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Proposal for Robot Hand and Forearm Design to Reproduce Human-to-human Physical Contact

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***Abstract*—If a robot can reproduce human-to-human physical contact, it may be used to relieve humans' stress for example. In our previous work, we made a prototype of an artificial hand aiming to reproduce human-to-human physical contact. It has both active touch functions and passive touch reproducibility. And, we conducted participant experiments for "human-like touch feel" evaluation and control experiments. We designed the temperature system, which the 1st prototype didn't have, keeping the elements of the 1st prototype that were evaluated "human-like" at the previous participant experiment. And aiming at reproducing communication, we added sensors to feel the other person (we referred to the result of the control experiment). We also designed the artificial forearm with the aim of moving the hand actively. We made the above designs, the 2nd prototype, and tested whether the design worked well.**

***Index Terms*—HRI, biomimetics, soft robotics**

I. Introduction

If we have a robot reproducing human-to-human physical contact, it may be used to some positive application. The effects of touch are, for example, people feel happiness through physical contact between humans[1], and the prosocial improvement called "Midas Touch"[2].

There are researches on devices that reproduce the touch of human[3], [4], [5]. Aiming at expressing the complicated tactile feel of the human body, which is difficult for these devices, we took an approach to make a human-mimetic robot reproducing the human body's tactile feel. And there are many human-mimetic hands[6], [7], [8]. These have functions for each purpose, and this research focused on "how the human touching it feels." Such like that, there are researches about the robot hand that take into account the impression of the human who touched them[9], [10], [11]. In this paper, with the aim of "it can do communication that makes human feel human-likeness," we report the robot hand and forearm that have a new design and methods of integration that these researches have not done.

We have a policy of evaluating and improving a prototype hand through experiments. In our previous work, we have made the 1st prototype (Fig. 1) and conducted participant experiments[12] and control experiments[13]. The 1st prototype had flesh made with the mold created from the 3d-data of a real human and had nails on the fingertips. Inside it, there is the skeleton that reproduces the firmness feel of bone, and elastic joints that reproduce the passive resistance of the joint. These joints can do flexion by wire-driven with pneumatic artificial muscles. In the participant experiment we conducted, participants evaluated the tactile feel of the hand and answered the points that it was human-like and that it was not human-like. And we conducted the force control of the

Fig. 1. The human-mimetic robot hand and forearm

Sensation (Physical stimuli)		Receptor (Unit)
High-frequency vibration		Pacinian corpuscle (FAII)
Low-frequency vibration		Meissner corpuscle (FAI)
Sustained pressure		Merkel cell (SAI), Ruffini corpuscle (SAII)
Thermal stimulus	Warm	TRPV1, TRPV2, etc.
	Cold	TRPA1, TRPM8, etc.

Fig. 2. Relationship between sensation (physical stimuli) and receptor[14]

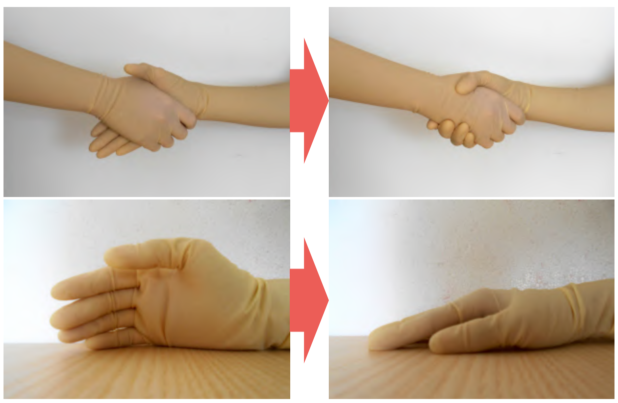


Fig. 3. Grasping hand and rotation of the wrist

hand's fingertip and we thought that it needed force sensors. Based on the results of these experiments, we designed the 2nd prototype.

II. Related work

A. Effects of touching, and substitution of it

Some effects of "touch" lead in a positive direction, such as feeling happiness[1]and improving sociality[2]. There are researches that replace human touch with something other than humans: reproduction of a hug with air actuators[4], [5] and reproduction of "Midas touch" with a vibration motor[3]. They did not consider the complicated tactile feel of the human body and this research proposes using the robot that reproduces such a complicated tactile feel.

