Control of IPMC Actuator using Self-sensing Method

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Abstract: IPMC (Ionic Polymer Metal Composites) is a kind of EAP (Electro-active Polymer) which generates bending motions by low driving voltage. Since it is light and soft, IPMC has potentiality to be used as an actuator and a sensor. The IPMC actuator is being applied to the field of artificial muscles that can substitute joints or muscles of human body. Moreover, external sensors are integrated into the robot system for the precise motion control. This paper proposes a method that can maintain position of the IPMC actuator and suggest a viability to handle a weak object with IPMC actuator itself without any additional sensor by the advanced self-sensing method which utilizes the accumulated charges inside the IPMC.

Keywords: IPMC, Self-sensing, Actuator, Sensor

1. INTRODUCTION

IPMC(Ionic Polymer Metal Composites) is a kind of EAP (Electro-active Polymer) which is produced by plating gold or platinum chemically on a perfluorosulfonic acid membrane which is known as an ion-exchange membrane. IPMC has a special feature that gets bent by small voltage (1~2V), and produces some voltage (millivolts) by external force to bend it. (Shahinpoor 2001)

When the voltage is applied between the both metal layers of IPMC, the IPMC bends to the anode, which was discovered by Oguro in 1992. (Chen 2005)

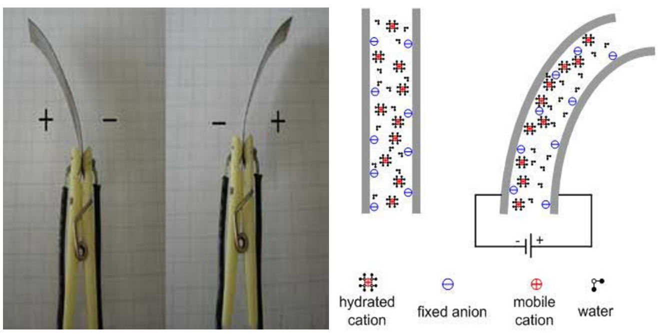

Fig. 1. Bending behaviour and the actuation principle of IPMC

Fig. 1 shows the principle of bending behavior of IPMC. If the voltage is supplied to the both sides of IPMC strip, hydrated cations, which are moving water molecules, inside the IPMC is moving towards the cathode. The moved hydrated cations make the IPMC be bent toward the direction of anode. This principle results IPMC to bend towards the anode. (Oguro 1992)

There are several advantages of IPMC. They are low input voltage (1~2V) and fast response. Also, it is chemically stable, durable, flexible, and movable in water or wet condition. It is possibly be miniaturized for weight saving, and silent actuation.

IPMC has been studied at a lot of research areas such as robotics, biomedics, aviation fields, and so on. Especially, in the application in the robotics area, Yeom et. al. developed a biomimetic jellyfish robot (Yeom 2007), and Kamachi et. al. made snake-like swimming robot(Kamamichi 2006). Also, IPMC has been utilized for artificial joints at biomedical application and wipers or grippers at the aerospace fields. (Ando 2008, Bar-Cohen 1999)

However, not only the research about use of IPMC as an actuator has not been done, but also the applications as a sensor has not been fully developed. When external physical force is exerted to the IPMC, the electromotive voltage generates because of the ions inside the IPMC are moved from one place to the other, while it is being bent. (Shahinpoor 1998) Since the voltage variation of IPMC is related to the amount of bending motion, the possibilities to be used as a motion sensor or a pressure sensor are possible. The features of it such as high sensitivity of the output voltage and physical flexibility make it utilized for the various kinds of applications.

Also, additional sensing equipments have been used to control the IPMC actuator accurately. Yamakita et. al. proposed the control method which utilizes the feedback signal from the vision camera sensor (Yamakita 2005), and Bhat et. al. made use of load cell as a sensor for precise motion control. (Bhat 2004)

The purpose of this research is to find out the viability of using one IPMC as an actuator and a sensor by applying a proposed self-sensing method without any additional sensors. Therefore, the result of this research is able to provide the control method for robotic hand to handle weak objects.

