Engineering

Mechanical Engineering fields

Okayama University *Year* 2005

Development of intelligent McKibben actuator with built-in soft conductive rubber sensor

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DEVELOPMENT OF INTELLIGENT MCKIBBEN ACTUATOR WITH BUILT-IN SOFT CONDUCTIVE RUBBER SENSOR

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ABSTRACT

This study aims at development of Intelligent McKibben actuator, in which soft rubber displacement sensor is integrated. Recently, McKibben actuator attracts engineers because of light weight, high output power and high compliance. But in case of using it for servo control at present, the systems need encoders or potentiometers, therefore the systems tend to grow the size and to take away from compliance which is an important advantage for safe and secure mechanism. We developed soft displacement sensor and incorporated it in McKibben actuator, named it Intelligent McKibben actuator and proved its potential.

Index Terms – Soft sensor, soft mechanism, McKibben actuator, Intelligent actuator,

INTRODUCTION

Recently, rescue robots which can contact with a human physically and power assist devices which are attached on a human body directly have been developed actively. In these mechanisms, it is very important to consider safety of the human.

The McKibben actuator is driven pneumatically and generates the contracting motion [1]. This actuator has advantages of flexible and light weight, therefore it has high safety mechanically. Actually, the robot and the power assist device using this actuator have been developed [2] [3]. Although, in the case of servo control using it, systems need sensors like potentiometers or encoders and valves in general, so the systems tend to grow the size and the weight. Moreover, a strong point that the McKibben actuator has the high compliance is spoiled.

By the way, sensors like pressure sensors and displacement sensors using rubber, which are soft and light weight, have been researched and developed [4].

The goal of this study is to make the McKibben actuator more intelligent, so that means incorporating a micro valve, a displacement sensor and a pressure sensor in the McKibben actuator. By doing this, the actuator can be controlled without external sensors and valves. In this paper, a soft displacement sensor made of rubber was developed and incorporated in the McKibben actuator. We named it Intelligent McKibben actuator. A test of position servo control using the single Intelligent McKibben actuator was carried out. Furthermore, we fabricated a robot arm system configured by two Intelligent McKibben actuators. The experiments showed that the Intelligent McKibben actuator has good potential.

SOFT DISPLACEMENT SENSOR

Figure 1 shows the configuration of the soft displacement sensor. Conductive resin ink is distributed on one surface of the rubber thinly. The ink includes carbon particles and binder in toluene. After distributing, by volatilization of the toluene, the thin carbon film which is elastically is formed on one surface of the rubber. The thickness of the film is controlled 100μm by the spin coater. Changing of the electrical resistance following extending and contracting motion of the rubber is used as a displacement sensor.

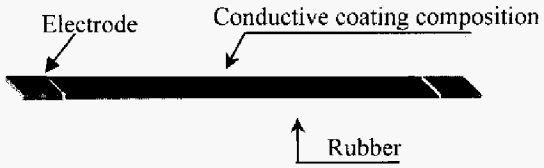

Fig.1 Configuration of soft displacement sensor

INTELLIGENT MCKIBBEN ACTUATOR

The soft displacement sensor is incorporated in the McKibben actuator. The configuration of the conventional McKibben actuator is that a rubber tube supplied air pressure is covered with a sleeve knitted thin fiber. Supplying air pressure to the rubber tube, the McKibben actuator generates the contracting displacement of the longitudinal direction.

Figure 2-a shows the internal configuration of an Intelligent McKibben actuator. When the Intelligent McKibben actuator is manufactured, the rubber tube supplied air pressure must be set with the contraction

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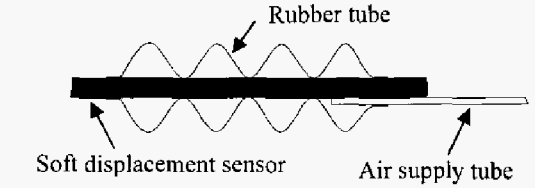
state by wrinkling, and the soft displacement sensor is incorporated in it. The sleeve covers over them. Figure 2-b shows the outlook of the Intelligent McKibben actuator.



