collide, these attributes can be used to determine whether the rebound will occur or not. These physical attributes include: *position*, *density*, *restitution*, *static/dynamic friction*, *velocity*, and *angular velocity*. The restitution and friction will affect energy loss when the rigid body moves. In our experiments, we use the parameters of restitution = 0.5 and both frictions = 0.2 to simulate the behavior of a real puppet. When an external force is given as an input, the PhysX engine is used to process the simulation to achieve desired effects.



(a) (b) (c) (d)

Figure 2. The initial (a) and the limit (b) state of the joint skeleton. The mesh (c) and the puppet clothes without texture (d).

Joint is a location to regulate the rotation and translation between two connected rigid bodies. PhysX offers all kinds of simple joint mechanisms, such as revolute joint, spherical joint, point-on-line joint, pulley joint and so on. Besides the joints, 6DOF (Degrees of Freedom) Joint is a complex but powerful mechanism. The six degrees means three coordinates (x, y and z) that rotate and translate. It is easy to combine the rigid bodies into a whole puppet by joints, and then define the DOF of each joint to restrict the movement of the puppet. We have also added the motor and spring attributes to the physics simulation.

2.2. Motion

Body language plays an essential role in a glove puppet show because the facial expression of wood carved head is immutable. The puppet motion is divided into two categories in our system: the primary motion and the secondary motion. Secondary motions are the one driven by other primary motions. For example, when a puppet moves up and down, its legs will swing back and forth. The leg swing motion is a secondary motion. In contrast, the movement of the puppet itself is a primary motion. In this system, a primary motion is controlled manually by a procedure or by user input while a secondary motion is computed by physical simulation. We indirectly control the secondary motions by using the physical attributes in a simulation. Therefore, it is crucial to specify correct parameters for these physical attributes. However, it is difficult to directly measure the attributes (such as mass, friction and so on) of each component. Therefore, we have conducted extensive experiments to tune the physical parameters to make the generated motion plausible compare to the real motion.

3. Cloth

Glove puppets are usually designed to express its characteristics through different costumes. It is crucial to be able to simulate the dynamics of cloth in order to enhance the puppet motions in a puppet show. We have implemented the cloth with geometry model and textures for different costumes. The physical attributes of cloth are also defined by mesh which includes the position of cloth particles (vertices) and constraints between these particles (edges). The attributes of the cloth include bending stiffness, stretching stiffness, density, thickness, friction and damping. Stiffness, friction and damping dominate the energy loss of motion. In our experiment, we set bending stiffness = 1, friction = 0.3, and damping = 0.8.

While the cloth mesh defines the internal physical property of a costume, texture mapping is used for cloth appearance. We use a planar projection in the UVW mapping to build the correspondence from 2D texture image to 3D cloth geometry. We scanned the pattern of a real puppet and edited the texture image by some image editing software. If we only use a single image for texture mapping, it will only give the cloth mesh color appearance. To reflect the surface variance of cloth, we adopt normal maps with local Blinn-Phong Illumination (Heidrich, 1999) to simulate the bumps and wrinkles on the cloth surface. The OpenGL shading language (Rost, 2009) is used to implement the bump mapping for the shading result in a real-time interaction. Three puppet's costumes with different textures and normal maps are show in Figure 3.

(a)
(b)
(c)

Figure 3. The leftmost images are Taoism costume (a), youth apparel (b) and female attire (c) of real puppets. The second column is the imitation of the real, and the rightmost two columns are the details of the imitations.

4. Results

Running is a common fundamental motion in a glove puppet show. Several complex motions can be extended from the running motion. We simulate the running motion by repeating the virtual puppet moves upward and downward. The running motion can then be produced by leg swinging. Based on the appropriate settings of physics attributes, a virtual puppet's feet can swing back and forth as a response to the vertical movement of a puppet. Figure 4 gives the simulation result of the virtual puppet compared to the real puppet running.

