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DEVELOPMENT OF A SKIN DISPLACEMENT SENSOR FOR THE PNEUMATIC POWER ASSISTED SYSTEM

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ABSTRACT

An importance of wearable device in the field of medical treatment has been strongly recognized. Also, the development of the power assisted system has been done to support the nursing care work for the elderly. The purpose of our study is to develop a wearable flexible displacement sensor which can measure the movement of human body by mounting on the skin surface. The tested sensor consists of two fixed electrodes, a slide electrode and a nylon string coated with carbon (NSCC). It works as a flexible potentiometer by sliding the slide electrode along NSCC while keeping the electrical contact. In order to keep a stable electrical contact even if NSCC bends flexibly, the slider is consisted of a brass cylinder filled with carbon black powder. In our previous study, we confirmed that the sensor worked well by carrying out the position control of a McKibben artificial muscle.

In this paper, we proposed and tested a skin displacement sensor using the flexible displacement sensor that can measure the bending angle of the human arm without measuring the joint angle directly. As a result, we confirmed that we can know the human motion indirectly using the tested sensor. We apply the proposed sensor to the control of the power assisted system by using a pneumatic rubber artificial muscle.

KEY WORDS

String type flexible displacement sensor, Skin displacement sensor, Soft sensor, Human interaction

INTRODUCTION

Recently, an importance of wearable devices in the field of medical treatment such as nursing care and rehabilitation has been strongly recognized [1]. In order to support the nursing care task, the power assisted device has to be worn on the human body directly. These wearable devices require the flexible movement to apply a supporting machine for the nursing care work. Also many kinds of wearable device such as a power assisting device and an active rehabilitation device need to realize the flexible and complex movement. The purpose of our study is to develop a flexible, lightweight and simple sensing system for human movement to develop the pneumatic power assisted system and a compact driving system using the flexible pneumatic actuator which can be safe and lightweight enough to be attached to the human body. In this paper, we propose and test a skin displacement sensor using the flexible displacement sensor that can know the movement of the human arm without measuring the human joint angle directly.

STRING TYPE FLEXIBLE DISPLACEMNET SENSOR

Construction and operating principle

Figure 1 shows the construction of a tested string type flexible displacement sensor (we call it "FDS" for short). The sensor consists of two fixed electrodes (that is an anode and a cathode), a slide electrode and a nylon string coated with carbon (we call it "NSCC" for short). It works as a flexible potentiometer by sliding the slide electrode along NSCC while keeping the electrical contact. Therefore, the slider needs the function of keeping a stable electrical contact even if NSCC bends flexibly.

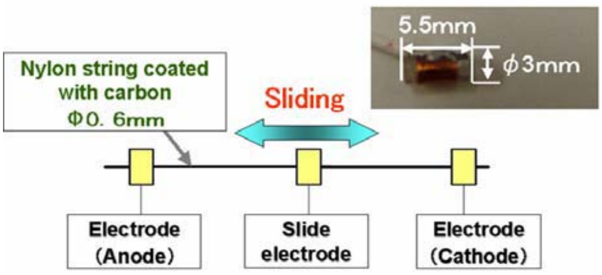


Figure 1 Construction and view of the tested flexible displacement sensor

Figure 2 shows the inner construction of the slide electrode. The slider consists of a brass cylinder that is filled with carbon black powder. The each side of the slider has a rubber sheet, a rubber packing and a plastic cover to keep a sealing. The slider is penetrated with a NSCC. By this construction, the slider can keep a stable electrical contact between the slider and NSCC. The carbon black powder prevents the wear of NSCC because it works as balls of a slide bearing. The tested flexible sensor can realize a longer measurement range than a conductive rubber displacement sensor [2]. The user can easily change a measurement range of the sensor.

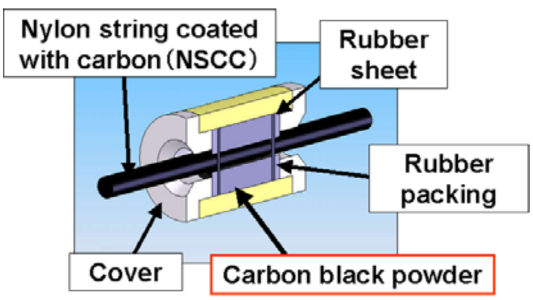


Figure 2 Inner construction of the slide electrode

Characteristics of the tested sensor

Figure 3 shows the relation between displacement and electric resistance of the sensor. We can see that the resistance of the sensor is proportional to the displacement between two electrodes. We also find little hysteresis in experimental results using the tested slide electrode even if one end of NSCC is not fixed on a table. It means that there is less friction between the tested slider and the NSCC.

