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PYGMY: A RING-SHAPED ROBOTIC DEVICE FOR STORYTELLING

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Abstract. *The human hand is an appropriate part to attach a puppetry device for storytelling. This paper presents a ring-shaped robotic puppetry device named Pygmy that attaches to the human hand and enables it to create a puppetry character by magnifying the finger expressions. This anthropomorphic device is a trial in the development of an interaction model of puppet-based storytelling through a robotic device on the hand. It is based on the concept of hand anthropomorphism, and it uses finger movements to create the anthropomorphic effect. Wearing this device is similar to having eyes and a mouth on the hand; the wearer's hand spontaneously expresses the puppetry with the emotions conveyed by the eyes and mouth. Interactive manipulation by controllers and sensors makes the hand look animated. We have observed that the character animated with the device facilitates user collaboration and interaction as though there were a living thing on the user's hand. Further, the users play with the robot by representing characters animated with Pygmy as their doubles. A video analysis of a case study with a parent and a child is also described in this paper because of its significance.*

Keywords: Device art, Storytelling, Hand expression, Wearable robot, Anthropomorphism

1. **Introduction.** Hands not only express emotions through gestures but have also been used in performance, communication, and art [1,2] throughout human history. Shadow puppetry, sign language [3], and hand paintings [4] prove that human hands are highly expressive. In particular, a shadow puppet requires finger expression because the hand acts as the character. The human hand has the ability to act as a living thing. For example, anthropomorphism can be realized by hand postures and movements such as bipedal locomotion – by two fingers on a desk, and a fox – by keeping the little finger and the forefinger extended upwards with the other fingers close together. This could be because of the flexibility and reflexibility of the hand. This high flexibility of the human hand can be attributed to the fact that it has many joints. Reflexibility refers to the ability of the hand to reflect a human's intentions and to easily operate interface devices such as keyboards and touchpads.

We have simulated the characteristic of "finger expression" that can be enhanced by appending an anthropomorphic device that produces the presence of a robot on the human hand. We have invented Pygmy to function as a storytelling robot that possesses easy-to-wear features for performances, communication, and storytelling. Pygmy is a ring-shaped anthropomorphic device that complements hand gestures, and it is embedded with certain face parts such as the eyes and the mouth. Users can generate various facial expressions by configuring the devices worn on their fingers. The presence simulated by Pygmy is required to play a performance role in order to impress the audience and the user.

2. **Related Works.** Research pertaining to wearable robots, interfaces that use hand metaphors, and anthropomorphization are similar in characteristic. To begin with, the examples of wearable robots include some puppetry and avatar robots, such as the accessory-type robot [5], which is worn as a necklace to convey personal information, and the shoulder-mounted robot known as Telecommunicator [6], which is a wearable robot providing the tele-presence function. These robots have a body and help reduce the physical distance involved in human-robot interactions for the purposes of storytelling and telecommunication. Pygmy is a robot that directly collaborates with the human body by exploiting human expressions and flexibility. Further, the considered user case is storytelling by two or more people in the real world. Pygmy focuses on the anthropomorphism of hand and aims to improve storytelling via puppetry.

In the context of storytelling, finger expressions are attractive because of their use in the entertainment industry. They also provide intuitive input methods for robot and computer graphics (CG) characters. Whadget [7] makes it possible for users to control the CG character motion on a tabletop computer using only two fingers. This is achieved by mimicking bipedal walking. Walky [8] is a robot that can walk and play soccer based on the instructions provided via a touchpad mobile device with a registered finger gesture. This is a finger-based interface method wherein fingers are considered to be a metaphor of human expressions. Pygmy also exploits finger postures and movements, but the finger behaves as a puppet independently.

Trials are being conducted for anthropomorphizing day-to-day objects. DisplayRobot [9] is an attachable robotic device with minimal facial features. It works as an agent describing the object to which it is attached. Although the viewpoint of reconfiguring a device to build an agent system is similar to that of DisplayRobot, Pygmy focuses on enhancing the body performance by attaching devices on the human hand. Nikodama [10] is also an anthropomorphized object; it has only two eyes. The fact that Pygmy is an interactive device manipulated by a controller or a sensor device that animates the human hand using finger expressions makes it different from the other anthropomorphic devices.

In conclusion, Pygmy is a novice device for storytelling using a human hand in an interaction of two or more people in the real world, such as children or a parent and a child.

3. **Design.** We have designed Pygmy in the shape of a ring to make it a standalone device. Pygmy must be designed for several applications such as a storytelling robot, a robot on a human hand, and an anthropomorphic device. To achieve this design, we follow the policy given below:

Flexibility: Each finger remains in contact with the device when it is worn. The device structure should be designed such that it does not interfere with the up-and-down finger movements. Further, because each person's finger size is different, the ring should be designed such that its size can be adjusted.

