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Wearable Power Assist Device for Hand Grasping Using Pneumatic Artificial Rubber Muscle

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Abstract: The purpose of this study is to develop a wearable power assist device for hand grasping in order to support Activity of Daily Living (ADL) safely and easily. In this paper, the mechanism of the developed power assist device is described, and then the effectiveness of this device is discussed experimentally.

Keywords: Power assist, Rubber Artificial Muscle, Pneumatics

1. Introduction

Due to the coming advanced age and few-birthrate society, there may not be enough working people in various fields such as medical welfare, agriculture and so on. Especially, the lack of caregiver and the increase of elderly will become a serious problem. To overcome the problems of increase in the domestic accidents with elderly, it is important to improve the Quality Of Life (QOL) of elderly and disabled persons. In such a situation, it is expected to develop a wearable device for elderly and disabled people. From above reasons, many kinds of power assist device such as the exoskeleton[1] to assist a human upper-limb motion, a power-assisting device[2] for the assist of self-transfer between a bed and a wheel chair and so on, have been developed.

The purpose of this study is to develop a wearable power assist device for hand grasping in order to support Activity of Daily Living (ADL) safely and easily. For realizing a wearable device, many technical subjects such as a small size mechanism, lightweight, a feel sense of wearing, and securing safety and sense of security, must be solved. In this paper, the mechanism of the developed power assist device which is lightweight and has a mechanical softness is described and then the effectiveness of this device is shown experimentally.

2. Power Assist Device

Fig.1,2 show the structure and the outlook of developed assist device. This device consists of the curved type rubber muscle put in backside of finger, and of the linear type rubber muscle put in a root of thumb. The each actuator of device is explained in the following.

2.1. Curved type rubber muscle

The curved type rubber muscle consists of a rubber tube with outer and inner diameter 8.4, 6[mm], and of a polyester bellows with the outer and inner diameter 16, 13[mm] as shown in **Fig.3**(a). For inhibiting expansion to axial direction, the polyester fiber bellows is reinforced

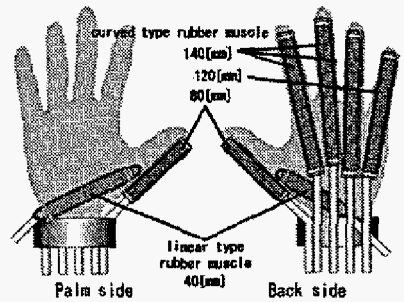
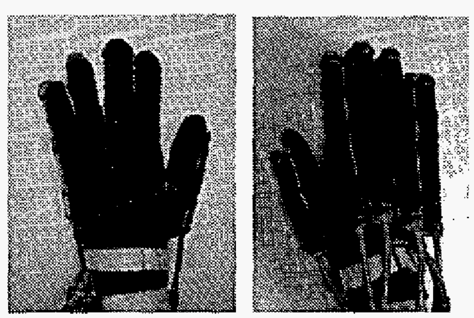


Fig. 1. Structure of power assist device

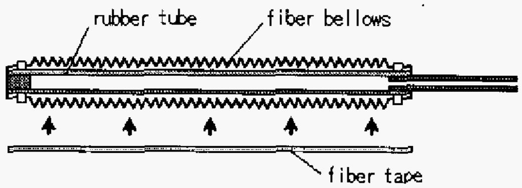
with a fiber tape. The length of rubber muscle is 140, 120, 80[mm]. The length is decided by considering the length of human finger. By the reinforcement, when the compressed air is supplied into the rubber muscle, the rubber muscle curves to the reinforced direction as shown in Fig3(c).

Fig.4(a),(b) show the experimental equipment and the fundamental characteristic for three kinds of rubber muscles. From the results, independent of the length of the rubber muscle, the maximum generated force is about 23[N] at 500[kPa] with all rubber muscles, and the force is linear relationship with the inner pressure over 150[kPa]. When the human hand grasps the cylindrical bar with diameter 60[mm], the contact force at the finger tip is about 14 ~20[N][3]. From this result, the enough generated force can be obtained.

