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Preliminary Study on Analysis of Pinching Motion Actuated by Electro-Active Polymers

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***Abstract*—**Hand exoskeletons have been developed in order to assist daily activities for disabled and elder people. A figure exoskeleton was developed using ionic polymer metal composite (IPMC) actuators, and the performance of it was evaluated in this study. In order to study dynamic performance of a finger dummy performing pinching motion, force generating characteristics of an IPMC actuator and pinching motion of a thumb and index finger dummy actuated by IMPC actuators were analyzed. The blocking force of 1.54 N was achieved under 4 V of DC. A thumb and index finger dummy, which has one degree of freedom at the proximal joint of each figure, was manufactured by a three dimensional rapid prototyping. Each figure was actuated by an IPMC actuator, and the maximum fingertip force was 1.18 N. Pinching motion of a dummy was analyzed by two video cameras in vertical top and horizontal left end view planes. A figure dummy powered by IPMC actuators could perform flexion and extension motion of an index figure and a thumb.

***Keywords*—**Finger exoskeleton, ionic polymer metal composite, flexion and extension, motion analysis.

I. Introduction

HAND exoskeletons have been developed in order to assist daily activities for disabled and elder people. They are also used for rehabilitation purposes as well as power assist devices [1]. Most hand exoskeletons are actuated by electric motors [2]-[4] or pneumatic actuators [5], [6]; therefore, they are rigid and heavy as well as require large power consumption. Currently, electro-active polymers have been applied to the actuators because of their flexibility, light weight and simple structures. A figure exoskeleton was developed using ionic polymer metal composite (IPMC) actuators, and the performance of it was evaluated in this study. In order to study dynamic performance of a finger dummy performing pinching motion, force generating characteristics of an IPMC actuator were measured, and pinching motion of thumb and index finger dummy actuated by IMPC actuators was analyzed.

II. Methods

An IPMC is composed of ionic polymer and metallic electrodes which are plated on the surface of polymer membrane. Once electric potential is applied across the electrodes, cations inside of the polymer membrane move to the negative electrode. The cations carry the water molecules to the negative electrode, which expands the volume of the polymer membrane near the negative electrode and bends an IPMC actuator toward the negative electrode. Nafion®117 perfluorinated membrane (DuPont, Wilmington, DE) was used as an ionic polymer membrane. Nafion® membranes were stacked and hot-pressed to manufacture the membrane of desired thickness. The electrodes were formed by electroplating platinum several times using a chemical reduction method. The IPMC membrane of 2.4mm thickness was cut into strips with a width of 20mm and a length of 40mm, and used as the actuators of the finger exoskeletons.

Voltages with opposite polarities were applied to the separate electrodes on each side of an IPMC strip by a DC power supply (IT6720, Itech, South Korea).The force generated by bending of a cantilevered membrane actuator decreased as the tip deflection increased, and the maximum tip force was achieved when the tip deflection was zero. The reactive force that blocked further deformation of an IPMC strip under electrical stimulus was defined as the blocking force. The blocking forces were measured using a load cell (2002, NICOM, South Korea). Details of the experimental setup were described in the previous study [7].

A thumb and index finger dummy was manufactured using a three dimensional rapid prototyping machine (Project 1500, 3D Systems, USA). The size of each finger was determined by anthropomorphic data on fingers, which were measured for 32 males aged 20 to 28 years. An index finger was consisted of the three joints which are the metacarpophalangeal (MCP), proximal interphalangeal (PIP), and distal interphalangeal (DIP) joints. A thumbwas consisted of the two joints which are the metacarpal-proximal phalangeal joint (MPP) and interphalangeal (IP) joints.

