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POWER ASSIST SYSTEM FOR CARRYING A LONG OBJECT WITH A HUMAN

(ANALYSIS OF HUMAN COOPERATIVE BEHAVIOR)

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1. Introduction

We study about a power assist system for carrying a long object with a human operator. When we carry such a long object, we grasp its ends and move it cooperatively. Our purpose is to establish how to design a power assist system which achieves such a task with a human operator. The system contains a robot arm, a force sensor and a controller. In the system, since it is difficult to measure the force applied by the human operator, we can not apply the conventional power assist method [Hayashibara 1995]. On the other hand, the humans can achieve such a task based on only the forces imposed on his/her hands. Therefore, we measure and analyze the human cooperative behaviors under carrying a long object, so that we apply them to the power assist system. In this paper, we show an experimental setup for acquiring the human cooperative behaviors and discuss about how to measure and analyze them. Then, we propose a model of the human cooperative behaviors in the horizontal line.

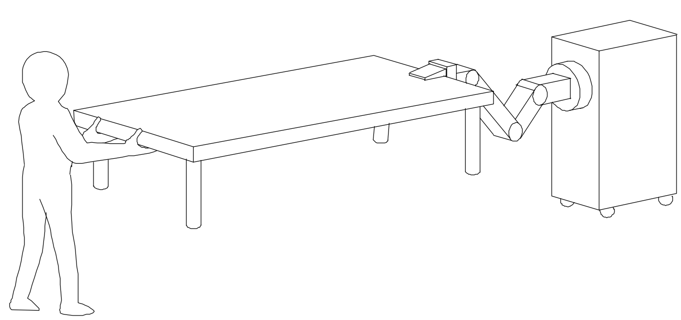

Figure 1. The power assist system under carrying a long object with a human

2. Experimental Setup

The figure 2 shows the experimental setup. It measures tracking motions and forces of the subjects under carrying a long object cooperatively. Two subjects hold the handles in their both hands and carry an object face to face with each other. One subject is given the target area on the computer display and tries to carry the object to the target area. We call him/her as a master. Another subject with a blindfold is not given the target area. He/She carries the object based on only the forces imposed on his/her hand. We call him/her as a slave. The specification of the object is the following. The distance between the handles is 1.0(m). The weight is 7.0(kg). Two six-axes force/torque sensors (NITTA JR3) are attached at its ends. Each sensor measures the force applied to the arm's tip of each subject. The tracking vision (OKK G220) with a CCD camera tracks two black markers on the top of the handles. Then, it calculates the position and the posture of the object. These measured values are stored in a computer (NEC PC-9821As) each 0.05(s). On the computer display, it indicates two symbols. Each symbol moves according to the position of the target area and the center of the object. The symbol '□' corresponds to the target area and the symbol '＋' corresponds to the object. The size of the symbol '□' is implied the size of the target area (0.05(m)×0.05(m)). When the subjects carry the object to the target area and keep inside for 2.0(s), the target symbol '□' moves discretely according to the position of the next target. When this task is repeated 6 times or the period of the experiment is over 20.0(s), the experiment will be finished.