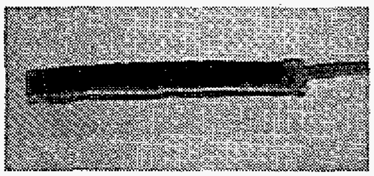


(a) Palm side (b) Back side

Fig. 2. Outlook of power assist device



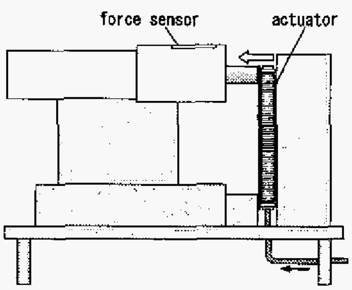
(a) Structure



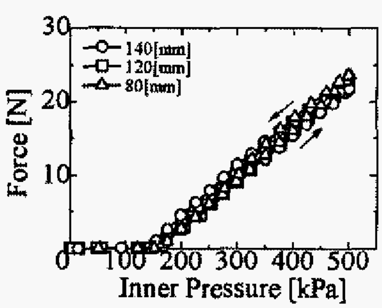
(b) Initial state

(c) Pressurized state

Fig. 3. Curved type rubber muscle



(a) Experimental equipment



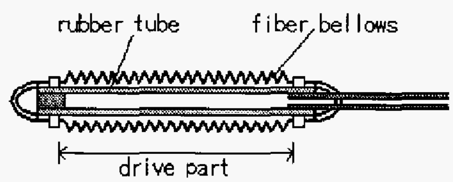
(b) Relation between inner pressure and force

Fig. 4. Fundamental characteristic

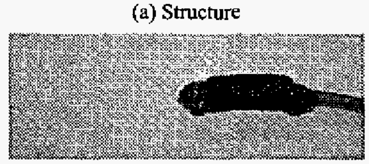
2.2. Linear type rubber muscle

To realize a motion at a root of thumb, the linear type rubber muscle has been developed. **Fig.5** shows the structure of linear type rubber muscle. This rubber muscle consists of a rubber and a polyester fiber bellows. It is the difference from the curved type rubber muscle that the fiber bellows is not reinforced with fiber tape. Therefore, when the compressed air is supplied, the rubber muscle extends to the axial direction as shown in Fig.5(c). For decreasing the inner pressure, the rubber muscle restitutes as shown in Fig.5(b). According to this axial restitution force, the motion of root of thumb can be realized. The linear type rubber muscle consists of a rubber tube with outer and inner diameter 8.4, 6[mm], and of a polyester bellows with outer and inner diameter 16, 13[mm]. The initial length of drive part of this rubber muscle is 40[mm].

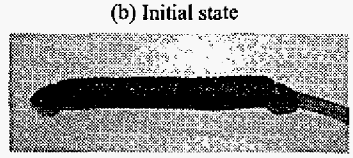
Fig.6 show the fundamental characteristics. Fig.6(a) shows the relation between the inner pressure and the extended length. The maximum extended length is about 76[mm] at 500[kPa] as shown in the result. Enough extended length for the motion of root of thumb can be obtained. Fig.6(b-1) shows the restitution force of the linear type rubber muscle. The extended length and the restitution force are measured by force sensor and potentiometer as shown in Fig.6(b-2). The supplied inner pressure is 0[kPa]. The McKibben type rubber muscle with the same size as the linear type rubber muscle is measured the same characteristics for evaluating the characteristics of the linear type rubber muscle. **Table 1** shows the comparison of characteristics of the linear and McKibben type rubber muscle. From the results, although the maximum restitution force of the linear type rubber muscle is smaller than the maximum contraction force of the McKibben type rubber muscle, the contraction rate of linear type rubber muscle is larger than the contraction rate of the McKibben type rubber muscles. In this device, in order to realize large movable range of the root of thumb, the linear type rubber muscle is fit to use more than McKibben type rubber muscle.