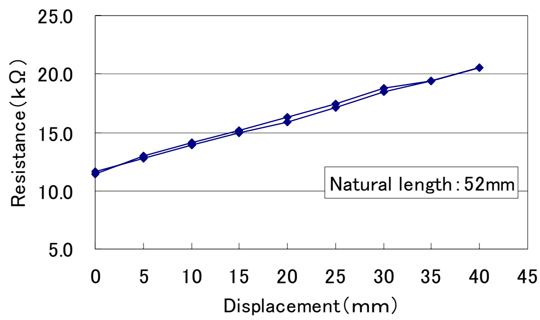


Figure 3 Relation between displacement and resistance of the tested sensor

In such a kind of the slide electrode including the carbon black powder in it, the leakage of the powder from the electrode chamber might become the problem of durability. We investigated the durability of the tested sensor. Figure 4 shows the relation between the number of repetition of sliding and the output voltage of the sensor. In the experiment of endurance test, the slide electrode is driven by the pneumatic cylinder that makes the slide electrode move for the distance of 30 mm within 0.3 seconds. In every 100,000 times sliding, the output voltage from the tested sensor in both points of maximum and minimum stroke of the pneumatic cylinder was measured. In Fig.4, each line shows the average of the measured output voltage of the sensor in each position. The vertical line shows the scatter of the measured data.

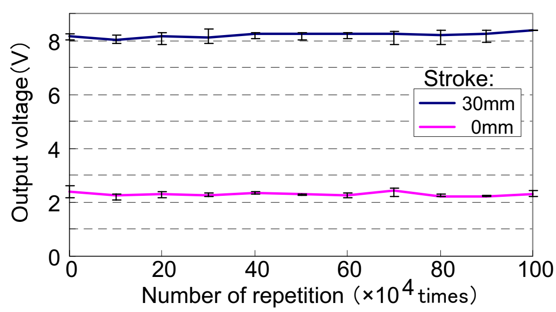


Figure 4 Experimental results for endurance test

We can see that the output voltage of the sensor does not change in the both position even if one million times sliding was applied to the sensor. It means that the tested sensor has good durability. In the experiment, we also found little leakage of carbon black powder from the slide electrode. Through the endurance test, we found that the sensor was able to be used even if the carbon powder was not filled in it.

POSITION CONTROL OF ARTIFICIAL MUSCLE

Position sensing of artificial muscle

As an application of the tested string type flexible displacement sensor to the sensing of robot actuator, we proposed and tested a position sensing system of a McKibben artificial muscle using the tested sensor. Figure 5 shows the relation between the displacement of the McKibben artificial muscle and the output voltage of the attached flexible displacement sensor. In addition, we apply a unique measurement method that the sensor can measure the whole displacement of the actuator by measuring a part of it. The setting position of the sensor in the actuator is parallel to the longitudinal direction of the surface of the actuator. The sensor connected with the actuator is shown in upper photograph in Fig.5. Also, the distance between a fixed electrode and slide electrode was set by 14 mm by considering the movement range of the slider for a supply pressure (from 0 to 500kPa). From Fig. 5, we can see that a linear relationship is established between the displacement of the artificial muscle and sensor output voltage. The correlation coefficient is 0.998. We can confirm that the whole displacement of the actuator is measured by measuring a part of it using the proposed method and the tested sensor.

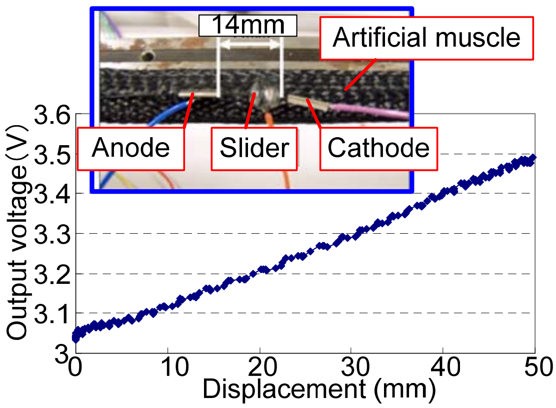
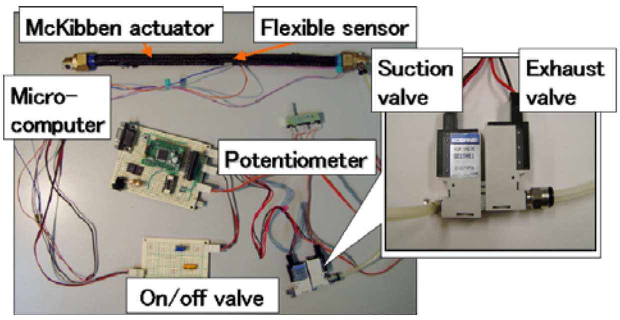