a. Internal configuration of Intelligent McKibben

b. Outlook of intelligent McKibben actuator

Fig.2 Configuration of Intelligent McKibben actuator

We fabricated the Intelligent McKibben actuator which is 5mm in diameter and 140mm in length (the soft sensor is 2mm x 140mm x 1mm) in the initial state. Figure 3-left shows the initial state and right shows the driving state with displacement. Because McKibben actuator generates axial contraction, and the maximum contraction rate is about 20%, the rubber sensor must be set more than 1.2 times as much as natural length of rubber in the initial state to escape the flexural buckling.

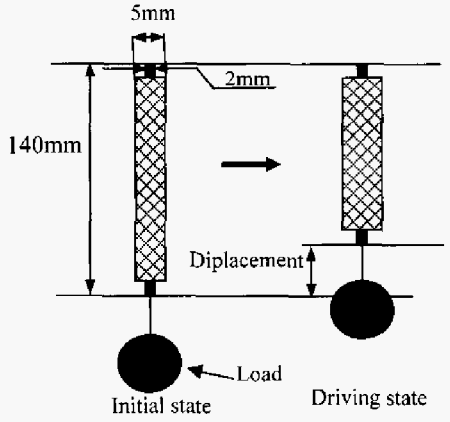


Fig.3 Initial state and driving state of Intelligent McKibben actuator

This Intelligent McKibben actuator has advantages as following;

1. It is easy to drive with the position servo control, because the actuator can obtain the self displacement using the soft displacement sensor.
2. The compliance of the soft displacement sensor is very high compared with the McKibben actuator, so the compliance of the system does not spoil.
3. Compared with the conventional McKibben actuator, the output power of the actuator does not reduce.
4. The soft displacement sensor is incorporated in the actuator, therefore it is capable to reduce the system size.

EXPERIMENT OF SINGLE INTELLIGENT MCKIBBEN ACTUATOR

The experiments of the position control using the single Intelligent McKibben actuator were carried out. Figure 4 shows the control system which consists of a PC used control, an air compressor, a regulator, an analog valve, and the Intelligent McKibben actuator. Notice that the potentiometer is used for the evaluation, is not for the feedback control. The control algorithm is the PI control, and K_f shows the feedback gain.

Figure 5 shows an experiment of position control using the single Intelligent McKibben actuator. The air pressure which is supplied to the analog pneumatic valve is 400kPa, and the load is 5N.

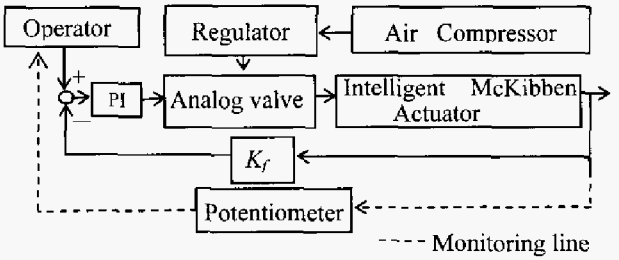


Fig.4 Configuration of servo system using single intelligent McKibben actuator

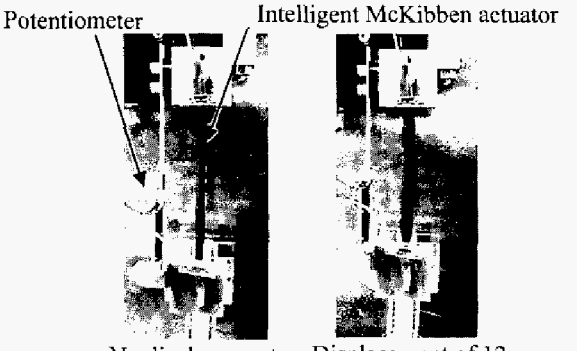


Fig.5 Experimental system of Intelligent McKibben actuator

Figure 6 shows the static characteristics of the soft displacement sensor incorporated in the Intelligent McKibben actuator. The characteristics of this sensor depend on the velocity of the deformation, because of the viscoelasticity of the rubber, but, in this section, the static characteristics (every plot points in Fig.6 are obtained with much time) are shown only. The electrical resistance of the sensor was measured from the initial state to driving state of displacement of 18mm. ■ was

measured following the contracting motion of the actuator with increasing the air pressure and ▲ was measured following the extending motion of the actuator with decreasing the air pressure. The result is almost satisfying; the hysteresis is small and the linearity is high relatively.

