Development of Simple 3D Measuring Device Using Low-Cost Wire Type Linear Potentiometer for Flexible Spherical Actuator

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***Abstract*— Rehabilitation devices help to recover physical ability of patients for keeping Quality of Life. This study aims to develop a potable rehabilitation device which can be safe to use while holding it by hands. In the previous study, the flexible spherical actuator using two ring-shaped flexible pneumatic cylinders was proposed and tested. As a displacement sensor of the flexible pneumatic cylinder, a wire type linear potentiometer was also proposed and tested. In this paper, a 3 dimensional coordinate measuring device for obtaining the relative coordinate between two stages in the actuator was proposed and tested. The measuring device consists of three wire type linear potentiometers and an embedded controller. The coordinate can be obtained by measuring distance from different three positions. As a result, it was confirmed that three tested sensor was possible to measure the coordinate between two positions of both stages.**

***Index Terms*—3 dimensional coordinate measuring device, wire type linear potentiometer, flexible spherical actuator**

I. Introduction

In an aging society in Japan [1], it is required to develop systems to aid in nursing care [2], [3] and to support activities of daily life for the elderly and the disabled [4]. A rehabilitation device also helps the elderly or the disable who is injured temporally to recover their physical ability for keeping Quality of Life. Based on this situation, in our previous study [5], to realize a home rehabilitation using low-cost devices, the flexible spherical actuator using two ring-shaped flexible pneumatic cylinders was proposed and tested as a portable rehabilitation device. An attitude control system using the tested device, a tiny embedded controller, four small-sized quasi-servo valves [6] and two accelerometers was also proposed and constructed. The attitude control of the device was executed. As a result, we confirm that the spherical actuator can give motions for rehabilitation to patients with sequential control scheme. In the next step, it is necessary to recognize the relative position between both handling stages on the rehabilitation device to prevent both hands to contact each other. Therefore, the flexible pneumatic cylinder with built-in wire type linear potentiometer was proposed and tested. A position control using the cylinder was successfully carried out [7]. However, it is difficult to measure the relative coordinate between both handling stages in the spherical actuator, because the actuator deforms while moving. Therefore, a three dimensional coordinate measuring device between both stages is required. In this paper, the three dimensional coordinate measuring device using three wire type linear potentiometers and an embedded controller is proposed and tested. The measuring method and experimental result are described in this paper.

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II. Flexible Spherical Actuator

Fig. 1 shows construction of a rod-less type flexible pneumatic cylinder developed in our previous study [8]. 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.

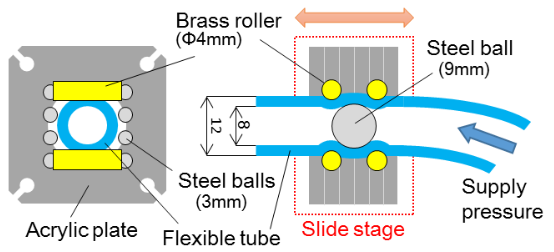

Figure 1. Schematic diagram of the flexible pneumatic cylinder.

Fig. 2 shows appearance of the tested spherical actuator using flexible pneumatic cylinders. The actuator consists of two ring-shaped flexible pneumatic cylinders which are intersected at right angle and each slide stage of the flexible cylinder is fixed on each handling stage. The actuator can give the passive exercise for user's shoulders and arms while they hold both handling stages with hands. In particular, compared with a wearable type rehabilitation device, the tested device does not give any

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fear to users, because the user can throw it as soon as they feel danger. Furthermore, although the device only gives the motion to hands, the upper limbs that includes wrists, elbows and shoulders are moved in conjunction, because each joint has specific bending direction and moving range. Thus, the actuator can also give passive exercises with a relatively larger area to the upper limb of the patient even if the moving area of the actuator is not so large. The size of the actuator is 260 mm in width and 270 mm in height. The total mass of the device is 310 g.

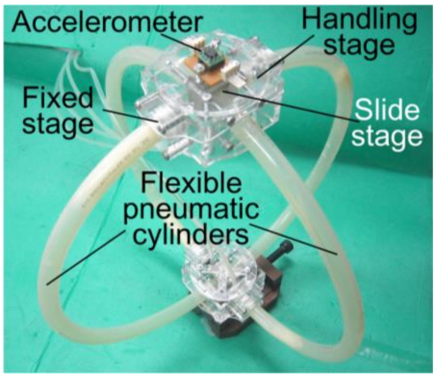


Figure 2. Appearance of the spherical actuator.

