Device for Assisting Grasping Function
(2nd Report : Maneuverability Evaluation)

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Abstract: A wearable device to assist fingering function for disabled is developed in this study. This is the second paper to report the progress in development of this assisting device. The device is developed for a patient who suffers from cervical spinal cord injury. In the first paper, it was reported that the patient could successfully pick up several types of objects with his paralyzed fingers by using this device. As a next step, the maneuverability of the device under grasping operation is discussed in this paper. Maneuverability of the system is experimentally evaluated. The dexterity in controlling finger force is compared between the cases that non-disabled examinees operate their finger with inherent abilities and that a disabled examinee operates his finger by using the assisting device.

Keywords: Mechanical glove, Muscle stiffness, Grasping function, Maneuverability Evaluation

1. INTRODUCTION

This study started with a request from a patient, a 23 year old male, who had an accident during rugby football training, damaging his cervical spinal code. As a result, he is disabled in his lower body and all the fingers in both hands. With a wheel chair he can move around. However the disability of his fingers causes significant inconvenience in his daily life. The purpose of this study is to develop mechanical assistance for disabled people like this patient to recover their disabilities and improve their QOL.

A wearable device is developed to recover the patient's fingering function. This device is put on operator's hand and helps his fingering function. Operator's forefinger is guided toward his fixed thumb by the mechanical glove. The forefinger is actuated by an air cylinder based on an operator's command signal. An unique sensor is developed in this study and used as a man-machine interface to control the device. The sensor is attached to one of his sound muscles called Flexor Carpi Ulnaris for wrist flexion. He can comfortably control its activation level. The muscle is called as command muscle since he can operate the assisting device through the activation of the muscle. The sensor detects the muscle activation level non-invasively. Based on the muscle activation level, the grasping timing and force are determined. It is confirmed through experiments that the patient can pick up small daily necessaries such as a pen and a cup with his finger by using this assisting device. The detail of the system configuration is described in the first report (Moromugi at el. [1]).

In this paper the maneuverability of the assisting device under fingering operation is evaluated through experiments.

2. CONFIGURATION OF DEVICE

Fig.1 shows the configuration of the assisting device. This device is composed of a mechanical glove, a muscle stiffness sensor, an air control unit and a computer. The operator sends command signals to the controller through the muscle stiffness sensor attached on his arm. The controller regulates air pressure inside the air cylinder of mechanical glove based on the command signals so that the fingering operation is achieved based operator's intention.

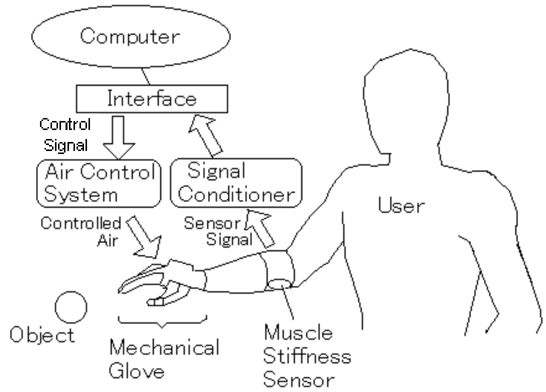

Fig. 1 Configuration of the assisting device

2.1 Mechanical glove

Fig.2 and Fig.3 show the developed mechanical glove and its structural sketch respectively. The mechanical glove is composed of a finger frame to flex a forefinger and a base to be attached on the hand and an air cylinder mounted on the base. The finger frame consists of three links, link 1, link 2 and link 3 as shown in the Fig.3. Each link is connected by small sub-links each other. All joints of the finger fame are driven simultaneously with the actuation of an air cylinder. The total weight of the mechanical glove is 110[g].

