

# Synthesis of Choreography for Service Robots by Poses Extracted from a Ningyo Joruri's Acting Script Using the Associative Model

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## Abstract

What we should do with service robots to attract people's attention and communicate more smoothly? We are proceeding with the robot OSONO project, which is referring to Ningyo Joruri puppets, with the theme of utilizing expressions that incorporate the "Performing arts and technology" that has been passed down through the ages. In this paper, we propose the associative model that clarifies the correspondence between Ningyo Joruri's acting script of the performance, which does not include any choreographic information, and the actual choreography in the performance by the meaning. This is the key to systematize the choreography from Ningyo Joruri acting scripts. And by using these, we verify that the natural choreography of the service robot was created and synthesized. This method can provide highly diverse and flexible choreography than choreography based on "emotion", which is widely used currently.

*Keywords:* Service Robot, Choreography, Joruri Puppets, Acting script, Associative model

## 1 Introduction

What we should do with service robots to attract people and communicate more smoothly? We are proceeding with the robot OSONO project with reference to Ningyo Joruri\*, Japanese traditional puppets performance, with the theme of utilizing expressions that incorporate the performing arts and technology that has been passed down through the ages.

In this paper, we propose an associative model that clarifies the correspondence between Ningyo Joruri's acting script of the performance, called "Yukahon" [17], which does not include any choreographic information, and the choreography by the meaning. We also propose a systematization method using the associative model. Records of the choreography on actual performances include those by theater critics [2][15], and traditional arts preservation groups [4], as well as the artistic discourse of puppeteers [18], but there is no comprehensive and systematic analysis of the meaning-making of choreography based on scripts. This associative model is valuable, since it shows an answer to the question why "Yukahon" has no instructions for puppeteers. Moreover, this method can provide highly diverse and flexible choreography than choreography based on

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"emotion", which is widely used currently. At the same time, we discuss a method to create and synthesize choreographies corresponding to the service robot usage scenarios without discomfort by controlling spatial and temporal elements, and introduce new findings through verification using the robot OSONO. While there are some robotics research related to Ningyo Joruri, such as research on a robot development for Bunraku expression [5]. and learning acting using AI [3], there is no analysis or systematization of the choreography for robots or application to service robots as the target.

In this paper, Chapter 2 introduces the current status of the OSONO project, and Chapter 3 clarifies the correspondence between the acting text, the choreography, and the meaning, by using the associative model concept. In addition, from the recorded video of the performance, based on this method, we will unearth enough choreography that can be used for service robots. In Chapter 4, we cover the method to create and synthesize choreographies. In Chapter 5, we will prototype a robot OSONO2 with 5 DOF (degree of freedom) for each hand and arm. In Chapter 6, we implement the choreography for service robots. In Chapter 7, we verify that a variety of natural choreographies can be synthesized by the static and dynamic evaluation. And we discuss DOF of hands and arms for the implementation, and we also discuss the other necessary concept for this implementation.

\*Note: Ningyo Joruri has been popular since the beginning of the 17th century and is one of the most typical theatrical forms in JAPAN.

## 2 OSONO Project

We have independently developed a design method for "Kashira"(head) with reference to Ningyo Joruri [6], and are developing a robot OSONO with physicality [7]. We have implemented gesture to waving and greeting on OSONO and are exhibiting at international robot exhibitions. In 2019, we implemented the beginning of the famous scene "OSONO no KUDOKI " with a small number of actuators. This OSONO and choreography are highly evaluated as "attractive" through a questionnaire to a group of puppeteers and ordinary people [10] [11]. Compared to the research on the mechanism with the motif of Bunraku dolls [5], the feature of this research is that it targets a comprehensive system of doll design, kimono(clothes), and the choreography. On the other hand, since the beginning of 2020, it has become difficult to carry out conventional face-to-face evaluation due to the pandemic of COVID-19, and as a solution, we have proposed and developed a remote acting system using transferring video data in real time and control OSONO using RSNP (Robot Service Network Protocol). and we are conducting demonstration experiments. In 2021, we exhibited at "robot showcase" online, synchronizing TOKYO Olympic Games, hosted by the Ministry of Education, Culture, Sports, Science and Technology of JAPAN Government [11]. As a first step toward applying OSONO to actual service activity, we chose the street fundraising, we extend OSONO to have actuators for hands and arms and legs, called OSONO2/TAYORI (Figure 1), with an inviting gesture and integrate the sensor and the audio effect. In addition, we demonstrated it in IREX 2022(International Robot Exhibition) in Tokyo, and we verify its effectiveness at large-scale exhibitions with the measurement of human flow by Laser Range Finder [14] [19]. As the result, it is revealed that this robot is well-accepted in that exhibition.



Figure 1: Robot OSONO2/TAYORI with reference to “Joruri puppet” exhibited at IREX 2022

### 3 Systematization of the Choreography by an Associative Model

In order for a robot designer to consider the choreography of a robot, it is required a choreography guideline, and a system that helps understand the meaning of each choreography, and providing various choreography. Since the guideline has already been proposed by us as "Ningyo-Joruri's gesture generation model" [8], this chapter describes the methodology of systematizing choreography using an associative model and extraction choreography for service robot from an actual performance.

#### 3.1 Ningyo Joruri's Form/Choreography with a Small Discovery

Based on the acting script and directing information, the choreography and basic movements such as "walking", "standing", and "sitting" are added to the acting. The choreography consists of classical forms which are traditional patterns of playing techniques, and unnamed forms (we call them "small gestures") or a combination of these. In classical forms, there are for male and female, and it is said that there are dozens of them, including the famous "Kurizu" and "Ushiro-buri" [20]. Sometimes small gestures are combined to create a new form suitable for the scene, according to a director of new programs [16], and an acting script is divided into sections and the above choreography are assigned to each section. Particularly, it is a small discovery that one choreography assigned to one keyword in the session. Particularly, it is a small discovery that one specific keyword in the session is mapped one choreography. Also, there is the case where two or more choreography is assigned to the session, the we will find multiple keywords where each of keyword is mapped to each choreography.

