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Development of Pneumatic Wearable Power Assist Device for Human Arm "ASSIST"

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ABSTRACT

In order to realize an assist of independent life for people in need of care and relieve a physical burden for care worker, an active support splint driven by pneumatic soft actuator (ASSIST) to support a human arm has been developed. ASSIST is constructed with the appliance and the rotary-type soft actuator. Since a weight and hardness of device involve a danger of causing a serious accident for users or neighbors, this device is constructed with components which are a lightweight and have a mechanical softness. In this paper, the structure of developed device is described, and then the control method based on the center of pressure is proposed. Finally, the assist effectiveness using the proposed control method is experimentally discussed.

KEY WORDS

Soft mechanism , Soft actuator , Pneumatic rubber muscle , Wearable robot

INTRODUCTION

Owing to a growth of advanced age society, it is predicted that a ratio of an elderly in a population will increase from current 20[%] to 36[%] in 2060[1]. In addition, an increase in a people in need of care is also predicted. Actually, a ratio of people in need of care in an elder population which was 10[%] in 2000 had increased to 15[%] in 2003[1]. Thus a decrease in a young people who engages in a care worker and an increase in an elderly in need of care have become serious problem in Japan.

However, 30% elderlies in all ones in need of care have slight symptoms, then they can live independently if disabled physical functions are assisted. From above reasons, many kinds of power assist device have been developed [2,3]. 3DOF robotic exoskeleton [2] of a floor type device can effectively assist a human upper limb according to an enough generated force. A wearable robotic orthosis[3] can support a working motion for a muscular weak human even if it is constructed with simple elements such as a spring-dumper system. However, a compatibleness of a weight, size and a function, a hardness of components are technical issues to improve an operationality and a human friendliness for preventing a serious accident for the users or neighbors. On the other hand, ASSIST[4] shown in **Fig.1** has a high human friendliness according to constructing with a pneumatic soft actuator which has a flexibility of a material, a power source and a high power weight ratio. It is the main advantage for the medical or the welfare application that the developed device has a flexibility due to not only the power source but also the body of actuator. However, the developed ASSIST has to solve a technical issue about controlling a device based on a human intention to improve a maneuverability. In this pa-

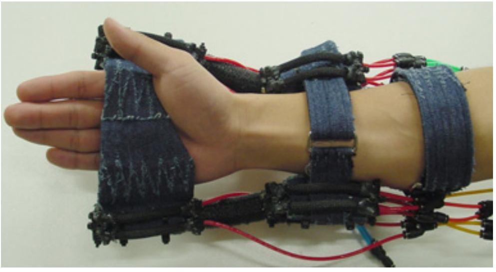


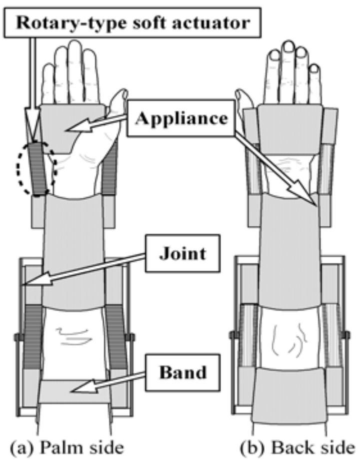
Fig.1: ASSIST to support a wrist

per, ASSIST extended an assisting part to a human elbow is described. In addition, a control method based on a human intention is proposed. Finally, a effectiveness of ASSIST operated on the proposed method is experimentally evaluated.

STRUCTURE OF ASSIST

Fig.2 shows the outlook and the structure of ASSIST.

(a)Outlook

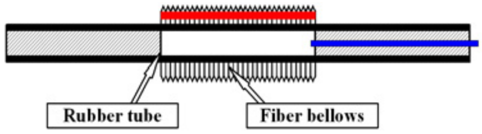


(b)Structure

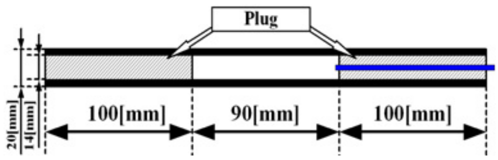
Fig.2: ASSIST to support an arm

ASSIST is constructed with an appliance made by forming a plastic used as an interface between an actuators and a human body. The joint are put for restricting the movable angle of ASSIST under an average maximum bending angle of a Japanese male. In this section, the structure and the characteristics of components are discussed.

