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Development of Flexible Displacement Sensor Using Ultrasonic Sensor for Flexible Pneumatic Robot Arm

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Abstract

In our previous study, the flexible robot arm using the flexible pneumatic cylinders for human wrist rehabilitation was proposed and tested. The low-cost bilateral control system using two embedded controller and tested robot arm was also proposed and tested. In this paper, to miniaturize the displacement measuring system and reduce its cost, the flexible and compact displacement sensor using the ultrasonic sensor is proposed. The measuring characteristics of the tested sensor are investigated. As a result, the flexible displacement sensor with the resolution of about 0.1 mm and the measuring sampling period of about 4 ms could be realized.

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1. introduction

The ratio of the elderly to young people is increasing in Japan. This causes a serious problem about lack of welfare caregivers for the elderly. The problem becomes worst when the society and the government failed to provide appropriate infrastructure to the aged and the disabled persons. The aged over 65 years old in Japan accounted for 26.6% from the total of population in 2015[1]. Therefore, in Japan, many studies have shown that the

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robotics can be used in the medical field such as supplying caregivers the extra strength which they need to lift patients[2] and also can be used in complex surgery[3]. In healthcare, robot can be used to assist in nursing care and also can support the activities of daily living for people with disabilities[4]. It must also have safety features such as not harming users and must have a flexible structure so as to be used in contact with human body[5]. Therefore, a novel flexible pneumatic actuator using low-cost embedded controller was proposed and tested in our previous study[6]. The flexible robot arm has been also proposed and tested for rehabilitation of human wrist[7]. The low-cost bilateral control system using the flexible robot arm for human wrist rehabilitation was proposed and tested[8]. In the next step, to use the tested wrist rehabilitation device at home, the miniaturization and cost reduction of displacement measuring system is required. In this paper, as a compact and low-cost measuring system with flexibility, the novel flexible displacement sensor using the ultrasonic sensor is proposed.

2. Wrist rehabilitation device for flexible robot arm

Fig.1 shows the construction and the view of a bilateral control system using flexible robot arms for wrist rehabilitation. Each robot arm consists of two round stages and three flexible pneumatic cylinders. The outer diameter of the upper and lower stage is 100 mm. Each tested cylinder is also arranged so that the central angle of two adjacent slide stages becomes 120 degrees on the point of 66 mm from the center of the stage. An end of each flexible cylinder is fixed to the upper stage. The size of the robot arm is 100 mm in outer diameter and 250 mm in height. The total mass of the robot arm is a little increased, that is 450g. In order to construct the small-sized and low-cost controller for bilateral attitude tracking control of tested robot arms, the control system as shown in Fig.1 was proposed. Fig.1 shows the construction and the schematic diagram of the whole control system of wrist rehabilitation device with bilateral control. The robot arm for patient (it is called "Slave arm" for short) consists of the flexible robot arm using three typical flexible pneumatic cylinders, an accelerometer, the embedded controller (Renesas Co. Ltd., SH7125) and six quasi-servo valves[9]. The flexible robot arm for physical therapists (it is called "Master arm" for short) also consists of an accelerometer, the embedded controller (Renesas Co. Ltd., SH7125) and three novel flexible pneumatic cylinders that can drive manually. Both robot arms have backbone flexible tubes connected with potentiometers to measure the displacement of the upper disk at center position. By using the measured displacement of the backbone flexible tube from the potentiometer and inclined angle from the accelerometer of upper stage, the displacement of each cylinder can be calculated based on the analytical model of the robot arm[9].

