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A robot hand using electro-conjugate fluid: Grasping experiment with balloon actuators inducing a palm motion of robot hand

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ABSTRACT

An electro-conjugate fluid (ECF) is a kind of functional fluid, which produces a jet flow (ECF jet) when subjected to high DC voltage. It is known that a strong ECF jet is generated under nonuniform electric field, for example, the field with a pair of needle and ring electrodes. We developed in our previous study a novel five-fingered flexible robot hand using the ECF. In this study, in order to improve the ECF hand we pay our attention to the flexion of palm because human often grasp an object with the flexion of palm. First, we propose a concept of five fingered robot hand which has balloon actuators driven by the ECF jet to produce the flexion of palm. The actuator is mainly composed of silicone rubber membrane and a rubber base with a slit, so that when the actuator is pressurized, the slit is opened, resulting in making the palm of the robot hand actuate. Finally we conduct grasping experiments based on Cutkosky's taxonomy of human grasping, and demonstrate the robot hand can grasp some objects with various shapes without any complex controller. The height, the width and the mass of the robot hand are approximately 70 mm, 40 mm and 40 g, respectively.

1. Introduction

Application areas of robotics and mechatronics technology have been spreading especially in the last two decades, which means robots are now widely used not only in industrial fields but also in the field closer to our daily lives. Hence, robot hands are getting much attention from researchers in the field of medical, entertainment, man–machine cooperation, etc. Common subjects for such robot hands are to be small enough in size, lightweight and flexible, mainly for the reason of physical safety.

Several types of robot hands using servomotors, shape memory alloys, ultrasonic motors, ionic polymer–metal composite, etc. have been developed [1–5]. In addition, a robot hand driven by pneumatic soft actuators is also actively developed because of its advantages as flexibility, compactness and high generative force [6–9]. The pneumatic soft actuator such as McKibben artificial muscle [8,9] mainly consists of a rubber tube covered with a fiber sleeve, a pneumatic power source, and a valve. The rubber tube configuration, control method and applications of the pneumatic soft actuators have widely been investigated so far, however, the essential problem with pneumatic actuators is the requirement for bulky power sources apart from the actuator itself. Furthermore, it requires pneumatic lines to supply air pressure to each actuator. Therefore the entire system must be large. Some other fluid driven actuators and microhands [10–13] are also developed, however the problems due to the bulky power source are still under investigation.

The authors also developed new types of robot finger/hand using the electro-conjugate fluid (ECF) [14,15]. The ECF is a kind of functional fluid which produces a powerful flow (ECF jet) when subjected to high DC voltage. Using the ECF jet pressure together with flexible rubber actuators enables an actuator to be small in size and constructively flexible. We introduced this attractive functional fluid to develop a flexible robot hand. The robot hand has five rubber-made fingers which are capable of bending with the ECF jet pressure.

The purpose of this study is to enhance the possibility of the above-mentioned ECF robot hand. That is, we realize the flexion motion of palm in this study because human hand generates dexterous grasping motions with the palm motion [16,17]. As the palm motion is based on flexion/extension of metacarpal and opposition of the thumb against other fingers as illustrated in Fig. 1, we will be developing an actuator which may realize these motions.

2. Electro-conjugate fluid

The electro-conjugate fluid is a dielectric fluid, which works here as a smart/functional fluid. Applying a high voltage of several kilovolts between electrodes inserted into the fluid with an

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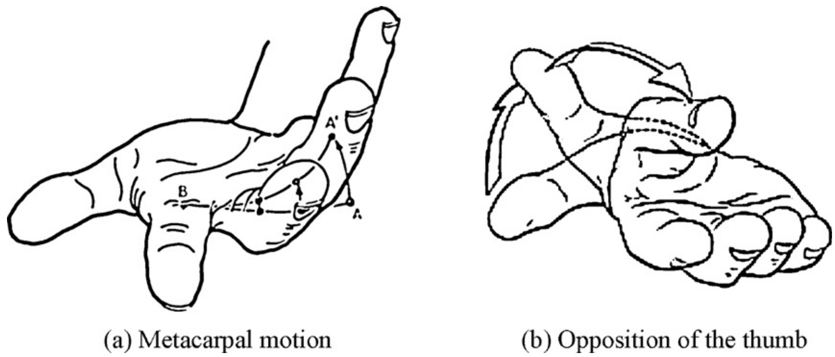

Fig. 1. Flexion motion of palm [17].

