# Haptic Interface for Middle Phalanx Using Dual Motors

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## ABSTRACT

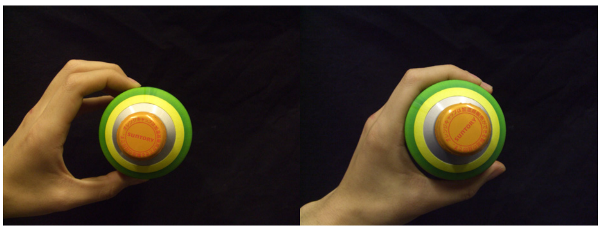
We propose a new haptic interface for the middle phalanx that bi-directionally transmits haptic information on "power grasp." This is a primary requirement for interactive tele-operation or telexistence. By using two motors and a belt, this device can sense and display the haptic information of the finger pad of the middle phalanx when grasping an object. Pressure and weight are the most important sensations with grasping. In this paper, we first examine the discrimination ability of the force direction on the middle phalanx to show validity of our proposal. We then examine gravity sensation on middle phalanges, and describe the mechanism of the first prototype.

***Keywords:*** *haptic interface, middle phalanx, grasping, gravity sensation, robot hand, telexistence*

## 1. INTRODUCTION

Imagine that you are grasping a cylindrical object such as a bottle. Typically, you would grasp it using all the parts of your hand. In fact, you would not only use the tips of your fingers, but also the middle phalanges.

As shown in Fig. 1, grasping in robot manipulation consists of two types—"precision grasp" and "power grasp" [1] [2]. "Precision grasp" implies holding an object with the tips of your fingers, so that you can manipulate it freely and dexterously. However, at the same time, stability is sacrificed and you might easily drop it. On the other hand, "power grasp" implies holding an object tightly using all the parts of your fingers. You can grasp it stably and safely. This type of grasping is appropriate for holding and carrying tasks, dangerous works, etc.



(a) Precision grasp (b) Power grasp

**Fig. 1: Two grasping modes.**

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**Fig. 2: Schematic illustration of the haptic interface for middle phalanx** (The device will put on every finger).

Today, haptic interfaces have become increasingly important in tele-operation and telexistence. In particular, many researches exist on hands and fingers that display haptic information from slave robot hands, called "master hand" [3] [4] [5]. Some researches analyze and display the slip sensation on fingertips [6] [7]. Nevertheless, from the viewpoint of grasping type, most of the researches have attempted to stimulate fingertips (or distal phalanges) of fingers. It appears that their aim was to transmit the haptic information of "precision grasp." Few researches have examined the importance of the haptic sensation on the middle phalanx.

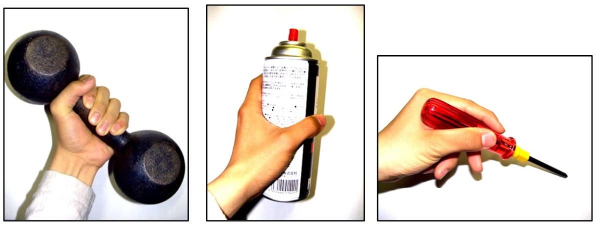
However, we observed that the "power grasp" situation is a common occurrence. When we hold up a beverage bottle to drink, or use almost any kind of hand tool such as a screw driver or a soldering bit, we use the middle phalanges to manipulate them stably and dexterously. Similarly, when driving a car, we handle a steering wheel, which is definitely a "power grasp" task. At the same time, in many "precision grasp" situations, not only fingertips but also middle phalanges are used. Chopsticks, pencils, and scissors are typical "precision grasp" tools; however, when we look closely, the middle and proximal phalanges play an important role in handling them stably. The roles of the middle phalanx are summarized in table 1.

One more important sensation in grasping is gravity. There also exist some researches on displaying gravity sensation on fingers focusing on slippage or deformation of fingertips [8] [9]. In addition, recent researches [10] [11] revealed that the slip sensation is used unconsciously to hold an object whose weight is unknown. In either case, shearing forces on the middle phalanges, which would be as important as those on the fingertips, have been largely unnoticed.

In this paper, in order to transmit the grasping and gravity sensations from a robot hand to an operator with higher realistic sensation, we propose a bi-directional haptic interface for the middle phalanx (Fig. 2), which works as a sensor and a display at the same time.

**Table 1: Roles of the middle phalanx**

- Power grasp
  - (a) Hold it tightly for the task
  - (b) Sense gravity to keep holding
- Precision grasp
  - (c) Support the middle part of a tool for stabilization




## 2. SENSITIVITY OF MIDDLE PHALANX

Information of the force direction plays an important role when you grasp an object. To quantitatively show that the middle phalanx is as important as the distal phalanx, we conducted an experiment to examine the threshold of differentiation of force directions on the middle phalanx in comparison with the distal phalanx.