#### 3.2 Associative model and Extraction of the Choreography

With reference to previous research in 3.1, we propose a method for extracting the choreography

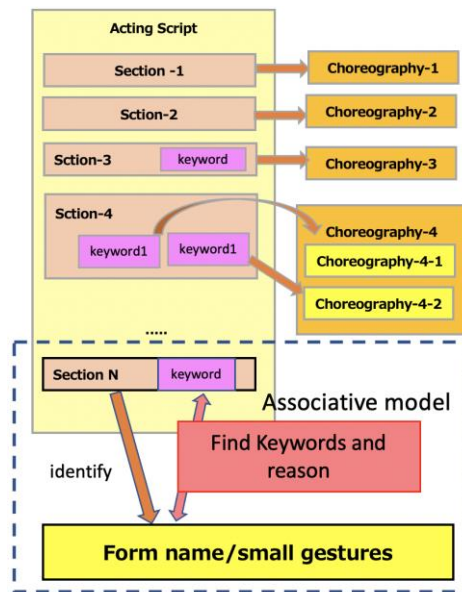


Figure 2: Proposed method for extracting the choreography by an associative model

from an acting script by an associative model [12], [13].

(1) As the first step, divide the acting scrip of one act into appropriate sections of about 30 seconds with seven-and-five syllable meter\*. Some choreography may extend before and after the division, but priority is given to the division by acting scrip.

\*Note: Seven-and-five syllable meter is a popular form of poem in which words of seven syllables and five syllables repeat one after another. This is widely used not only in Japanese poetry also in Ningyo Joruri's acting script.

It should be remarkable here that, as it might be obvious to puppeteers, the entire play of Ningyo Joruri is composed of almost Seven-and-five syllable meter, and actual division result of the acting script is also based on Seven-and-five syllable meter.

(2) If a famous classical form is used for a divided section, specify the name of the form. If not, identify the small gesture. A small gesture may be associated with the form and/or may consist of multiple small gestures. Actually, the number of small gestures included in one section is 2 or less. If it is a well-known play, performance records[15] are available, and various performance videos can also be available. If there exists an acting script [4] created for the inheritance of tradition, the description is very valuable.

(3) In each session, find the keywords that are associated with the choreography, the interpretations and reasons that lead to the choreography. Ultimately, the correspondence between this keyword and the reason / interpretation and choreography is the Associative model.

Figure 2 shows an overview of the above method.

Table 1 is an Associative model on "OSONO no KUDOKI (OSONO says)" of a performance by Shimonaka-za[4], which we created by the above method. The first column is the section number, the second column is the result of dividing the entire text according to (1), a word in bold is the keyword which reminiscent of the choreography. The third column is the interpretation/reason that derives the choreography. The 4th column is description of small gesture, or the name of the form (# marked). For example, in the section 1, the text is "Hanshichi-san, where are you and what are you doing, now?", The choreography in the 4th column is that stretches, looks around and look far away. This is thought to be a choreography associated with the "where and why" in

part of the text. In other words, from the words "where and why", the interpretation is "searching" and "worrying". As the result, choreography "stretch and look around" are selected. With this model, if you are a puppeteer, you can easily recall the choreography of this play. Although, there is no instruction to the puppeteer in the script Yukahon, if the puppeteer remembers this associative model, these instructions may not be necessary. Moreover, using this model has the great advantage of being able to understand why and how the choreography is selected.

Table 1: Associative model on "OSONO no KUDOKI (OSONO says)"

No.	Text in each section and <b>associate key words (in bold)</b> [ Japanese and English translation]	Reason on Choreography selection	Choreography (# marked is classical form)
1	今頃は半七様どこにどうしてござらうぞ。Hanshichi-san, <b>where</b> are you and <b>what</b> are you doing, now?	Look for, Worry	#Kurizu (Rotate the head deeply), Look around, Look far away
2	今更返らぬことながら, I can't get it back now,	move	(moving the position)
3	私といふ者ないならば, If I were <b>not</b> here,	I, Self	#Uchi-mi (Point to the chest)
		Deny	Shake hand in front of the face
4	舅御様もお通に免じ, <b>I asking for my father-in-law,</b>	Pointing, Request	To stage right, Bowing
5	子までなしたる, <b>Having a child,</b>	Dimly	"Nagashi" (Walk vaguely)
6	三勝殿を, Sankatu-dono(name)	Point	Point to the stage right
7	とくにも呼び入れさしやんしたら, If you <b>call in</b> her early.	Call in	# Maneki (Call in)
8	半七様の身持ちも直り, <b>Hanshichi's</b> behavior is improved	Embarrassed	Right sleeves toward mouth, Lean the body
9	御勘当もあるまいに, <b>Disownment</b> will be forgiven	Request	Bowing
10	思へばへ、 <b>Remember</b>	I, Think	#Aburaya (Put the left hand up and the right hand gently on the left elbow. After spending time, spread both sleeves, rotate the head deeply and cover with both sleeves)
11	去年の秋の煩ひに, In the <b>disease</b> of last autumn,	Disease	Raise the palms up, praying, and fall down to the left, and up again and to the right
12	いつそ死んでしまいうたら, If I could be <b>dead</b>	Battle	#Kata-uchi (Put the left hand forward and rub the left arm twice with the right hand to hit it once. Next, do the same operation in the opposite direction)
13	かうした難儀は, such <b>hardship</b>	Heart-ache	Heart-to-heart
14	出来まいも, <b>would not have occurred</b>	Regret	#Yoshida naki (Crying violently)
15	お気に入らぬと知りながら, <b>Knowing that you don't</b> like me	Deny	Shak hand in front of the face
16	未練な私が輪廻ゆる。 Because <b>I can't give up,</b>	I, Self	Sode awase (Match sleeves)
		worry	# Kurizu ( Rotate the head deeply)
17	添ひ臥しは叶はずとも, even if <b>not allowed</b> to sleep aside	My wish	"Soto-mi" (Perform "Sugata" while sitting)
18	お傍にゐたいと辛抱して, I've put up with because <b>I want</b> to be with you.	Request	Bowing
		(move)	(moving the position)
		(prepare)	(prepare)
19	これまであなたがお身の仇, It's very <b>hard</b> because I've been doing that so far.	Sad	#Ushiro-buri (see above)
20	今の思ひにくらぶれば, <b>Comparing to what I think now,</b>	(return)	(return)
21	一年前にこの圍が死ぬる心がエ、マツかなんだ,	I, Think	Put the right hand in the collar
		Dimly	Nagashi (Walk vaguely)
22	A year ago, <b>I couldn't</b> decide to die	Sad, Regret	# Ushiro-buri (see above)
23	堪へてたべ半七様, 私やこのやうに思うてゐる, I'm patient. <b>I think</b> like this.	I, Think	#Sugata (Seeing self in the water mirror at the feet)