B. Artificial hands with each purpose

There are many artificial hands that imitate a human body, but each has its own purpose. For example, there is the hand aiming to do dexterous manipulations like humans[8], and the hand with tactile transfer functions to do manual work remotely[6]. In addition, prosthetic hands, such as herohand[7], aim to have a function for living freely and empower aesthetics. In this research, we design the robot focusing on "how the touching human feels."

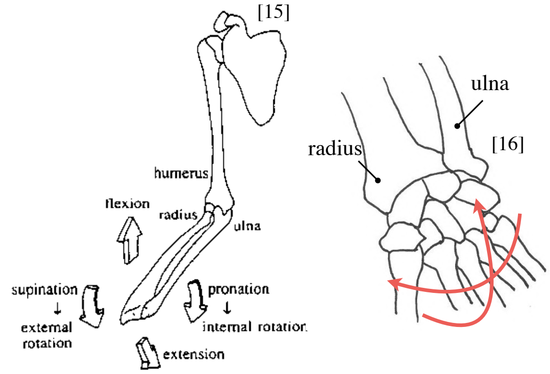


Fig. 4. Left: Human's radius and ulna[15], Right: Human's wrist (made this fig referring to[16])

C. Anthropomorphic hands considering the impression of touching

There is the hand that imitates a human for the purpose of human-robot-interaction[10]. It has flesh, bone, and grip strength control system. And its impression was evaluated. There is also the imitation hand equipped with flesh, bone, passive elastic joints, and temperature control system for touch care[11]. Imitating the child's hand with flesh, bone, tactile sensor is also researched[9]. The point of view is also different in imitation hands that take tactile feel into account. We aim to reproduce physical communication that makes people feel human-likeness by the new integration method. We will describe this design.

III. What to focus on when we design the robot

When we feel the human body by touch, we use many receptors. In this paper, we focus on physical stimuli. Fig. 2 shows the relationship between stimuli and receptor. We focused mainly on sustained pressure and thermal stimuli and consider force sensation.

A. Improvement of 1st prototype hand

The "Human-like" features of the 1st prototype hand were softness, firmness gradation by flesh and bone, nails, range of motion, elastic joints, and shape (more than 20% participants pointed). In the "Not Human-like" features of it, "without temperature" was highest (79% participants pointed). We implemented features that have been evaluated as human-like and designed temperature system newly. And, we thought that "stringy" of the tendons on MP joints may be felt human-like. So, we implemented it newly, too.

The purpose of our study is to reproduce communication, and in this paper, we focused on grasping hand (Fig. 3). We actually grasped a hand and assumed that flexion of five-finger was necessary. Also, we thought a rotation of the wrist was needed because when we will design action other

