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A Study of Human Grasping Ability and its Application to a Robot Hand

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Abstract

In this paper, we discuss the smooth hand-over of an object from a man to a robot and vice versa. In order for a robot to grasp an object or release a grasped object stably without using object model, as a man does, one of the basic approaches is the physiological method motivated by the study of human hands. So, we analyze human's grasping behavior by measuring grasp and friction forces simultaneously as a man grasps a experimental device which is designed for grasping or hand-over. Also, we investigate two methods that can predict when and how fingers will slip upon a grasped object. And then, we propose a method of the hand-over of an object between a man and a robot by applying human's capability to a robot hand control.

1. Introduction

Besides industrial purposes, robots increasingly play a vital role in nonmanufacturing fields such as medical and household applications. In these fields, it is necessary to consider the hand-over of an object between a man and a robot. However, for a robot to grasp an object or release a grasped object stably without using object model, as a man does, one of the basic approaches is the physiological method motivated by the study of human hands [1]. Generally the human hand is capable of a wide range of grasps, and the selection depends on the size and shape of the object as well as the task to be performed [2]. Also, with information from fingertip sensors, a man use a grasp force just greater than the minimum required for grasping the object, thus minimizing effort and avoiding object damage [5]. In this paper, our study of human grasps focuses on this human control ability of grasp forces.

We begin by designing a simple experimental device for grasping or hand-over. And we then analyze human's grasping behavior by measuring grasp and friction forces simultaneously as a man grasps the object, to understand the relationship between the sense of fingers and the ability of grasp. Especially, since slip detection plays a vital role in ability to successfully grasp, we investigate two methods that can predict when and how fingers will slip upon a grasped object.

We then perform the hand-over of an object between men, and propose a method of the hand-over an object between a man and a robot by applying human's capability to a robot hand control.

2. Human grasping characteristic

Typically, human grasping is divided into the following three phases [2].

1) Preshape : This is where the hand is configured in preparation to grasp the object while it is reaching for the object.
2) Acquisition or grasping : The hand moves toward the object in the preshape configuration, and once the contacts are in place, grasps it with suitable forces.
3) Manipulation : This ranges from moving only the wrist to the hand being able to impart arbitrary forces to the object.

In this research, we consider only the second phase, that is, acquisition or grasping, and to keep the analysis of human grasping tractable, we make the following assumptions,which are for grasping a two-dimensional object by applying two contact forces:

1) Rigid-body models with point contacts between the fingertips and the grasped object.
2) No sliding or rolling of the fingertip.
3) Prismatic grasp with two fingers (thumb and middle finger) [1].

Based on the above assumptions, we designed a simple experimental device as shown in Fig.1, to measure the grasp and friction forces simultaneously as it is grasped. And, CH_i are the force sensors using strain

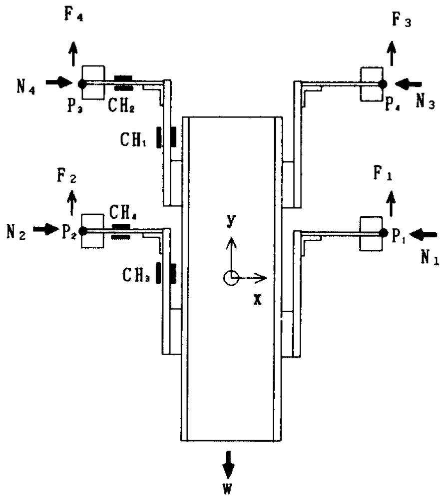

Fig.1 Experimental device

gauges where CH_1, CH_3 are for measuring grasp forces and CH_2, CH_4 are for friction forces.