Table 2: System table of choreographies

Tag to choreographies	Choreographies
I, Self (from a third-party perspective)	“Uchi-mi” (Point to the chest), “Sugata-mi”(see Table 1), “Sode-awase”(Match sleeves), “Soto-mi”(see Table 1)
Deny, No	Shake hand in front of the face, the head violently, both hands and feet
Sad, Heart-ache, Heart-to-heart, Painful	“Kurizu” (Rotate the head deeply)
Embarrassed	Right sleeves toward mouth, Lean the body
Regret, Thinking	Cry with her hands on her knees, or, attached to her sleeves, ....
Request	Bowing with pointing to the other party or its direction
Dimly	“Nagashi” (Walk vaguely)
Disease, Suffering	Praying, fall down
Call in	Call in

### 3.3 Systematization of Choreography

In 3.2, the choreography is extracted, and the associative model made it possible to understand the meaning of choreography in the act. From the view point of the robot designer, it is indispensable not only this, but also systematization that allows to choose the choreography from the meaning and message you want to express. To do this, take out the interpretation / reason that leads to the association in the third column and the choreography in the fourth column in Table 1, and sort them by the third column. As a result, a choreography systematized table appears (Table 2). To enhance this system table, create an associative model for other programs and merge it to this system table. Comparing the number of classical forms of Ningyo Joruri with the number of classical forms included in one act, it is considered that almost all classical forms can be covered by additional analysis of two or three acts.

### 3.4 Extract the pose and the choreography

Figure 3 shows a sketch of call-in and point (section number 7 in Table 1) extracted from the performance. The first one is "Ready", the second is "Maneki"(call-in), and the 3rd one is "Pointing". The sketch, we define, is the set of the poses (still images) that are characteristic of the chronological and arranged in time order, to in order to express dynamic gesture as static in a document. As in the form "Maneki"(call-in) form, the gestures to invite and the gestures to point



Figure 3: Sketch of “call-in and point” from OSONO no KUDOKI by the performance of Shimonaka-za (Hayashi, 2019)

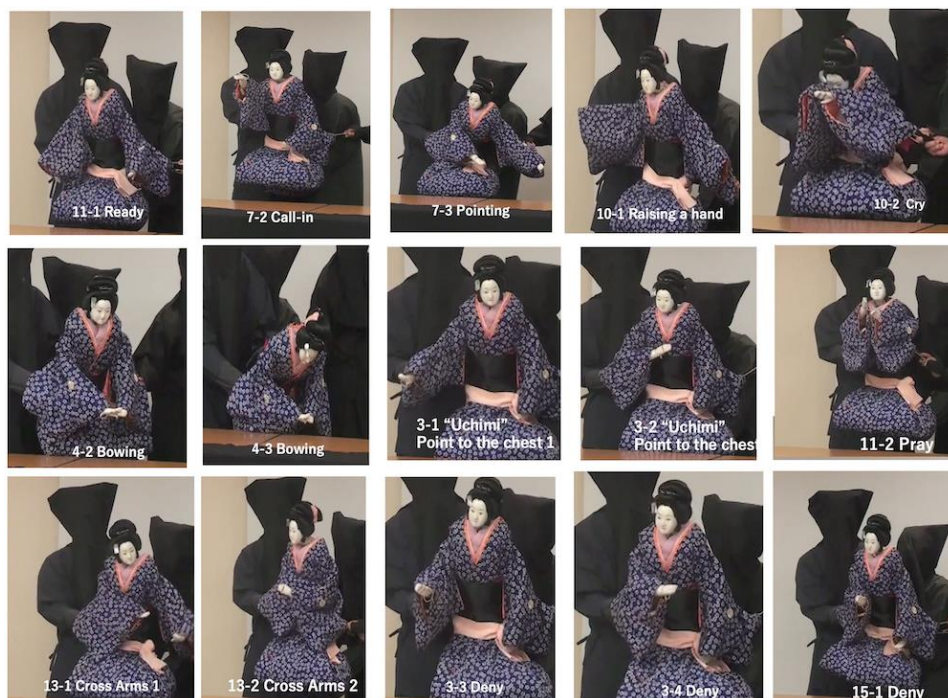


Figure 4: Typical poses of small gestures that characterize "OSONO no KUDOKI". The poses were extracted by the method of this paper from the performance of Shimonaka-za (Hayashi, 2019).

to are repeated twice on the left and right, we treat by each gesture as small gestures.

As the same way, collecting sketches for the small gesture corresponding to the section number in Table 1 and classifying the similar poses into one class, we get the typical poses for small gestures of "OSONO no KUDOKI" as Figure 4. The number "X-Y" in each pose of Figure 4 is the pose number. X is the section number in Table 1, Y is the sequence number in the same section. In fact, we got 53 poses and 15 classes in total.