2. A SELF-SENSING METHOD

Although IPMC has been utilized for two independent applications which are an actuator and a sensor, it has never been used for both sensor and actuator at the same time with same device. The reason is the output voltage is too low to use it as a sensor, or sensed signal, which is come from it during actuation, contains inaccurate data caused by signal distortion or noise. Thus, most of researches represent the control method using additional sensors such as laser sensors, PVDF, vision camera, and so on. However, the size of the additional sensor is too big to apply or attach to the tiny actuator made by thin IPMC plate. Therefore, the physical characteristics of IPMC itself, such as resistance, electrical voltage and current are mainly used to detect the current status. (Punning, Kruusmaa 2007)

If voltage is supplied to the IPMC, ions inside it move to the cathode. As a result, the IPMC membrane is to be bent towards the direction of anode. (Fig. 1) This phenomenon produces a voltage gradient around the metal electrodes. Due to its chemical structure, the IPMC can accumulate the electric charges in materials. While the IPMC is used as an actuator, this method allows finding out the status of bending motion if the charged voltage at IPMC is measured. However, if voltage is measured during exertion of driving voltage for the IPMC actuator, it does not indicate the IPMC's own charged voltage. In that case, the accurate voltages cannot be detected. When the input voltage is assigned to IPMC, the instantaneous open-state status is made by the analogue switch and relay. (Fig. 2) During that status, the charged voltage at the IPMC strip is measured, which is its own voltage. As a result, the position of the IPMC actuator can be known by the voltage level of itself during the open-state status. (Ko 2008)

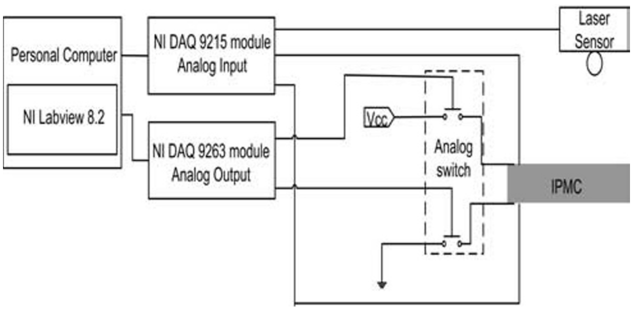

Fig. 2. Block diagram for voltage sensing of IPMC

According to the previous research by Ko et. al., the bending position is related with the charged voltage inside the IPMC actuator. Fig. 3 represents that the detected voltage of IPMC at the open-state status is in inverse proportion to the curvature of the IPMC strip.

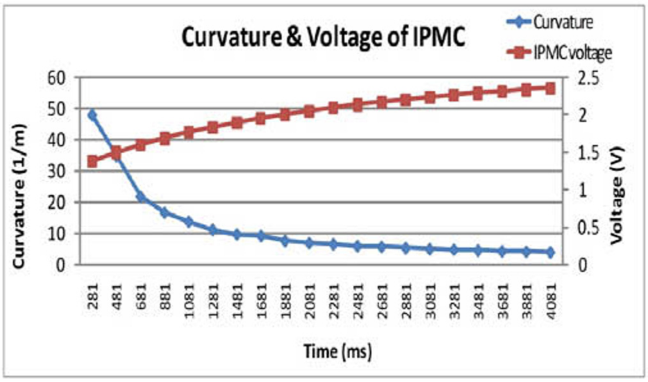

Fig. 3. Relation between bending curvature and IPMC's own voltage

If the relationship between the charged voltage and the bending curvature is used, the curvature is able to be predicted by the level of voltage caused by the accumulated voltage.

This principle makes the actuator keep certain position and is able to be applied to the robotic hand in order to handle weak object by the precise position control without any additional sensors. This is the proposed self-sensing method that the IPMC strip is used as a sensor and an actuator at the same time. However, if the experiments are done repeatedly, the bending status becomes different and the charged voltage is also varied because of chemical characteristics. Since the voltage value does not indicate the absolute bending status, it should be used as a relative data for position control. For the further work, the tiny gripper for the delicate handling will be developed using the proposed self-sensing method in this paper.