In the design of the user interface for the system, we have used mouse scroll to control the position of puppet. A user can directly control the puppet to learn the running motion. We have also used sensor devices (such as Wii remote) to manipulate the puppet. With such a system, we expect to be able to archive more realistic feedbacks and be helpful in teaching and learning how to play glove puppet.

5. Conclusions and Future Work

In this work, we present a virtual puppet system with physics-based motion simulation and bump-mapping materials for the puppet's clothes. In this system, a user can control the running motion of the virtual puppet interactively, and practice the skills of puppet manipulation. We hope this virtual puppet system can preserve and promote the art of glove puppet show. Furthermore, it will be interesting to combine the real and virtual puppets together to create a new form of puppet show.

The current system has some limitations: we cannot handle the collisions between two different cloths. This limitation constrains us to add more decoration on cloth. Furthermore, we hope to extend our system in several ways. We focus only on the running motion of puppet in current system. But we are interested in adding walking, rolling and back flips motions into our system and making a vivid demonstration. For the cloth, further studies will focus on investigating decoration and variation of texture, and we can also add some decorations like headdress and flag to reflect the characteristics of different roles. Besides the puppet, some stage props, like horse, table, chair and even the show platform, can make our work more complete in establishing the new form of performing art with glove puppet shows.

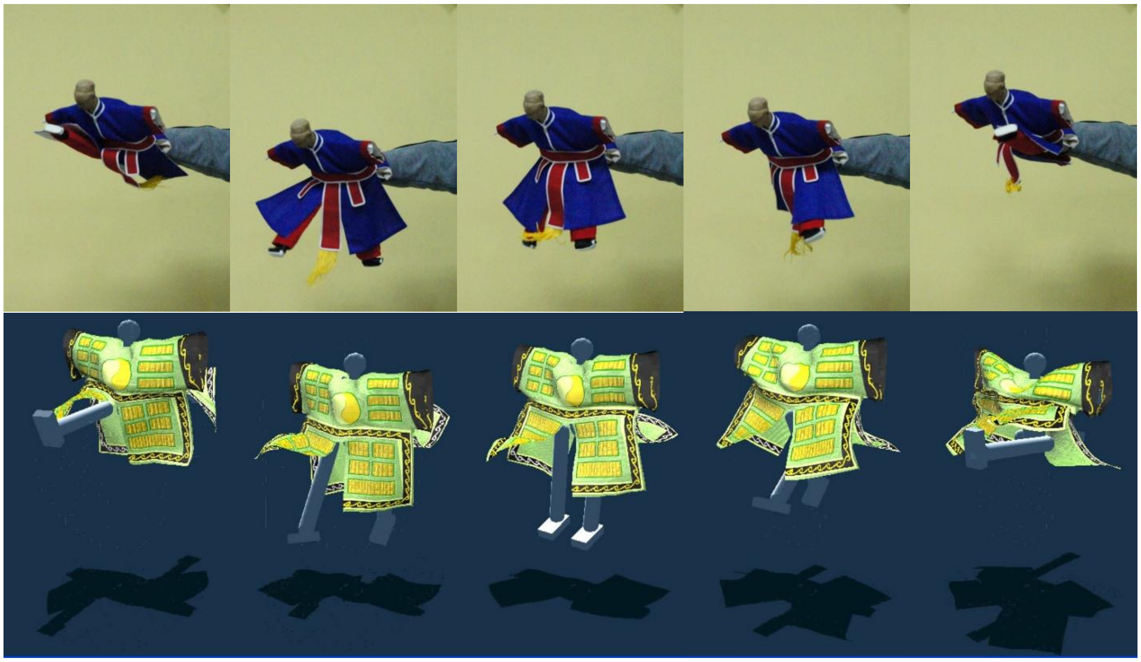


Figure 4. The running motion sequences of a real puppet (top row) and our virtual glove puppet (bottom row).

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Acknowledgments

This work is supported in part by National Science Council (contracts NSC-99-2221-E-004-014) and by the Top-University project of NCCU, Taiwan.