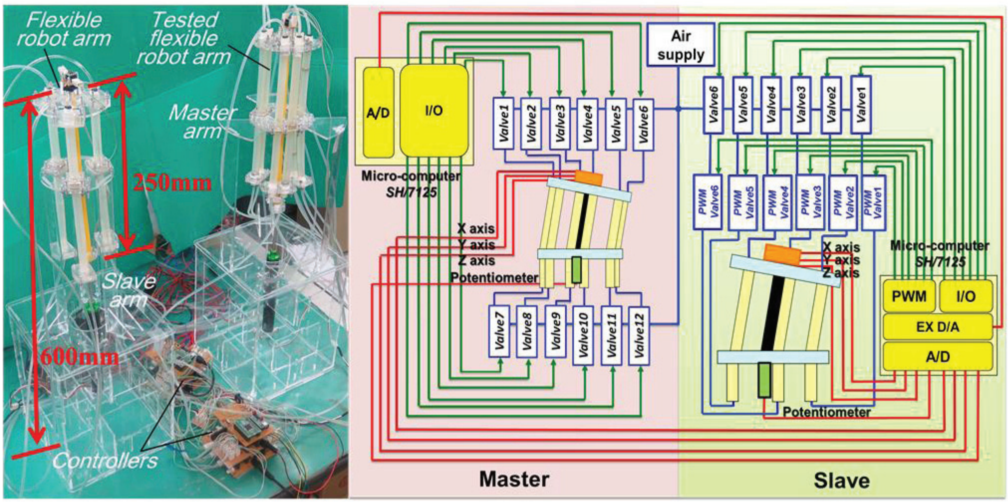

Fig. 1. Construction and schematic diagram of bilateral control system using flexible robot arms for wrist rehabilitation.

Figure 2 shows the transient view of movement of both robot arms in bilateral control using the tested system[8]. It can be seen that the slave arm can trace the movement master arm. As an attitude control method, in the case that the deviation is between -5 and 5 mm for each cylinder, the master arm's controller keeps so that the master arm can be driven manually. In Fig.2, blue and red arrows show the direction of moving force given by the operator and the master arm, respectively. From Fig.2 (5), it can been seen that the steel balls in the cylinder are driven so as to pull the master arm toward the opposite direction to operator's desired direction when the slave arm is fixed by hand. It can be confirmed that the bilateral control in the tested system can be realized by using simple control method.

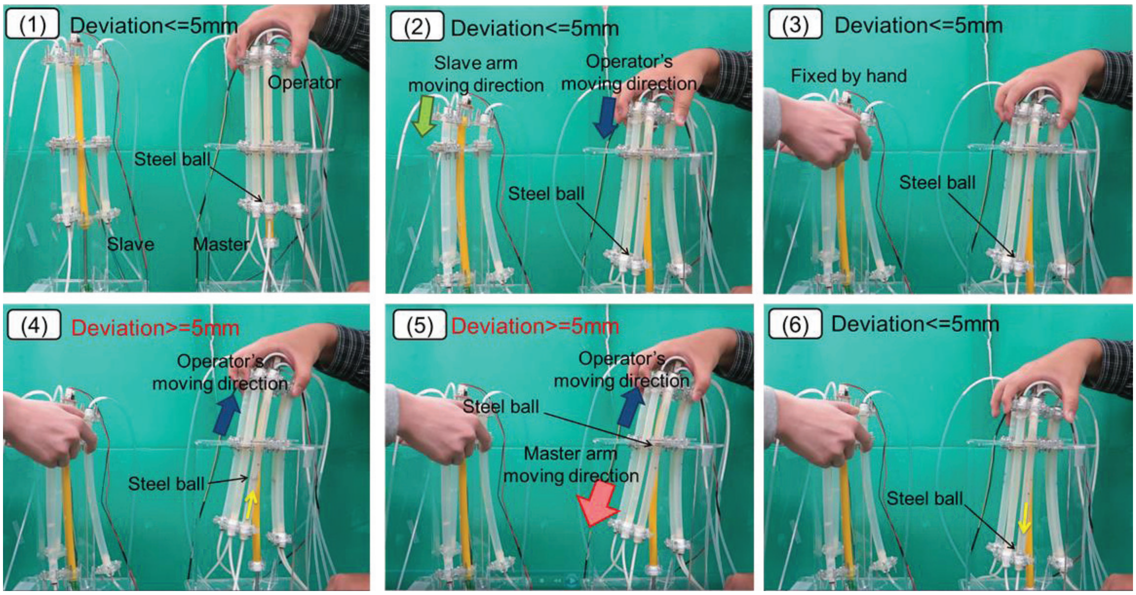

Fig. 2. Transient view of movement of both robot arms in bilateral control.