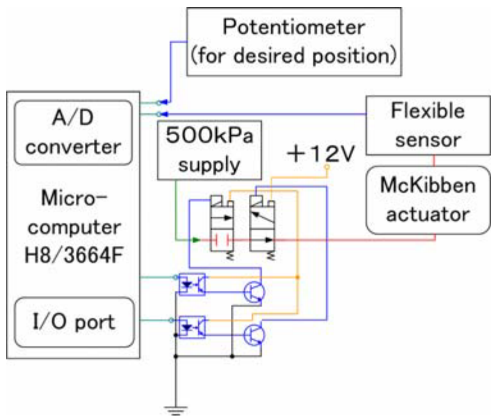
Figure 5 Relation between displacement of artificial muscle and output voltage of sensor

Compact position control system of artificial muscle

Figure 6 (a) and (b) show the construction and the schematic diagram of the position control system of the artificial muscle with the flexible displacement sensor, respectively. In Fig.6 (a), the system consists of a potentiometer to give the desired position, a microcomputer (Renesas Technology Co. Ltd.. H8/3664) , a Mckibben artificial muscle (FESTO Co. Ltd. MAS-10) with the tested flexible sensor and two on/off control valves (KOGANEI Co. Ltd. G010HE-1). The suction and exhaust valves are connected in series as shown in Fig.6. The position control of the actuator is done as follows. First, the microcomputer gets the voltage from the tested sensor and the reference voltage through a 10 bit A/D converter in the microcomputer. In operation, the microcomputer drives the suction or exhaust valves through the transistors according to the deviation from the desired position. When the deviation exists within a certain range, both valves are turned off. In the case when the deviation is larger, the suction valve is turned on and the exhaust valve is turned off. In other cases, both valves are driven so as to become the opposite state of the previous case.



(a) Construction of control system



(b) Schematic diagram of control system

Figure 6 Position control system using artificial muscle and skin displacement sensor

Figure 7 shows the transient response of the displacement of McKibben actuator. In Fig.7, each blue and red line show output voltages from potentiometer for desired position and the flexible sensor, respectively. From Fig.7, we can see a vibration of the actuator occurred in the range of smaller displacement because of the control using on/off valves. As a whole, it can be considered that the movement of actuator can trace well the desired position even if a simple control method such as on/off control is used. In addition, we can confirm that the dynamics of tested flexible sensor is very fast so as to measure the vibration of the actuator.

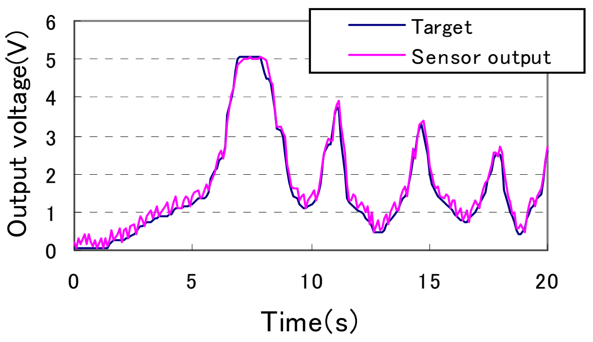


Figure 7 Transient response of displacement of the artificial muscle using tested control system