Reconfigurability: The ring-shaped design makes it easy for users to wear and remove the device from their body quickly, and it enables the user to customize the device for generating various patterns of facial and animal expressions. Reconfigurability helps users simulate puppetry characters in various forms with anthropomorphic parts.

Scalability: To diversify the pattern, the device arrangement can be changed freely according to the finger posture. The device can be added dynamically by the user. It can also be extended using Bluetooth modules for wireless communication.

Human likeness: This policy must be considered strongly because impressions made by the appearance of the robotic device are crucial for simulating the user's feeling of the presence generated by the robotic device. The eyes and mouth should be chosen as the minimal parts forming the human face. Although we also considered the design of a realistic eyeball and a mouth, these features were only painted on the device in order to avoid giving it a weird appearance. The eyelids of the eye module were painted in light orange, and the eyeballs were painted in two colors, black and white. The mouth was also painted light orange, and the inside was painted red.

Safety: We needed to design the device so that it could be used by children as well. Because of the need to attach the device to the body, we ensured that the microcontroller board and the battery were fixed inside a plastic case. The motor was connected with a vinyl lead so that it could not be touched or fall out of the device.

Responsiveness: This is an important factor for interactions. The developed device guarantees fast response. We designed the entire system without a perceivable delay.

Miniaturization: The miniaturization of the ring-shaped device is indispensable for a better implementation in order to achieve flexibility, reconfigurability, and human likeness. We designed a small microcontroller circuit and structure within the device. The size of the device is crucial for the quality of experience because the proportion of the device size to the human hand should be the same as that of the eye size to the face.

4. Pygmy.

Pygmy comprises a face and mouth unit, a ring-shaped sensor device, and a controller for the user to manipulate the device. The device and the controller are connected to a host computer using a wireless transmission via Bluetooth and XBee.

4.1. Miniature implementation.

Miniaturization was indispensable in designing Pygmy. The device consists of face parts simulated using a motor, microcontroller, and polycarbonate battery. An integrated circuit (IC) on the circuit board controls the motor via pulse-width modulation (PWM). The face parts can be moved at a great speed. We designed a circuit board such that the small motor and battery could be embedded within the device. The device is controlled via Bluetooth (Figure 2).

4.2. Interaction with sensors and controller.

We developed a ring-shaped sensor containing an accelerometer so that its movements could be passed to the open level of the eye ring. In the same way, the microphone passes its volume level to the mouth ring. The user can control the face parts by moving the finger with the accelerometer or by talking to it. We built a controller for intuitive operations; this controller contained buttons that resembled the eyes and a mouth (Figure 3). Three buttons were arranged at

FIGURE 1. Pygmy worn on the hand

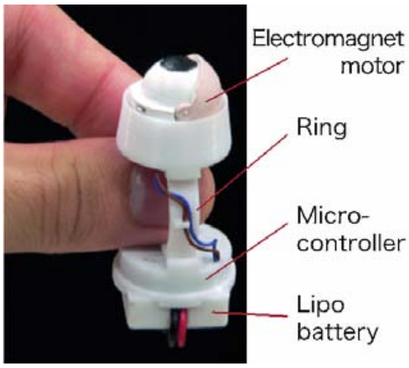

Figure 2. Device structure

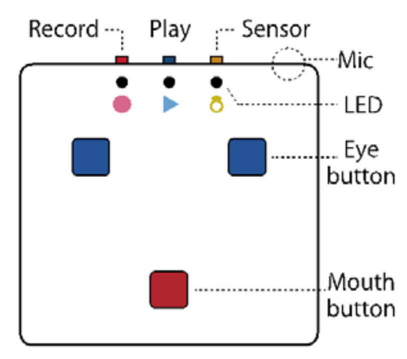

Figure 3. Controller

the top of the controller for functions such as record, play, and input sensor change. By changing the input, we could select operations (from the controller) and inputs (from the sensor). Further, this controller could store the operation history generated by the first controller and by the sensor for 1 min.

5. **Usability Test: Two Persons.** In order to evaluate the device, we observed the spontaneous interactions between users. The subjects were divided into pairs. All the ten subjects who participated in this study were computer science majors. Instructions for using the controllers and sensors were provided, and the motions were recorded. At the end of the experiment, the subjects completed a questionnaire.

We gave the subjects the following tasks after providing the instructions for using the device.