(a) Structure

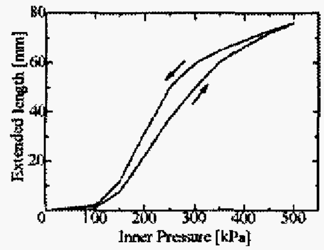


(b) Initial state

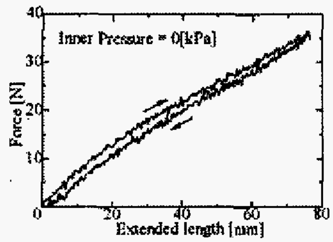


(c) Pressurized state

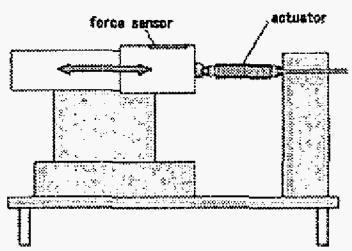
Fig. 5. Linear-type rubber muscle



(a) Extended length



(b-1) Restitution force



(b-2) Experimental equipment

Fig. 6. Fundamental characteristics

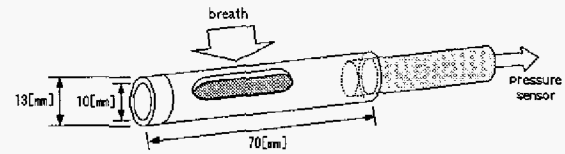
Table 1. Comparison of characteristics

	Contraction rate [%]	Maximum restitution (contraction) force [N]
Linear type	65	35
McKibben type	27	170

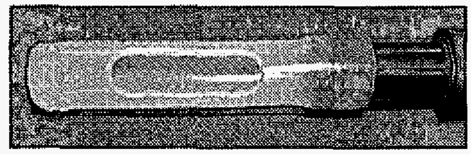
2.3. Expiration switch

In order to operate this device based on a human intention, the input device for this device must be developed. In this study, the expiration switch is developed as the input device, since the expiration switch is usually used by disabled people simply.

This switch consists of a silicone rubber tube with the outer and the inner diameter 13, 10[mm] and the length 70[mm] as shown in **Fig.7**(a). One end of tube is stuffed a rubber, and the other end is connected with an air pressure sensor. Fig.7(b) shows the outlook of the expiration switch. Whenever the increased pressure by the expiration attains over threshold P_t, the assist device is switched ON or OFF as shown in **Fig.8.** In this figure, P_r means the reference inner pressure for the rubber muscles.



(a) Structure



(b) Outlook

Fig.7. Expiration switch

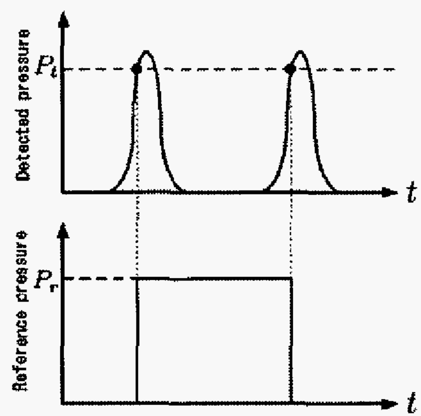


Fig.8. Relation between P_t and P_r

3. Experiment

3.1. Fundamental motion

The flexion and the extension of the index finger, and the flexion, the extension and the opposition of the thumb with the assist device are done as the fundamental experiment. In this experiment, the assist device is put on the right human hand, and then the angles of DIP, PIP, MP joints of the index finger and IP, MP, CM joints of the thumb as shown in **Fig.9** are measured when the assist device is operated. θ_0 as shown in **Fig.10** means the initial angle, and $\delta\theta$ represents the increased angle when the assist device is operated. At CM joint of the thumb, θ_0 is defined as shown in **Fig.11**.