Fig.2 Mechanical glove

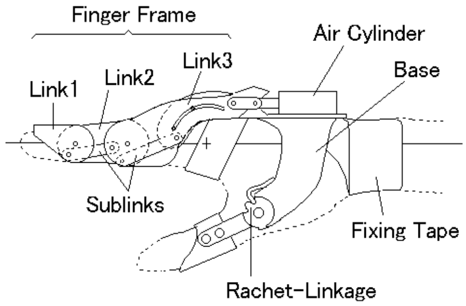

Fig.3 Structure of mechanical glove

Fig.4 Muscle stiffness sensor

2.2 Muscle stiffness sensor

An innovative sensor is developed as a man-machine interface to detect operator's intention for controlling the assisting device (Moromugi et al. [2]). The sensor detects stiffness information form a target muscle. The activation level of the muscle can be estimated from the obtained stiffness data of the muscle because the muscles always get stiff when they act. The muscle activation obtained from the sensor is used to derive a command signal thus the operator can maneuver the mechanical glove with desired force at proper timing. It would be the best if the muscle of the operator's forefinger were still active and available as command muscle. However, muscles of the operator's fingers are completely inactive. Thus the muscle, Flexor Carpi Ulnaris, that is originally for wrist flexing is used as the command muscle.

Fig.4 shows the muscle stiffness sensor. This sensor has two components, a flat disk (32mm in diameter and 12mm in thickness) and a button (6mm in diameter and 4mm in height) in the center of the disk. The whole weight of the sensor without the cable is 34g. This sensor is attached on the target muscle and tightened by a belt. Two small pressure sensors are used to measure the force loaded on the button and the force on the entire sensor.

The stiffness is represented by stiffness parameter S which is a function of these two forces.

2.3 Control System

Fig.5 shows the configuration of the control system. A personal computer (PC) sends and receives signals through a Field Programmable Gate Array (FPGA) to control the air cylinder of the mechanical glove. Muscle stiffness information and air pressure inside the air cylinder are fed to the PC through a signal conditioning circuit. FPGA generates Pulse Width Modulation (PWM) signals to control solenoid valves. A pair of solenoid valves is used to control air pressure of each chamber of the air cylinder. One is for pressuring and the other is for exhausting. Air pressure inside the both chambers is always monitored with air pressure sensors. A duty ratio of PWM signal is decided to control each valve so that the pressure inside the air cylinder always follows the reference pressure. The reference pressure is given by the equation (1).

$$\begin{aligned} P_{RE} &= P_B \\ P_{RF} &= P_B - P_{0F} + K \times S \end{aligned} \tag{1}$$

where,

P_{RE} : Reference pressure of chamber for extending
P_{RF} : Reference pressure of chamber for flexing
P_B : Base pressure
P_{0F} : Offset pressure for extending finger under no command signals
K : Control gain
S : Muscle stiffness parameter

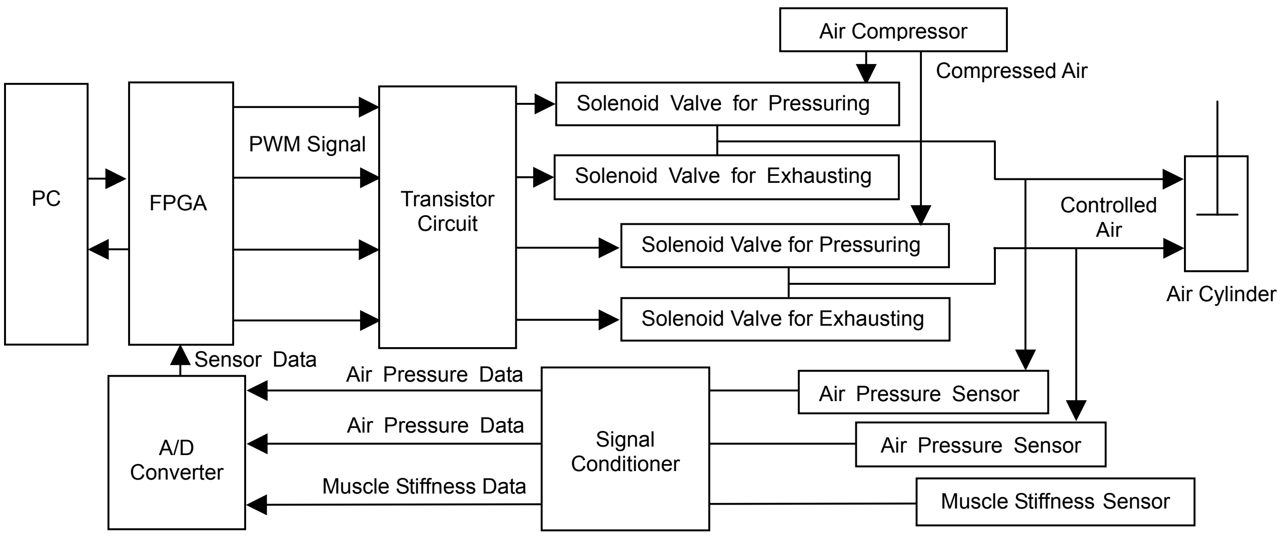

Fig.5 Control system

The compressed air is supplied from an air compressor to the solenoid valves for pressuring.