1. Control the device using the controller
2. Manipulate the anthropomorphized parts on the other subject's hand
3. Use the accelerometer and microphone sensors
4. Use the record and play functions
5. Express animal and human motion by hand
6. Talk while moving the hand
7. Play freely

The subjects were also interviewed about the device's impression and their experience with the device (Figure 4). The questions in the questionnaire are shown in Table 1; they are evaluated using a 7-point Likert scale. In this table, there are three columns that provide the mean, standard deviation, and percentage of positive response (written as "%", is the rate of who answered higher than the mean value).

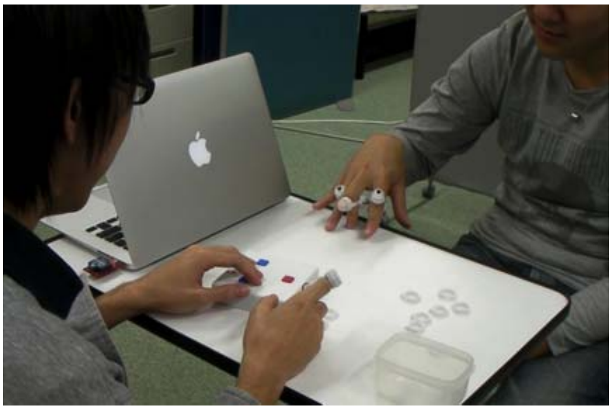

FIGURE 4. Usability study

TABLE 1. Questionnaire on device operation

Question	*Mean*	*SD*	*%*
1. Ease of operation	4.4	6.3	100
2. Ease of motion generation	4.5	3.1	90
3. Ease-of-use of controller	6.4	0.66	100
4. Excitement because of the working of the device	6.1	0.94	100
5. Ease of expressing emotions via characters	4.3	1.79	70
6. Feeling as though the user's hand were another living thing	5.7	1.00	90
7. Ability of playing by changing finger postures	6.0	1.48	90
8. Excitement when you speak while synchronizing with the device motion	6.1	1.37	80

5.1. **Result.**

5.1.1. *Usability.* Items 1-3 in Table 1 represent the evaluation of the usability of the ring-shaped device and the controller. From the positive response and the mean value obtained through the evaluation, we concluded that Pygmy could provide user satisfaction from the perspectives of physical design, communication between the devices, and cooperation with the controller. Moreover, for the question "What did you think was difficult about the operation?" the following responses were obtained:

- Two people said that there was no problem;
- Two issues were reported regarding the preparation of the device and the considerable time taken for establishing wireless communication with the host computer;
- Two issues were reported regarding the delay caused by the controller operation;
- One issue regarding the lack of appropriate correspondence of the movement of the eye part to the up-and-down movement by the accelerometer was reported;
- One issue regarding the difficulty of deciding the direction of the hand movement when the user wore the device on his finger was reported.

5.1.2. *Character generation.* Users enjoyed making faces and characters using their hands. We found that users could generate several expressions by attaching the device to their palms and the back of their hands. For example, they demonstrated a face looking down by bending their entire hand forward. To show an angry or a troubled face, the degree of the eyelid was changed by turning the fingers (Figure 5). Some users changed the arrangement of the face parts freely to display a human face or an animal. By interviewing

Figure 5. Collaboration and trial for making facial expressions

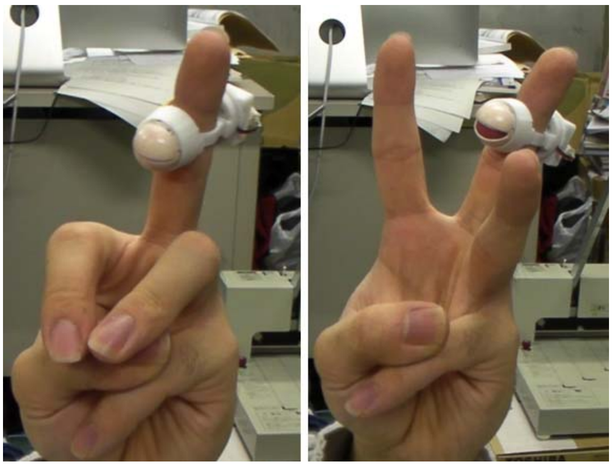

Figure 6. Human expressions

the subjects, we could list the different types of gestures observed in the usability study (Figure 7). For one gesture, only the index finger was equipped with the mouth ring; the rest of the expressions were provided by the other fingers that did not have any rings on them (Figure 6).

5.1.3. *Collaboration.* It was observed that the users used facial expressions to query one another when they gestured in cooperation (Figure 5). While controlling face parts on the other person's fingers, the users coordinated the timing of pushing the button with the motion of the other person's fingers. The users were also instructed to speak along with the operation; we watched the users talk to the other person while controlling that person's device.