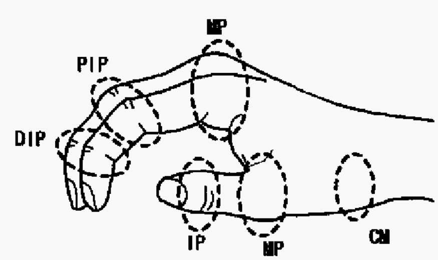


Fig.9. Disposition of joints

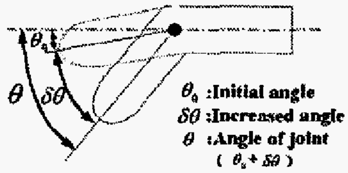


Fig.10. Initial angle and increased angle of finger

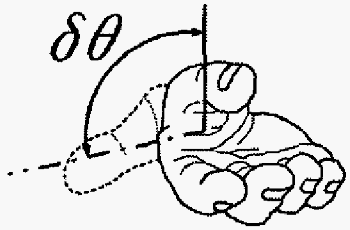


Fig.11. Definement of $\delta\theta$ at CM joint

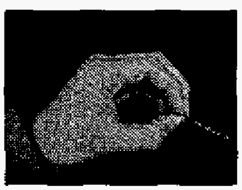
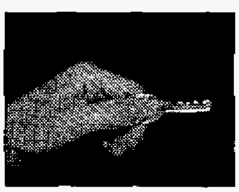
Table 2 shows the each initial and increased angle of the index finger and the thumb. **Fig.12** and **Table 3** show the scenes of the required finger works for spending a daily life and the joint angles in these finger works. The bottom column of Table3 shows the each maximum joint angle in these works. From comparison between Table 2 and 3, although the DIP joint angle with assist device is slightly smaller than the DIP joint angle without one, another joint angles with the assist device are larger than the joint angles without one. From the results, the required works in daily life can be realized by using this device. **Fig.12** shows the scenes when these finger works is realized by the assist device.

Table 2. Experimental results with assist device

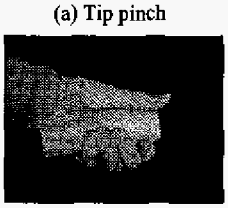
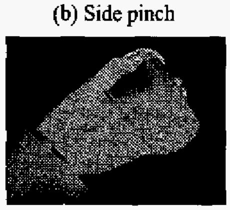
	Index finger [deg.]			Thumb [deg.]		
	DIP	PIP	MP	IP	MP	CM
θ_0	8.8	17.0	32.0	10.9	18.0	26.7
$\delta\theta$	39.3	68.0	20.9	50.3	18.0	70.2
θ	**48.1**	**85.0**	**52.9**	**61.2**	**36.0**	**96.9**

Table 3. Joint angles in various finger works

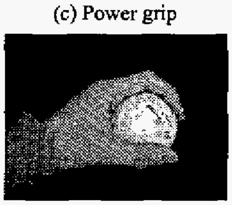
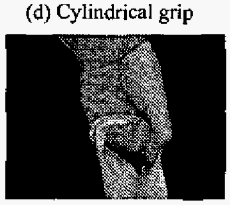
	Index finger [deg.]			Thumb [deg.]		
	DIP	PIP	MP	IP	MP	CM
(a)	40	50	35	45	0	90
(b)	40	60	40	35	15	50
(c)	45	50	30	0	0	50
(d)	30	45	0	20	0	90
(e)	35	45	20	25	0	70
(f)	50	50	50	40	0	90
MAX	**50**	**60**	**50**	**45**	**15**	**90**

(a) Tip pinch (b) Side pinch

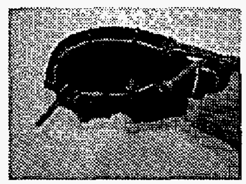



(c) Power grip (d) Cylindrical grip

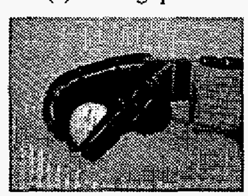
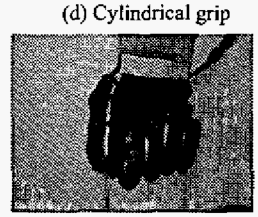
(e) Spherical grip (f) Hook grip