Regarding the extraction, in the past case, we used Open Pose, but this case, a person extracted the pose using a hand-made pose editor. The reason is that analyzing one act of Ningyo Joruri by Open Pose, it recognizes not only one puppet but also three puppeteers, and it becomes necessary to remove the movements of these puppeteers in the post-processing, and it takes too a very long time.

## 4 Robot Implementation

In this chapter, we will examine the physical robot required to implement the extracted and systematized small gestures, and implement them as OSONO2 robot.

### 4.1 Arm and shoulder movements

The OSONO choreography introduced at the beginning of this paper is a scene hung by a lantern. Her hands are tied to the lantern, and there are no actuators on the arm and shoulder joints, and they hang with a thread and move freely as the torso moves. However, in order to implement multiple scenes and various choreography, it is necessary to have many controllable joints, and it

is also important that the range of motion of the joints is large.

On the other hand, from a design point of view, it should be avoided that the design is sacrificed by the number, size, and joint drive method of the actuators. We developed OSONO2 (Figure 5), which is the 1/4 model (1/4 the size of a human being, the height to the waist is about 23 cm) with 3 joints and 2 actuators on an arm. In order to expand the range of motion of the joints, we try to drive the three joints directly with three servomotors. The robot, referencing Joruri puppet, wears a loose "kimono" (Japanese clothes), so even if actuators are equipped on her arms, there is a limit, but the design unnaturalness is reduced. In addition, when the hands and arms become heavier, the moment of the arms increases and a hunting phenomenon, which causes unexpected

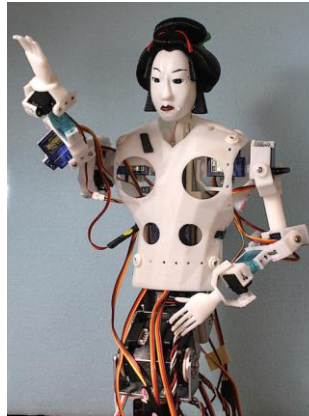


Figure 5: 1/4 model robot OSONO2 with 5 actuators to each arm

vibration, occurs, to avoid them OSONO2 adopts 2g, 4g, and 9g ultra-small servomotors, and the free horn of the servo motor is equipped with a ball bearing.

## 4.2 Wrist movements

Wrist movements include rotation and bending (extension, flexion). Suppose that we turn our palm up to invite in one scene, but in the next scene we are pointing something, we need to rotate our wrist. Bending of the hand is used to emphasize the intention, to express a symbolic expression such as ordering to stop, to make a decisive pose. In the Joruri puppet, levers are on both arms to express the extension and the flexion of wrist. In other cases, bending the wrist is sometimes used to turn the hand greatly inward, such as putting the hand together or putting the hand on the chest. "Wrist bending is extremely important from the perspective of expression", says the puppeteer. However, due to the bending of the wrist, the number of actuators increases and the moment of the arm becomes larger, which will make the design unnatural and has a disadvantage in mounting. In OSONO2, we implement the rotation of the wrist and we will evaluate the effect of the implementation for the hand bending.

## 4.3 Knee movement

Techniques for improving the appearance of the choreography by expressing large movements such as standing, "seiza" sitting, half-sitting, and bowing are widely used. Thus, in OSONO2, an actuator that assumes bending of the knee has been added to the rotation of the waist position and the back and forth movement. Since the weight of the entire fuselage is applied to this part, a



high-power servo motor is used.

#### 4.4 Kimono (Japanese clothes)

This prototyped Kimono is made of the left and right sleeves and kimono (top), kimono (bottom), and obi(belt) separately, and attached to the torso housing of OSONO2 with hooks and tape. Since servos are attached to the arm, the sleeves cannot be sewn, and the cuffs and sleeves are hooked after wearing. Since servo motors are on the shoulders and arms, the shoulders are wide and the sleeves are a little bit large, but the finish is less uncomfortable.

#### 4.5 Summary

OSONO2 has 16 manipulators in total. They are for the front and back of the neck, blinking, opening and closing of the mouth, rotation and bending of the hands for both hands and arms, rotation for the waist and knees, and the front and back of the torso. Arduino MEGA, which supports many IO pins and larger memory capacity, is used to control actuators.

## 5 Generating Choreography for Service Robots

### 5.1 Creating Choreography for Service Robots

Messages and gestures that are likely to be used by service robots that come into contact with