The experiment system is shown in Fig. 3. It is composed of a contact board and two voice-coil type linear actuators (Emic Corp., 511-A) to drive the board horizontally and vertically. By fixing the dorsal side of the finger, we placed the board on the ventral side of the distal or middle phalanx.

The threshold of differentiation of force directions was measured by the constant method. The first reference stimulus was a vertical force, and the second comparison stimulus was a force that has a certain angle $\theta$ ranging from –90 to +90 [deg]. Both stimuli continue for 2 s, as shown in Fig. 4. This was repeated 10 times for every 5 [deg]. The participant was asked to state the relative change of direction as either “thumb side” or “little finger side.” On the basis of the responses, the number of “thumb side” responses was fit with the cumulative density function of a normal distribution.

Fig. 5 shows the results obtained from four participants, and Fig. 6 shows the average. From these results, the points of subjective equality (PSE) and 75% determination thresholds from PSE (75% DT) were measured (Table 2).

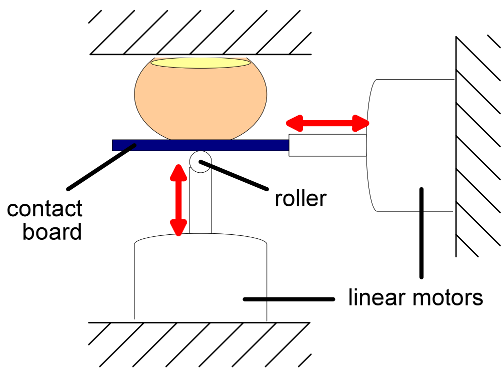



**Fig. 3: The experiment setup to measure discrimination ability of force direction.**

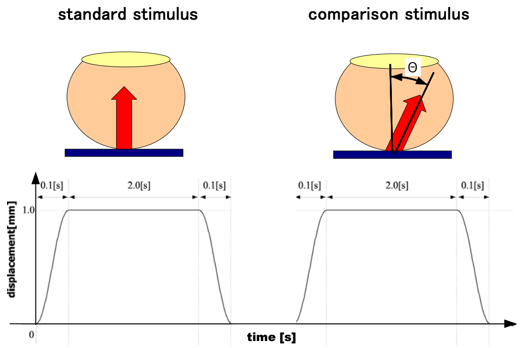



**Fig. 4: Stimulation patterns**

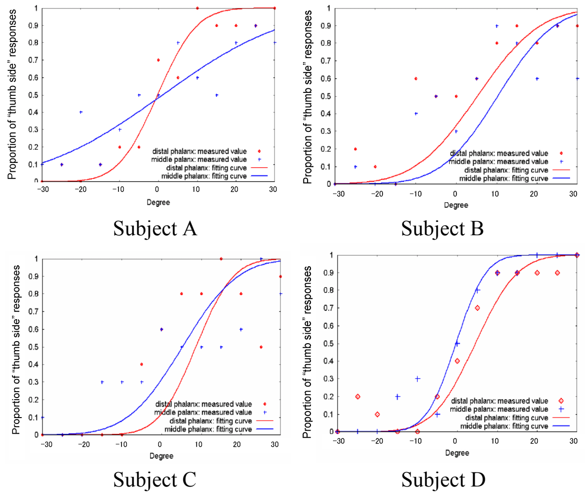



**Fig. 5: Results of the experiment on the force direction sensitivity of distal and middle phalanges.**

The proportion (vertical axis) of “thumb side” answers were plotted vs. $\theta$ (horizontal axis). The red dots/lines represent the distal phalanges. The blue dots/lines represent the middle phalanges.

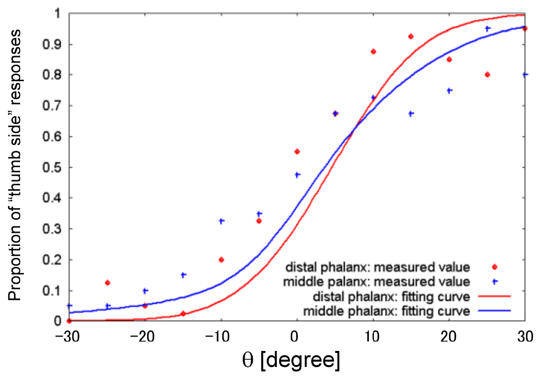



**Fig. 6: Average of the 4 subjects in Fig. 5**

**Table 2: Points of subjective equality (PSE) and 75% determination thresholds from PSE (75% DT)**

| | distal phalanx | | middle phalanx | |
|---|---|---|---|---|
| | PSE | 75% DT | PSE | 75% DT |
| A | –0.2 | 5.4 | +1.1 | 17.0 |
| B | +8.6 | 4.9 | +5.3 | 7.4 |
| C | +5.2 | 8.2 | +10.3 | 7.3 |
| D | +4.5 | 5.6 | –0.3 | 4.0 |
| Ave. | +4.5 | 6.0 | +4.1 | 8.9 |

[deg.]