Fig. 12. Scenes of various finger works




(a) Tip pinch (b) Side pinch


(c) Power grip (d) Cylindrical grip

(e) Spherical grip (f) Hook grip

Fig. 13. Scenes of finger works with assist device

3.2. Contact force control

By installing the tactile soft sensor[4][5] at the fingertip of index finger of assist device as shown in **Fig.14**, the contact force control with the cylindrical bar is realized. **Fig.15** shows the structure and the principle of tactile soft sensor. This sensor consists of the silicone rubber sheets with thickness 0.5, 2[mm] and the circular perforated silicone rubber sheet with diameter 11[mm], thickness 2[mm], and the circular rubber sheet with diameter 10[mm]. When the external force is applied to the sensor, the inner pressure of the sensor increases according to the deformation of the upper rubber sheet. By measuring the inner pressure with the connected air pressure sensor, the external force can be detected. **Fig.16** shows the relation between the inner

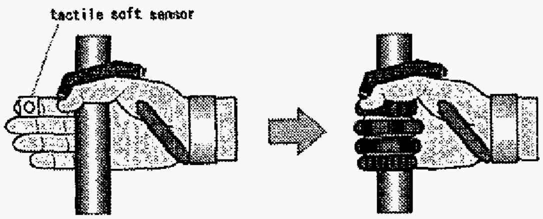
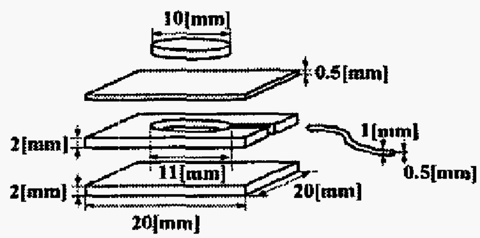
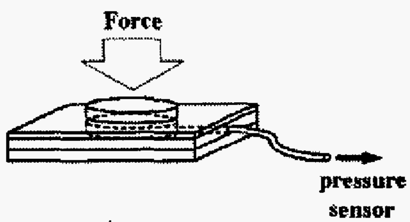


Fig. 14. Image of experiment



(a) Structure



(b) Principle of sensor

Fig. 15. Tactile soft sensor

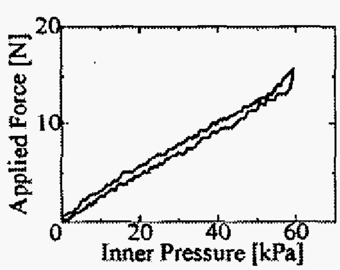


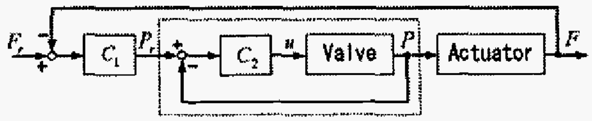
Fig. 16. Relation between P and F

pressure and the applied force. In this experiment, the external force is beforehand calibrated by Fig.16.

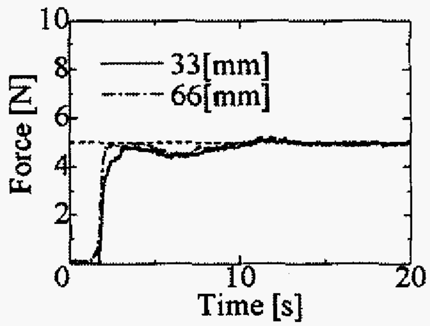
The inner pressure of the curved type rubber muscle is defined by the force control system as shown in **Fig.17**(a). F_r, P_r represent the desired contact force and the reference inner pressure. F, P represent the detected contact force and inner pressure. Fig.17(b) shows the experimental result. In this experiment, the desired force is 5[N], and the contact objects are two kinds of cylindrical bars with diameter 33, 66[mm]. As shown in the figure, the contact force at the fingertip can be control at the desired contact force.