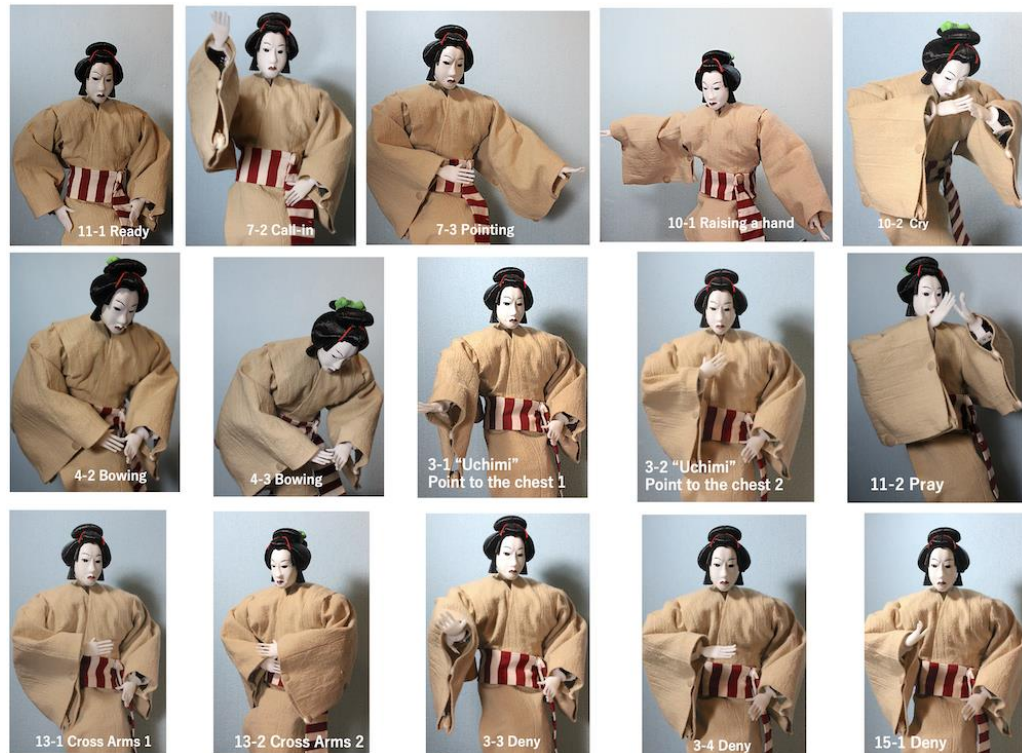


Figure 6: Typical poses of small gestures in "OSONO no KUDOKI" expressed by the robot OSONO25

visitors are listed as follows: welcome, call-in / alert, point / guidance, gratitude, consent / nod, denial, apology, perplexity / surprise, request, and appease customers, holding hands, giving a signal / look, bowing [9]. On the other hand, according to Tables 1 and 2, in "OSONO no KUDOKI", 11 of these gestures are included as describes below. However, welcome, appease customers, and consent/nod are not included, which is considered that these are of direct conversation to others, because this scene is performed alone. In the following, we describe in detail how the choreographies used in the robotic service can be derived from Tables 1 and 2. We will also discuss some other effective choreographies that are not included in Tables 1 and 2.

- Welcome: This can be represented by Pose 4-2 and/or Pose 4-3 bowing in Figure 4 and Figure 6. This is also used to say hello and good-bye.
- Call-in / Alert, Talk someone: Call-in can be represented by Pose Call-in 7-2. Adding Pose 7-3 Pointing, it means to lead here (see also 3.4).
- Point / Guidance: Pose 7-3 pointing is fit to point objects and directions. This gesture has many variations such as by one hand, two hands, and direction of objects. Pose 10-1 looks alike.
- Gratitude: Pose 4-3, Pose 4-4 are fit. Pose 11-2 Pray can be added for emphasis.
- Consent / Nod: (not included in Figure 4 and Figure 6) The nod is a simple up-and-down movement of the head, but it is a very clear expression of agreement. It is more impressive if the movement includes not only the head but also the shoulders and torso [1]. Also, although somewhat archaic, knee-slapping and hand-clapping are also used as agreement gestures.
- Denial: Pose 3-3 deny, Pose 3-4 deny can be used with waving hands or shaking head. There is also an emphatic gesture of averting the hands. Pose 3-1 "point to the chest 1" and Pose 3-2 "point to the chest 2", which are pointing to itself, may be added. The waving frequency is relatively slow as one or 2 seconds.
- Apology: Pose 4-2, Pose 4-3 bowing can be also used to represent the apology. This can be emphasized by adding Pose 11-2 pray.
- Perplexity / Surprise: Pose 13-1, Pose 13-2 Across arms can be used to express distress. It can be expressed with give-up with both arms outstretched, but it is not included in Ningyo Joruri performance. The Surprise can also be expressed by moving suddenly from ready position or bowing position to raising the body.
- Request: Combination of Pose 4-3, Pose 4-4 bowing, Pose 7-3 Pointing, and Pose 11-2 Pray will represent the request. In item 4 of Table 1, it is assumed that "my father-in-law" is in the behind of the right stage, and "SANKATSU (lady)" is in the behind of the left stage, Mrs. "OSONO" is bowing to the right and asking/requesting for "my father-in-law" with pointing the left of "SANKATSU".
- Appease customers: Combination of Pose 4-3, Pose 4-4 bowing, Pose 7-3 Pointing, and Pose 11-2 Pray also can be used as well as the request case mentioned above. In this case, bowing also represents the apology.

- Hands together: Pose 11-2 pray and pose 10-2 cry are in this category. If the hands are positioned over the mouth, it can express holding back laughter.
- Giving a signal / exchanging: It is represented by pointing something with rotating the body. Nod is also used for this purpose.
- Bowing: Pose 4-2 bowing represents lite, and Pose 4-3 bowing represents deep. The nod is also useful.

Therefore, almost poses required by the service robot can be supplied from this performance. However, some choreographies, such as bowing, can be used for different messages, such as greeting, thanks, apology, and the message intended to be expressed from the choreography may not be uniquely determined. To reduce this conflict, the message of the choreography can be clarified by linking to lines or by concatenation of multiple short choreographies.

## 5.2 Choreographic Synthesis

In the previous section, it was mentioned that most of the poses used in the service robot are supplied from the OSONO no KUDOKI performance. However, simply combining these poses

