Slip Based Pick-and-Place by Universal Robot Hand with Force/Torque Sensors

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***Abstract*—A multi-fingered robot hand receives much attention in various fields. We have developed the multi-fingered robot hand with the multi-axis force/torque sensors. For stable transportation, the robot hand must pick up an object without dropping it and places it without damaging it. This paper deals with a pick-and-place motion by the developed robot hand. In this motion, the robot hand detects a slip by using the multi-axis force/torque sensors and implements the pick-and-place motion according to the detected slip. The effectiveness of the proposed grasp selection is verified through some experiments with the universal robot hand.**

I. Introduction

Recently, various robot hands have been developed so far. The Gifu hand has 5 fingers and 20 joints with 16 DOF [1], and the KH hand type S has 5 fingers and 20 joints with 15 DOF [2]. These robot hands are relatively light weight and are equipped with multi-axis/force torque sensors and the tactile sensors with a conductive ink. The TWENDY-ONE hand has 4 fingers and 16 joints with 13 DOF [3]. This robot hand is equipped with the six-axis force sensors and the array-type tactile sensors. Many other robot hands have been developed and researched all over the world [4], [5]. We have also developed the universal robot hand I [6] and II [7]. The universal robot hand II has five fingers with 20 joints, the array-type tactile sensors, and the multi-axis force/torque sensors.

Slip detection is a essential and important function for a dexterous manipulation of various objects. It is supposed that human is able to grasp an object with a minimum of force using the slip detection. In order to detect the slip in the industrial fields, the slip sensors have been proposed so far. Son et. al. have developed the multi-element stress rate sensor [8]. This sensor has four piezoelectric films in a semi-cylindrical silicon rubber to develop a sensor that detected vibration when a partial slip occurred on the surface of the sensor. Teshigawara et al. have developed a center of pressure (CoP) tactile sensor [9]. This sensor uses a pressure conductive rubber to detect a central position of a load distribution and a total load. This approach cannot detect slip according to the posture and the shape of robot hands. Melchiorri integrated a matrix tactile sensor with a force/tactile sensor to detect linear and rotational slip [10]. This method needs to measure the static friction coefficient of the object beforehand to detect linear slip. Shirafuji et al. used piezoelectric polyvinylidenefluoride (PVDF) films to detect slip [11]. In addition, they achieved slip prevention by strain gauges with neural network processing. This prediction can only be applied to objects that the robot hand has manipulated in precedence. Many other research works concerning the slip sensor have been studied so far [12]–[14]. We have also developed the slip detection with the multi-axis force/torque sensor [15], [16]. When the slip occurs during manipulating the object by the robot hand, torque acting on the robot fingertip changes by the slip. The robot hand can detect the slip by observing the torque acting on the robot fingertip by the multi-axis force/torque sensors. Moreover, we have proposed the anti-slip control based on the slip detection. However, it is difficult to control grasping force because the slip detection method cannot measure slip rate. Therefore, the robot hand must determine the number of the fingers without avoiding the slip.

This paper deals with a pick-and-place motion by the developed robot hand. In order to execute the transportation by the universal robot hand, the robot hand must hold the object during the pick-up motion and release it without giving up excessive force to it. When the robot hand lifts and moves the object, the slip between the robot fingers and the object occurs. Therefore, the robot hand adjust the number of the fingers for pick-up motion according to the occurrence of the slip. In the same way, the robot hand release the object when the slip occurs. The effectiveness of the proposed slip based grasp selection is verified through experiments with the universal robot hand.

II. Hand/Arm Robot with Universal Robot Hand

The hand/arm robot consists of the developed universal robot hand II and an industrial manipulator as shown in Fig. 1. The universal robot hand has 5 fingers like a human hand. The height from the bottom of the palm to the top of the middle finger is 290 mm, the length from the thumb to the little finger is 416 mm when the hand is opened. The PIP joint and the DIP joint synchronize like a human finger. The thumb has 4 DOF (IP joint, MP joint, CM1 joint and CM2 joint), the other fingers have 3 DOF (DIP-PIP joint, MP1 joint and MP2 joint) and the robot hand has 16 DOF.