FIGURE 7. Different gestures for animals (top to bottom, left to right): a face, an elephant, a bird, a crab, a fox, a butterfly, an octopus, and a giraffe.

5.1.4. *User experience.* Item 4 in Table 1 denotes the positive evaluation from all subjects about interactions carried out using the sensing device and the controller. Further, it evaluates the communication and play task when the subjects used the ring-shaped device. The users evaluated the experience positively based on factors such as

- the option of arranging face parts;
- the ease of winking and expressing surprise;
- the ability to communicate using non-verbal gestures;
- the ability to make various facial expressions using a combination of devices;
- minimal changes in the arrangement;
- a feeling that the an actual face is one's own hand.

On the other hand, the negative feedback was based on a number of factors such as

- difficulty in animating characters because of few previous experiences of displaying expressions using hands;

- the inability to imagine a performing character;
- boredom due to the monotonous motion of the mouth part.

5.1.5. *Impression created by the wearable robot.* We carried out another survey to determine the impression created by the device as a wearable robot. Table 2 shows the questions asked before and after the usability study. The first objective of this study was to make a small wearable robot, because some of the wearable robots that have already been presented are difficult to wear. This survey revealed that the device could potentially be accepted in situations such as human-robot interactions. Item 3 of Table 2 indicates that the robotic device was at least better than the other wearable robots. In this survey, we first described what wearable robots are, as they are already known through certain related works.

TABLE 2. Differences in the opinions before and after the study

Question	*Mean*	*SD*	%
1. Do you want to wear the wearable robot?	4.4	2.01	60
1′. The same question after the study.	4.6	1.62	80
2. Do you want wear the device if it is ring shaped?	4.8	1.47	50
2′. The same question after the study.	5.3	1.85	80
3. Do you feel that wearing the robot is an obstacle? (A lower value indicates a more positive response)	5.4	1.2	20
3′. The same question after the study.	4.0	1.1	30

5.1.6. *Robot presence.* Some users reported that they felt that the device was a living thing, as shown by the response to Item 6 of Table 1. This shows that there is a possibility of implementing the device as a storytelling robot. The human hand is a part of the body that is used for accessing objects in the world; hence, puppetry using the user's hand will act as an information interface to the real world. In a future work, we intend to propose some of the applications that Pygmy will realize. Table 2 presented the responses to questions on the use of Pygmy as a wearable robot and its presence. These responses indicated that Pygmy was acceptable as a storytelling device; this impression improved the evaluation of Pygmy as a wearable robot.

Further, we observed that when users talked with other subjects in the collaboration task, the users made the character's face and vocalizations mirror their actions or those of the other person while performing with Pygmy. The results revealed that Pygmy could act as a double of its user.

5.2. **Case study: parent and child.** Pygmy has another implementation as a standalone device. A robotic device works only with a sensor implanted in the ring part. By embedding sensors such as an accelerometer and a touch sensor, Pygmy can act according to the finger motion of a user. This demonstration is already shown in [11], and it uses a sensor system proposed in [12].

In this case study, we set the experimental environment for observing the interaction between a parent and a child. The environment comprised a room with white walls with only a video camera and some puppetry devices. For 30 min, the subjects – a 2-year-old child and his mother – played with Pygmy, the other puppets, and toys. We asked the mother not to play with Pygmy intentionally in order to avoid forcing the child to play with it.

Figure 8. Interaction between child and parent was improved by using Pygmy

After the experiment, we analyzed a video captured during the experiment; this video focused on the interaction between the mother and the child. The main user of the robotic device was the mother who wore the device on her finger and made puppetry characters such as a dog or a frog while uttering the animal's name and mimicking its cry. She changed some parts of Pygmy and the finger on which she wore the device. A scene of their interaction is shown in Figure 8.

The child was engaged in the puppetry characters that mother made. Note that he had never made puppetry characters by himself because he is comparatively young to have the skill to express characteristic puppetry. The most interesting thing to note in this analysis was that the child looked at a puppetry character made by his mother and tried to touch it. After this reaction, when he was asked to give a toy apple to the puppetry character, he picked the apple and extended it to the mouth of the puppetry character on the mother's hand.

6. Discussion.

6.1. Validity of design policy.

A considerable amount of feedback on the policy of the original design was obtained from the user study. Based on this feedback, we reconsidered each policy as follows:

Flexibility: It was difficult to stabilize and equip the device in every position of a finger because of the structure of the ring-shaped device. Depending on the position of the equipment, the face part could appear to be swinging and convey an odd expression. Moreover, since the casing of the IC board and battery was large, it was considered that the operation in the position where the finger was completely bent so as to grasp the hand was difficult.