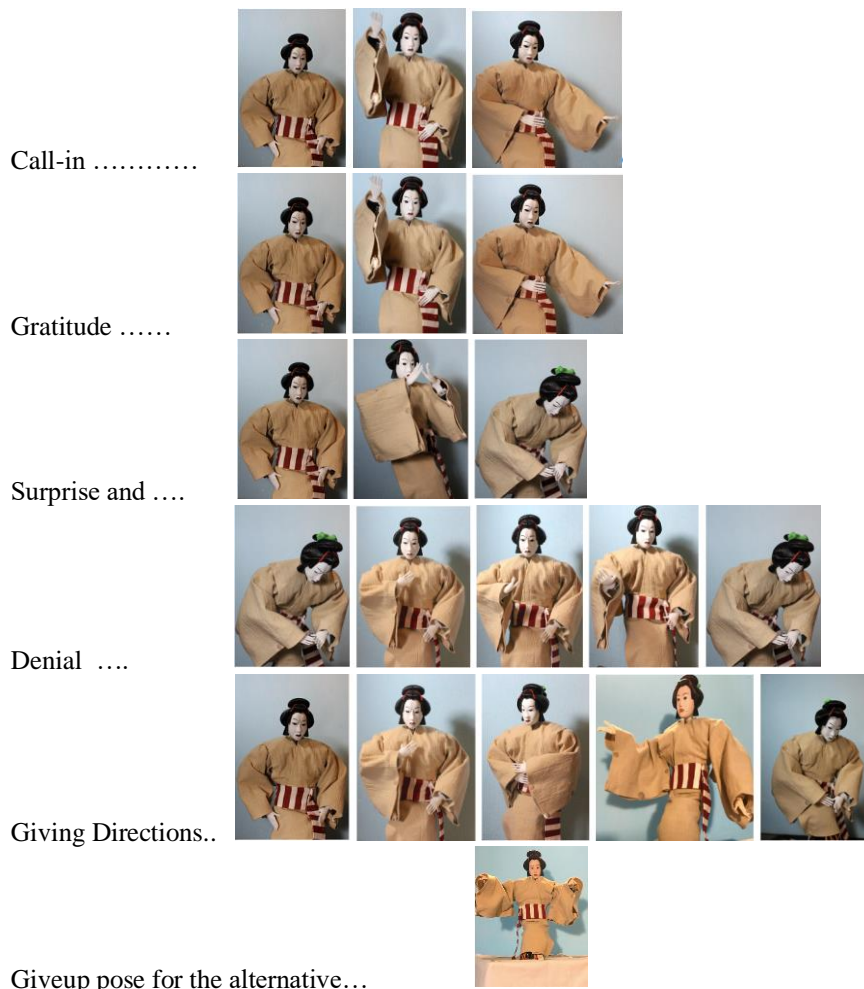


Figure 7: Poses of Synthesized choreography for service robots from typical poses of small gestures in "OSONO no KUDOKI"

will result in unnatural and undesired choreography in some times. In this section, we will attempt to synthesize actual naturalistic choreography for service robots as mentioned in 5.1, while using these poses exhaustively. Evaluation and discussion will be given in a separate chapter.

Each transition from a pose to another pose is a linear approximation, but after one pose is taken, it is paused for a certain time. In Ningyo Joruri and Kabuki, this is called "Kime". Transition time and pause time are important to make the choreography natural. If the pause time is too short, the meaning will be difficult to be recognized, and if it is too long, the movement will be awkward. In the following examples, the individual transition times and pause times are also noted. Figure 7 shows sketches of these synthesized choreography for service robots from typical poses of small gestures in "OSONO no KUDOKI".

- Call-in: Actual Poses, transition times, and pause times are: Pose 11-1 Ready 7-2 call-in (transition time 1 second), waving the right palm or arm (1 sec, 4 times) Pose 7.3 pointing (transition 1 sec 1 sec, pause 0.5 sec) return to Pose 11-1 Ready (trans. 1 sec). Robot OSONO25 can waving its palm, but OSONO24 can waving its forearm instead.
- Gratitude: Actual Poses, transition times, and pause times are: Pose 11-1 Ready Pose 11-2 pray (trans. 0.3 sec, pause 0.5 sec) Pose 4-2 bowing (trans. 0.3 sec, pause 0 sec) Pose 4-3 bowing (trans. 1 sec, pause 0.5 sec) return to Pose 11-1 Ready (trans. 1 sec). Depending on what is being thanked, the bow can be a light bow (Pose 4-2 bowing) or the Pose 11-2 pray can be omitted.
- Surprise and Denial: This choreography consists of a series of surprise, denial, and bowing at the beginning. This is modeled a famous play called "a scene of the palace in Sendai-hagi". That is on a conversation between Masaoka (the protagonist), who is bowing deeply, and Sakae Gozen (the antagonist), who is standing, in which Masaoka is surprised by something unexpectedly said and immediately looks up and denies it, saying, "Outrageous". Actual Poses are Pose 4-3 bowing (trans. 1 sec, pause 0.5 sec), Pose 3-2 point to the chest (trans. 0.2 sec, pause 0.3 sec), Pose 3-3 deny (trans. 0.5 sec, pause 0 sec), Pose 3-4 deny (trans. 0.5 sec, pause 0.5 sec) and Pose 4-3 bowing (trans. 0.5 sec, pause 0.5 sec). In some cases, a robot may not be able to achieve this adequately because people get up extremely quickly. However, if the story cannot be envisioned, it may be difficult to convey the surprise by the sudden movement.
- Giving Directions: Outline is (1) nod while hearing a question, (2) thinking with crossing arms, (3) replying "over there" with pointing the way with one hand, (4) Say "You're welcome" with bowing lightly, when thanked. The actual sequence of poses is: Pose 11-1 Ready, Pose 3-2 point to the chest (trans. 1.0 sec) Nod (2 sec, 3 times), Pose 13-2 cross arm (trans. 1.0 sec, pause 1.0 sec), Pose 10-1 raising hand (trans. 1.0 pause 1.0) and Pose 4-2 bowing (trans. 0.5 sec, pause 0.5 sec). If it is hard for the robot such as OSONO24 to crossing arms, a give up pose may be an alternative, which is not included in OSONO no KUDOKI's poses.

Discomfort may occur when connecting the two poses. For example, in the case of the Giving Directions, if the ready posture (Pose 11-1 ready) is more forward than the upper body in a light bow (Pose 4-2 bowing), the bowing will be made again when returning to the ready pose after the light bow. Thus, in the synthesis of the pose, it is necessary to control the spatial elements as mentioned above and the temporal elements such as the transition time of the pose and the time

interval of the "decision" as described in the Call-in section to synthesize a natural pose.