This result shows that the PSE are biased to the thumb side, probably due to the asymmetric setup of our experiment (cantilever structure of the contact board). A particularly interesting point is that the 75% DT are not very different between distal and middle phalanges. In some cases, the middle phalanx shows higher direction sensitivity than the distal phalanx. This result indicates that there is little difference between the distal and middle phalanges in the threshold of differentiation of force directions. In this experiment, the stimuli were almost static and SAII receptors were considered to play a major role in the recognition of the force direction. It is known that SAII receptors are almost evenly distributed on a finger [12], which supports our results.

According to this result, we proposed a hypothesis that the middle phalanges discriminates the force direction of pressure when an object is held using the "power grasp." On the basis of this hypothesis, the haptic interface for the middle phalanx should have the ability to display the direction of the force as well as determine its magnitude.

## 3. DISPLAYING GRAVITY SENSATION

Focusing on the deformation of middle phalanx of the finger in grasping, we preliminary examined ability of our proposal in displaying gravity sensation. To reproduce the deformation caused by the weight of object, we made two experimental devices shown in Fig. 8 and set them on the little finger and the thumb of operator (Fig. 9). This device composed of a belt, a motor (Maxon Motor Corp., RE25, 20W, gear ratio = 18:1), and a supporting frame to limit the motion of the belt in correct shearing direction. There is sticky disk between finger and belt so that not slip sensation but deformation of finger occurs.

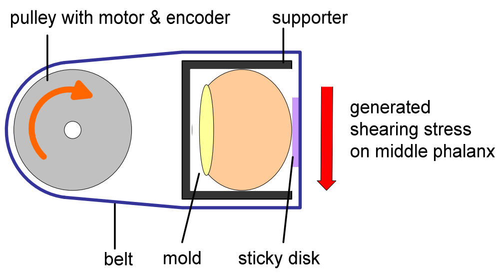



**Fig. 8: Construction drawing of the experimental device to display gravity sensation on middle phalanx by generated shearing force on the belt.**

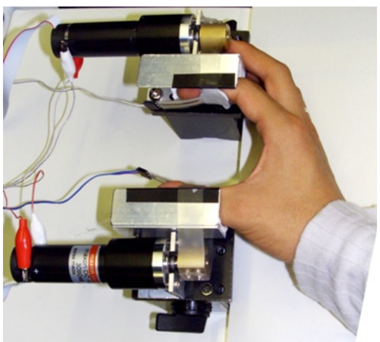


**Fig. 9: Displaying gravity sensation of virtual object (like a bottle) on middle phalanges of the operator's index finger and thumb using a pair of experimental devices in Fig. 8.**

By fixing dorsal side of the fingers on the mold not to move, we drove the motor. Then the belt goes down so that the finger of examinee dragged through the sticky disk and become deformed. A brief question how the examinees felt when this device dragged their finger showed that they certainly felt some gravity sensation, as if they were grasping some weight. The weight displayed in this method was measured by the reconciliation method. First, the examinee grasped an object of certain weight only with naked middle phalanges of index finger and thumb. Second, wearing the experimental devices, the shearing stress was generated and the examinee adjusted the shearing range on the middle phalanges so that the gravity sensation is same as the real object which grasped first. One result of this experiment is shown in Fig. 10.

In this preliminary experiment, we confirmed that the middle phalanx can discriminate the gravity of objects and the shearing stress on palmer surface of middle phalanx can reproduce this gravity.

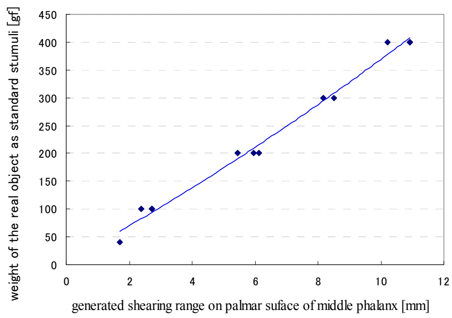



**Fig. 10: One result of the preliminary experiment on displaying gravity sensation on middle phalanx.**

## 4. PROTOTYPE MECHANISM

To transmit the grasping and gravity information with tele-operation and telexistence, the following features are required.