Fig. 3 shows the transient view of the spherical actuator. The supply pressure is 450 kPa. From Fig. 3, it can be seen that the actuator can create the different attitudes easily. In addition, from the view of the movement of both arms, we found that it gave the motion for not only wrist but also arms. Generally, the passive exercise such as proposed motion is useful to recover the moving area of joints and the function of nerves and muscles. It was also found that the measuring device (accelerometers) be able to also observe the inclined angle between both handling stages in the actuator. However, we observed that both hands attacked each other in the experiment. The relative coordinate between both stages cannot be recognized because of lower stiffness of the actuator.

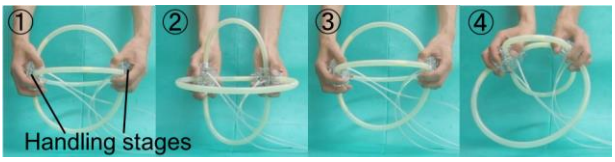


Figure 3. Transient view of the spherical actuator.

III. Low-Cost Wire Type Linear Potentiometer

Fig. 4 shows construction of a low-cost wire type linear potentiometer developed in our previous study [6]. It consists of a steel ball connected with wire type linear potentiometer and a tube end connecter as shown in Fig. 5 for sealing. The tested potentiometer consists of a helical potentiometer (BOURNS Co. Ltd., 3590S-A26-104L) that can measure 10 times rotational angle, a clockwork wire spool with diameter of 22 mm and a flexible stainless steel wire with diameter of 0.4 mm. Both shafts of the potentiometer and the wire spool are connected each other. From a rotational angle of the helical potentiometer and the diameter of the wire spool, the maximum length for measurement of about 0.7 m can be expected. The resolution of the potentiometer using 10 bit A/D converter is about 0.74 mm. The cost of the linear potentiometer except for the stainless steel wire is inexpensive, that is about 8 US dollars. In the previous study, the flexible pneumatic cylinder with built-in wire type linear potentiometer that the cylinder head is connected with the wire of the tested potentiometer through special sealing mechanism as shown in Fig. 5 was developed.

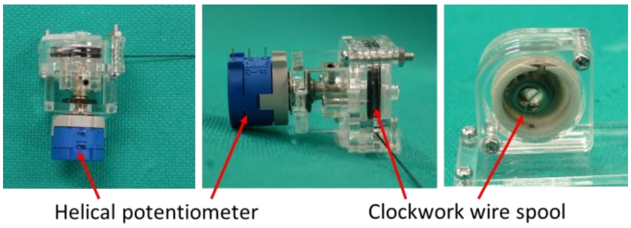


Figure 4. Low-cost wire type linear potentiometer.

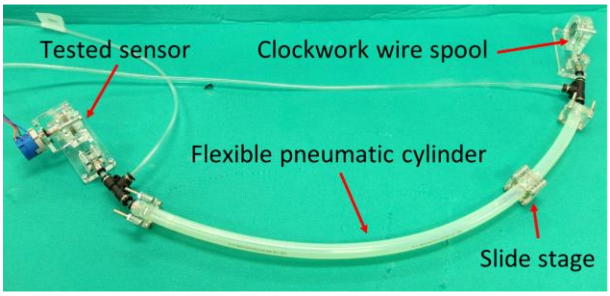


Figure 5. Flexible pneumatic cylinder with wire type linear potentiometer and special sealing mechanism.

However, in order to apply the spherical actuator to rehabilitation devices, it is required to measure not only displacement of the flexible pneumatic cylinder but also the relative coordinate between both handling stages because of its flexibility of the spherical actuator. Therefore, we aim to develop a low-cost three dimensional coordinate measuring device that can apply rehabilitation devices without higher production cost like a camera system.