For a stable grasp, the object must be in equilibrium: i.e., there is no net force or moment [3], [4]

$$N_1 = N_2, F_1 = F_2$$
$$N_3 = N_4, F_3 = F_4$$
$$F_2 + F_4 = \frac{w}{2} \quad (1)$$

where N_i is the grasp force, F_i is the friction force, and w is weight of the device. Another condition for stability is that the friction forces satisfy the Coulomb law:

$$F_i \leq \mu_i N_i \quad (2)$$

where μ_i is the coefficient of friction. Thus for a stable grasp we obtain

$$F_2 + F_4 = \frac{w}{2} \leq (\mu_2 N_2 + \mu_4 N_4) \quad (3)$$

The basic performance of these force sensors is ascertained by measuring the grasp and friction forces simultaneously as a man grasps the object at positions P_1 and P_2 with two fingers and increases the grasp force. Fig.2 shows that the friction force is always constant though the grasp force is increased, which presents that grasp forces can be isolated from friction forces.

Since slip detection plays a vital role in ability to successfully grasp, we are interested in knowing when a finger will slip. From (2) we compute the ratio

$$\frac{F_i}{N_i} \leq \mu_i \quad (4)$$

Note that F_i/N_i equals to be μ_i as the finger starts to slip. We have measured the coefficient of friction between human fingertips and the object by grasping the object with a grasp force greater than the minimum required for lifting the object and then releasing it slowly. Fig.3 shows that the coefficient of friction is approximately $\mu_i = 0.5$.

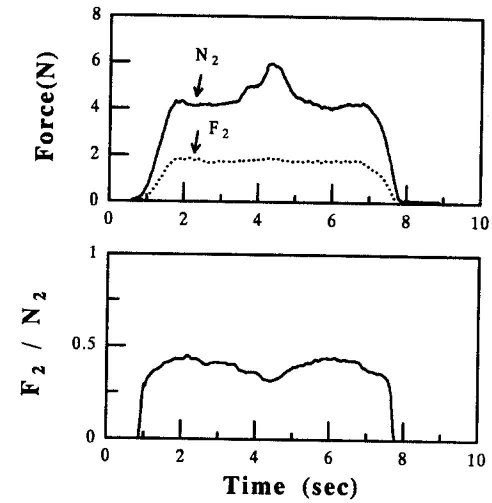

Fig.2 Grasp and friction forces in human grasping

Another way to look at the onset of slipping is to construct a potential function, V_i, such that

$$V_i = F_i - \mu_i N_i \quad (5)$$

which indicates how far a finger is from the edge of slip. But, in general we would like to know not only how far a finger is from the edge of slip, but also whether a given force applied the grasped object will cause it to move closer or farther from the edge, and how fast. Therefore, we define the change in the potential function as

$$\delta V_i = \delta F_i - \mu_i \delta N_i \quad (6)$$

Fig.3 shows that δV_i is plus during releasing the object,which presents that the finger is progressing toward the edge of slip.

From these results, we can see that when a man grasp an object, he can control grasp force successfully with no slip by the friction force, that is, weight of the object which is felt .

3. The hand-over of an object between men

In section 2, we have measured the grasp and friction forces as a man grasps the object and the coefficient of friction between the human fingertips and the object, and investigated the onset of slip.