3.3. Evaluation of effectiveness

For evaluating the effectiveness quantitatively, the method of Mosso's ergograph known as one of method to measure muscular fatigue is applied to this experiment. **Fig.18** shows the outline of experiment. A finger attached a weight through a wire bends sinusoidally. The displacement of weight is measured by a potentiometer. In this experiment, the changing amplitude of displacement with



(a) Force control system



(b) Contact force

Fig. 17. Contact motion with cylindrical objects

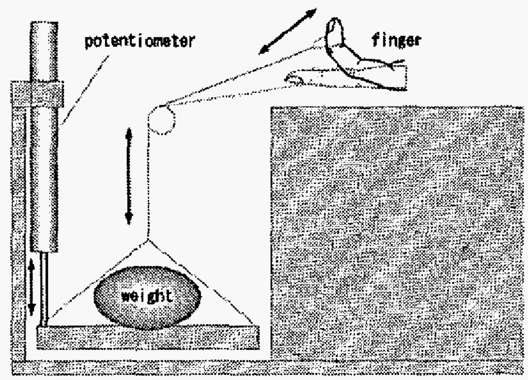


Fig. 18. Outline of experiment

time is applied as an evaluation of effectiveness. The weight is 1[kg] and experimental time is 200[s].

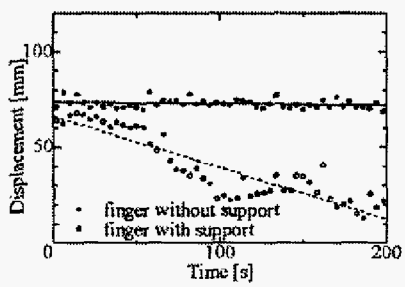
Fig.19 shows the experimental results without and with the assist. These figures show the change of maximum displacement of weight. In this figure, a solid-core and hollow dots represent the displacement with and without assist, a solid and dashed lines represent the approximated lines by the least square method of the change of maximum displacement.

From the results, since the change of amplitude with the assist is smaller as the change without assist, this power assist device is effective to decrease the muscular fatigue.

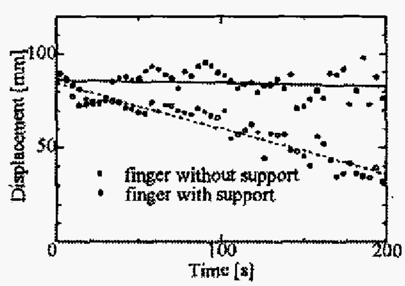
4. Conclusion

In this paper, the mechanism of developed power assist device has been described and then the fundamental motion and the contact force control, the evaluation of the effectiveness have been discussed experimentally. The main results of this study can be summarized as follows:

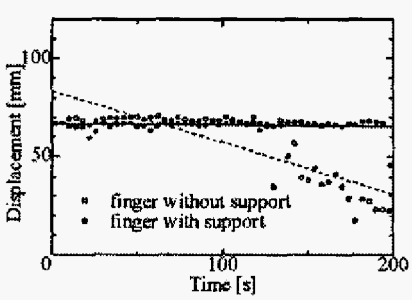
1. Although the DIP joint angle with assist device is slightly smaller than the DIP joint angle without one, another joint angles with the assist device are larger than the joint angles without one. From the results, the required works in daily life can be realized by using this device.
2. By installing the tactile soft sensor at the fingertip of assist device, the contact force at the fingertip can be control at the desired contact force. From this result, the equipper may realize the high level work in a daily life based on the contact force control.
3. For evaluating the effectiveness quantitatively, the method of Mosso's ergograph known as one of method to measure muscular fatigue is applied to this experiment. From the results, since the change of amplitude with the assist is smaller as the change without assist, this power assist device is effective to decrease the muscular fatigue.



(a) Subject A



(b) Subject B



(b) Subject C

Fig. 19. Experimental results

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