3. MANUVERABILITY EVALUATION

People operate their fingers very dexterously with delicate control. The assisting device must have enough maneuverability for users. Maneuverability of the assisting device is evaluated through experiments comparing the controllability of pinching force achieved with the assisting device and the inherent ability of non-disabled people.

3.1 Experiments

The accuracy of the pinching force is compared between the case of the patient with the assisting device and the case of non-disabled examinees with their own ability. Before the maneuverability evaluation, the basic property of the assisting device is examined. The pinching force of the mechanical glove is recorded under stepwise input signal. Eq.(1) shows the control algorithm of the assisting device. The mechanical glove is kept opened under the condition that the command muscle is relaxed. As the command muscle is activated, the pressure inside the cylinder chamber for flexing finger is increased. Fig.6 shows the pinching force measured under a stepwise input signal. The maximum pinching force is about 2.3 [N]. This limitation of pinching power comes from the capability of air compressor. There are also limitations of increasing/decreasing ratio of pinching force. The maximum increasing and decreasing ratio of the pinching force is about 0.5[N/s] and 0.75[N/s] respectively. This limitation comes from the capability of solenoid valves. Based on these limitations, the amplitude and the frequency of the reference pinching force are decided for the maneuverability evaluation.

The patient introduced at the beginning of this paper and 3 non-disabled examinees take part in this experiment. All examinees are male. Examinee A, examinee B and examinee C are 30, 32 and 22 year old respectively. In the experiment, examinees pinch a pressure sensor with their forefinger and thumb. The pinching force measured by the pressure sensor is displayed on the computer screen. A reference pinching force that is sinusoidal curve with amplitude 0.7[N] and randomly variable frequency, 0.18-0.25[Hz] is also displayed on the screen. The examinee is required to control the pinching force to be equal to the reference force for 15 second during the experiment. The Root Mean Square Error (RMSE) between the measured pinching force and the reference pinching force is recorded as a score to evaluate the maneuverability. The Experiment is conducted for three cases.

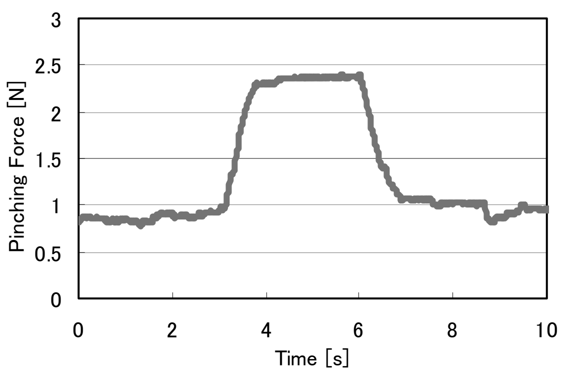

Fig.6 Pinching force of mechanical glove under step input

Case1: A disabled patient executes pinching operation using the assisting device. (Fig.7)
Case2: Non-disabled examinees execute pinching operation using their own fingering function. (Fig.8)
Case3: Non-disabled examinees execute pinching operation using the assisting device. (Fig.9)

