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TRAJECTORY OF CENTER OF PRESSURE AND POSTURE OF FINGERTIP DURING LIFTING TASK

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SUMMARY

In this paper we conducted analysis of lifting task focusing on the trajectory of center of pressure (*CoP*) and posture of fingertip while human subjects lift up, hold and replace an object with their index finger and thumb. *CoP* was computed from the forces and torques measured by a 6-axis force sensor installed in the lifted device, while posture of the index finger and thumb was measured by a motion capture system and three optical markers attached to the fingernail and thumbnail. The result of the lifting task experiments under different friction and weight conditions showed coordination between the grip force and load force. The trajectories of the *CoP* during the lifting task had similar trend regardless of the experimental conditions, and were divided into two distinct phases. From the data of finger posture, the first phase was speculated due to change in the finger posture coming in contact with the device, while the second phase was speculated due to skin deformation in the direction of the load force.

INTRODUCTION

Human can lift up an object with adequate grasping force and without slippage even when the weight and friction of the object are unknown. Johansson *et al*. showed that the grip force changed in parallel with the load force to overcome various forces counteracting the intended manipulation [1]. The balance between two forces provides a relatively small safety margin to prevent slips.

Unlike previous studies that extensively dealt with the coordination between the grip force and load force, in this paper we conduct analysis of lifting task focusing on the trajectory of the *CoP* and posture of an index finger during precision grasp.

METHODS

Figure 1 shows the device used in our experiment. Both sides of the device (Figure 1 (a) for an index finger and (b) for a thumb) are composed of detachable disks with radius of 30mm supported by 6-axis force sensors (NANO-1.2/1-S30, Bl. Autotec, Ltd.). We prepared three conditions for the friction, sand paper (No.100), polyethylene plate and release paper of double–faced adhesive tape. Also, we prepared three conditions for the weight, 300g, 500g and 700g, by hanging a plumbic sinker at the bottom of the device as shown in Figure 1 (c). Thus each subject performed lifting task in nine different conditions. For measuring posture of the device as well as that of finger and thumb, optical motion capture system (Vicon MX40, Vicon Co., Ltd) was used. For this purpose, three optical markers were attached to the fingernail and thumbnail, while eight optical markers were attached to the central column of the device for computing the finger posture relative to the contact surface. During the experiment, the force and torque data were sampled at 400 Hz by a 16-bit AD converter connected to the motion capture system, while the position of the optical markers were sampled at 100 Hz. All the sampled data were stored in a CSV file for further off line data analysis.

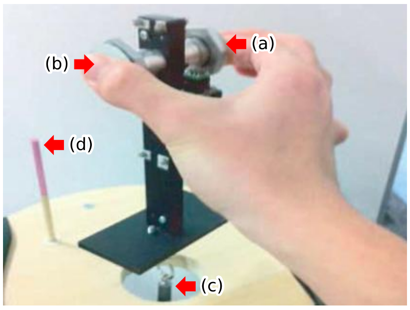

Fig. 1: Measurement device for the lifting task experiment.

The *CoP* at each time frame was computed from equation (1) by using the measured forces and torques, and constraint that the *CoP* was always on the contact surface [2]

$$CoP = \frac{1}{\|\boldsymbol{f}''\|}\left(\boldsymbol{f} \times \boldsymbol{t} + R\|\boldsymbol{f}''\|\boldsymbol{f}\right), \qquad (1)$$

where $\boldsymbol{f}$ is the force vector, $\boldsymbol{t}$ is the torque vector, $\boldsymbol{f}''$ is the force component parallel to the normal direction of the contact surface, R is the distance between the origin of the 6-axis force sensor and contact surface. The posture of finger and thumb relative to the contact surface were computed from the measured marker positions by multiplying inverse of rigid body transformation matrix representing the motion of the device.

Three right-handed healthy subjects (1 woman and 2 men, from 22 to 37 years old) participated in the present study. Each subject lifted up the device placed on a table about 100 mm from the tabletop indicated by thin bar shown in Figure 1 (d), held it for about 5.0 seconds, and replace it to the initial position, after having preliminary trials to be well adapted to each experimental condition. Thus in this experiment we did not consider effects of order.

RESULTS AND DISCUSSION

All plots in this paper were obtained from the force sensor in the index finger side and were the average of all trials across all subjects.

Figure 2 (a) and Figure 3 (a) show the grip force (solid line) and the load force (dot line) during the lifting and holding for different friction and weight conditions, respectively. Overall tendency of these forces were consistent with those reported in Johansson’s article. The grip force increases as the coefficient of friction decrease, while both the grip force and the load force increase as the weight of the device increase. The coordination between the grip force and the load force was clearly demonstrated in Figure 4 (a) for different friction and (b) for different weight.