3. Flexible displacement sensor using ultrasonic sensor

In order to use the tested wrist rehabilitation device at home, the miniaturization and cost reduction of displacement measuring system is necessary. To construct the compact and low-cost measuring system with flexibility, the novel flexible displacement sensor is required. Fig.3 shows the construction of the proposed sensor using ultra sonic sensor. The tested flexible sensor consists of a typical ultrasonic sensor(PARALLAX Inc. 28015-RT), an acrylic cover with two tube connecters and a flexible tube with inner diameter of 8 mm and outer diameter of 12 mm connected to two flexible tubes with inner diameter of 2.5 mm and outer diameter of 4 mm. In order to measure the distance between upper and lower stage, the sliding stage is required. Therefore, the ring shaped neodymium magnet with inner diameter of 13 mm, outer diameter of 25 mm and the thickness of 5 mm and a steel ball are used as a slide stage. The measuring system consists of the tested sensor, the slide stage and an embedded controller (Renesas Co. Ltd., SH7125). The cost of the tested sensor that includes the ultrasonic sensor and a magnet is inexpensive, that is about 35 U.S. dollars. The cost is about one fourteenth of the cost using the potentiometer. The measuring procedure is as follows. First, the embedded controller of measuring system sends the trigger pulse for 5 micro seconds. Then, the ultrasonic transmitter is driven for 200 micro seconds by the signal with frequency of 40 kHz. The generated ultrasonic wave passes through the flexible tube with the inner diameter of 2.5 mm as a transmission tube. It reaches at the end of the tube, and is transmitted to the flexible tube with inner diameter of 8 mm. After that, the ultrasonic wave reflects at the slide stage, and reaches at the ultrasonic receiver through another flexible tube with inner diameter of 2.5 mm. The embedded controller can calculate the distance between the ultrasonic sensor and the slide stage by measuring the time until the receiver detects the ultrasonic wave from the transmitter. It means that the distance can be expressed by the multiplication of the measured time and the speed of sound. By this method, the tested displacement sensor can measure the displacement of slide stage even if the flexible tube bends.

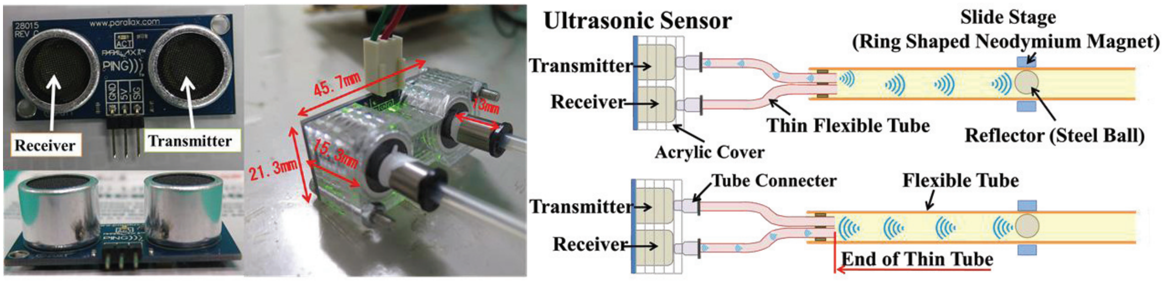

Fig. 3. Construction and measuring principle of flexible displacement sensor using ultrasonic sensor.