- On the remote robot's side, the power and direction of force on the palmer side of the middle phalanx must be sensed.
- On the operator's side, the power and direction of force on the palmer side of the middle phalanx must be displayed.
- The device should not hinder the grasping behavior of the robot or operator.

We designed a prototype (Fig. 11) that fulfills these requirements on both the remote robot's side and the operator's side. The prototype (Fig. 12) has a pair of geared EC motors (Maxon Motor Corp., EC6, 1.2W, gear ratio = 15:1) with a rotary encoder to activate a belt. The belt depresses and drags the palmer side of the middle phalanx of a finger. The two motors work in a complementary manner to obtain a bi-directional force.

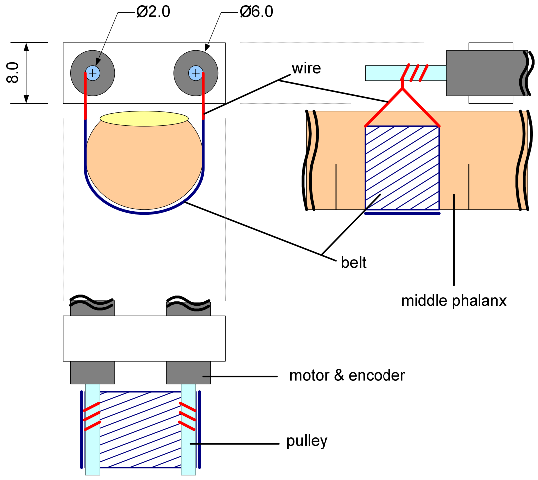
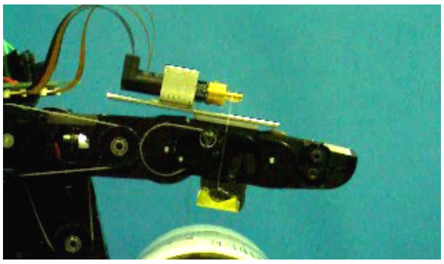
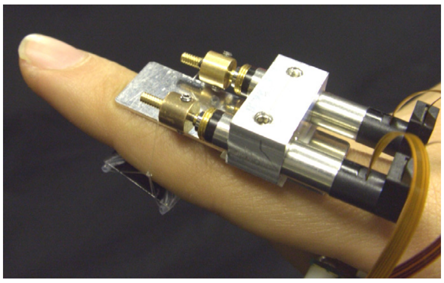



**Fig. 11: Construction drawing of the prototype mechanism of haptic interface for middle phalanx**



(a) Remote robot's side



(b) Operator's side

**Fig. 12: Wearing the first prototype**

## 4.1 VERTICAL STRESS

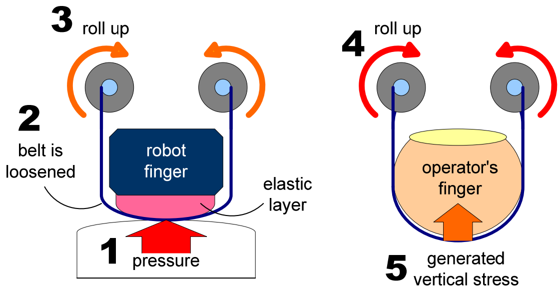
The most fundamental sensation of grasping is the vertical stress. The prototype transmits this type of force sensation in the following way.

1) Remote robot's side (sensing) (Fig. 13a)

An elastic layer is placed between the robot finger and belt. By applying constant currents to both motors, the wires are pulled with constant tension. When an object touches the ventral side of the finger, the elastic layer is squeezed and the belt is loosened. The motors roll up the belt with constant tension. We acquire the force information by measuring this rotation.

2) Operator's side (display) (Fig. 13b)

The measured force information is transmitted to the operator's side. We drive the motors to roll up the wires and present the same amount of force as that on the remote robot's side. The prototype device can generate a force of up to 6.5 [N]. When compared with "Cyber Grasp (Immersion Corp.)," which can generate 12 [N] per finger, this force is sufficient for a first prototype.




(a) Robot's side (b) Operator's side

**Fig. 13: Sensing (a) and displaying (b) vertical stress**

## 4.2 SHEARING STRESS

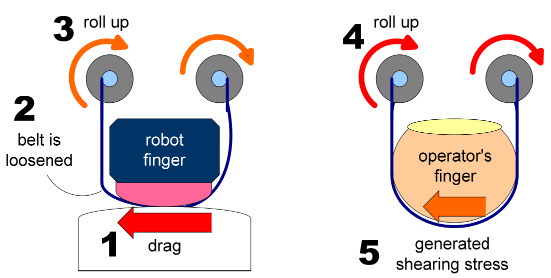
When you hold an object such as a bottle, you feel the shearing stress between the bottle and your finger; this feeling is very significant and represents the important information to not drop the bottle.