In this measurement, the position control was carried out by using the potentiometer.

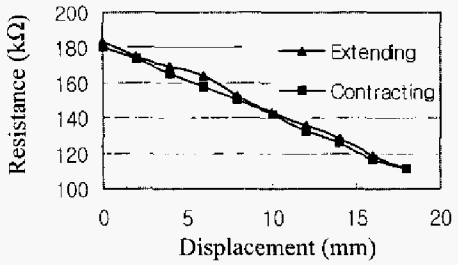


Fig.6 Static characteristics of soft displacement sensor incorporated in McKibben actuator

Using the system which is shown in Fig.5, an experiment of the position servo control was carried out, in which the electrical resistance of the soft displacement sensor incorporated in the Intelligent McKibben actuator was used as the feedback value.

Figure 7 indicates that the experimental result of the servo control, the target value is the pulse function whose amplitude is 14 mm, cycle is 15 seconds. The actual value shows the output of the potentiometer. The error between the target value and actual value exists about 1 mm; a main reason is that this experiment bases on the static characteristics of the sensor only.

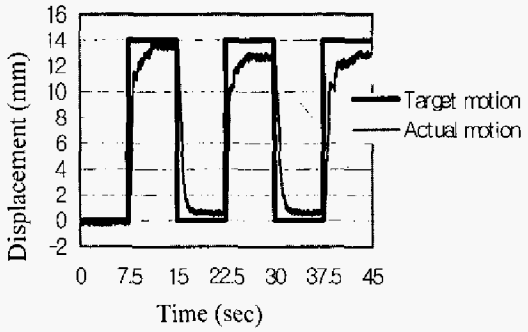


Fig.7 Experimental result of servo control using single Intelligent McKibben actuator

ANTAGONISTIC MECHANISM

The rotational angle control of a robot arm by using two Intelligent McKibben actuators set antagonistically was carried out. At present, almost the conventional robot mechanisms using McKibben actuators are realized by consisting of the multiple McKibben actuators [5]. Moreover the control accuracy of the antagonistic mechanism can be better than in the case of using the single Intelligent McKibben actuator.

Figure 8 shows the robot arm system using two Intelligent McKibben actuators (Intelligent McKibben actuator 1 and 2) linked by the pulley belt. The rotation angle θ of the robot arm is realized by the extending and the contracting motion of them. And the actual rotational angle can be measured by the potentiometer which works directly with the pulley. In the initial state of the system, it is necessary to supply the actuators with the offset displacement of 50% of the maximum displacement, because, to realize the rotation, when one actuator extends, the other has to contract.

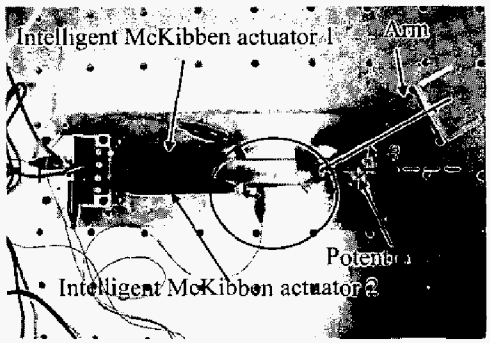


Fig.8 Configuration of robot arm system

In before section, the experiment based on the static characteristics, although, the characteristics of the soft sensor depend on the deformation velocity because of the viscoelasticity of the rubber. To realize the accurate control, it is important to introduce the dynamic characteristics. The dynamic characteristics of the sensor were confirmed by the experiment. The electrical resistance was measured following the arm rotational motion (sinusoidal motion of the amplitude of 30 degree and the cycle of 6.3 seconds) which was controlled by the potentiometer. Figure 9 shows the electrical resistance of the soft displacement sensors, the horizontal axis and the vertical axis show the arm angle and the resistance respectively. Shortly after driving, the resistance was disturbance (named initial disturbance) compared with after that. It is caused by the viscosity of the rubber. After the initial disturbances, the resistance of two sensors shows the linearity almost, however when they were approximated to the linear equation, the determination coefficients were R^2=0.9083, 0.9395 which are not high linearity enough.