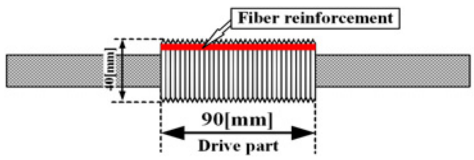
The rotary-type soft actuator for an elbow consists of a rubber tube and a polyester bellows as shown in **Fig.3**(a). The outer and inner diameters and length of rubber tube are 20, 14, 290[mm], respectively as shown in Fig.3(b). Both ends of rubber tube are plugged by polyurethanes with diameter 14[mm] and length 100[mm]. The outer diameter of polyester bellows are 40[mm] as shown in Fig.3(c). The bellows is reinforced with a fiber along the axial direction as shown in the figure. Depending on the reinforcement, when the compressed air is supplied into the actuator, the actuator expands to the circumferential direction as shown in **Fig.4** .



(a)Section of actuator



(b)Rubber tube



(c)Fiber bellows

Fig.3: Rotary-type soft actuator

Fig.5 shows the fundamental characteristics of actuator. Fig.5(a) shows the relation between inner pressure and bending angle under unloaded condition. Fig.5(b) shows the relation between bending angle and generated torque. The torque is calculated from the generated force of actuator fixed at each angle as shown in **Fig.6** when the maximum pressure is determined 500[kPa] in considering withstanding pressure of the actuator.

Fig.7 shows the torque characteristic of ASSIST

(a) Initial state

(b) Pressurized state

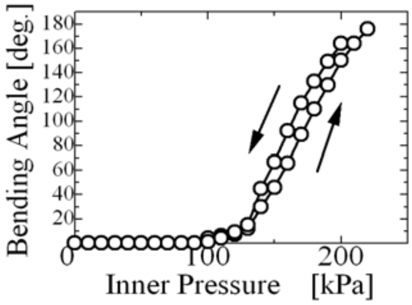
Fig.4: Outlook of rotary-type soft actuator

when two actuators are put in the forearm appliance. A mass of a forearm and a palm of male is about 2.5[kg][5]. A center of gravity of them is assumed to locate on a center of a forearm[6], about 2.8[Nm] per one actuator is required to keep a posture of a forearm horizontally. From the results, the torque of ASSIST to keep a posture and to lift a load about 4[kg] can be obtained in the movable angle.

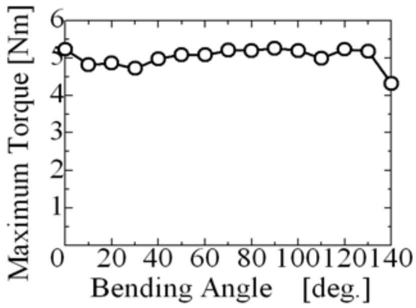
OPERATION BASED ON HUMAN INTENTION

Two tactile soft sensor is put in the appliance as shown in **Fig.8** to detect the contact force between the appliance and the forearm. **Fig.9** shows the structure of developed sensor. Developed sensor is made by two vinyl chloride sheets and sponge as shown in Fig.9(a). An extent of an oblique line in Fig.9(b) represents a welded part. When the external force is applied to the sensor, the inner pressure is increased according to the decrease in the inner volume. By detecting the inner pressure, the external force can be detected. **Fig.10** shows the fundamental characteristic of the developed sensor.

When the forearm bends as shown in **Fig.11**, the angle between the appliance and the forearm increases or decreases by $\delta\theta_i$. According to $\delta\theta_i$, the center of pressure between the appliance and the forearm is changed on y axes shown in **Fig.12**. The