IV. Improvement of Wire Type Linear Potentiometer

In order to realize the low-cost 3D measuring system, the wire type linear potentiometer is useful because the estimated cost of its material is less than 10 US $. However, the tested linear potentiometer has a little problem that the rotary shaft of the spool and the helical potentiometer are not connected directly. This flexible connection of both shafts causes measuring error. In addition, to measure the relative coordinate between handling stages of the actuator based on a principle of triangulation, it is necessary to realize a high resolution measurement in the appropriate range. Thus, an improved wire type linear potentiometer as shown in Fig. 6 was proposed and tested. Compared with the previous potentiometer, the spool is directly connected to the shaft of the potentiometer while keeping smooth motion.

Further, the diameter of the clockwork wire spool is shortened from 22 mm to 10 mm. As a result of the improvement, the resolution of the sensor was improved to 0.45 mm. The size of the potentiometer becomes smaller, that is 30 mm in height, 30 mm in width and 42 mm in length. The mass of the potentiometer is 44 g. The maximum length for measurement is about 260 mm.

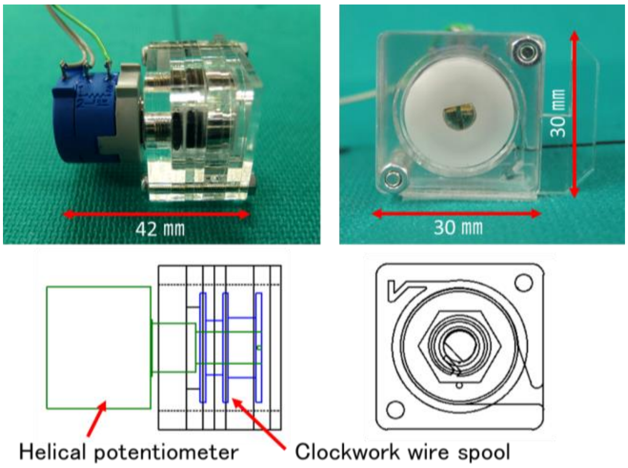


Figure 6. Construction of improved wire type linear potentiometer.

V. 3D Coordinete Measuring Device

Fig. 7 shows a 3 dimensional coordinate measuring device using three potentiometers mentioned above. The end of wire of each potentiometer are connected each other. Each wire outlet from the potentiometer are arranged so that each distance from the measuring origin is kept at certain distance d. The device can measure the coordinate of top of wire based on a principle of triangulation. Fig. 8 shows the measuring principle of the device. From a geometric relationship, following equations related to the distance d and coordinate of measuring point (x, y, z) can be obtained.

$$D_1^2 = (x-d)^2 + y^2 + z^2 \tag{1}$$

$$D_2^2 = x^2 + (y-d)^2 + z^2 \tag{2}$$

$$D_3^2 = (x+d)^2 + y^2 + z^2 \tag{3}$$

Equations (4) to (6) are derived from (1) to (3).

$$x = \frac{1}{4d}\left(D_3^2 - D_1^2\right) \tag{4}$$

$$y = \frac{1}{4d}\left(D_3^2 - 2D_2^2 + D_1^2\right) \tag{5}$$

$$z = \sqrt{D_3^2 - (x+d)^2 - y^2} \tag{6}$$

From (4) to (6), it can be seen that the coordinate can be obtained by measuring each distance D_1, D_2 and D_3.

Fig. 9 shows appearance of an experimental setup of the 3D measuring device that confirming the measuring accuracy of the device. The setup consists of the tested 3D measurement device, two kinds of ring-shaped disks with different inner diameters of 100 and 160 mm. Two disks are set on the base plate with various height by using spacer rods. In the experiment, the tip of the measuring device moves along the inner bore of the disks.

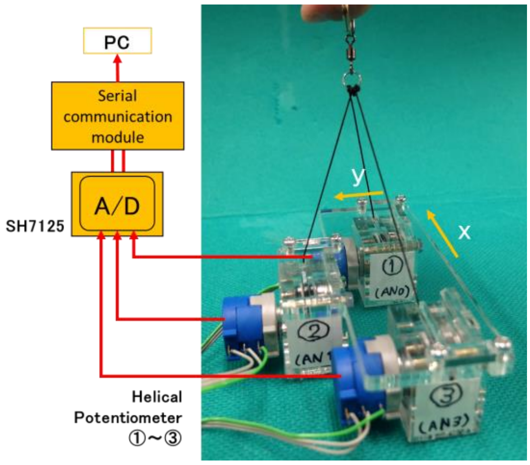


Figure 7. 3 dimensional coordinate measuring device.