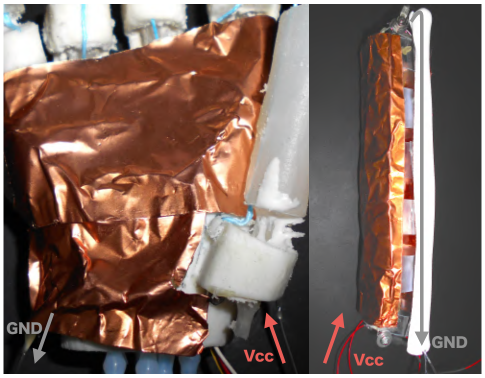


Fig. 5. Temperature system for the palm and forearm

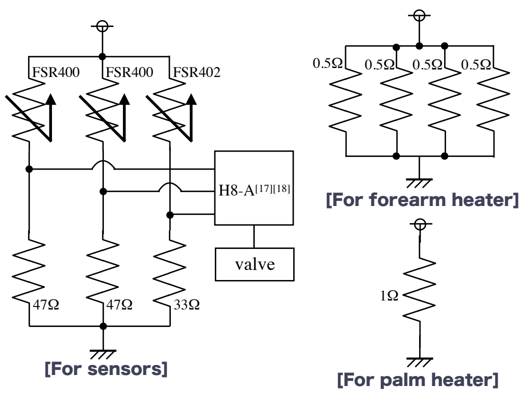


Fig. 6. Circuit diagram

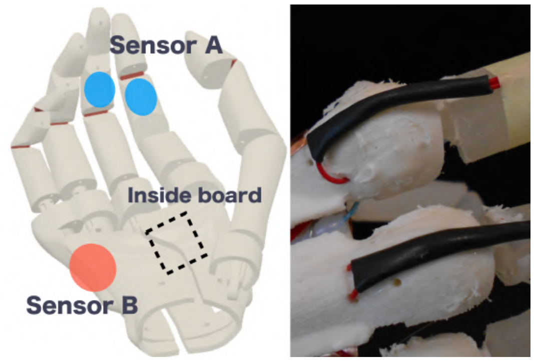


Fig. 7. Sensor position and "stringy"

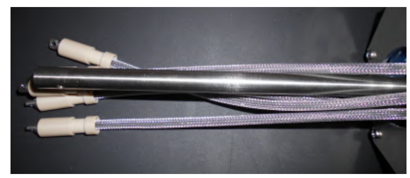


Fig. 8. Small diameter PAMs

Fig. 9. PTFE tube with inserted rings

than grasping a hand, stroking for example, in the future, the palm must be parallel to the opponent's back (Fig. 3). We implemented sensors and actuators to enable the above.

B. Design of anthropomorphic forearm

The features that were evaluated as human-like for the hand are also implemented in the forearm. Specifically, these are softness, firmness gradation by flesh and bone, range of motion, joint flexion, and shape. The forearm had flesh and bone. It can reproduce the feel of the internal ulna and radius (Fig. 4: Left). The human's wrist is shown in Fig. 4: Right. We designed the wrist of the robot that had two degrees of freedom and elasticity and a limited range of motion. We implicated body temperature system, too.

IV. How to design and make

A. The design and production of the hand

1) Human-like tactile expression: As shown in Fig. 5, the temperature system was made of the nichrome wire and copper foil (this was referred to [11]). Flowing current (Fig. 6 [For palm heater]) through the nichrome wires heated flesh, and copper foil dispersed it.

We expressed "stringy" with sensor cables covered thermal shrinkage tubes on the back of the MP joints (Fig. 7).

The designs of softness, firmness gradation by flesh and bone, nails, range of motion, elastic joints, and shape were almost the same as the 1st prototype[12]. The differences were "skin was a single glove", "how to glue nails", and "hardness 0 urethane gel wasn' t placed on the fingertips."

2) Placing sensors and implementing flexion: The sensors were placed at the position shown in Fig. 7 (Sensor As were FSR400, Sensor B was FSR402, inside board was for these sensors). These sensors were connected to the board called "H8-A"[17], [18] (Fig. 6 [For sensors]). These were read on the middleware called "nervous"[19]. We programmed it using the language called "euslisp"[20].

The flexions of the five fingers were wire-driven. The wires passed from the tip of the finger through the tube to the inside of the forearm via the wrist. There were 5 pneumatic artificial muscles (PAMs) inside the forearm and each muscle pulled the wire of each finger. These had one solenoid valve, which was connected to H8-A.

