Development of Electric Flexible Spherical Actuator for Rehabilitation

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***Abstract*—This study aims at developing a potable rehabilitation device which can be safe to use while holding it by both hands. In the previous study, a novel flexible pneumatic cylinder that can be used even if it is deformed by external force has been developed. A portable rehabilitation device using the flexible spherical actuator that consists of two ring-shaped flexible pneumatic cylinders was proposed and tested. In this paper, an electric flexible spherical actuator utilizing electric motors, timing belts and pulleys is proposed and tested. An attitude control of the actuator using the built-in controller is executed. As a result, it can be confirmed that the attitude control of the tested actuator with limitation of moving area can be realized.**

***Index Terms*—electric flexible spherical actuator, flexible driving mechanism using timing belt, rehabilitation device, flexible pneumatic cylinder**

I. Introduction

In an aging society, it is required to develop a system to aid in nursing care [1] and to support activities of daily life for the elderly and the disabled [2], [3]. Rehabilitation devices help the elderly who is injured temporally to recover their physical ability for keeping Quality of Life (QOL). The actuators used in such a system need to be flexible so as not to injure the human body [4]. The purpose of this study is to develop a portable rehabilitation device that can be safe enough to use it while handling it with human hands. In our previous study, a flexible pneumatic cylinder that can be used even if the cylinder is deformed by external forces has been proposed and tested [5]. We also developed a spherical actuator using the flexible pneumatic cylinders, which can be used on a table as a rehabilitation device for human wrist and arm [6]-[8]. A portable rehabilitation device using the flexible spherical actuator that consists of two flexible pneumatic cylinders was proposed and tested. The flexible spherical actuator can create larger bending motion along the spherical surface. However, these pneumatic drive rehabilitation devices require a compressor for continuous driving. In general, it is heavy, bulky and noisy. Therefore, these pneumatic drive devices are unsuitable for using in home. In this paper, development of a potable rehabilitation device that can be driven by only using electric power is aimed. In order to realize the flexible device, a flexible spherical mechanism using timing belts with rotary joints, pulleys, gears and electric motors is proposed and tested. An electric flexible spherical actuator utilizing the flexible spherical mechanism and an embedded controller is proposed and tested. An attitude control of the tested actuator is also carried out.

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II. Previous Flexible Spherical Actuator

A. Flexible Pneumatic Cylinder

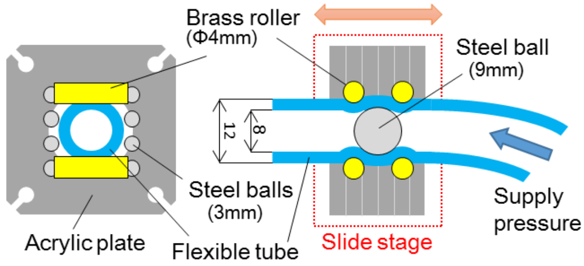

Figure 1. Construction of the flexible cylinder.

Fig. 1 shows construction of a rod-less type flexible pneumatic cylinder developed in our previous study [5]. The cylinder consists of a flexible tube as a cylinder and gasket, one steel ball as a cylinder head and a slide stage that can move along the outside of the cylinder tube. The steel ball in the tube is pinched by two pairs of brass rollers from both sides of the ball. The operating principle of the cylinder is as follows. When the supply pressure is applied to one side of the cylinder, the inner steel ball is pushed. At the same time, the steel ball pushes the brass rollers and then the slide stage moves toward opposite side of the pressurized while it deforms the tube.

B. Flexible Spherical Actuator

Fig. 2 (a) shows appearance of the previous spherical actuator using the cylinders. The actuator was developed as a rehabilitation device for upper limbs. We imaged that patients hold both handling stages which are top and bottom stages in Fig. 2 (a) by their both hands while rehabilitation. Two slide stages of each flexible cylinder are not connected with one side base, that is, each slide stage of the flexible cylinder is fixed on each handling stage as shown in Fig. 2 (b). The size of the actuator is 260 mm in width and 270 mm in height. The total mass of the actuator is 310 g.

Fig. 3 shows the transient view of the movement of the actuator. In an experiment, a sequential on/off operation of the control valve every 0.8 seconds was done. The

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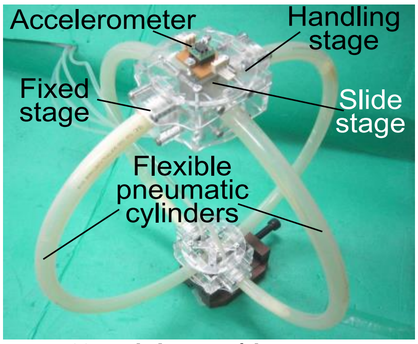
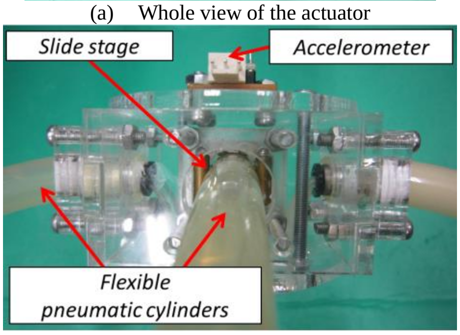
supply pressure is 450 kPa. From Fig. 3, it can be seen that both handling stages can change the position while the cylinders bend and twist. It can be confirmed that the device can create the different attitudes easily.



