Hand bone frame conversion for motion retargeting in a body motion capture system to manipulate virtual Taiwanese hand puppet

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Abstract

Taiwanese hand puppet theater is a traditional craft with over a hundred years of history. This project merges Taiwanese hand puppet theater with technology, preserving its traditional qualities while breaking new ground. We used motion capture technology for the transdisciplinary co-creation of three-dimensional animation and performance art. Taiwanese hand puppets are manipulated using the hand; the limitations of the bone frame of the hand create the unique movements of the humanoid puppets. Motion capture equipment cannot directly translate the human skeleton to the bone frame of the hand, and performers cannot physically imitate the motions of the hand. Thus, to enable motion capture equipment to manipulate a virtual Taiwanese hand puppet in real-time through a human body and make the virtual Taiwanese hand puppet move in the traditional manner, we wrote a puppetry system that converts the VRM of human skeletons to the bone frame of the hand. This system serves as a reference for motion retargeting to manipulate virtual puppets.

Keywords

Taiwanese hand puppet theater, motion capture, motion retargeting, bone frame

Introduction

Taiwanese hand puppet theater originated during the Ming Dynasty of China (1368-1644). Around two centuries ago, glove puppetry spread from Fujian Province to Taiwan, where it flourished and became a performing art unique to Taiwan[1]. In 1950, the Golden Ray Theater ushered in a new era for Taiwanese hand puppet theater. Their novel style included large puppets with new colors, clothing, and hairstyles, as well as lighting and smoke effects. These changes promoted the evolution of Taiwanese hand puppet theater[2]. The movements of Taiwanese hand puppets are controlled by the hands of the puppeteers. The unique movements of these puppets are a notable aspect of this art form, and deeply familiar for audiences. With the development of modern technology, virtualizing traditional puppet theater has become possible, and body motion capture technology has matured. Linking the physical motions of Taiwanese hand puppets to the bodies of performers so that they can manipulate the puppets to make traditional movements opens up opportunities for novel performance formats that retain the unique characteristics of Taiwanese hand puppet theater. Our goal is not to replace or reproduce Taiwanese hand puppet theater, but to present a different performance format using new technology. Regarding motion retargeting, there has been considerable research, whether through motion capture[3] or video recognition[4], primarily focusing on mapping the human skeleton to a biological or robot skeleton. This still follows the rules of IK (Inverse Kinematics) skeleton, and there has yet to be research on mapping the human skeleton to the puppet's bone frame of the hand. Therefore, before undertaking motion retargeting, it is essential to first understand the differences and limitations between the human skeleton and the bone frame of the hand. The proposed system was applied to a transdisciplinary performance, in which a virtual puppet was projected onto a thin veil and a performer behind the veil manipulated the virtual puppet with his body (Figure 1). This system could be combined with other body motion capture systems and promoted to other virtual hand puppet performances (Appendix A).

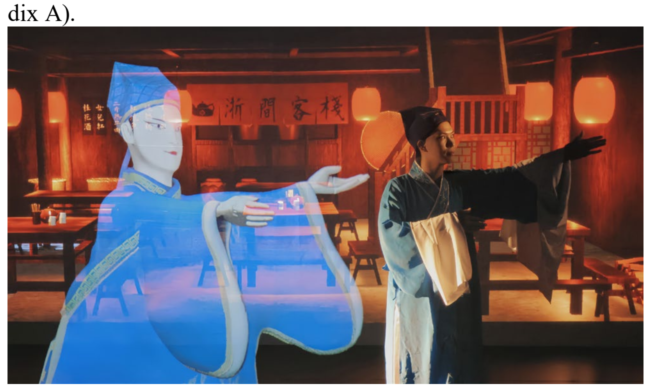

Figure 1. Transdisciplinary performance in which body motion capture was used to manipulate a Taiwanese hand puppet. ©Respect Copyright.

Automatic Conversion of Human Skeleton Bone Frame of Hand

Motion capture technology has matured to control virtual avatars[5] and manipulate virtual puppets[6]. However, Taiwanese hand puppets are manipulated using the hand; the limitations of the bone frame of the hand create the unique movements of these humanoid puppets. Most existing motion capture equipment cannot directly translate the human skeleton to the bone frame of the hand, and performers cannot physically imitate hand motions. Thus, to enable motion capture equipment to manipulate Taiwanese hand puppets via the human body so that the puppets move in the traditional manner, we designed a puppet manipulation system that automatically converts the VRM of human skeletons to the bone frame of the hand. The proposed system can be applied to other virtual puppets. With Unity 2020.3.18f1 as the development tool and Xsens motion capture equipment, which includes 17 wireless sensors and

5G wireless transmission as an example, the conversion process(Figure 2) is explained as follows:

- Use motion capture equipment to capture the absolute coordinates of each joint of the human skeleton without changing the motion capture program or the VRM of the human skeleton structure.
- Appoint the absolute coordinates of the human skeleton joints onto a temporary virtual puppet. Use an algorithm to convert the absolute coordinates of the head, torso, arms, and legs, and then convert the joint coordinates to coordinates that fit the joints of a Taiwanese hand puppet.
- Appoint the new joint coordinates to the frame of a Taiwanese hand puppet.