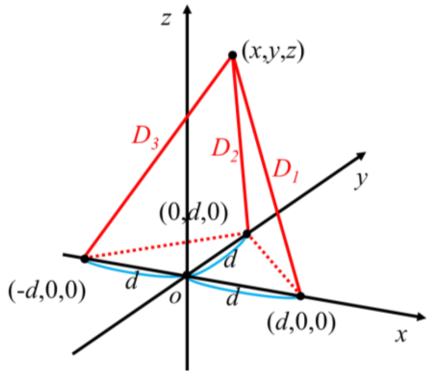


Figure 8. Measuring principle of the device based on triangulation.

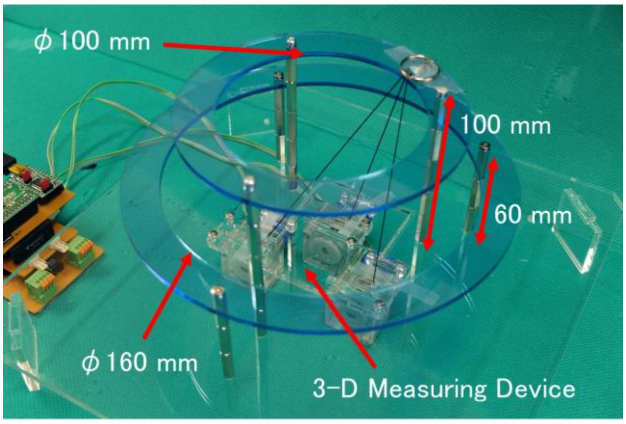
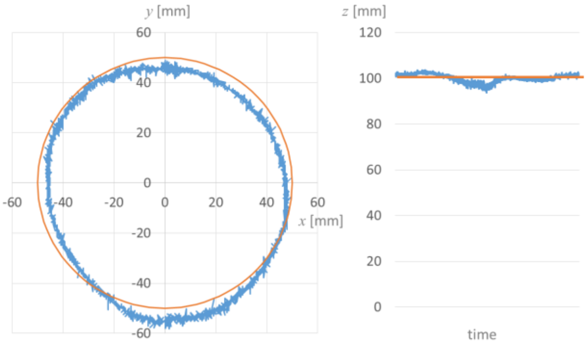
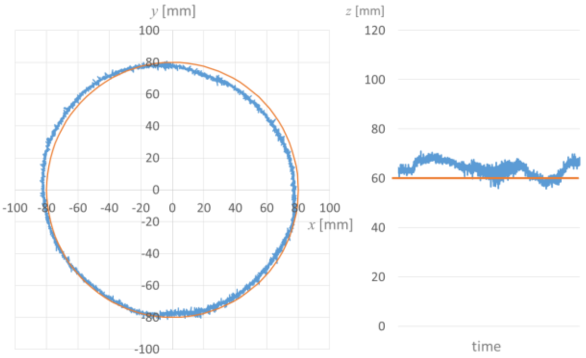


Figure 9. Experimental setup of 3D measuring device.

Fig. 10(a) and Fig. 10(b) show the experimental result using various bore and height mentioned above. The coordinated (x, y, z) is calculated by the embedded controller (Renesas Co. Ltd. SH7125) based on (4) to (6) through A/D converter. In Fig. 10, blue lines show the trajectory of x-y and z, respectively. Red lines show the true value of trajectory. From Fig. 10, it can be seen that the device can measure the coordinate within error of 5 mm. This measuring accuracy is sufficient to apply the spherical actuator that does not require precise positioning.



a) Case of diameter of 100mm and height of 100mm



b) Case of diameter of 160mm and height of 60mm

Figure 10. Experimental result using the tested device.

VI. CONCLUSIONS

The 3 dimensional coordinate measuring device that consists of three wire type linear potentiometers and an embedded controller was proposed and tested to obtain the relative coordinate between two stages in the flexible spherical actuator. As a result, it was confirmed that the tested device was possible to measure the coordinate between two positions within error of 5 mm.

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