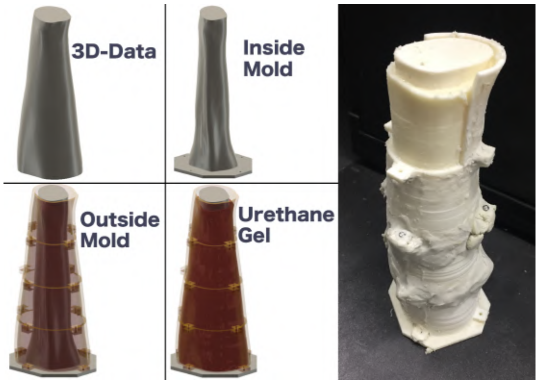


Fig. 10. Molds for making flesh

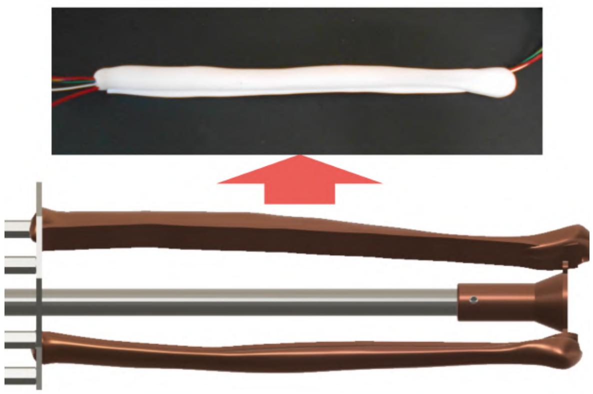


Fig. 11. Main shaft with bones mimicking ulna and radius

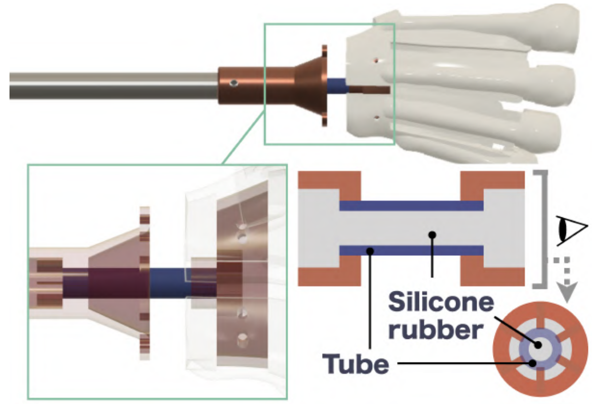


Fig. 12. Flexible unit for the wrist

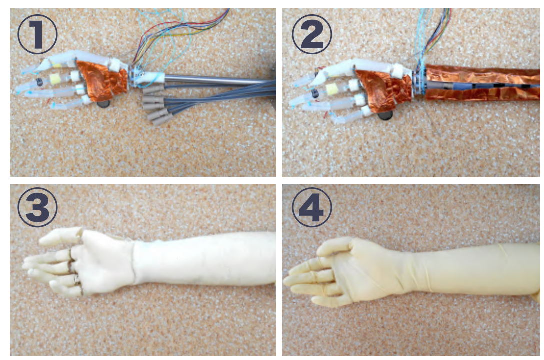


Fig. 13. Assembling the hand and forearm

In consideration of storability into the forearm and flexibility, we used small diameter PAMs (Pneumuscle, KOGANEI) (Fig. 8). We selected the muscles that give the necessary stroke and performance referring to the previous experiments.

We selected the Teflon for tubes considering low friction, however, these were difficult to be fixed. We inserted rings (20-3RI-H, Flowell) into the end of the tube (PTFE tube, Flowell) as shown in Fig. 9.

We fixed the bump by using wires or making it go through the hole of the skeleton.

B. The design and production of the forearm

1) Expression of softness, firmness gradation by flesh and bone, and temperature: The forearm had a human-body-shape flesh. We made an outside mold for flesh from a real human 3D-data shown in Fig. 10. Also, we made an inside mold to design firmness gradation by flesh and bone. These molds were made by 3D-printing. The inside mold was put into the outside mold, and urethane gel was poured into the gap of these molds.

As shown in Fig. 11, we made bones that express the feel of the ulna and radius by selective laser sintering (SLS). It is the aluminum main shaft that actually joins the wrist The bones mimicking ulna and radius were used to express the touch feel and cover the cables of the sensors and the nichrome wires. These bones joined the wrist with the nichrome wire for palm.

The forearm temperature system was the same as that of the hand (Fig. 5). Several polystyrene plates were fixed in a cylindrical shape on the ulna mimetic bone, and a copper foil and four nichrome wires were pasted on it (Fig. 6 [For forearm heater]).

2) Design of the elastic joint and range of motion: The wrist design is shown in Fig. 12. In order to express the passive elasticity of the wrist's joint, we made a flexible unit made of polymer material. This unit's both ends of a 6mm air tube were fixed with glue, and both ends and inside were filled with silicone rubber. Both ends had bumps on a circle as shown in Fig. 12. These bumps and glue constrained so as not to rotate at the wrist. There was the oval frame around the tube, limiting the range of motion.