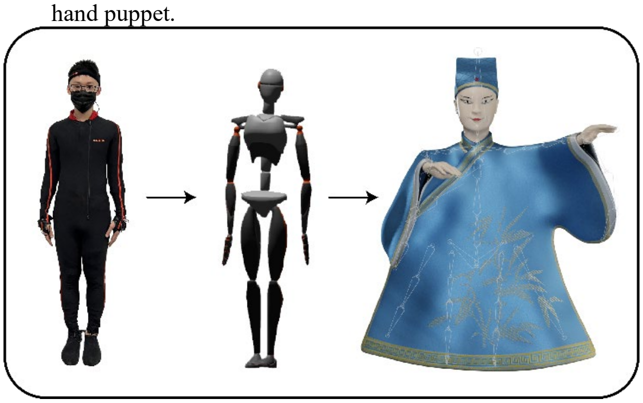

Figure 2. Skeleton-to-hand conversion process. ©Respect Copyright.

Algorithm of Four Skeleton Parts

Head

The head of the puppet corresponds to the puppeteer's index finger. The rotation angle limit of the head is as follows:

- The finger can curl inwards towards the hand to rotate the puppet around the x axis to lower the head of the puppet. However, as the index finger can only bend slightly toward the back of the hand, the head of the puppet can only be raised slightly. Thus, the range of rotation around the x axis is limited to between 0 and 50 degrees. vHead is the rotation angle Vector3(x,y,z) of the head, and the formula is as follows:

  vHead.x = Mathf.Clamp(vHead.x, 0, 50);

- The index finger cannot rotate around the z axis, so the head of the puppet cannot be turned. Thus, the rotation around the y axis is limited to 0 degrees. vHead is the rotation angle Vector3(x,y,z) of the head, and the formula is as follows:

  vHead.y = 0;

- The index finger can rotate around the z axis to turn the head of the puppet left and right. However, because the rotation angle of the index finger is very small, the range of rotation around the z axis is limited to between -30 and 30 degrees. vHead is the rotation angle Vector3(x,y,z) of the head, and the formula is as follows:

  vHead.z = Mathf.Clamp(vHead.z, -30, 30);

Torso

The torso of the puppet corresponds to the hand of the puppeteer as follows:

- When the performer rotates his or her torso, the entire puppet will turn. When the performer shifts, the entire puppet will also shift.
- The performer can bend over to make the puppet bend over.

Arms

The arm algorithm is to achieve the hand puppetry movement. The limitations are as follows:

- As the puppet's arm cannot bend with the performer's arm, there are no joint structure limitations for the puppet's elbow.
- Under the framework structure of the human inverse kinematics (IK), dotHand is the control point Vector3(x,y,z) of the puppet's wrist. This is used to limit the displacement of dotHand to fit the arm movements of a puppet, as shown in Figure 3. We discuss the main limitations in the following:

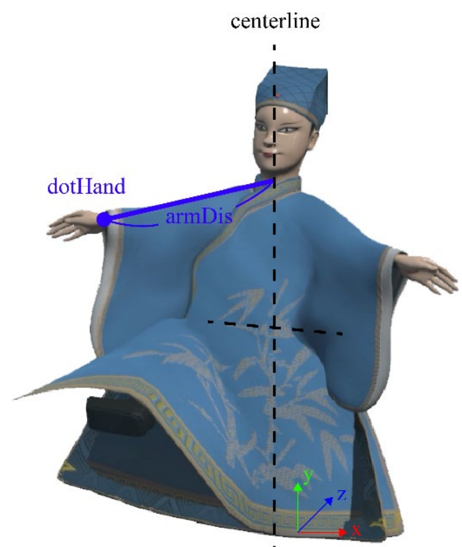

Figure 3. Schematic for arm algorithm of Taiwanese hand puppet. ©Respect Copyright.