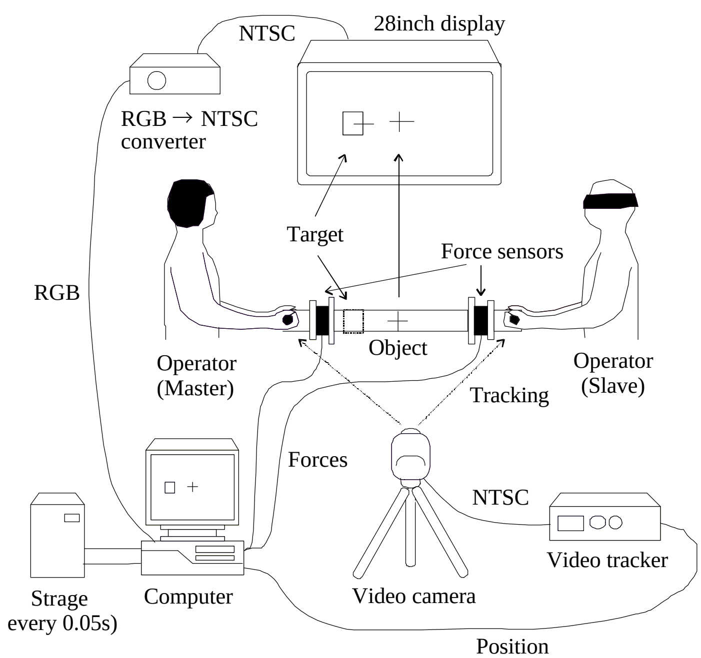

Figure 2. The experimental setup

3. Experimental Method

Using the above experimental setup, we measured cooperative behaviors in the horizontal direction through the subjects. The positions of the target area were determined randomly on the horizontal line 0.4 long previously. The origin of the measurement was placed near the center of the object when the experiment is started. At that time, the subjects stood with straightening his back and held the handles with closing their sides like the figure 2.

Before the experiment, we explained about the experiment and asked the followings: 1) move the object to the target area as quick as possible, 2) keep the object level with the ground, 3) fix their own bodies and move only their arms. Furthermore, we also asked the subjects to practice the operation until he/she thought themselves to become skilled (at least 5(min)). In the practice, we used a set of target positions different from one for the experiment. The experiment was performed by five males in their twenties.

4. Experimental Results

The figure 3 shows one of the experimental results. Other results are similar. The upper one illustrates horizontal trajectories of the centers of the object and the target area. The lower one illustrates the forces applied to the arms' tips of the master and the slave. In the figure, we find that the subjects can carry the object to the target position smoothly and the forces applied on two subjects are almost symmetric with respect to the horizontal axis. It means that the master generates the forces to carry the object, the slave applies the opposite forces from them. Then, we can consider its behavior as a part of a load. When the slave is applied force from the master, he/she may generate assist force in the same direction. However, it is less

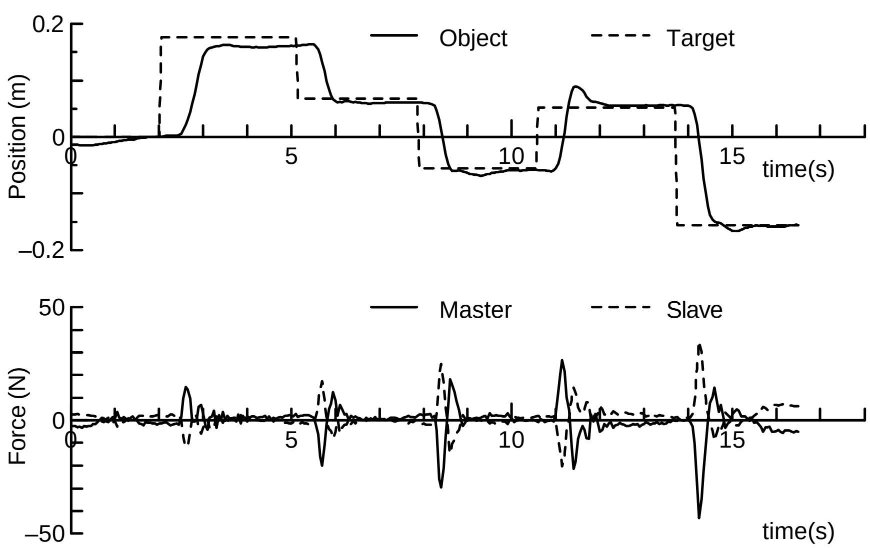

Figure 3. The experimetal result

than the force enough to move his/her hand with a desired velocity. In consequence, we can find that the dynamics of the arm's tip of the slave can be described as sum of inertia and viscous friction as the following equation:

$$f_s = m\ddot{x}_s + b\dot{x}_s \tag{1}$$

where f_s is the force applied to the slave. $\dot{x}_s$ and $\ddot{x}_s$ are the velocity and the acceleration of the arm's tip respectively. Therefore, m and b correspond the coefficients of the inertia and the viscous friction at the arm's tip respectively. From this equation, we can estimate the acceleration of the arm's tip $\ddot{x}_{sest}$:

$$\ddot{x}_{sest} = \frac{f_s - b\dot{x}_s}{m} \tag{2}$$

The figure 4 shows the estimated acceleration $\ddot{x}_{sest}$ derived from the equation (2). It also shows the acceleration $\ddot{x}_s$ derived from the measured position. The acceleration $\ddot{x}_s$ is obtained by calculating a difference and applying a low pass filter with the time constant t = 0.05(s) twice for the measured position x_s. The values of the model's parameters are decided heuristically as m = 8(Ns^2/m), b = 20(Ns/m). We can find that the model is almost appropriate to describe the dynamics of the arm's tip of the slave. However, the estimation at low frequency band is not so appropriate. Therefore, we also add a high pass filter to the model as the figure 5. The figure 6 shows the measured acceleration and the estimated acceleration derived from the model in the figure 5 with the time constant T = 1.0(s). We can find that the estimation is more appropriate. Because, even if the subjects stay the object, they sometimes apply a certain force. When the human carries an object cooperatively, such forces at low frequency band may not cause motion. This high pass filter is efficient to eliminate such inner forces. In consequence, it may be appropriate to apply an impedance controller with a high pass filter based on the figure 5 to the power assist system in the horizontal line.

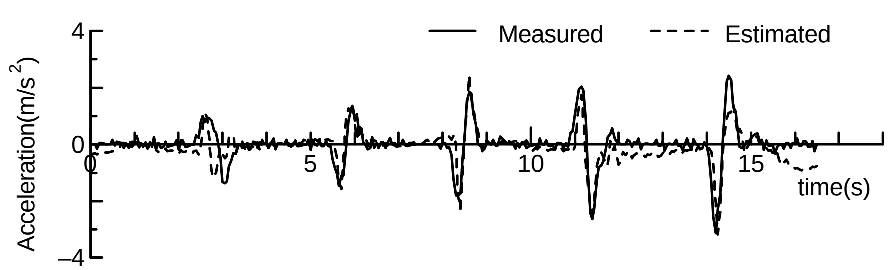

Figure 4. The estimated acceleration and the measured acceleration

m = 8, b = 20

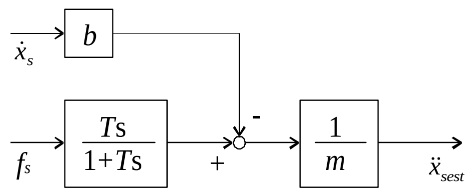

Figure 5. The model of the arm's tip of the slave

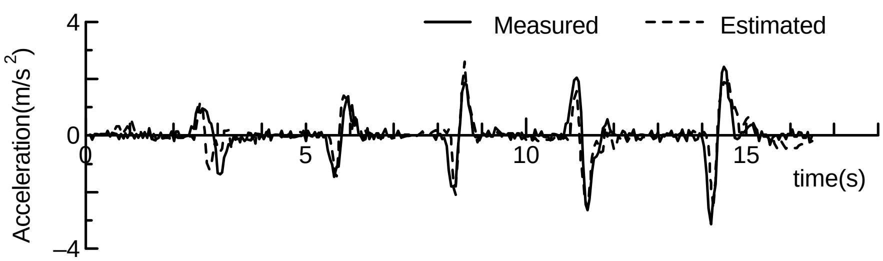

Figure 6. The estimated acceleration with the high pass filter

m = 8, b = 20, T = 1.0

5. Conclusion

In this paper, we have discussed how to design the controller of the power assist system, which carry a long object with a human operator. Since humans can achieve such a task, we made an experimental setup and acquired a human cooperative behavior in the horizontal line through the operators. In consequence, we found it may be appropriate to apply an impedance controller with a high pass filter to the power assist system in the horizontal line.

To establish the control law of the power assist system, the following will be studied in the future:

1. Measuring the human cooperative behavior in all directions,
2. Confirming the effectiveness of the control law by using the experimental power assist system.

6. Acknowledgement

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