4. Experimental result of the measuring using tested sensor

In order to investigate the performance of the tested sensor, the experiment of measuring displacement of slide stage is carried out. Fig.4 (a) shows the experimental set up for measuring the displacement of the slide stage. The experimental equipment consists of the tested sensor, a scale and two fixed stage for tube end and the slide stage. In the experiment, a steel ball with the outer diameter of 5, 6 or 7 mm in the slide stage was used. Fig.4 (b) shows the relation between the displacement of the slide stage from the end of tube and the counting value of the embedded controller. The counting value means the time until the receiver detects the ultrasonic wave from the transmitter that excluded 250 micro seconds from the beginning of the receiving signal. It is because the ultrasonic sensor generates the signal corresponding to the time after 750 micro seconds from the trigger signal. Therefore, the embedded controller starts to measure this signal after 1000 micro seconds from the trigger signal. In Fig.4 (b), each coloured line shows the difference of outer diameter of the steel ball. The solid and broken lines show the case that displacement of slide stage increases and decreases, respectively. From Fig.4 (b), it is found that there is a larger measuring error in case using smaller diameter of ball. It can be seen that the largest ball is useful to apply the reflector.

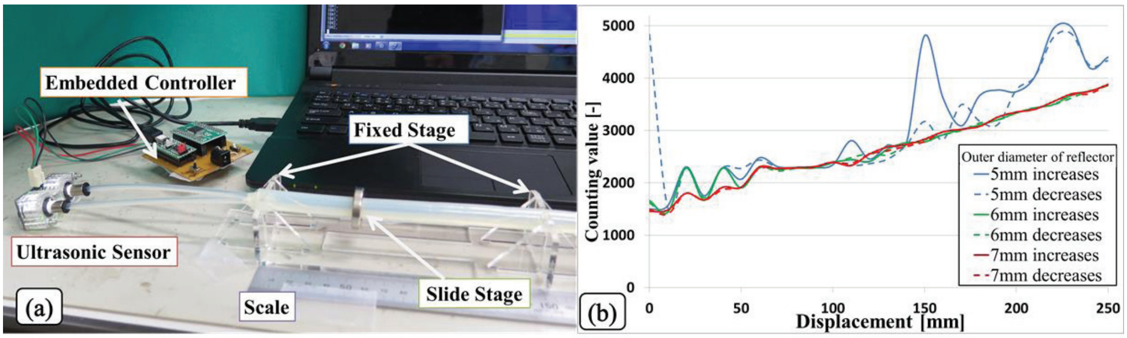

Fig. 4. (a) Experimental set up ; (b) Relation between displacement of slide stage from end of tube and counting value.

In order to investigate the influence of the length of thin tube, the sensor using thin tube with different length of 100, 140 and 200 mm were investigated. Figs.5 (a) and (b) show the relation between the displacement of the slide stage and the counting value by using steel ball with the outer diameter of 7 mm and an acrylic cylindrical reflector with outer diameter of 7.5 mm and the length of 9 mm, respectively. The cylindrical reflector has a steel ball with diameter of 5 mm in order to trace the motion of the magnet. In Figs.5 (a) and (b). Each coloured line shows the difference of length of thin tube. The solid and broken lines show the case that displacement of slide stage increases and decreases, respectively. In both figures, it is found that there is insensitive range around 2200 counts. Until now, this phenomenon is not made clear. However, it can be seen that it is better to use the cylindrical reflector and the thin tube with the length of 140 mm from the view point of less influence of this phenomenon and more linear relationship. The resolution of the sensor can be calculated from the counting sampling period of counting (0.602 micro seconds) and speed of sound (343.26 m/s at 20 degree Celsius), that is about 0.1 mm. This resolution is enough to apply the displacement sensor of the flexible robot arm. In addition, it seems that the error appeared in the range of the short distance is caused by the echo sound in thin area when the cylindrical reflector closes to the end of tube. However, this range from 0 to about 50 mm is not used as a flexible displacement sensor of the flexible robot arm. The sampling period for measuring using the embedded controller is about 4 ms at in the case of measuring displacement of 200 mm.