3.3.1. Puppet arms falling inward

As the middle finger and the ring finger cannot naturally fall like the arms do against the legs when a human is standing, the puppet's arm will move slightly inwards in front of the torso when the performer's arms hang down. In the system settings, armDis equals the distance between dotHand and the centerline along the x axis. When the x axis is less than the difference between the y values of armDis and dotHand, the right and left displacement of the x axis will be fixed between the two. The condition setting and formula is as follows:

$$if\ (x <= armDis - y)\ [2]$$

3.3.2. Puppet arms extending forward
z denotes the z coordinate of dotHand; i is the parameter of the arms extending forward adjusted depending on the size of the model; y is the current height of dotHand. This equation makes the puppet's arms extend slightly more forward as the performer lowers his or her arms. This, combined with Eq. 3.3.1, imitates the basic hug-like pose that puppets assume in repose (Figure 4). The equation is as follows:

$$z \mathrel{+}= i - y.$$

Figure 4. Basic puppet pose. ©Respect Copyright.

3.3.3. Limiting puppet arms from swinging behind body
As the fingers can only bend backwards slightly, the system fixes z at 0 when the z value is less than 0, thereby limiting the puppet's arms from rotating backward behind its torso.

$$if\ (z < 0)[3].$$

Legs

The legs of the puppet mostly require the aid of the puppeteer's other hand to make kicking and walking motions. The limitations are as follows:

- As the puppet's knees and ankles cannot bend with the performer's knees and ankles, there are no joint structure limitations for the puppet's legs.
- Limiting puppet legs from swinging behind body and height to which legs are raised, to prevent the legs from being lifted too high. As the walking and kicking motions of Taiwanese hand puppets require the aid of the puppeteer's other hand to swing forward. Taking the right leg as an example, vRLeg is the rotation angle Vector3(x,y,z) of the leg. Negative values indicate the front of the puppet. This formula restricts the rotation angle along the x axis to be within the range of 0 to -50 degrees, preventing the puppet's legs from rotating backward when above 0 degrees and limiting the height at which the puppet can lift its legs when below -50 degrees, as shown in Figure 5. The formula is as follows:

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$$vRLeg.x = Mathf.Clamp(vRLeg.x, -50, 0);$$

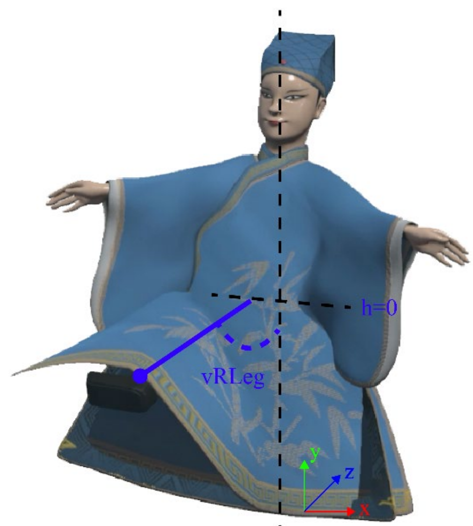

Figure 5. Schematic for legs algorithm of Taiwanese hand puppet. ©Respect Copyright.

Discussions

This system has been used in the interdisciplinary performance "Fame in Hand," which reimagines the origin legend of Taiwanese hand puppetry. The play integrates traditional Taiwanese opera, physical hand puppets, and virtual hand puppets in its performance. It describes how the protagonist discovers his innate puppetry talent, progressing from body puppetry to realizing that his true calling lies in hand puppet manipulation. Based on the assessments and feedback from actors and professional Taiwanese puppeteers, the virtual hand puppets have been incrementally adjusted to align with the traditional movements of Taiwanese puppetry. While the system strives to obviate the need for performers to explicitly mimic the physical movements of puppetry, inertial motion capture technology faces inherent limitations. For instance, devices like Xsens cannot capture overly rapid movements, necessitating a collaborative effort with performers to minimize such quick actions in the choreography. Moreover, certain maneuvers in traditional puppetry, such as acrobatic throws and rolls during martial scenes, present challenges for physical replication by actors. These movements require supplementary animation techniques for accurate depiction. Addressing these constraints will be a focal point for future enhancements of the system.

Conclusions

This project is based on Taiwanese hand puppet theater and utilizes the physical characteristics of hand puppet manipulation. It involves the development of a body motion capture system divided into four parts: the head, torso, arms, and legs skeleton. This system allows the motion capture system to manipulate virtual hand puppets in real-time through the human body while still simulating the movements of hand puppet skeletons. Therefore, performers do not need to consciously mimic the movements of hand puppets, yet the virtual puppets can exhibit the movements of hand puppetry. The purpose of this system is to break the traditional format of puppetry theaters and spark the interest of the younger generation in this vanishing traditional art form through innovative performances, encouraging them to delve deeper into the world of traditional Taiwanese hand puppetry.

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Appendix A

Introduction video of this project: https://youtu.be/hN3P5KCSBck