# Interacting with Humanoid Robots: Affective Robot Motion Design with 3D Squash and Stretch Using Japanese Jo-ha-kyu Principles in Bunraku


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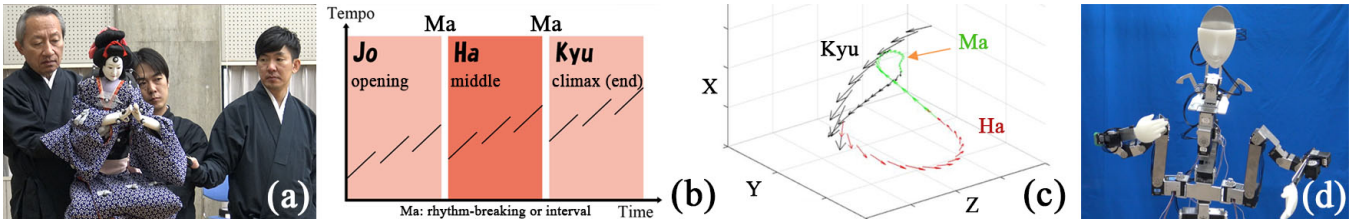


**Figure 1: (a) Manipulations of Bunraku puppet in the theater. (b) A schematic picture to explain Jo-Ha-Kyū. (c) The puppet head joint motion trajectories in four key-frames. (d) A real life-size humanoid robot designed by using 3D Squash and stretch structure based on Bunraku puppet.**


## ABSTRACT

The Bunraku puppets' affective motions are often praised as "one of the most beautiful motions in the world" by UNESCO. We characterize 3D "squash and stretch" motion in Bunraku puppet plays and realize them in a real life-size robot with unique mechanical structures. Our results reveal that the music tempos and the puppet movements of "squash and stretch" follow the principle so-called "Jo-Ha-Kyū," which is artistic modulations in traditional Japanese performances. Our research reveals that the affective robot motion design with the 3D "squash and stretch" and Jo-Ha-Kyū principle is one of the keys in affective human-robot interactions.




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## CCS CONCEPTS

• **Human-centered computing** → *Interaction design.*

## KEYWORDS

human–robot interaction, robotics, squash and stretch, Bunraku

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## 1 INTRODUCTION

The Bunraku plays (Figure 1 (a)) create strong empathies and emotions among the audiences using a traditional Japanese performance principle, so-called "Jo-Ha-Kyū," which are the artistic modulation mechanism in rhythms or tempos, etc., in traditional Japanese performances. Puppeteers manipulate puppets using complicated techniques similar to the animation principle in 3D.

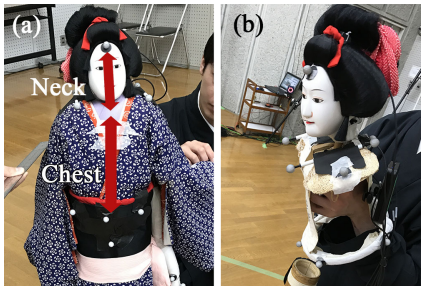


**Figure 2: (a) Length of the Bunraku puppet's neck and chest. (b) Structure of the Bunraku puppet's upper body.**

In the present talk, we design affective robot motions and implement these into a life-size robot with the "squash and stretch" mechanism, and realize these motions squashing and stretching head and chest joints using the unique mechanism in this robot with Jo-Ha-Kyū. After applying Bunraku puppet motion into our robot, the 3D "squash and stretch" can be retargeted smoothly and synchronized with Jo-Ha-Kyū rhythms. Based on our methods, motion designers can create 3D affective expressions for robots or avatars using 3D "squash and stretch" with the Jo-Ha-Kyū principle.

## 2 BUNRAKU PUPPETS "SQUASH AND STRETCH" WITH JO-HA-KYŪ PRINCIPLE

The Jo-ha-kyū is a principle to modulate basic musical components such as tempos [YAMADA 2017]. As shown in Figure 1 (b), each Jo, Ha, and Kyū can also be divided into smaller Jo, Ha, and Kyū, recursively. The short intervals or rhythm-breakings between the two sections are "Ma," which is the rhythm-breaking interval [TAMBA 1981]. Puppeteers also use different techniques such as "squash and stretch" to synchronize puppet motions to tempos in the Jo-Ha-Kyū, as shown in Figure 1 (c). Figure 2 shows the structure of the Bunraku puppet. The motions are synchronized with the music tempo, which follows the Jo-Ha-Kyū, to render the affective puppet expressions with its affective motion in 3D "squash and stretch."

In the present research, we collect the length of the neck and chest of the Bunraku puppet from its waist data, with the music tempo from "Sugisakaya" chapter (150s) selected chapter from a famous Bunraku play named "Imoseyama Onna Teikin." According to the story, the "Sugisakaya" can be divided into three parts: Jo, Ha, and Kyū. We calculate the neck and chest length from the waist , which is also the measures of Bunraku's "squash and stretch" for the neck and chest. In the Kyū part, Gidayū (chanter) raises the tempo to create tension in the story, and the correlation coefficient between music beat and the neck length is $r = -0.61$, and the chest length is $r = 0.61$. This strongly suggests the negative and positive correlation between the tempo and, respectively, the squash in the neck and stretch in the chest exist. Accordingly, the puppet's neck shrinks, and the chest stretches to express the tension in the story to synchronize with the Jo-Ha-Kyū modulations.

## 3 A REAL LIFE-SIZE ROBOT MOTION DESIGN

To demonstrate the Bunraku squash and stretch motions, we develop a real life-size robot that can simulate the puppet motions.

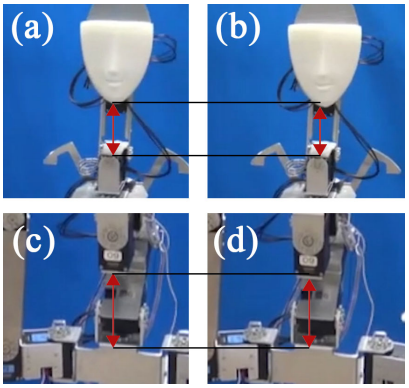


**Figure 3: Implementation comparison of squash and stretch. (a) (b) Neck comparison. (c) (d) Chest comparison.**

As shown in Figure 1 (d), this robot has a special skeletal structure that is different from usual humanoid robots. To reproduce the affective puppet motions, we use music beats in the chant to extract key-framed Bunraku puppet motions that include "squash and stretch." Figure 3 shows the way the squash and stretch are realized in robot mechanics in each joint. After retargeting the puppet motion data into the robot with the special mechanism, the puppet motion with 3D "squash and stretch" following Jo-Ha-Kyū principle is reproduced.

## 4 CONCLUSIONS

In summary, (i) we analyze the Bunraku motions with the Jo-Ha-Kyū modulations focusing on 3D "squash and stretch;" (ii) Bunraku puppets' squash and stretch motions measured as the puppet neck and chest length from its waist modulate in accordance with Gidayū's chant and shamisen tempo in both short and long time scales, recursively. The neck and chest length, respectively, have negative and positive correlations with music tempo speeds; (iii) Implementing the squash and stretch motions that are consistently incorporated in the Jo-Ha-Kyū principle into a robot, the robot can express its emotions more smoothly than those without the squash and stretch. We believe the robot motion designs using such as Bunraku squash and stretch with Jo-Ha-Kyū modulations can generate smooth human interactions with the communication robots, avatars in VR system, and so on in the future.

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