(a) P-$\delta\theta$



(b) $\delta\theta$-τ_{max}

Fig.5: Fundamental characteristics of actuator

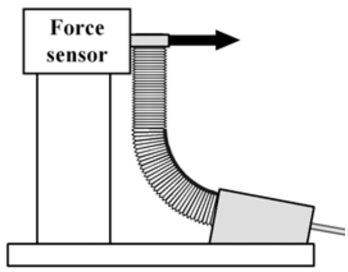


Fig.6: Experimental condition

origin is the middle point between the centers of the sensor. A center of pressure y_a is calculated as:

$$y_a = \frac{l(F_1 - F_2)}{2(F_1 + F_2)} \tag{1}$$

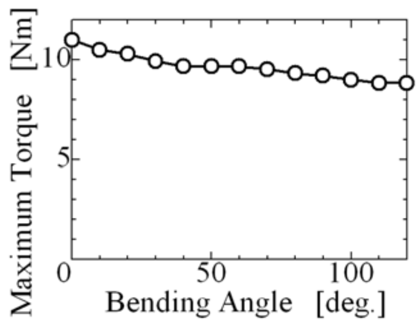


Fig.7: Torque characteristic of ASSIST

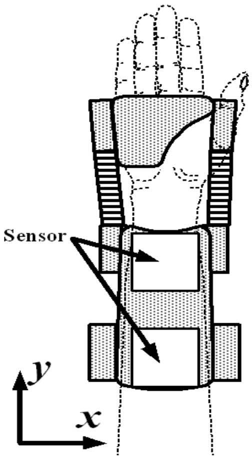
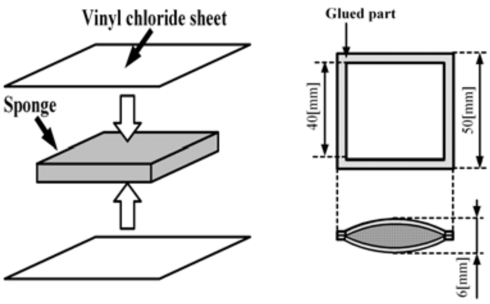


Fig.8: Arrangement of tactile soft sensor



(a) Structure (b) Shape

Fig.9: Structure of tactile soft sensor

F_1, F_2 represent the detected forces by tactile soft sensors, l is the distance between the center of the sensors. In this device, l is 150[mm].

Fig.13 shows a block diagram of a control system based on the center of pressure. In the figure, y_{ini} is the initial center of pressure, P, P_r are the measured and reference inner pressure. P_{min} is the pressure to abolish the dead zone of the actuator. $\theta, \theta_r, \delta\theta_i$ are the bending angle of ASSIST, the bending angle of the elbow, the angle between the appliance and the forearm.

In case the bending angle of ASSIST θ does not follow θ_r intended by a human, the angle between the appliance and the forearm increases or decreases by $\delta\theta_i$ as compared with the initial state. Then, let the center of pressure is y_a when $\delta\theta_i$ is produced, the difference δy between y_{ini} and y_a can be regarded as the parameter of the bending angle error According to controlling the inner pressure P of the actuator by the reference one P_r obtained from P_{min} and the output of PI controller δP for the input δy, ASSIST can follow the movement of the forearm without measuring θ and θ_r. The inner pressure is controlled by the flow control type servo valve (FESTO MPYE-5-1/8 LF-010B) and the pressure sensor (COPAL PA-500-502G).