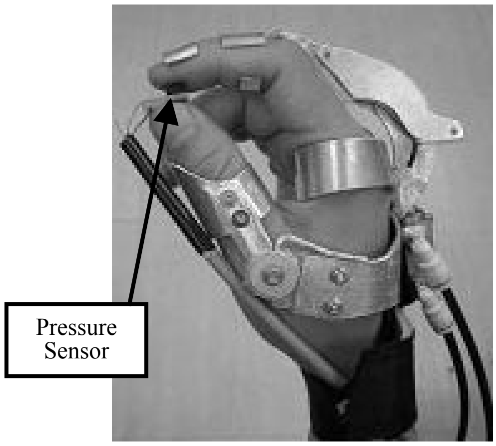

Fig.7 Case1: Fingering operation of patient with assisting device

Fig.8 Case2: Fingering operation of non-disabled examinee

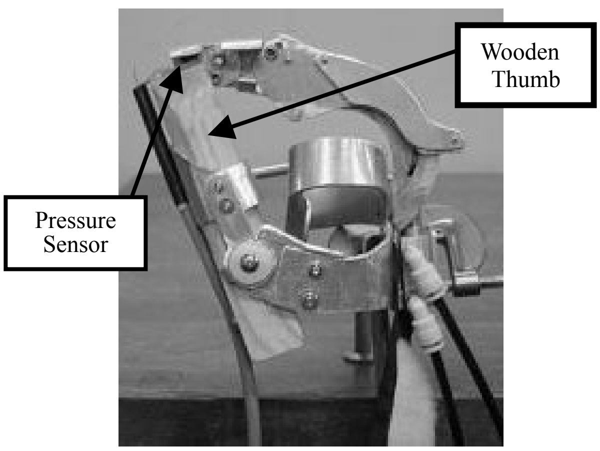

Fig.9 Case3: Fingering operation of non-disabled examinee with assisting device

In the Case3, the mechanical glove is tested on a bench because it is found out that finger moves unconsciously when the non-disabled examinee try to operate the mechanical glove. A wooden thumb is attached to the mechanical glove to set a pressure sensor on it instead of the operator's finger so that pinching force can be measured without unintentional affect of examinee's muscular function.

3.2 Results

Fig.10 shows patient's pinching force measured in the experiment of Case1. It is clear that the patient succeeded to control the assisting device to match the pinching force to the reference force displayed on the computer screen. Fig.11 and Fig.12 show examinee A's pinching force measured in the experiment of Case2 (without assisting device) and Case3 (with

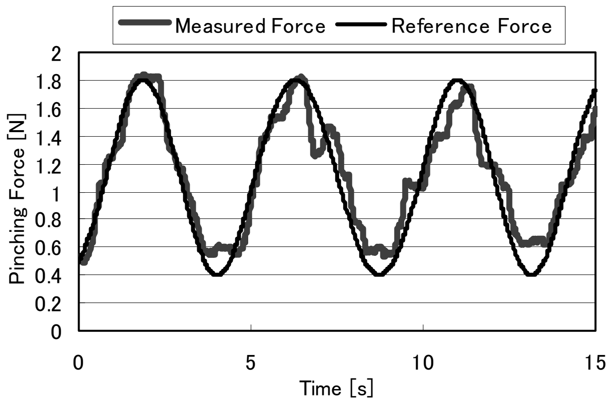

Fig.10 Experimental data of patient (Case1)

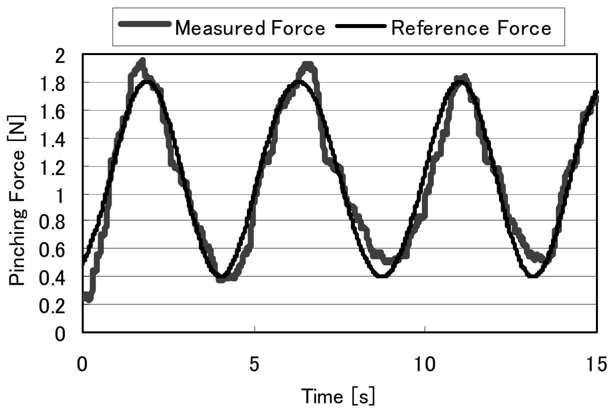

Fig. 11 Experimental data of Examinee A (Case2)

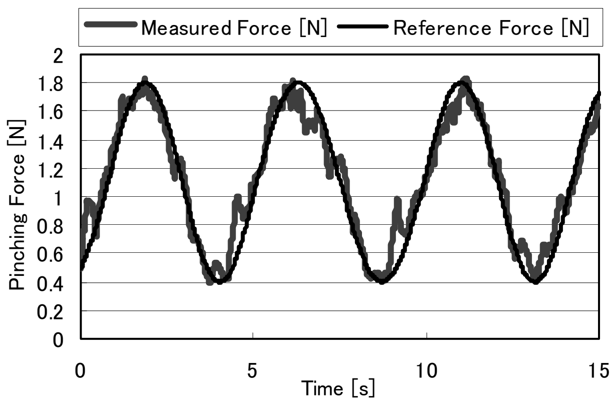

Fig.12 Experimental data of Examinee A (Case3)