This robot hand has the tactile sensors on the finger pads, and the multi-axis force/torque sensor in the fingertips. The tactile sensors have 3 layer structures (the electrode pattern

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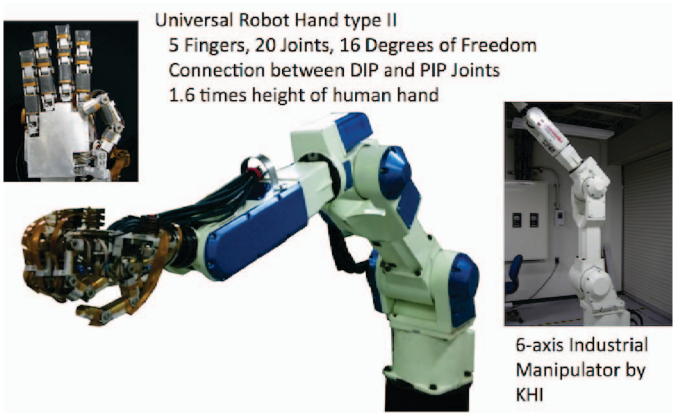

Fig. 1. Hand/Arm Robot with Universal Robot Hand II

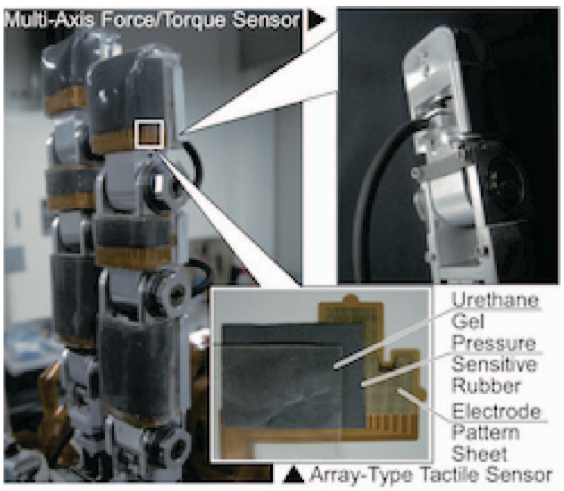

Fig. 2. Universal Robot Hand II with Force/Torque Sensor

seat, the pressure sensitive rubber, and the urethane gel), and this sensor can measure the pressure distribution by contact. The multi-axis force/torque sensors are made by BL AUTOTEC, LTD. and can measure the force and torque applied to the fingertips.

The industrial manipulator is manufactured by Kawasaki Heavy Industries, Ltd. This industrial manipulate has 6 D.O.Fs. The control system for the hand/arm robot consists on the hand controller, the arm controller, and the hand/arm coordinator. The hand and arm controller control the universal robot hand II and the industrial manipulator according to orders from the hand/arm coordinator, respectively. The hand/arm coordinator instructs the hand and arm controller according to facing situation.

III. Slip Based Pick-and-Place by Universal Robot Hand

A. Slip Detection by Force/Torque Sensor

The tactile sensors of the developed robot hand has the urethane gel. When the robot hand picks up an object, the object firstly contacts the urethane gel on the robot fingertip. Here, when an object is subjected to external force during contact between the robot hand and the object, the slip occurs between the robot fingertip and the object.

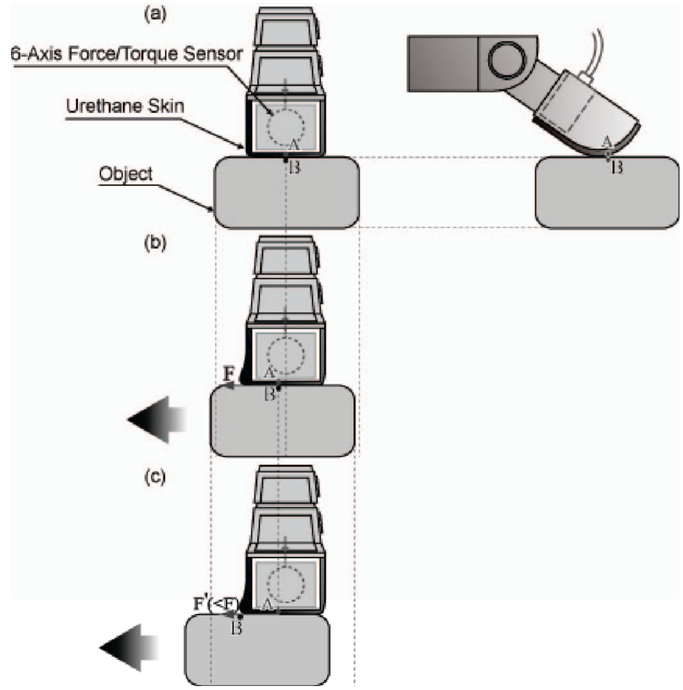

Fig. 3. Procedure of Slip Generation

Figure 3 shows the procedure of slip generation. Here, the contact point A on the robot fingertip and the contact point B on the object are defined as shown in Fig. 3(a). When the object is moved by external force, the contact point B moves in the direction of the external force. In the case that the moving distance is slight, the contact point A and the contact point B keep the contact as shown in Fig. 3(b) because the external force deforms the urethane gel on the robot fingertip. Here, the robot fingertip is subjected to the static frictional force F according to the external force. If more external force is applied to the object, the contact point A and the contact point B are separated as shown in Fig. 3(c). At this time, the slip occurs between the finger and the object. When the slip occurs during contact between the robot hand and the object, the robot fingertip is subjected to the kinetic friction force $F\prime$. If the universal robot hand recognizes the static frictional force F as shown in Fig. 3(b), the generation of the slip can be detected. Here, the torque measured by the force/torque sensors is varied by the generation of the slip. Consequently, the slip is detected by observing the torque of the robot finger. In this method, the robot hand calculates the standard deviation of the torque at 50 steps before the current step. If the standard deviation of the torque is higher than the predefined threshold, the system recognize the generation of the slip.