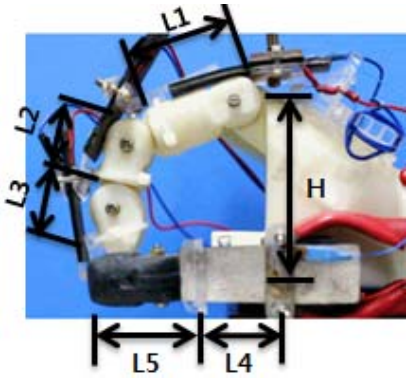


Fig. 1 An index and thumb finger dummy equipped with an exoskeleton

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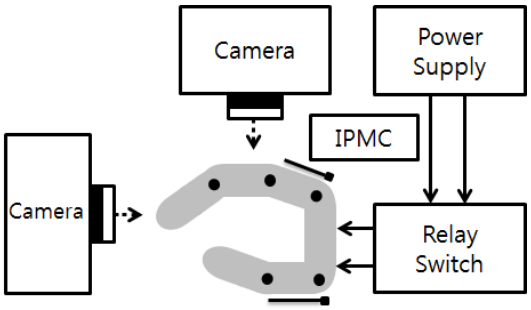


Fig. 2 Experimental setup for pinching motion analysis

The length of each phalange of an index finger was 49.6mm, 42.6mm, 20.8mm for L1, L2, and L3, respectively. The length of each phalange of a thumb was 27.8mm, 31.6.6mm, 49.6mm for L4, L5, and H, as shown in Fig. 1.

Pinching motion was recorded by two video cameras (EOS 60D, Canon, Japan), and analyzed as shown in Fig. 2. An IPMC actuator was equipped on the metacarpophalangeal (MCP) joint of an index figure and another actuator was equipped on the metacarpal-proximal phalangeal joint (MPP) joint of a thumb dummy. Each finger has one degree of freedom, and other joints were fixed. Dummies were positioned in full extension state, and electric potential difference of 4 V was applied for flexion motion of a dummy. Once pinching motion was achieved by contacting of each flexed fingertip, electric potential was applied in the reverse direction for extension of a dummy.

III. Results

Blocking force of an IPMC actuator (40x2.4x30mm) was measured as a function of time. An IPMC strip was cantilevered, and a load cell was placed at the tip of the free of an actuator. 4V of direct voltage was applied across the electrode using a power supplier, and measure blocking force is shown in Fig. 3. The blocking force increased slowly and the maximum blocking force (1.52N) was measured at 230s. Once the maximum blocking force was achieved, the electric potential was shut off and the blocking force was decreased afterwards.

The force generated by a finger dummy actuated by an IPMC was also measured in order to estimate the actuation force of a finger exoskeleton. The metacarpal and proximal phalanges were positioned in a horizontal plane and the angles of MPP joint was 90 degree.

The actuator positioned at the tip of a proximal phalange generated a horizontal blocking force at the tip of a thumb dummy, and it was measured as a function of the time (Fig. 4). The horizontal positions of an actuator tip and figure tip were coincided so that the moment of arms of the actuator force and the fingertip force were the same. 4V of direct voltage was applied, and the maximum fingertip force of 1.18 N was generated in 110 s. This force was about 77% of the blocking force of an IPMC actuator.