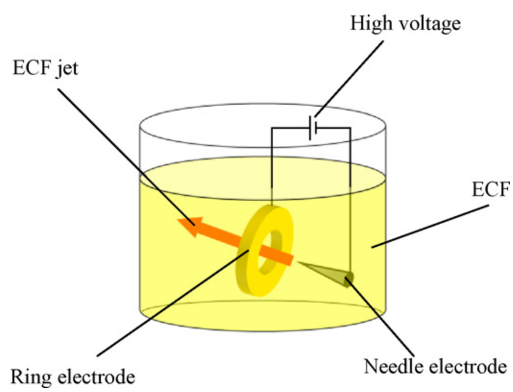

Fig. 2. Schematic diagram of ECF jet.

interelectrode gap of several hundred micrometers, we can observe a powerful jet flow (ECF jet) between the electrodes as shown in Fig. 2. This phenomenon observed in the electro-conjugate fluid is called an ECF effect in particular [14]. Although the mechanism of ECF effect is still under investigation [18,19], the ECF jet can be observed especially under a non-uniform electric field, for example, between a needle–ring electrode pair as shown in Fig. 2. A high voltage is required to generate the jet flow; however, the current needed is quite low at approximately several microamperes [20].

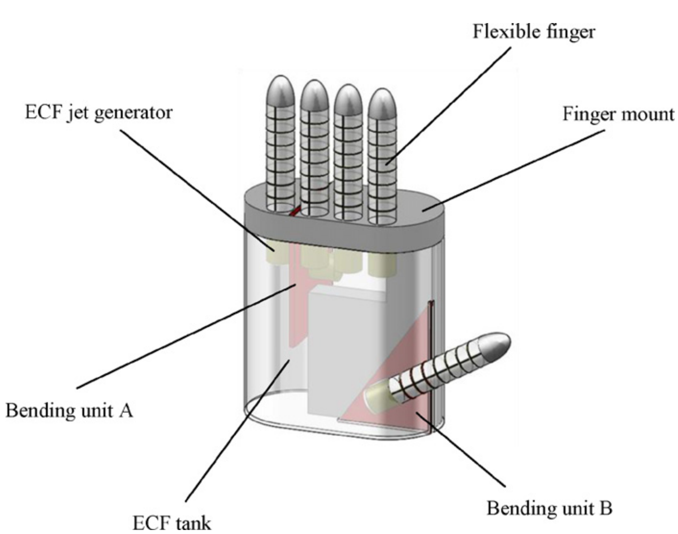

Fig. 3. Concept of the ECF robot hand.

3. Concept

Fig. 3 shows a conceptual view of the robot hand, mainly composed of flexible fingers, ECF jet generators, bending units, a finger mount, and an ECF tank (palm of the hand). The robot hand is filled with the common ECF. Each ECF jet generator has electrode pairs inside and is located at the end of the flexible finger and the bending unit. The fingers are appropriately restricted with fibers [15], which allow them to bend when the inner pressures are increased with the ECF jet generated from the ECF jet generators. The details of ECF flexible finger could be found in our previous paper [15].

This chapter proposes a novel concept to realize the palm motion shown in Fig. 1, in order for our ECF robot hand [15] to have capability of generating more dexterous grasping motion.

The idea is to introduce the bending units to the palm. The unit consists of a balloon actuator and a rubber plate, which is connected with the balloon actuator using elastic hinge as shown in Fig. 4. The balloon actuator has a silicone rubber membrane on a silicone rubber base as shown in Fig. 4(a). Edges of the membrane are glued to the silicone rubber base. The membrane is much thinner than the base so that it expands like a balloon as shown in Fig. 4(b) when pressurized. As the bending unit has the balloon actuator and the plate as shown in Fig. 4(c), we can open the slit with the balloon actuator motion. In addition, it is possible to enlarge the flexion angle (slit open angle) when we arrange two or more balloon actuators in series as shown in Fig. 4(d). If we appropriately position the bending units in the palm of ECF robot hand and actuate them with the ECF jet, it is possible to realize the palm motion. Note that every component mentioned can be integrated in a single robot hand unit.

Multi-fingered robot hands have been widely studied, but there have been few examples imitating the palm motion. The above-mentioned concept is a possible solution for the next generation dexterous robot hand having following features.

- The hand is small in size, lightweight, flexible and is capable of generating dexterous grasping motion.
- Although the hand is driven by fluid power, the working fluid is completely enclosed in the robot hand.
- All components including actuators, tank and pressure sources are integrated in the hand.
- The configuration is quite simple in comparison with the previously developed pneumatic robot hands, which require external compressors.

Additionally, the configuration of the robot hand is quite simple so that the proposed robot hand overcomes the difficulty of spaghetti cord problems, from which many robot hands are suffering.