SKIN DISPLACEMENT SENSOR

Construction and operating principle

It is very useful to measure the movement of human body such as a joint angle indirectly. It is because that such a sensing system does not prevent the human motion and an easy sensor configuration at the point of moving part of human such as a joint. When the human body moves, the muscle also moves. At the same time, the skin covering the muscle moves. Therefore, we propose and test a skin displacement sensor. Figure 8 shows the construction of the skin displacement sensor. The upper photograph in Fig.8 shows the general view of tested sensor. The lower photograph shows the view in the case when the sensor is pasted on the human arm. The sensor consists of the FDS set on a flexible plastic sheet that has bellows and an electric circuit pattern using the conductive paint. The middle figure in Fig.8 shows the electric circuit of the sensor. The electric input and output line are gathered in one end of the sensor. Each end of the FDS is connected with a power supply and GND line. The slide electrode is connected with the sensor output line. The operating principle of the sensor is as follows. First, the both end of the sensor as shown in the lower photograph in Fig.8 are pasted on the human skin as a sticking plaster. When the body and skin moves, the distance between both pasting points of the sensor is changed. This change causes the pulling and pushing force acted on one end of the FDS. By this method, the sensor measures the displacement of the skin.

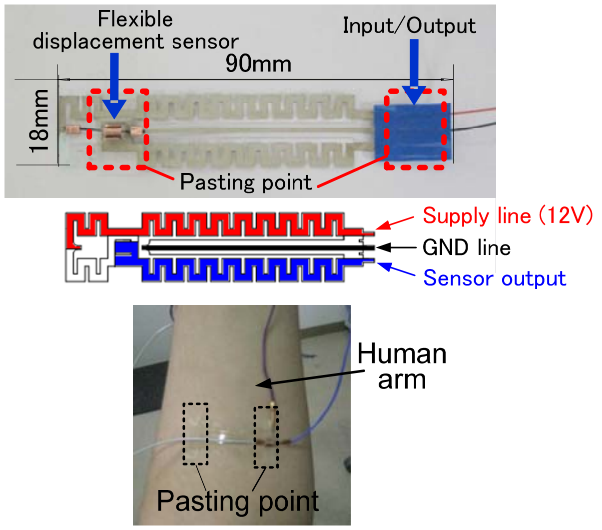


Figure 8 Construction of the skin displacement sensor

Sensing for human motion using skin displacement sensor

Figure 9 shows the experimental setup using the skin displacement senor. The equipment consists of the sensor pasted on the human arm and a voltmeter to measure the output voltage from the sensor. In the experiment, we measure the bending angle of the elbow by taking photographs of the posture of the elbow and the output voltage of the sensor.

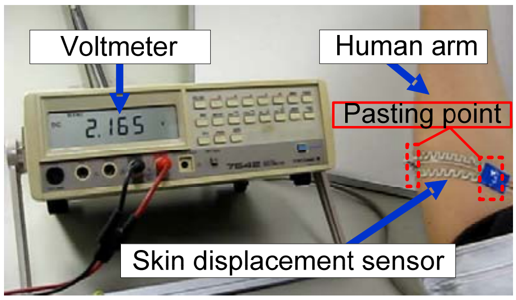


Figure 9 Experimental setup for the tested sensor

As a pasting point of the sensor, we select the skin over the muscle that is related to drive the elbow such as a biceps brachii, a brachialis, a brachioradialis and a triceps brachii as shown in Fig.10.

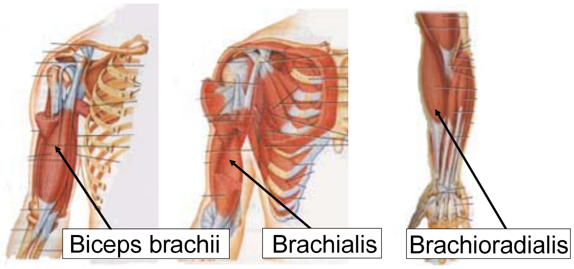
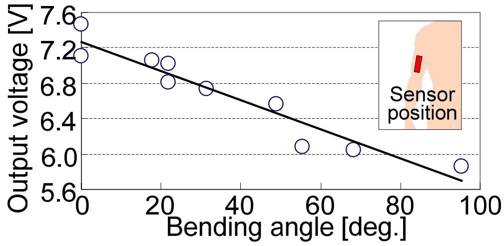
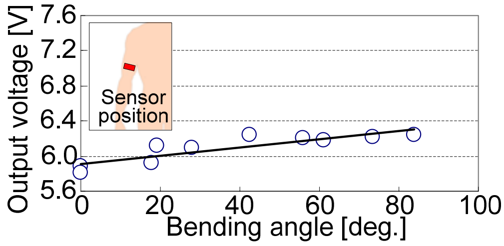


Figure 10 Muscles which are related to drive the elbow [4]