3. MODELING

The IPMC's actuating and sensing properties have been focused for about two decades, but the analysis of the IPMC's mechanism and application for the control system are seldom studied. Several models of IPMC actuator have been introduced, but they have been developed in order to understand their electromechanical characteristics while it is actuating. [Punning 2007] Since they are not applicable for expressing sensory property, new model is introduced in this research, which describes the relationship between the position and the accumulated charge of the IPMC. The transfer function for the IPMC, which is determined by measuring the charged voltage of IPMC using the experimental set-up (Fig. 2) is needed in order to do position control of IPMC using conventional control theory such as PI control. The initially charged voltage level of the IPMC and the time constant (τ), which is time for reaching 63.2% of input voltage, need to be measured in order to decide the transfer function of IPMC. [Lim 2005] Fig. 4 shows the variation of the charged voltage during the application of 5V-input. According to the experimental result, the initially charged voltage (V_i) is 1.6V, and the time constant (τ) is approximately 400 seconds. Therefore, the transfer function of the IPMC is described as (1)

$$G(s) = (V_i + \frac{V_i}{\tau s+1})/5 = (1.6 + \frac{1.6}{400s+1})/5 \quad (1)$$

The simulation result using the determined transfer function is described at Fig. 5, which is different from actual characteristics at Fig. 4. Thus, the time constant is modified into 70 through several experiments which make almost same result as Fig. 4.

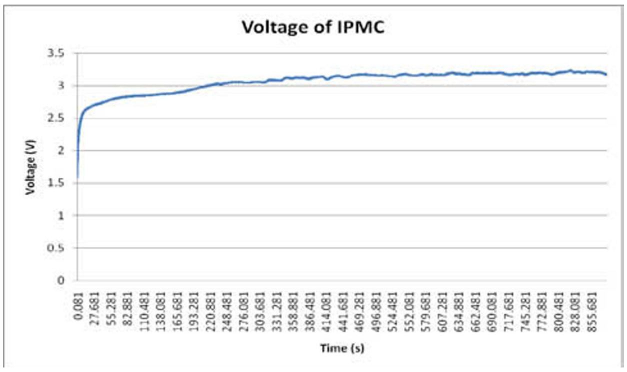

Fig. 4. Voltage of IPMC

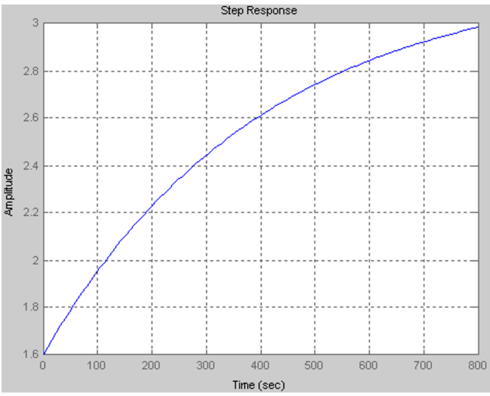

Fig. 5. Step Response of IPMC (τ=400)

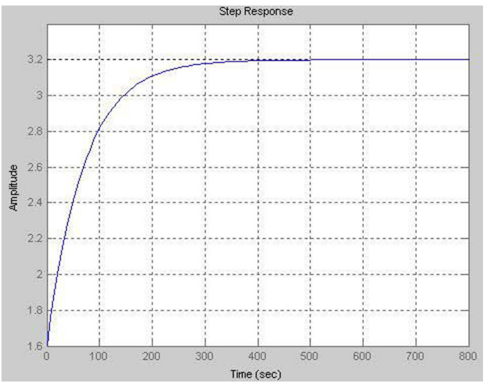

Fig. 6. Step Response of IPMC (τ=70)

As a result, the transfer function of IPMC described at equation (2) is utilized for the experiment of position control.