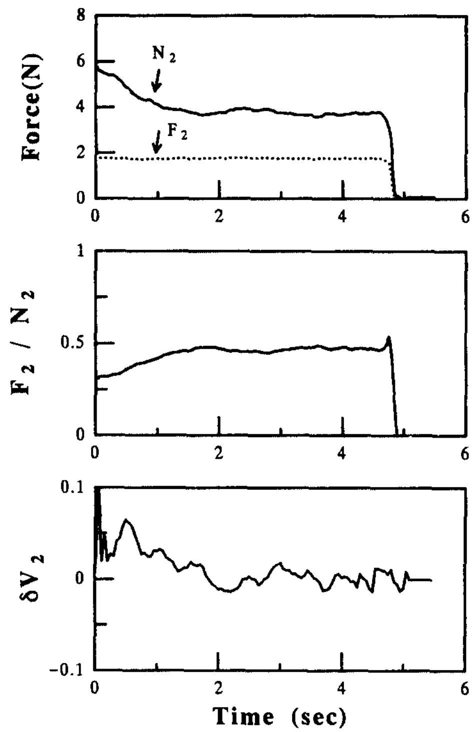

Fig.3 The friction coefficient between fingertips and the object

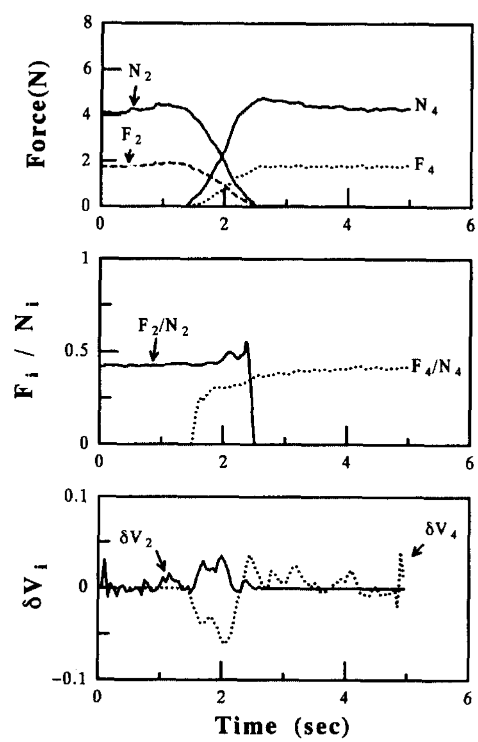

Fig.4 Hand-over of the object between men

Based on these results, we performed the hand-over of the object between men, from the standpoint of applying human's capability to a robot hand control. We used the following procedure. At first, the giver grasps the object at positions P_1 and P_2 with his thumb and middle finger, and then the receiver moves to contact the object at positions P_3 and P_4. And once the contacts are in place, the giver hands over the object to the receiver. For humans, the smooth hand-over of an object seems like a simple task, yet analyzing the details involved shows us that it is very complex and there are many issues to be considered. In particular, we need to consider following three problems.

1) How does the giver know the receiver's contact?
2) Which one starts to act first for controlling the grasp forces?
3) How do both of them control the grasp forces though one doesn't know the force of the other side?

As a matter of course, the giver can know the receiver's contact by visual information. Through experiment, we find that the giver can feel slight vibrations on the fingertips or variations in weight of the object as the receiver contacts the object.

Fig.4 shows the results of the hand-over between men, where N_2, F_2 are the giver's forces, and N_4, F_4 are receiver's. We find that during handing over the object, F_2/N_2 becomes to be greater and closer to μ_2. Also, δV_2 is plus, and δV_4 is minus, which shows that the giver's finger is progressing toward the edge of slip. From this result, we can see that the giver releases the grasp first, and accordingly the receiver grasps the object.

Finally, we can see that the grasp forces of them are controlled by the weights of the object which are felt.

4. Robot hand mechanism and force control

In this research, we constructed a robot hand which consists of two parallel fingers operated by a DC servo motor with harmonic drive through rack-pinion as shown in Fig.5. And, the hand is designed to generated 20 N of force at the fingers.

Fig.6 represents the block diagram of the control system. The hand system can be described such that

$$\frac{\Theta_m(s)}{\Omega_r(s)} = \frac{99.16s + 11919.6}{s(s^2 + 218.36s + 11919.6)} \qquad (7)$$

where Ω_r is the command motor velocity, and Θ_m is motor position. For designing the digital force controller,