## 6 Evaluation of Poses and Choreography

In this chapter, we will evaluate how natural the choreography can be expressed when the choreography through whole of one act is implemented in a robot, and also evaluate DOF of the robot arm and hand needed for adopting the choreography. There are two aspects to the evaluation, one is the Pose evaluation as the static evaluation, another is the dynamical evaluation.

### 6.1 Pose evaluation

We compare poses expressed by OSONO2 with the typical poses of actual performance in Figure 4. Regarding the robot, we use OSONO2 having 5 actuators for each arm (we call OSONO25), and OSONO2 with limiting movable actuators to 4 for each arm (we call OSONO24). Figure 6 shows typical poses of small gestures in "OSONO no KUDOKI" expressed by the robot OSONO25. And Table 3 is the result of comparison of these poses in Figure 4 with the poses in Figure 6 of OSONO25, and comparison with correspondent poses of OSONO24. The number in each pose is the pose number as the same as Figures 4. If Robot's expression is close to the original, it is evaluated as acceptable "A", otherwise, depending on the degree, evaluated as somewhat difficult to accept "B" or as difficult to accept "C".

Table 3: Evaluation on the poses

Pose number	OSONO24 case	OSONO25 case	Explanation of the pose, comments
11-1	A	A	A pose of seiza sitting. By rotating the wrist. No unnaturalness.
7-2	A	A	A pose of invitation. As changing the palm direction. No unnaturalness.
7-3	A	A	Point to the left outside with both hands.
10-1	A	A	To put both hands together, put one hand at a time.
10-2	B	A	A pose to cry with both hands together. The orientation of both hands is a little unnatural in OSONO24.
4-2	A	A	A pose to align both hands to start bowing. No unnaturalness.
4-3	B	A	A pose in which the head and torso are tilted deeply by bowing. A little unnatural because the hand angle cannot be controlled only by rotating the wrist in OSONO24.
3-1	A	A	A pose to prepare for a gesture "Uchimi" (pointing myself). No problem.
3-2	C	A	A pose to pointing toward the chest(myself) in "Uchimi". Difficult to point the palm to the chest.
11-2	B	A	A pose to pray with both hands together. Hard to put both hands together enough in OSONO24 case
13-1	B	A	A pose to move the right hand to start crossing arms. It is hard to bend the arm toward the body side in OSONO24 case
13-2	C	B	A pose with arms crossed. Unable to cross arms enough. In OSONO24/OSONO25 cases
3-3	A	A	A pose with the hands facing outward as a negative gesture
3-4	A	A	A pose with the hands facing inward as a negative gesture
15-1	C	A	A pose with the hands facing outward as a negative gesture. A pose that emphasizes movement particularly by turning the hand away.

The standing posture of 13-1, 13-2, the “seiza” sitting posture of 1-1, and the posture of the half-sitting of 7-1, 7-3 are easy to recognize and effective. Various expressions can be obtained by adding these movements. There is no unnaturalness in the positional relationship between the "obi"(band) and the servo motor.

As the result, we have confirmed that OSONO25 can represent typical small poses with no problem. OSONO24 is not good at moving hands together, putting hands together, or wrapping arms in front of the body. But fortunately, such movements are not used commonly in the choreography used in service robots. As a conclusion, a little awkwardness as a movement remains, but even OSONO24 can sufficiently represent the necessary gesture for the service robot as long as the hands need not to bend inside deeply. Furthermore, if the problem caused by the arm moment does not happen, OSONO25 can well represent almost whole choreography in Ningyo Joruri acting script.

## 6.2 Dynamic Evaluation

The purpose of this evaluation is to verify whether it is possible to synthesize natural and understandable choreography, used in service robots, from typical poses of actual Ningyo Joruri puppet performances. At the same time, DOF required for the arms and hands will be taken into account.

### 6.2.1 Evaluation Environment and Evaluation items

Four choreographies for OSONO24 and Four choreographies for OSONO25, eight choreographies in total, were created for the four categories described in 5.2. Call-in, Gratitude, Surprise and Denial, and Giving Directions, are implemented in a robot OSONO25. The choreographies for OSONO24 were realized by restricting the back and forth movement of the hands of OSONO25 in the software manner.

Each of the choreographies was presented as a video to the evaluators, and the evaluators answered the following questionnaire about each choreography: (1) Which of the five categories does each video fit into? Five categories are: Call-in, Gratitude, Surprise and Denial (divided into Surprise and Denial), and Giving Directions, (2) Did you find this correspondence easily? (5 levels, with 1 .. understood immediately, and with 5 .. not understood at all), (3) Do you feel any discomfort (unnaturalness)? (5 levels, with 1 .. not at all, and with 5.. very unnatural), (4) Do you feel the choreography is good? (5 levels, with 1 ..very good, and with 5 .. not good). This questionnaire was administered to a total of 19 undergraduate and graduate students and faculty members in the sciences (including 6 international students). In real Ningyo Joruri, the choreography is performed with lines, but in this case, no lines were attached to the choreography in order to focus on the message of the choreography.

### 6.2.2 Evaluation results of Dynamic Evaluation

The below are the evaluation results of the dynamic evaluation, also the results are shown in Table 4:

- The quality of all the choreography were relatively good. Particularly, Giving Directions and Gratitude (in OSONO 25 case) are good enough.
- Although the discomfort is slightly inferior to 3.1 and 3.2 for “Call-in”, and “Surprise” in

OSONO24 case, the discomfort does not seem to be a major problem. The tendency of the evaluation result on good choreography and the evaluation result on discomfort is almost the same.