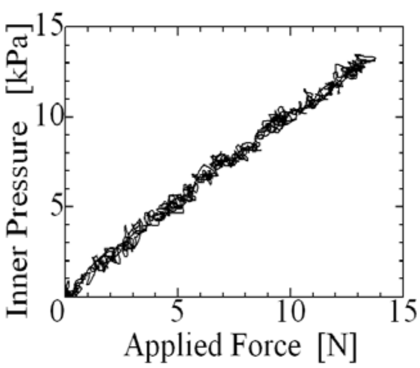


Fig.10: Characteristic of tactile soft sensor

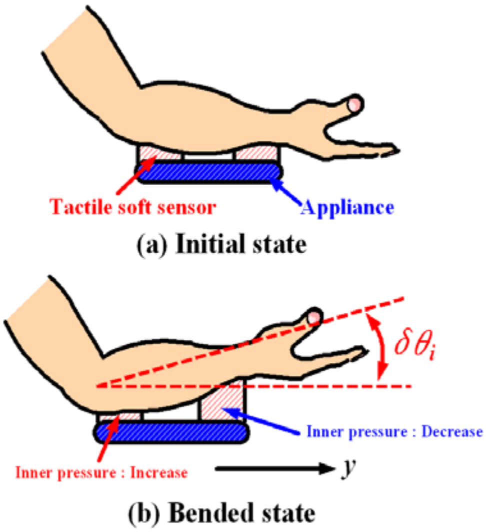


Fig.11: Principle of operation

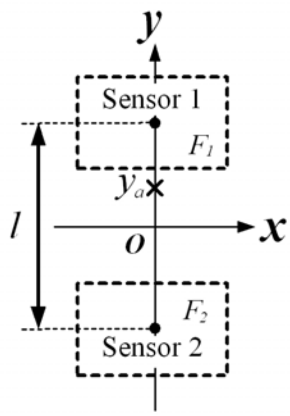


Fig.12: Detection of center of pressure

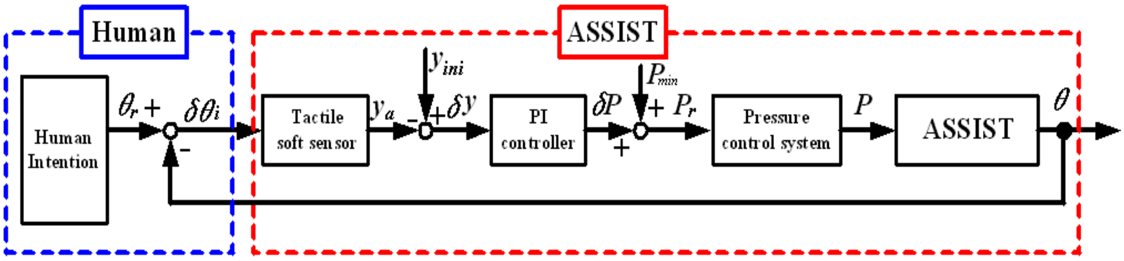


Fig.13: Control system

EXPERIMENT

· DETECTION PRECISION

The center of pressure is measured to verify a detection precision. In the experiment, an acrylic plate (Width 50[mm], Length 200[mm], Thickness 3[mm]) is put on the tactile soft sensors attached to the appliance as shown in **Fig.14**. A force is applied to the acrylic plate at distance of 20[mm], and the applied force is 10[N].

Fig.15 shows the experimental result. From the figure, since the center of pressure can be detected exactly, it is expected that ASSIST can be controlled using the center of the pressure.

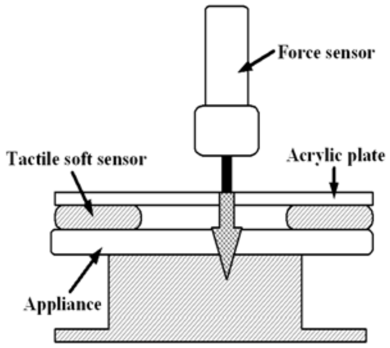


Fig.14: Experimental equipment

· FUNDAMENTAL EXPERIMENT

Fig.16 shows the experimental result when the subjects bends the forearm stepwise and sinusoidally to verify the proposed control method. In the step motion, in order to confirm that ASSIST can be stopped at an intended angle, the subject who equips with ASSIST increases or decreases the bending angle of the forearm at intervals of 10[s]. The forearm is bended with 4[s] period in the sinusoidal motion. The bending angle of the elbow θ_r is changed stepwise and sinusoidally, even though it is desirable that $\delta\theta$ is 0, the reference pressure P_r can be obtained according to change of $\delta\theta$ as shown in figures.

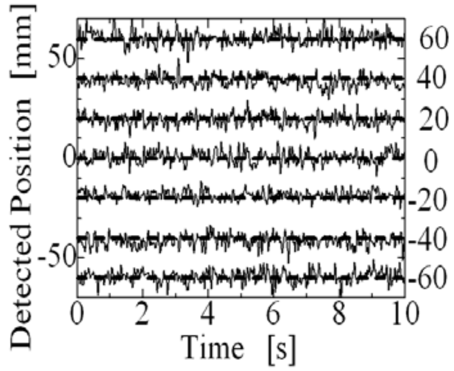


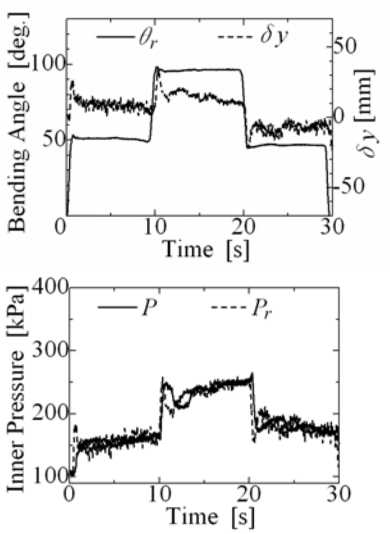
Fig.15: Detection precision of center of pressure