3) Design of the rotation of the wrist: We made the rotation of the wrist by rotating the aluminum main shaft with a servo motor.

Fig. 14. Nail on the fingertip and ”stringy”

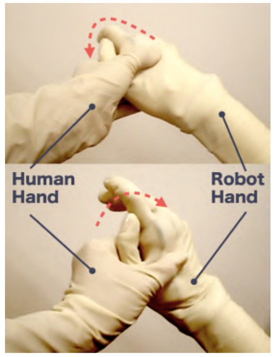


Fig. 15. Passive movement of the robot wrist

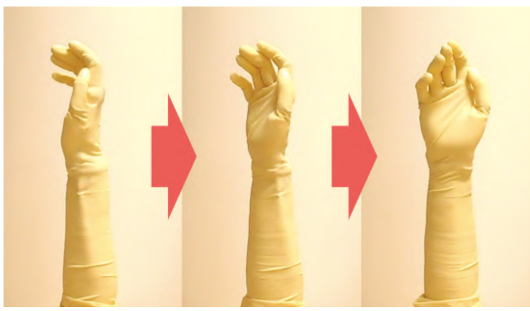


Fig. 16. Rotation of the robot wrist

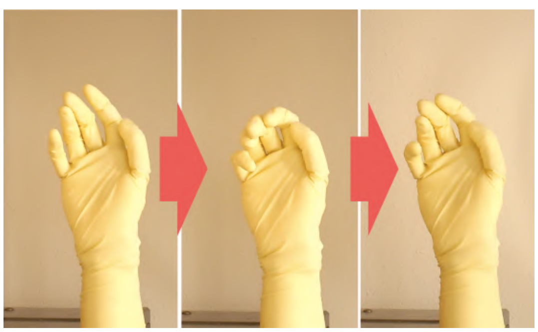


Fig. 17. Flexion of the robot fingers

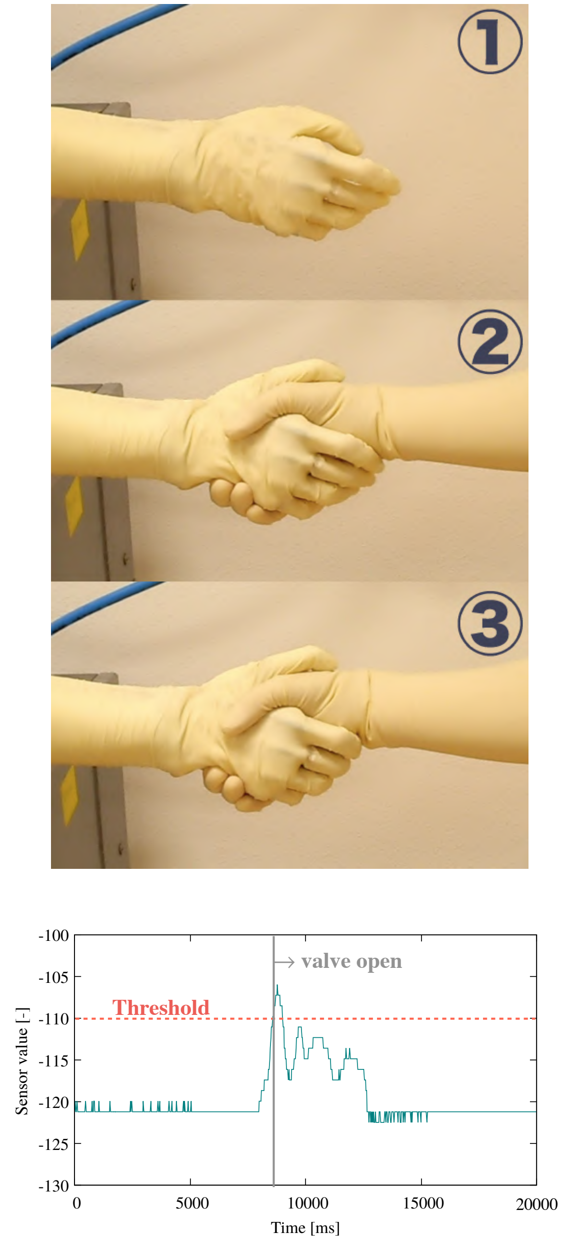


Fig. 18. Grasping hand communication and the graph of the sensor on the side of the hand