B. Slip Based Pick-Up Motion

In the pick-up motion by the multi-fingered robot hand, there is a weight limitation of an object according the number of the robot fingers. Figure 4 shows the flowchart of the slip based pick-up motion. In this motion, firstly, the robot hand uses 2 fingers in order to pick up an object. Here, if it is lighter than the object which the 2 fingered robot hand can pick up,

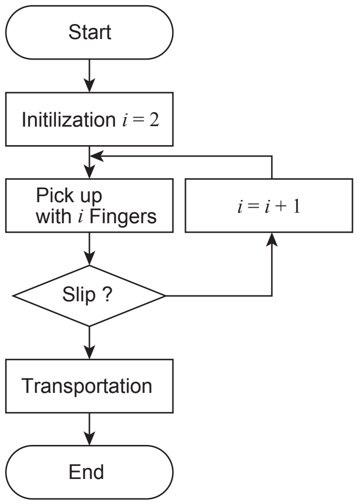

Fig. 4. Flowchart of Slip Based Pick-Up Motion

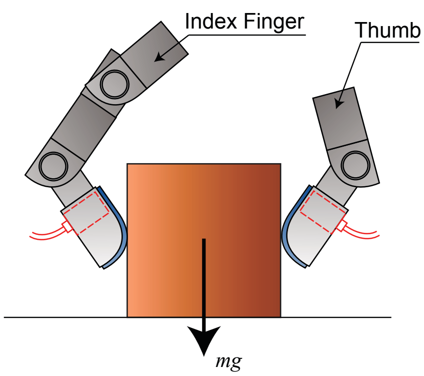

Fig. 5. Pick-Up Object

the robot hand picks up it in order to transport it. Otherwise, the slip between the robot fingers and the object occurs. In this case, the robot hand adds more fingers for picking up without dropping the object. Therefore, the robot hand can pick up the object with the minimum numbers of robot fingers by the slip based pick-up motion.

An experiment is carried out for verifying the slip based pick-up motion as shown in Fig. 5. In this experiment, the system measures the torque when the robot hand picks an object up. The robot hand cannot pick the object up by using 2 fingers, but can pick up by using 3 fingers. Figure 6 shows the the standard deviation of the torque at 250 steps before the current step in this experiment. Here, the robot hand uses 2 fingers till around 25 (s), and then 3 fingers from around 30 (s). In this figure, the peak value around 15 (s) generates when the 2 fingers contact the object and the peak value around 35 (s) generates when the 3 fingers contact. The peak value around 20 (s) generates when the robot hand drops the object because the object cannot be picked up by 2 fingers. In fact, the standard deviation of the torque increases by occurring the slip between 2 fingers and the object. Then, the robot hand increases one more fingers in order to pick the object up. Consequently, the robot hand can pick the object up by using 3 fingers around 35 (s).