Scalability: The ring type was effective from the perspective of the simplicity of attachment and detachment. However, locating rings of the appropriate size according to the size of the user's finger was inconvenient during first use, and there were users who found it difficult to remove the device because their finger joint was thick. Hence, it is necessary to devise a universal structure suitable for fingers of various sizes or forms.

Reconfigurability: Since the ease of rearranging the device was guaranteed, the user could create and direct expressions freely. However, as there was some discomfort caused by the device size, further miniaturization is required for attaching two or more devices to one finger.

Responsiveness: The responsiveness of the device can be improved by the addition of wireless communication, which requires rebooting because of the problem caused by the server program. Further, the communication distance was restricted to approximately 1 m since the Bluetooth antenna approached the microcomputer.

Responsiveness and safety: Although the power supply of the ring-shaped device was the battery, the power supply was turned on and off by removing and inserting the battery. It is necessary to implement functions for turning the device on and off according to the user command for the sake of safety and convenience. Moreover, since the battery capacity was low, the device operation was limited to 20-30 min; hence, it is necessary to improve the battery capacity for extended use.

Human likeness: Although the design for the personification of a simple structure was adopted, we attempted to implement a complete extension of the anthropomorphism of the human hand. Although only hands and fingers were used for the personification, the users stated that powerful animation and presence were realized by adding eyes and a mouth to the personification.

6.2. **Significance of physical device.** The device could be moved using a motor in the eyelid and the jaw of the personified part. The animation of the body part such as a hand or a finger, which is not anthropomorphized usually, could be significantly realized because this part could be moved physically. For example, when a light-emitting device (LED) was used as the face part, although expressions could not be recognized by the direction of the finger because of the plane structure of the display or the CG of the eyes or mouth projected on the finger, it was possible to dissociate oneself to the surrounding finger or hand. This led to the physical vibration observed at the time of the rotation of an eyelid across the hand, for example, and the subject memorized the interactive feeling by using a device and adopting a physical mechanism.

6.3. **Limitation.** It is clear that a user's imagination is crucial for exploiting hand expressions. The proposed device is successful in extending and directing its likeness to a living thing. In order to use Pygmy as a communication tool, it is necessary to improve the functionalities for practical use from the perspective of design or function. Moreover, certain users could not create certain forms without instructions because their understanding and methodology was different. However, user trials, which included different finger positions, helped achieve various expressions. Certain specific emotions seemed impossible to express because of the size limitation related to the embedding of an additional motor. Therefore, it is important to design systems and devices that can incorporate results from the user trials. In the future, it is necessary to improve the user instructions and sensing for increased interactivity.

6.4. **Robotic device for storytelling.** From the perspective of storytelling, Pygmy is appropriate for this application. In the analysis of interaction between a child and a parent, the mother easily made various puppetry characters and expressed their characteristic story, including animals and other living things. She changed the figures and their configuration by herself within 5 s in order to engage and get her child's attention. In this study, Pygmy plays a significant role in the reconfiguration and scalability of its own part in the storytelling.

6.5. **Applicable research field.** From the results of the usability study, we concluded that the subjects used Pygmy as their double, which suggested that Pygmy had the ability to act as a storytelling puppet. Further, Pygmy can be used as a telecommunication robotic device and storytelling device for collaboration among children and their parents. Furthermore, by acting as a puppet on a hand, Pygmy provides a new interaction model because this type of robotic device is comparatively close to the user and can be worn on the user's body.

6.6. **Future works.** We showed that Pygmy not only is a small robotic device but also can behave as an anthropomorphic puppetry robot for the user and another person around the user. With its functions, Pygmy can act as a communication device such as a telepresence robot and toy for establishing a relationship between babies and their parents. Moreover, it is an intelligent system to recognize the finger posture for performance generation, and achieves automatic operation without the use of a controller. Further, as a wearable agent robot, Pygmy can interactively provide information about what the user watched or touched.

7. **Conclusion.** We proposed a ring-shaped robotic device for storytelling and verified its significance by two experiments comprising a user study. Using a ring-shaped anthropomorphic device that enhances hand expressions by incorporating posture and motion, we could produce a character, a facial expression, an emotion, and a puppet-type facsimile of an animal. Pygmy also established its presence as a puppetry robot. In the usability study, the users understood the concept of hand anthropomorphism and performed it with the device; they could converse while using the device. We also found that the user could resolve device limitations by collaboration. The impression created by Pygmy as a wearable robot was improved by its usability and presence magnified by its anthropomorphic appearance.

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