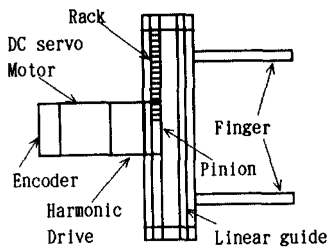

Fig.5 The mechanical structure of a robot hand

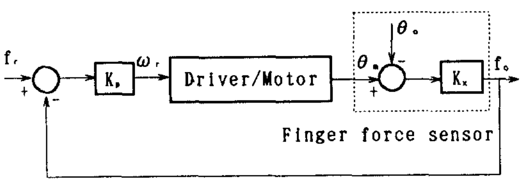

Fig.6 Block diagram of control system

we must determine the finger force sensor stiffness, K_x. In general form, the stiffness of a grasp is a linearized expression of the relationship between forces applied to the grasp and the resulting motions, that is,

$$K_x = \frac{\partial f}{\partial x} \tag{8}$$

The stiffness is easy to determine experimentally, applying known force and recording deflection, so we measured the stiffness is approximately $K_x = 80.0\ N/rad.$.

Based on the equation (7) and stiffness K_x, we obtained controller gain K_p to be 0.25 by simulation.

5. Hand-over of an object between a man and a robot hand

To implement the smooth hand-over of an object from a man to a robot and vice versa, we utilize the results of hand-over between men.

The giver can know the receiver's contact not only by visual information, but also by feeling slight vibrations on the fingertips or variations in weight of the object. During handing over the object, the giver releases the grasp first, and accordingly the receiver grasps the object. The grasp forces of a man and a robot hand are controlled by the weights of the object which are felt.

In this research, although in practice one can't know forces of the other side, for the sake of simplicity the robot hand uses the receiver's grasp force sensor, CH_1 on the object, to detect the human's touching the

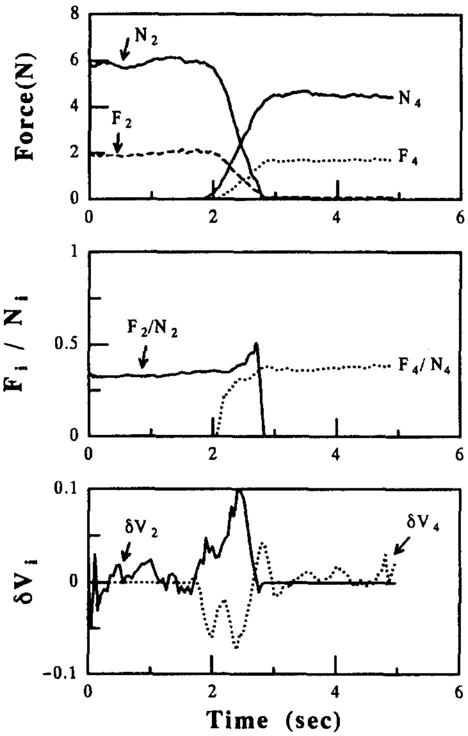

Fig.7 Hand-over from a robot hand to a man

object. And the grasp force of the robot hand is calculated by measuring the weight of the object which is felt such that

$$N_i = \frac{F_i}{\mu_i} \mp \alpha \tag{9}$$

where $-\alpha$ is a decremental force, which is for releasing the grasped object first, and $+\alpha$ is a incremental force, which is for grasping the object with a force greater than the minimum required for lifting the object.

The results of the hand-over from the robot hand to a man are represented in Fig.7, where the coefficient of friction between the robot hand fingertips and the object is approximately $\mu_i = 0.4$ by measurement, and $\alpha = 0.5\ N$, which is obtained by experimentally.

6. Conclusions

For implementing the hand-over of an object between a man and a robot, we have discussed the physiological approach to controlling a robot hand.

We designed a experimental device for grasping or hand-over, and analyzed human's grasping behavior by measuring grasp and friction forces simultaneously as a man grasps the object, and investigated the onset of slip on the fingertips. Based on these results, we then performed the hand-over between men, and proposed a method of the hand-over between a man and a robot by applying human's capability to a robot hand control.

Additionally, we plan to use a 6-axis force/torque sensor to measure the weight of a grasped object and to detect human's touching an object. We also plan to experiment the hand-over of an object between a man and the PUMA 561 robot.

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