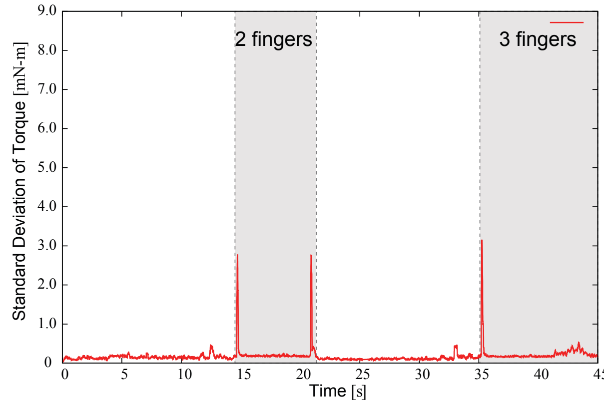

Fig. 6. Pick-Up Motion with 2 or 3 Fingers

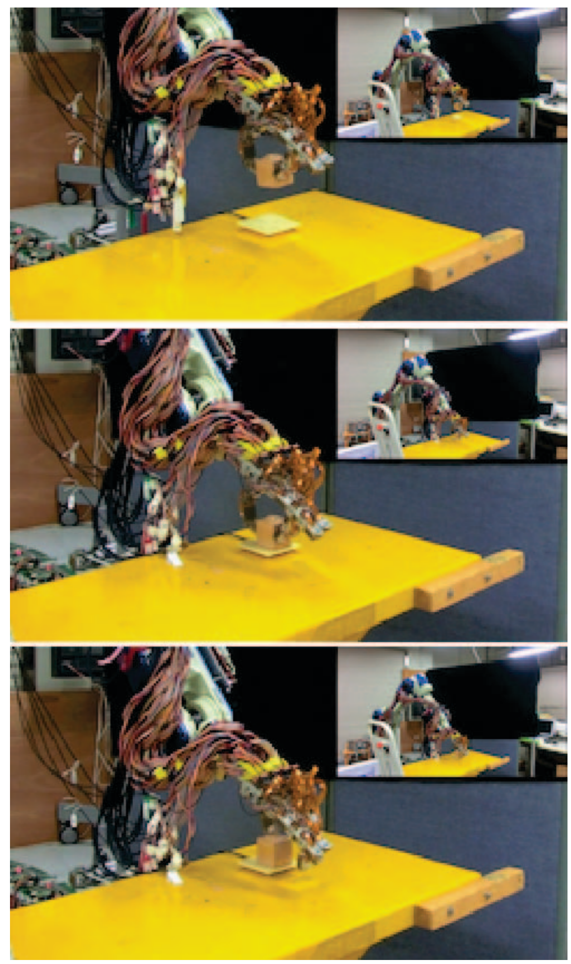

Fig. 7. Experiment for Slip Based Place Motion

C. Slip Based Place Motion

When the robot hand places the object, the robot must avoid breaking up it. Here, if the high pressure is produced downward by holding it, the robot breaks up it. Moreover, in this case, the slip between the robot fingertip and the object occurs. In this method, the robot hand release his fingers from the object when the slip occurs.

An experiment is carried out for verifying the slip based

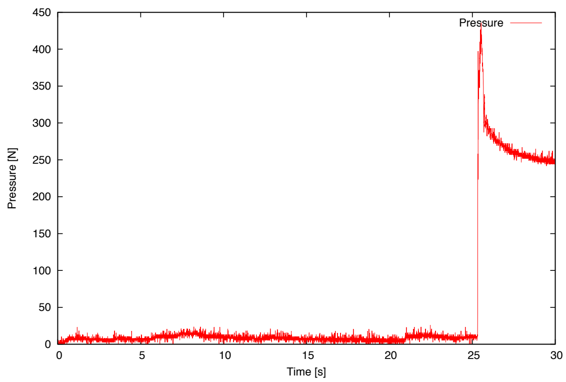

Fig. 8. Experimental Result w/o Slip Based Place

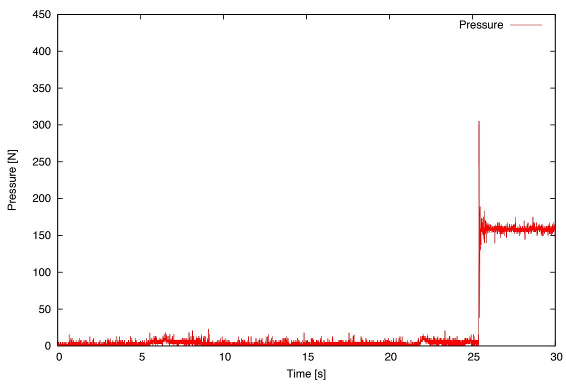

Fig. 9. Experimental Result with Slip Based Place

place motion as shown in Fig. 7. In this experiment, the robot hand measures the torque in order to recognize the slip and the system measures the pressure on a desk by a force/torque sensor. Figure 8 and 9 show the experimental result without and with the proposed slip based place, respectively. In this experiment, the robot hand transports the object until 25 [sec] and then places it around 25 [sec]. In the case that the robot hand does not use the slip based place, the robot hand gives the force downward after 25 [sec]. However, by using the slip based place, the robot hand does not give excessive force to the object as shown in Fig. 9.

IV. Conclusion

This paper proposed the pick-and place motion by the developed robot hand. In order to execute the transportation by the universal robot hand, the robot hand must hold the object during the pick-up motion and release it without giving up excessive force to it. When the robot hand lifts and moves the object, the slip between the robot fingers and the object occurs. We had developed the slip detection with force/torque sensor in order to avoid dropping the object. Moreover, the robot hand adjusted the number of the fingers for pick-up motion according to the occurrence of the slip. In the same way, the robot hand released the object when the slip occurred The effectiveness of the proposed slip based grasp selection was verified through experiments with the universal robot hand.

The robot hand adjusted the number of the fingers not only in the pick-up phase but also in the transportation phase. In the transportation phase, the robot hand must consider force, such as centrifugal force, in the same manner as gravitation. In the future work, a adjustment method of the number of fingers is proposed in consideration of force which the object has in the transportation phase.

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