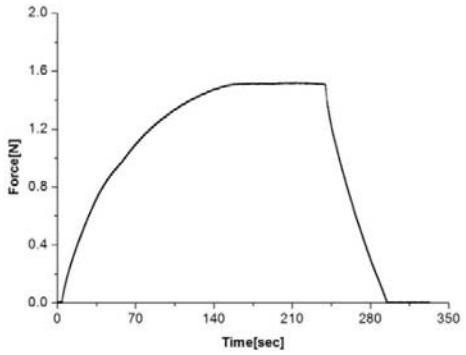


Fig. 3 Blocking force of an IPMC actuator

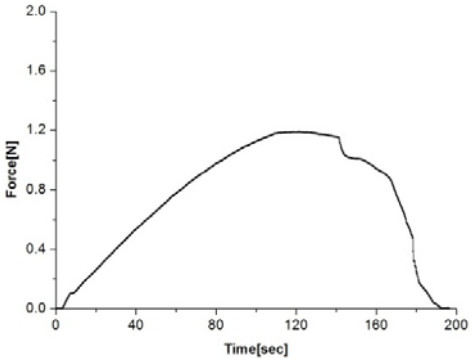


Fig. 4 Tip force of a thumb dummy actuated by an IPMC actuator

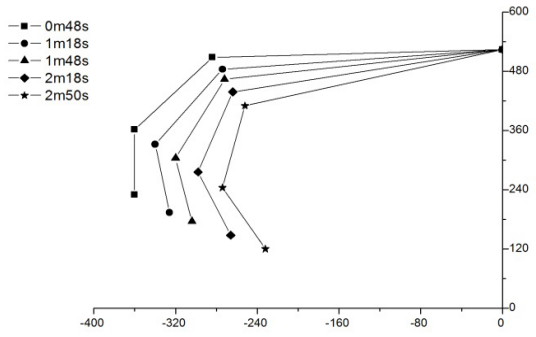
Pinching motion of a dummy was analyzed by two video cameras in vertical top and horizontal left end view planes. Positions of each joint and fingertip of a finger dummy were measured in the vertical plane while those of a thumb were measured in the horizontal plane. 4V of direct voltage was applied to the actuator of each figure for finger flexion during 122 s. Voltage was applied in the opposite direction for figure extension during 104 s. Positions of each joint and fingertip of an index finger and a thumb at five different times are shown in Fig. 5.

IV. Conclusion

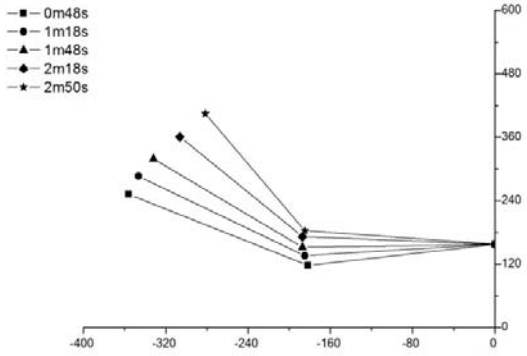
In order to design a figure exoskeleton with flexible actuators, an index finger and thumb dummy was constructed based on the anthropomorphic data of 32 males. Each figure has one degree of freedom at its proximal joint and other joints were fixed. One IPMC actuator was equipped at each finger and flexion and extension motion of each finger was achieved by bending of flexible IPMC actuators. The maximum figure tip force generated by an IPMC actuator without bending was 77% of the blocking force of an IPMC actuator. A figure dummy could perform flexion and extension motion of an index figure and a thumb powered by 4 volts of DC. Flexion of pinching motion required 226 s while extension was completed within 104 s.

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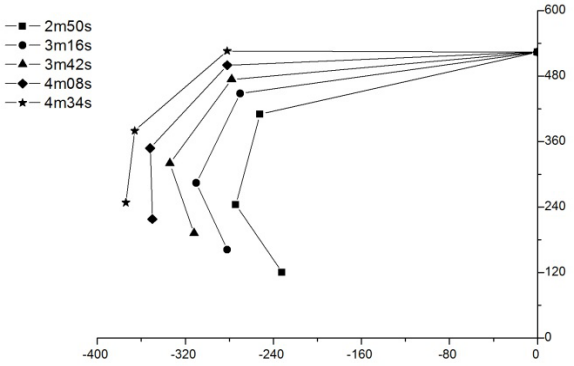
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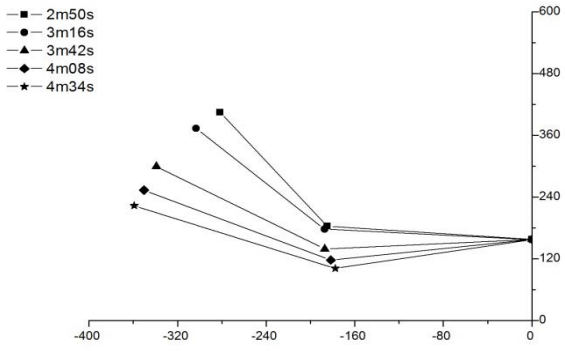
(a) Flexion motion of an index finger



(b) Flexion motion of a thumb



(c) Extension motion of an index finger



(d) Extension motion of a thumb

Fig. 5 Positions of joints and the fingertip of a finger dummy for flexion and extension

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