we subtracted two sensors, as doing so, two initial disturbances can be canceled out, as shown in Fig.10. It realized the high linearity of the sensor model (the determination coefficient achieved 0.9705). Several similar experiments were carried out with changing the cycle and the amplitude, and all the results showed that the linearity was improved fully. Therefore the value which is obtained by subtracting two sensors which are

incorporated in actuator1 and 2 is used for the feedback value.

Figure 11 shows the result of the experiment, in which the target motion is the sine function whose amplitude is 25 degree and cycle is 6.3 seconds. As shown in Fig.10, when the sensor model was created, the small hysteresis existed, therefore the error between the target motion and actual motion was occurred slightly. Although, compared with Fig.7, the result shown in Fig.11 is much better. In addition, considering applications of the McKibben actuator as mentioning in the introduction section, the high compliance is more important than the strict positioning accuracy like a micro order positioning. So, as the result of the experiment which was carried out without the external sensors, it satisfies sufficiently.

CONCLUSION

In this paper, the Intelligent McKibben actuator in which the soft displacement sensor was incorporated was developed. And the experiments showed that the Intelligent McKibben actuator had good potential.

The following results are achieved in this paper.

1. The soft displacement sensor based on rubber was developed.
2. The Intelligent McKibben actuator in which the soft displacement sensor was incorporated was developed. And the servo system using it was realized.
3. The rotational robot arm system using two Intelligent McKibben actuators was manufactured, and by subtracting two sensors, the robot arm was controlled with enough accuracy without the external sensors.

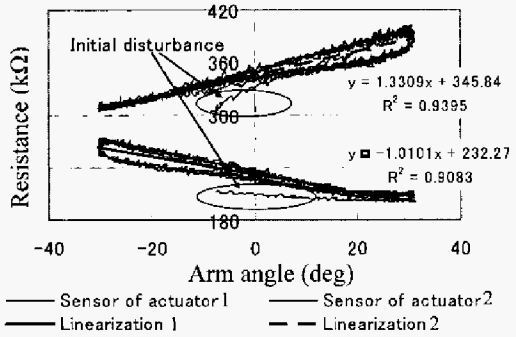


Fig.9 Dynamic characteristics of sensor 1 and sensor 2

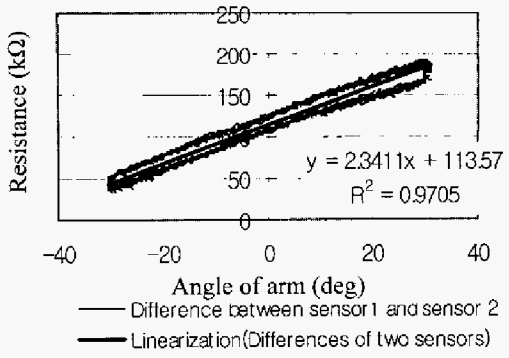


Fig.10 Differences between sensor 1 and sensor 2

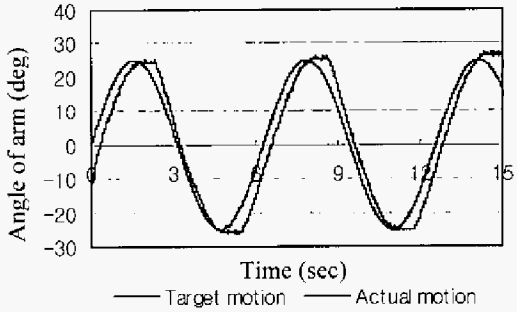


Fig.11 Experimental result of antagonistic mechanism

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