These results mean that the actuator can change the bending angle depending on the change of θ_r.

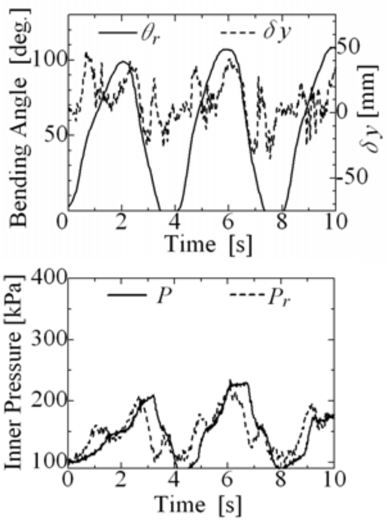
From the above, ASSIST can be operated by using the proposed control method. The effectiveness of ASSIST operated by the proposed method is discussed in the following. In this experiment, a subject bends an elbow under the load 3[kg] put on the forearm as shown in **Fig.17**(a). ASSIST is put the load on the forearm appliance as shown in Fig.17(b). **Fig.18** shows the results. EMG signal is measured at a biceps muscle of the upper arm. Since the magnitude of EMG is decreased, a human who equips with ASSIST can bend the forearm by the less muscular force as compared with a human without ASSIST.

CONCLUSION

The movement of the forearm can be detected by introducing the center of pressure calculated from the tactile soft sensor. Therefore, ASSIST can be operated by the movement of the forearm as the human intention input signal. In adition, when the human forearm lifts a load, ASSIST operated by the proposed method is effective to realize the power assist based on a human intention.

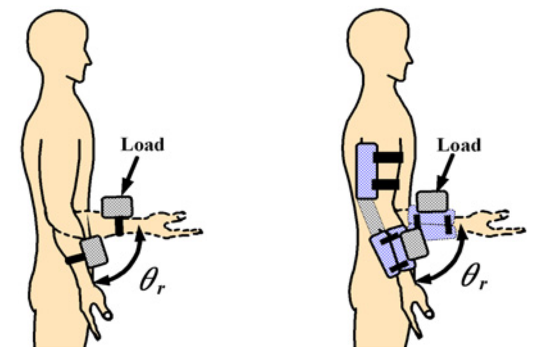


(a) Step motion



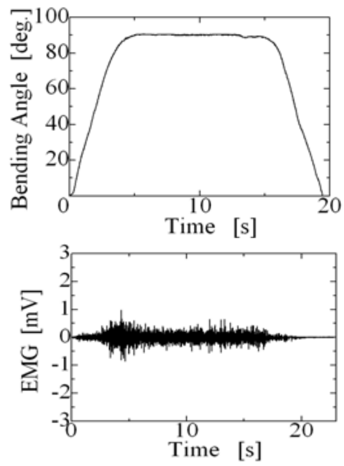
(b) Sinusoidal motion

Fig.16: Experimental results

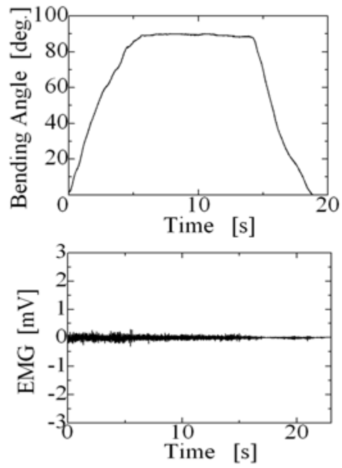


(a) Without ASSIST (b) With ASSIST

Fig.17: Experimental condition



(a) Without ASSIST



(b) With ASSIST

Fig.18: Verification of effectiveness

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