The trajectories of the *CoP* in the vertical direction were shown in Figure 2 (b) for different friction and Figure 3 (b) for different weight. In these plots, the trajectories were biased so that they will be zero when the device was held stably. The trajectories of the *CoP* had similar trend in all conditions, although there were slight differences in recovery rate from 0.1 to 1.0 seconds in Figure 2. They started from approximately zero and moved downward for the first 0.1 seconds (first phase). Then they gradually moved upward and finally got to the stable position (second phase). Considering the fact that the trajectories took the lowest position when the load force begun to increase, the trend in the trajectories was speculated to have direct relation with the posture of the fingertip.

The posture of fingertip relative to the contact surface computed from the measured marker positions were shown in Figure 5. Figure 5 (a) illustrates the postures at the first and the last time frame of the first phase, while (b) illustrates those at the first and the last time frame of the second phase. These two figures clearly demonstrate that there was change in the finger posture coming in contact with the device in the first phase, while there was translational finger movement along the direction of the load force in the second phase. These change in posture and translational motion were speculated to be the dominant cause of the trends observed in the trajectories of *CoP*. Interestingly the distance between the lowest position and stable position was about 2.5 to 3.0 mm for all conditions, although the contact force, especially the grip force differ among conditions. This suggests that the change of contact region induce by the lateral skin deformation differs depending on the coefficient of friction, and the lateral skin stiffness increases as the grip force increase.

CONCLUSIONS

In this paper we conducted analysis of lifting task focusing on the trajectory of the *CoP*. It was shown that the trajectories of the *CoP* during the task had similar trends regardless of the experimental condition, especially the distance between the lowest position and stable position was about 2.5 to 3.0 mm for all conditions.

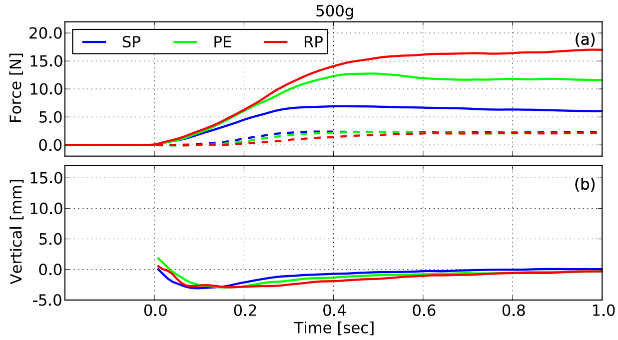

Fig. 2: Result of the experiment for different friction conditions when the weight was 500g.

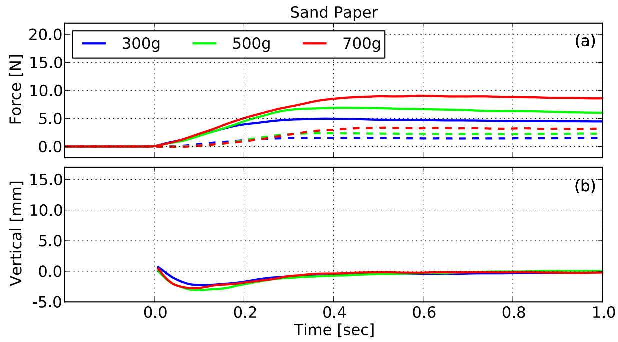

Fig. 3: Results of the experiment for different weight conditions when the contact surface was sand paper.

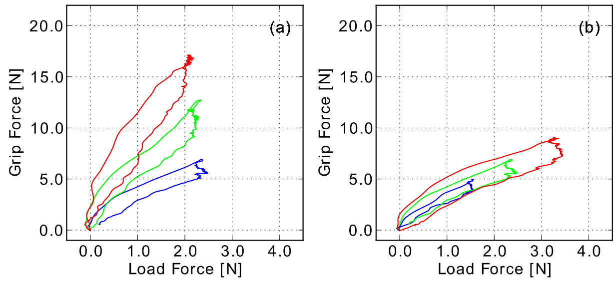

Fig. 4: Coordination between grip force and load force.

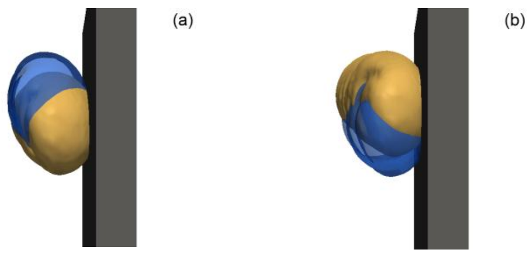

Fig. 5: Postures of fingertip during the lifting task, (a) first phase and (b) second phase.

REFERENCES

1. R. S. Johansson and G. Westling: “Roles of glabrous skin receptors and sensorimotor memory in automatic control of precision grip when lifting rougher or more slippery objects”, Experimental Brain Research, p.550–563, 1984.
2. A. Bicchi: “Intrinsic contact sensing for soft fingers”, IEEE International Conference on Robotics and Automation, pp.968–974, 1990.