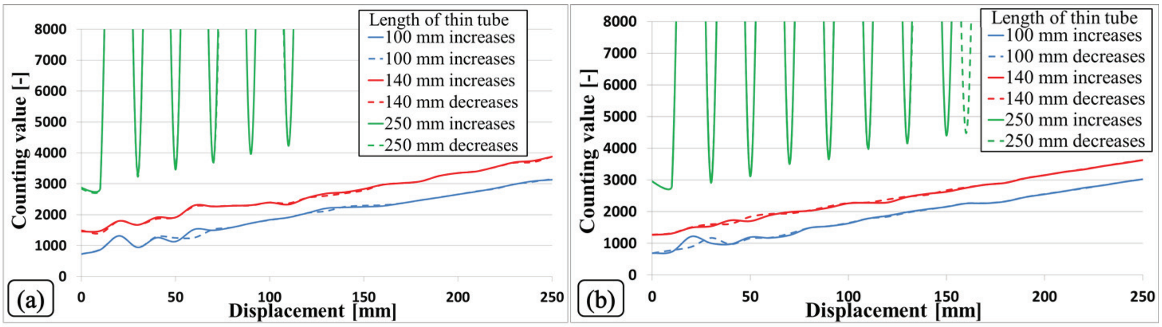

Fig. 5. Influence of length of thin tube
(a) Ball type reflector with outer diameter of 7 mm; (b) Cylindrical reflector with outer diameter of 7.5 mm.

Fig.6 shows the transient view of the experiment for measuring using the tested sensor while the tube is bending randomly. In the experiment, the slide stage is fixed at certain position. From Fig.6 it can be seen that the counting value is little change even if the tube is bending. It is concluded that the tested sensor is useful to apply as a flexible displacement sensor of the proposed robot arm because of its flexibility and compact sensor configuration.

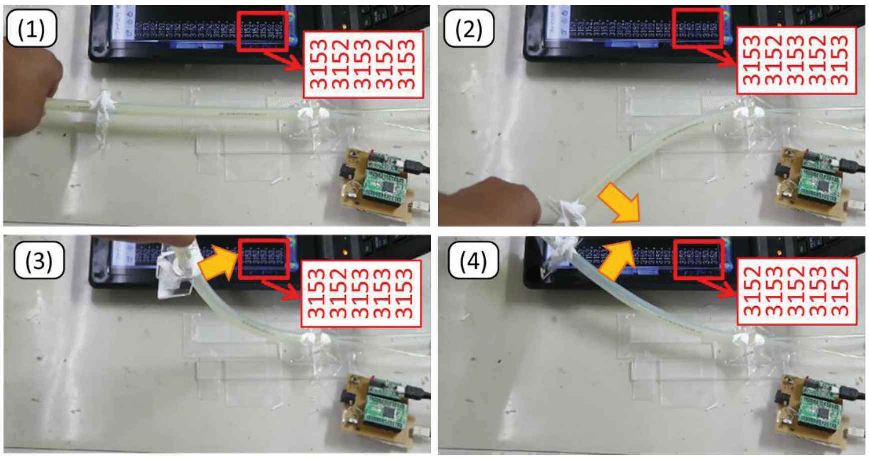

Fig. 6. Transient view of experiment of tested sensor.

5. Conclusions

This study aiming at developing the compact flexible displacement sensor for flexible robot arm can be summarized as follows.

The flexible displacement sensor that consists of the ultrasonic sensor, the acrylic cover, the flexible tube connected to two thin flexible tubes and the slide stage using the ring-shaped magnet and the reflector was proposed and tested. The measuring principle of the sensor was introduced. The measuring characteristics of the sensor ware investigated for various size of the reflector in the slide stage and various length of thin tube. As a result, the larger diameter of reflector is useful. The length of 140 mm of thin tube is suitable to apply the sensor because of smaller insensitive range and more linear relationship. The resolution of about 0.1 mm is enough to apply the displacement sensor of the flexible robot arm. The sampling period of about 4 ms for measuring is also useful as a displacement sensor to control the flexible robot arm.

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