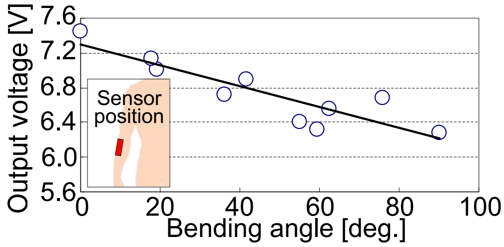
Figure 11 (a) and (b) show the measuring results when the sensor is pasted on the skin over the biceps muscle parallel and vertically to the muscle, respectively. Figure 11 (c) and (d) show the results when the sensor is pasted over the brachioradialis muscle vertically and parallel to the muscle, respectively. Figure 11 (e) shows the case when the sensor is pasted on the forearm muscle in diagonal direction. Each small illustration in Fig. 11 shows the pasting point of the skin displacement sensor. Each graph in Fig.11 shows the relation between the bending angle of the elbow and the output voltage of the sensor. From Fig.11, we can see that the relation between the bending angle of the elbow and output voltage of the sensor is almost linear in all cases. Each gradient of solid line in the graph shows the sensitivity between the sensor output voltage and the bending angle of the elbow. The increasing and decreasing of the output voltage according to the bending angle in each figure mean that the extended and contracted force are applied to the skin displacement sensor, respectively. As an estimation of the optimal pasting position of the sensor, Table 1 shows the correlation coefficient and the differential output voltage of the sensor when the elbow angle changes from 0 to 90 deg. From Table 1, we can see that the case when the sensor is pasted vertically over the biceps brachii muscle as shown in Fig.11 (a) is superior than other cases because of the higher correlation coefficient (that is -0.957) and the larger output voltage (that is 1.607 volts) for bending. The value of -0.957 in the coefficients of correlation means that the relationship between the skin displacement and bending angle of the elbow measured by the tested skin displacement sensor is almost linear. As a result of these trials, we can say that the tested skin displacement sensor has a possibility of indirect measurement of human motion.



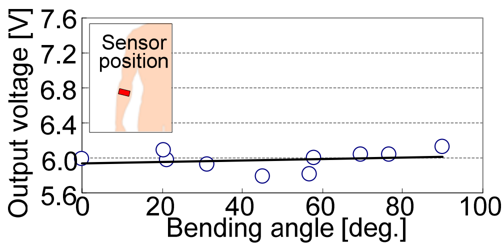
(a) Biceps brachii (parallel direction)



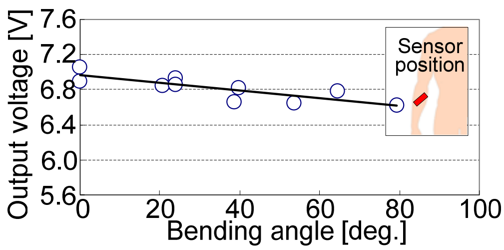
(b) Biceps brachii (vertical direction)



(c) Brachioradialis (parallel direction)



(d) Brachioradialis (vertical direction)



(e)Forearm (diagonal direction)

Figure 11 Relation between bending angle of the elbow and output voltage of the skin sensor

Table 1 Estimation for pasting point

Pasting point	Correlation coefficient	Differential voltage (V)
Biceps brachii (parallel direction)	-0.9565	1.607
Biceps brachii (vertical direction)	0.8693	0.431
Brachioradialis (parallel direction)	-0.8846	1.167
Brachioradialis (vertical direction)	0.2213	0.341
Forearm (diagonal direction)	-0.8259	0.440

CONCLUSIONS

This study for developing a wearable flexible sensor can be summarized as follows.

1) We proposed and tested a new type of flexible displacement sensor using nylon string coated with carbon. We also proposed and tested a small sized pressure control system to drive a McKibben actuator using on/off valves. As a result, we confirmed that the tested sensor was useful to apply to the position control system using the McKibben actuator because of its compact configuration of sensor and actuator so as not to lose the flexibility of the actuator.

2) We also proposed and tested the skin displacement sensor that can measure the human motion such as a joint movement indirectly. As a result of measuring the elbow angle, we can confirm that the tested skin displacement sensor has a possibility of indirect measurement of human motion.

In our future work, we are going to develop an intelligent skin displacement sensor that has a function of electromyogram as an interface between humans and machines in order to develop the pneumatic power assisted system.

ACKNOWLEDGMENT

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