$$G(s) = (1.6 + \frac{1.6}{70s+1})/5 \quad (2)$$

4. CONTROLLER DESIGN AND RESULT

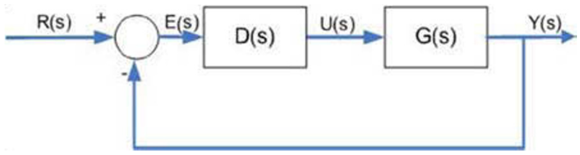

Fig. 7. Structure of Controller

In order to control the certain position of IPMC strip during actuation, the controller needs to be developed. (Fig. 7) R(s) is a reference voltage which is determined by instantaneously detected voltage of the IPMC strip at the certain position. The controller always keep IPMC's internal voltage maintain to the reference voltage. Y(s) is the measured actual voltage of the IPMC strip which is modeled as G(s). E(s) means error which is a difference between the reference voltage and actual voltage of the IPMC strip. D(s) is the controller. It makes U(s) which is the input signal to drive the IPMC actuator. When the U(s) is generated by the controller D(s), E(s) is utilized for suitable input signal to the IPMC actuator. The D(s) is designed by the PI controller described as (3), which is good at improving the steady state performance.

$$D(s) = K_P + \frac{K_I}{s} \quad (3)$$

The coefficients of the controller, which are K_P and K_I, should be determined so that the G(s) can work correctly. In order to find the suitable coefficients, the simulation is performed by following steps. First, a step input of 1V is applied to the IPMC. Second, K_P is decided as 50 to reduce the overshoot. Third, when the K_I is 1, the result is converged for the step input (1V). Finally, the controller D(s) is decided like equation (4), and the simulation result is showed at Fig. 8, when the input of 1V is assigned.

$$D(s) = K_P + \frac{K_I}{s} = 50 + \frac{1}{s} \quad (4)$$

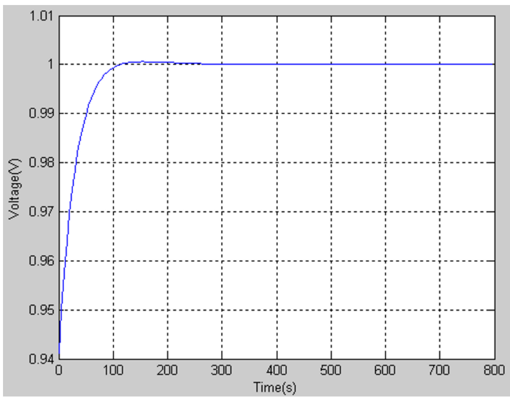

Fig. 8. Simulation Result for D(s) (K_P=50, K_I=1)

The position control of IPMC actuator performed using the developed model and controller by simulation method in order to prove if the proposed algorithm works correctly. The scenario of position control is described following steps. Step

1, the power is assigned for the IPMC to actuate. Step 2, the assigned power is removed, when the IPMC reaches the target position. Step 3, the controller make the IPMC staying that position using the sensed data from the IPMC itself. For the simulation, the initial condition is assumed that the charged voltage is 3V, when the power for actuation is removed. According to the simulation result express at Fig. 9, the charged voltage of IPMC is maintained with 3V, which makes the position of IPMC controlled.

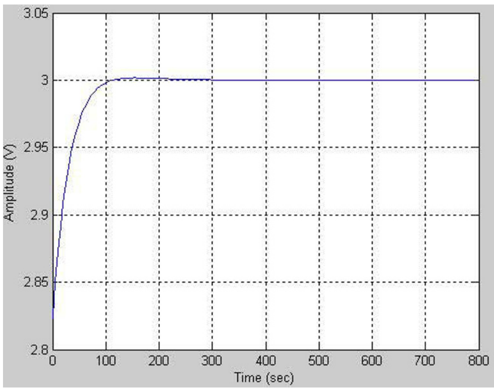

Fig. 9. Simulation Result of Position Control

5. CONCLUSION

This paper proposes viability of a method that can maintain position of the tiny IPMC actuator. Also, it can be applied for the handling a weak object with IPMC actuator itself without any additional sensors by advanced self-sensing method which utilize the accumulated charges inside the IPMC. The new model for including the sensory characteristics is proposed, and the PI controller for the position control of IPMC is developed. The simulation is performed in order to prove if the proposed method works. Therefore, IPMC is able to be applied easily to the robotic hand which is manufactured with IPMC. The most important feature for using the proposed method is being able to develop tiny gripper with position control. For the further research, the experiment of position control of IPMC actuator will be executed and the experimental result of the application for the real robot finger will be provided.

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