C. Assembling the hand and the forearm

Fig. 13 shows the procedure of assembly (1. skeleton 2. copper foil 3. fleshes 4. a latex glove). After the above, as shown in Fig. 14, the nail chip was adhered to the fingertips on the latex glove with double-faced tapes.

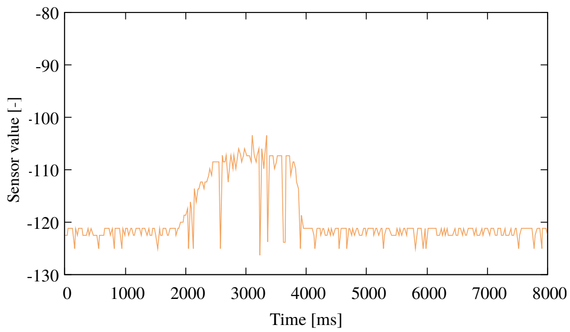
V. Evaluation of the Hand and Forearm

A. About touch feel

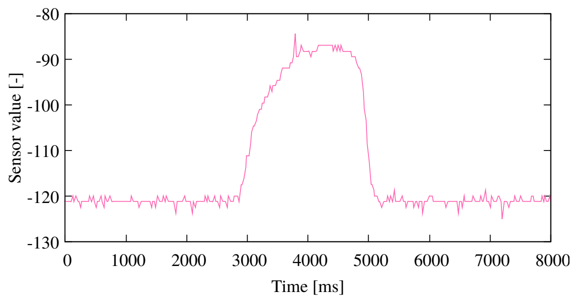
When we touched the hand and forearm, we could feel the firmness of bones inside flesh. And we could also feel ”stringy” (Fig. 14). It showed the hand and forearm expressed softness, firmness gradation by flesh and bone, and ”stringy.”

We bent the wrist (Fig. 15) to the limit of movement and released it. At this time, we could feel the joint’s elasticity. Thanks to using tubes, the fingers did not bend even when the wrist was bent.

In addition, we applied about 2 [A] to the nichrome wire on the palm and about 4 [A] (in total) to the nichrome wires on the forearm. We could feel the warmth when we touched the palm and forearm. However, where the thickness of the flesh was different, the temperature was different. So, we have to improve the design of the temperature system in the future.



Sensor A of index finger



Sensor A of middle finger

Fig. 19. Graphs of each sensor A

B. About movement for communication

When the servo motor was rotated 90 [deg], the wrist was rotated as shown in Fig. 16. And, when 0.35 [MPa] was added to PAMs, the fingers bent as shown in Fig. 17. When we changed the inside pressure 0.35 [MPa] to 0 [MPa], thanks to the joint's elasticity the fingers returned near to the first pose.

We set the threshold for sensor B on the side of the robot hand (sensor value = -110 [-]), and a human gripped the robot hand (Fig. 18(2)). Then, the sensor B reacted and the solenoid valve opened. And 0.35 [MPa] was applied to PAMs, and the fingers bent. Then, the human hand was grasped (Fig. 18(3)). It shows the possibility that the robot can do physical communication (such as grasping and shaking hands) with humans.

The graphs when each sensor A was pushed over the flesh are Fig. 19. Sensor As were placed on the index and middle fingers at the between PIP joints and DIP joints. These sensors could react to forces over the flesh. However, these sensors did not react when grasping a hand, which also needs to be improved in the future.

VI. Conclusion and Future Work

Based on our previous research, we proposed and made the improved 2nd prototype. We considered many details of the robot design in this paper. However, we have to evaluate whether these details contribute "human-like" for the human who touched it or not by participant experiments. And we have to improve the temperature system design and the sensors. In the future, we will design physical communication movements other than grasping hands.

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