(a) Whole view of the actuator



(b) Detail of the handling stage

Figure 2. Pneumatic flexible spherical actuator.

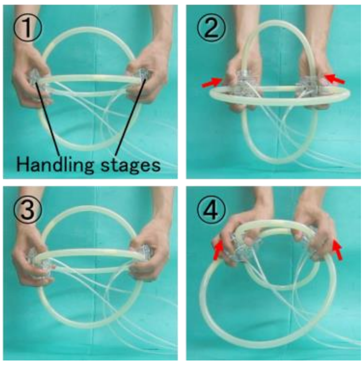


Figure 3. Transient view of the movement of the actuator.

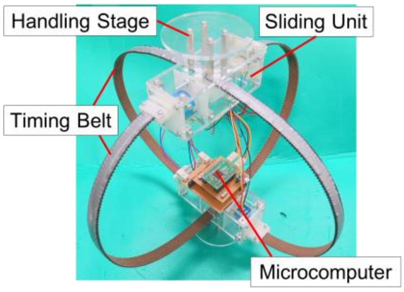
The potable rehabilitation device using the flexible spherical actuator mentioned above requires a compressor in order to drive it for a long time. However, it is unsuitable to use it in home because it is heavy, bulky, and noisy. If there is a flexible spherical actuator that can be driven by only electric power, it is more suitable as a home rehabilitation device.

III. Electric Flexible Sperical Actuetor

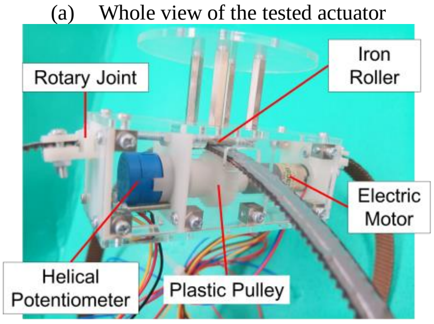
A. Construction

Fig. 4 (a) shows appearance of a tested electric flexible spherical actuator. To realize flexibility similar to the previous actuator, the flexible mechanism using timing belts instead of the flexible pneumatic cylinder is proposed and tested. The mechanism consists of two pulleys with pitch diameter of 28.65 mm in the handling stage and two timing belts with rotary joints corresponding to the flexible tube in the sliding units. As same as the previous spherical actuator using flexible pneumatic cylinders, two belts are intersected at right angle at the point of the sliding unit. On behind of the timing belt, there is a thin iron belt with the width of 5 mm and the thickness of 0.5 mm to increase the stiffness of the belt. They are bonded each other by using plastic glues and gum tapes. The rotary joint of the belt made of plastic clip and a steel screw. Each rotary joint in both ends of the timing belt is connected to one sliding unit. An electric motor (S.T.L.JAPAN Co. Ltd., HS-GM43-CSI) and a plastic pulley for driving the belt are installed into each sliding unit. The timing belt is pinched by the pulley and an iron roller with the outer diameter of 5 mm. From the opposite side of the motor, a helical potentiometer (BOURNS Co. Ltd., 3590S-A26-104L) for measuring the rotational angle is also connected to the pulley as shown in Fig. 4 (b). The size of the actuator is 280 mm in width and 340 mm in height. The total mass of the actuator is 680 g. Compared with the previous actuator, the size and mass of the tested actuator are larger. However, the actuator is not needed any pneumatic power source to drive it. It is suitable for portable devices.

An operating principle of the actuator is as follows. The pulley is rotated by the motor in the sliding unit. Then, the timing belt is driven by the pulley. Because both ends of the belt are connected to the other sliding unit, the sliding unit is driven according to the movement of the belt. Thus, two handling stages on the sliding units can move along the belts. They can give bending motions for users while handling both stages.



(a) Whole view of the tested actuator



(b) Detail of the sliding unit with handle

Figure 4. Electric flexible spherical actuator.

B. Control System

Fig. 5 shows the schematic diagram of the attitude control system of the electric flexible spherical actuator.