- In terms of clarity, "Surprise and Denial" in OSONO24 case is inferior, because it contains Pose 3-2 point to the chest which is also inferior in the static evaluation of table 2. This is probably due to its unskilled pose for OSONO24. In addition, in the two call-in choreographies, the meaning is conveyed well, but the clarity is inferior. This might be because it includes Pose 7-3 pointing but does not clearly indicate what it refers to. For example, it might be improved if a donation box could have been provided as the object what it refers to.
- In the view of whether the intended message was conveyed, "Call-in" and "Giving Directions" conveyed almost correctly 63%-74% of the respondents in total of OSONO24 and OSONO25. On the other hand, "Surprise" was conveyed correctly at 32%-53%, while "Surprise" was misrecognition as "Gratitude" at 16%-42%. Also, "Gratitude" was correctly received by 42%-63%, but, misrecognition as "surprise" by 32%-53%. This means that about half of the responses were misrecognition in the latter two cases. This reversal of "Gratitude" and "Surprise" that occurred in spite of no major problems in quality of choreography and discomfort will be discussed again in the next consideration section.

### 6.3 Consideration on the Dynamic Evaluation

#### 6.3.1 The reversal of "Gratitude" and "Surprise"

Here we examine the reasons for the reversal of "Gratitude" and "Surprise". Despite the fact that the gesture was evaluated as neither uncomfortable nor difficult to understand, "Gratitude" was

Table 4 : The evaluation results of the dynamic evaluation

Choreography	quality	no discomfort	easy to understand	Judgment Result					
				Call-in	Gratitude	Giving Direction	Surprise and Denial	Breakdown	
								Surprise	Denial
Call-in	3.7	3.3	2.9	63%		26%	11%		11%
Call-in*	3.3	3.4	3.0	68%		21%	11%		5%
Giving Direction	2.5	2.5	2.1	11%		63%			
Giving Direction*	2.6	2.4	2.3	21%		74%	5%	5%	
Surprise and Denial	2.6	2.4	2.3		42%	11%	32%	11%	21%
Surprise and Denial *	3.8	3.0	2.9		16%	11%	53%	11%	42%
Gratitude	3.8	3.0	2.9		42%	5%	53%	37%	16%
Gratitude*	3.8	3.0	2.9	5%	63%		32%	26%	5%

\*OSONO24 case

Dark shaded is the correct answer, light shaded is wrong answer.

taken as "Surprise," probably because Pose 11-2 pray is interpreted as "raising both hands involuntarily in surprise" rather than "worshipping and thanking". In another word, in modern times the prayer pose is hard to conscious and taken to mean different things

By our questionnaire results, "Surprise and Denial" is recognized as "Gratitude" by many respondents. It is reasonable that in spite of "Surprise and Denial" is made up of Pose 4-3 bowing, Pose 3-2 "point to the chest 2", Pose 3-3 denial, and Pose 3-4 denial, the respondents estimated low as Denial because the waving an arm gesture caused by Pose 3-2, Pose 3-3 and Pose 3-4 is slower than respondents are expected. And the meaning of Pose 4-3 bowing is so clear that it may have overshadowed the meaning of the other gestures, especially the sudden rising which represents "Surprise" from the bow.

### 6.3.2 Message oriented Choreography, Modern and traditional choreography

There are two types of choreography. That is, those that have a clear meaning in itself and those that do not. We shall call the former Message oriented Choreography. For example, in Table 4, "Call in" and "Giving Direction" have a high degree of comprehension, therefore waving a hand gesture and nod gesture included in them are very message oriented choreography. In addition, the pointing gesture of "Giving Direction" is also message oriented. On the other hand, the pointing gesture used in "Call-in" is less comprehension because the specific object being pointed at is unclear. Thus the bowing gesture is a strongly message oriented, "Surprise" is accepted as "Gratitude" in sometimes in Table 4.

On the other hand, the negation gesture is also very message oriented, but in the case of this "Surprise", it was not well accepted, we guess because the speed of waving was slow. To understand this, the concept of "modern and traditional waving" can be introduced to make it clear to understand. In other words, if the slow speed of hand wave of the denial gesture is interpreted as a traditional choreography, it is interpretable that it is hard to be recognized as a modern one. The give-up gesture that appears in "Giving Direction" has the same effect as folding arms and is not uncomfortable. This can be said to be a modern gesture.

### 6.3.3 Choreography improvements

To improve these choreographies, and resolve the problems described in (1) according to the above consideration, the strategies are as follows (Figure 8):

- For Gratitude, keep the bowing gesture, with a small overshoot for emphasis, and eliminate the "pray" pose which might cause misunderstanding.
- For Surprise, eliminate the "bowing" gesture, which cause misunderstanding strongly, and add Pose 11-2 pray, the clasping of hands, which was often evaluated as surprise, and speed up the waving arm in a modern way to easy-to-understand.

As the result of the re-evaluation, in the view of whether the intended message was conveyed, "Gratitude" and "Surprise" conveyed almost correctly 86% - 100% of 8 respondents. This verifies the above strategies work very well.





Figure 8: Improved choreography

## 6.4 Choreography improvements

Using typical poses in OSONO no KUDOKI, a part of an actual Ningyo Joruri puppet performance, we verified that it is possible to synthesize the choreography used for service robots without discomfort. As we learned from the survey, people are sensitive to individual fine movements, so we need to choose poses and movements that take into account the strength of the message and whether the gestures are modern or traditional choreography, so that the intention is conveyed without misunderstanding. On the other hand, to realize these choreographies, a robot with five DOF in each hand and arm is required. However, by using appropriate alternative poses as needed, a robot with four DOF in each hand and arm are enough.

## 7 Conclusion

We proposed a method of systematizing the choreography and a method of extracting gestures and poses using an associative model with targeting one act of Ningyo Joruri. In addition, we extracted gestures and typical poses by these methods from "OSONO no KUDOKI". By using these, it was verified that the natural choreography of the service robot was created and synthesized. Additionally, this method using an associative model is valuable, since it shows an answer to the question why "Yukahon" (acting script) has no instructions for puppeteers. Moreover, this method can provide highly diverse and flexible choreography than choreography based on "emotion", which is widely used currently.

And this method is considered to be very useful for projects to preserve traditional performing arts and to foster successors. We continue to the Service robots and the robot user interface technology.

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