1) Remote robot's side (sensing) (Fig. 14a)

Similar to the case of vertical stress, we apply constant currents to the motors. When an object touches and drags the ventral side of the finger, the belt trails along the object. In this case, the two motors rotate in the same direction.

2) Operator's side (display) (Fig. 14b)

The measured shearing stress on robot finger is transmitted to the operator's side. We drive the motors to roll up one wire and release the other. In this way, the drag sensation can also be transmitted by these devices. The current prototype has a frequency range of only 0–25 [Hz]. We will improve it up to several hundred hertz, so that the transient "slip" sensation will be presented by combining high-frequency stick-slip and static drag.




(a) Robot's side (b) Operator's side

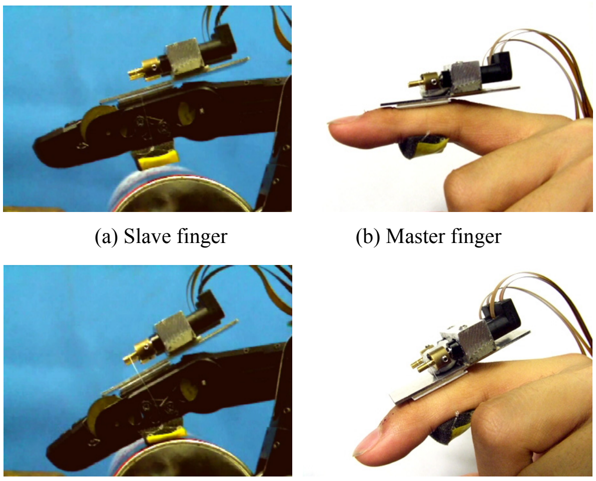
**Fig. 14: Sensing (a) and displaying (b) shearing stress**

## 5. EXPERIMENT ON HAPTICS TRANSMISSION

We tested the prototype in the haptic transmission for tele-operation (Fig. 15). We placed one device on the middle phalanx of the index finger, and another one on the robot finger (Tech Experts Inc., Universal Robot Hand). We placed an elastic layer on the robot finger to measure the pressure, as discussed in the previous section.

In this master-slave system, an operator's finger posture was measured by a bending sensor (Measurand Inc., Shape Sensor). The information is sent to the slave side to operate the robot finger. When the robot finger touches an object, the haptic device on the robot side measures the pressure, whereas that on the operator's side presents the sensation, as described in sections 3.1 and 3.2.

In this experiment, the participants were able to clearly recognize the pressure and drag sensation when the slave hand touched an object. The experiment has already revealed two problems of the prototype. One is that the resolution of pressure was not sufficient. The other is that we also felt a tactile sensation on the dorsal side of the finger. The latter problem is due to the fact that the device was not kept away from the finger. In our next prototype, we propose that using a fixation mechanism be used to solve this problem, while keeping the system compact.



(a) Slave finger (b) Master finger

(c) Slave finger (touch) (d) Master finger (display)

**Fig. 15: Haptics transmission on middle phalanx**

Posture of the operator's finger (b) is transmitted to the slave robot finger (a). When the slave finger (c) touches the bottle, the touch sensation is transmitted to the operator's finger (d) using dual motors on this device.

## 6. CONCLUSIONS

We suggested that the haptic information of the middle phalanx could be as important as that of the distal phalanx. A haptic interface for the middle phalanx that can sense and display the force direction as well as the force was proposed. The device is compact and does not hinder the free motion of the fingers. By focusing on the deformation of the middle phalanx of the finger when we grasp an object, we proposed a method to display the gravity sensation of the object.

The prototype device shown in section 5 has some problems now. The generating power from the motor is not so sufficient in exchange for its smallness. The force direction in displaying shearing stress is not correctly tangency because we have omitted the supporting frame shown in Fig. 8. Our future work is to modify the mechanism so as to sense and display with sufficient temporal / directional resolution.

This paper just showed the concept and first prototype mechanisms. We had examinations on this paper so as to look into the feasibility of study on the haptic interface for middle phalanx. These examinations are still too preliminary and we have to study more on grasping and gravity sensation that are provided in this method. In near future, we will mount the next prototype mechanisms on the established master hand system so as to show availability of haptic telexistence on the entire finger.

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