The control system consists of the tested actuator with two helical potentiometers, two motor drivers (TOSHIBA Co. Ltd., TA7291P) to operate two electric motors and an embedded controller (Renesas Co. Ltd., SH7125) as an attitude controller. The attitude control of the actuator is done as follows. The desired position of each sliding unit is given by sequential data. For measuring the position of each sliding unit, the embedded controller gets output voltages from each potentiometer through a built-in A/D converter. According to the deviation between the desired and the controlled position, the motors are driven through the motor drivers based on a control scheme, and then the handling stages are driven. A sampling period of the control is 3 ms. As the control scheme, On/off control scheme with a dead band was used. The dead band is 3 mm around the desired position.

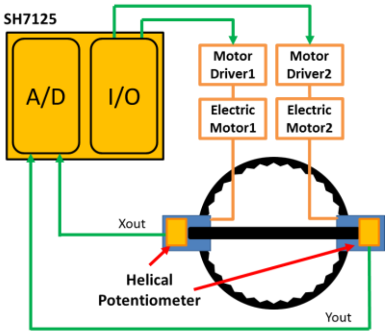


Figure 5. Attitude control system of the tested actuator.

C. Experimental Results

Fig. 6 shows the transient view of the tested actuator while handling it by both hands. Fig. 7 shows the transient responses of the displacement of both cylinders in the attitude control of the actuator when the desired position of the each belt is changed every 150 mm alternately from the neutral position. Note that, the neutral position means that the slide unit is located at middle position of belt stroke. In Fig. 7, broken lines show the desired position (x_r and y_r) and solid lines show the controlled position (x and y) of each sliding stage in the actuator, respectively. From Fig. 7, it can be found that the displacement of each belt can trace each desired position. It can be confirmed that the attitude control can be realized by the proposed actuator.

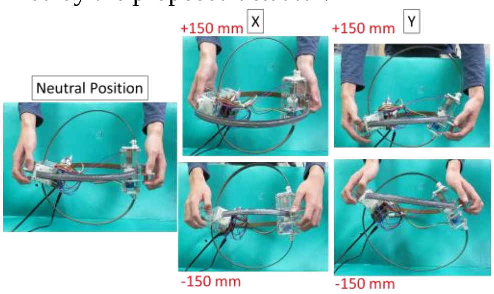


Figure 6. Transient view of the movement of the tested actuator.

Fig. 8 shows the result when the desired positions for x and y directions of the belts change at the same time. From Fig. 8, it can be found that two sliding units cannot reach at the desired position. It is caused by the fact that the belt in the point of the sliding unit has not compliance for twist motion due to pinched mechanism between the pulley and the roller. In other word, the sliding unit cannot be driven when the belt is twisted. However, this limitation of the actuator can be improved by applying the special mechanism that the pinched mechanism of pulley and roller can rotate so as to decrease twisting motion.

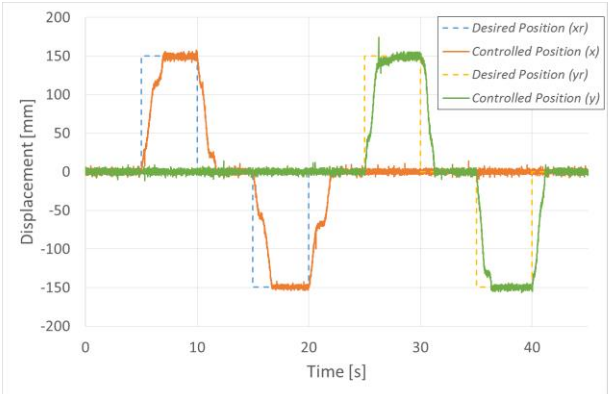


Figure 7. Transient response of the attitude in the single drive motion.

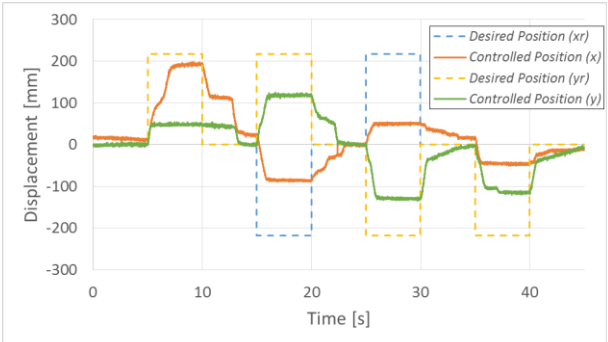


Figure 8. Transient response of the attitude in the double drive motion.

IV. Conclusions

In order to develop a home rehabilitation device driven by only electric power, the electric flexible spherical actuator using the timing belts with rotary joints, pulleys and electric motors was proposed and tested. The construction and the operating principle of the actuator were described. The attitude control system using the tiny embedded controller was proposed and tested. The attitude control using the tested actuator was also carried out. As a result, it can be confirmed that the tested special actuator can give motion to the patient under the limited of moving area that is + or - 150 mm from the neutral position. The method to improve the restriction of the actuator is proposed. We are aiming to improve the compliance for twist motion of the pinched mechanism in the tested actuator as a future work.

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