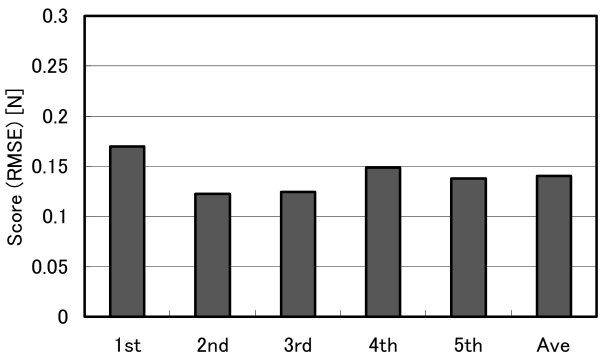

Fig.13 Score (Case1)

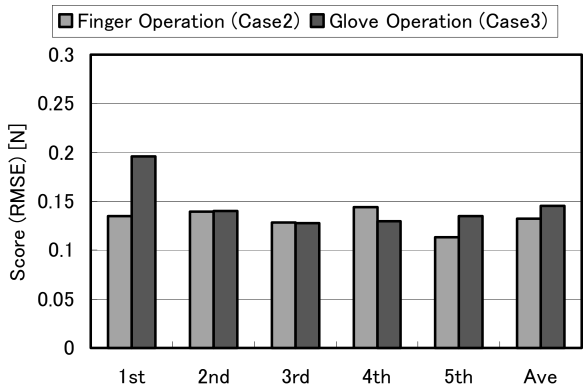

Fig.14 Score of examinee A (Case2 & Case3)

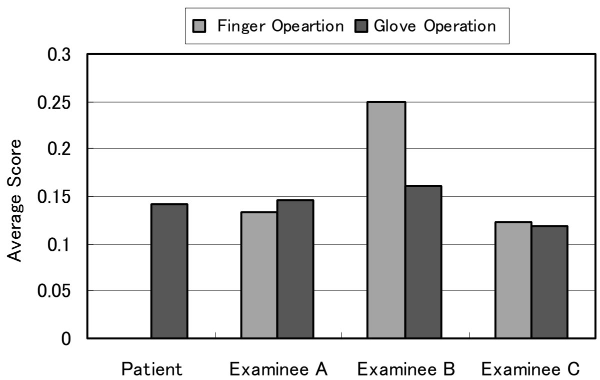

Fig.15 Five times average score of all examinee (Case1, 2 and 3)

assisting device) respectively. The data of Case2 are rather smoother than that of Case3 however no remarkable difference can be recognized in the amount of error under finger force control between these two cases. The patient's scores obtained through five measurements and the average value are shown in Fig.13. Learning effect can be recognized at the first part of the measurements. Fig.14 shows the examinee A's score of five measurements in both Case2 & Case3. It can be seen that the level and the tendency of the error is quit similar between these three data in Fig.13 and Fig.14. Similarly, the same measurement is repeated for the examinee B and examinee C. The average score of all the examinees are shown in Fig.15. By the help of assisting device the patient's score becomes similar to that of non-disabled examinees. The assisting device successfully recovers patient's fingering function and achieves the similar level of dexterity on controlling the finger force.

6. CONCLUSIONS

A wearable device that assists fingering function is developed for a disabled patient and its maneuverability is experimentally evaluated. Dexterity on controlling fingering force is evaluated in the following three cases. In the first case a patient who completely disabled fingering functions operated his finger by the help of the assisting device. In the second case non-disabled examinees operated their finger by their own ability. In the third case non-disabled examinees operated their finger indirectly by using the assisting device. No remarkable difference can be recognized in dexterity of fingering operation between these three cases. It can be said that the assisting device developed in this study recovers fingering function of disabled with the equivalent level to that of ordinary people on finger force control. It is demonstrated that the assisting device has enough maneuverability for its control through the experiments.

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