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Design analysis and fabrication of arrayed tactile display based on dielectric elastomer actuator

Hyung Seok Lee[a], Hoa Phung[a], Dong-Hyuk Lee[a], Ui Kyum Kim[a], Canh Toan Nguyen[a], Hyungpil Moon[a], Ja Choon Koo[a], Jae-do Nam[b], Hyouk Ryeol Choi[a,*]

[a] School of Mechanical Engineering, Sungkyunkwan University, Republic of Korea
[b] Department of Polymer System Engineering, Sungkyunkwan University, Republic of Korea

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ABSTRACT

The tactile display is an important tool to help the human interact with machines by using feels of touch. In this paper, we present a multiply arrayed tactile display device with Dielectric Elastomer Actuator (DEA). The device employs the liquid coupling between the touch spot and the actuator as the transmission of force. It is designed to ensure the comfort of touch and the safety of operation for the users while contacting with the human skin. The operating principle is explained in details, and a systematic design analysis is given. The displacements of tactile display is about 240–120 μm at 3–10 Hz, which satisfies the frequency requirements for simulating the Merkel cells as well as the Meissner corpuscles and the force is over 40 mN to simulate the finger tip. In addition, a dedicated fabrication method and performance measurements are explained.

1. Introduction

To provide the tactile sensation to a user, a device needs to stimulate the human skin receptors such as Meissner corpuscles, Merkel cells, Pacinian corpuscles and Ruffini endings [1]. Most tactile displays are developed to stimulate Markel cells for pressure, Meissner corpuscles for low-frequency vibration, and the Pacinian corpuscles for high-frequency vibration. In addition, it is reported the mean perceptual thresholds for the index finger is 33.5 mN and that of the middle finger is 32.1 mN [2]. Thus, tactile displays are needed to satisfy displacement threshold-frequency characteristics and perceptual force thresholds. There are many problems in applying tactile displays to real products, which are related not only to performance factors like displacement, response time, and the force of the devices, but also compactness, lightness, energy efficiency, easy fabrication, low cost, etc.

Previously, many transducers for tactile displays have been investigated [3–15]. Wagner et al. [7] developed a tactile shape display with a 6-by-6 array using RC servomotors. The display has large displacement, appropriate actuator density, and simple construction, but needs to be improved in terms of weight, cost and compactness. Nakamura et al. [8] used shape memory alloy(SMA) to develop a torso-based haptic device. Because SMA undergoes large stresses and strains, the displacement and force of the device are large. Despite these advantages, the device has a limitation of low bandwidth and frequency. Tactile displays using focused ultrasound by Iwamoto et al. could provide enough force to transfer tactile sensation to a user with high resolution [9]. Klein et al. developed a tactile display using electrorheological fluid [10], whereas Liu et al. used magnetorheological fluid [11].

Recently, electroactive polymer (EAP) have been investigated as transducers for tactile displays. Dielectric elastomer as an electroactive polymer, is light in its weight and cost effectiveness with high energy efficiency, and does not need additional means to change electric energy to mechanical one. Dielectric elastomer also features ease of fabrication with compact size and simple manufacturing procedure. Considering these points, dielectric elastomer has been studied by many researchers for tactile displays. Choi et al. developed a tactile display as a braille display for visually disabled, based on the dielectric elastomer [16]. Koo et al. presented a wearable tactile display device based on elastomer actuator [17]. Carpi et al. proposed hydrostatically coupled dielectric elastomer actuators for haptic interface with dielectric elastomer actuators [18]. Chakraborti et al. demonstrated a compact dielectric elastomer tubular actuator for refreshable braille displays [19], and the tubular actuator is based on fiber actuators made by Arora et al. [20]. Niu et al. reported a Braille application of the tactile display [21].

In this paper, a multiply arrayed tactile display is presented as illustrated in Fig. 1. By employing dielectric elastomer actuator, a tactile display can be realized with notably simple mechanical

* Corresponding author. Tel.: +82 31 290 7449; fax: +82 31 290 7507.
E-mail address: hrchoi@me.skku.ac.kr (H.R. Choi).

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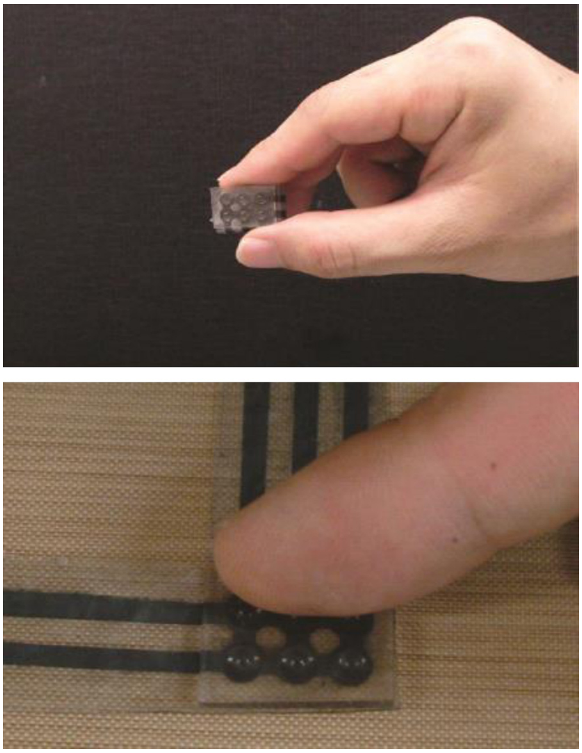

Fig. 1. Arrayed actile display with liquid coupling.

structure. The proposed device consists of a frame with a touch layer, rigid coupling, and an actuator that generates vertical motion to push the touch layer up or down. It is an electrically driven actuator, which can generate either small-scale vibratory motion or linear displacement. As the result, it provides stimulation at the touch layer with the human skin. In addition, since the manufacturing process is very simple, the device can be easily miniaturized, enabling extension into arrayed on. Such devices can be used in a wide variety of commercial applications, such as mobile devices, games, robotics, etc [16,22–27]. The design also has the hydraulic amplification mechanism to enhance the displacement. Due to amplification, there are some researches for tactile display [30–32]. Miki et al. [30] developed a vibrational Braille code display with large-displacement micro-electro-mechanical systems (MEMS) actuator arrays, he also presented a hydraulic displacement amplification mechanism and studied its dynamic response when combined with a piezoelectric actuator [31] and demonstrated a MEMS-based hydraulic displacement amplification mechanism with completely encapsulated liquid [32]. In this paper, the design idea of the proposed device is introduced, and a prototype is presented. The performance is also validated experimentally.

This paper is organized as follows. In Section 2, the operating principle of the proposed tactile display is explained. Section 3 addresses the modeling and design analysis and dedicated fabrication method is detailed in Section 4. In the next, preliminary experiments are performed for evaluating the performance of the device and the results are shown in Section 5. Finally, concluding remarks are given and future works are discussed in Section 6.

2. Operating principles

As shown in Fig. 2, the actuation principle of a dielectric elastomer is similar to the electromechanical transduction of a parallel two-plate capacitor, which can be explained with the following equation [28].

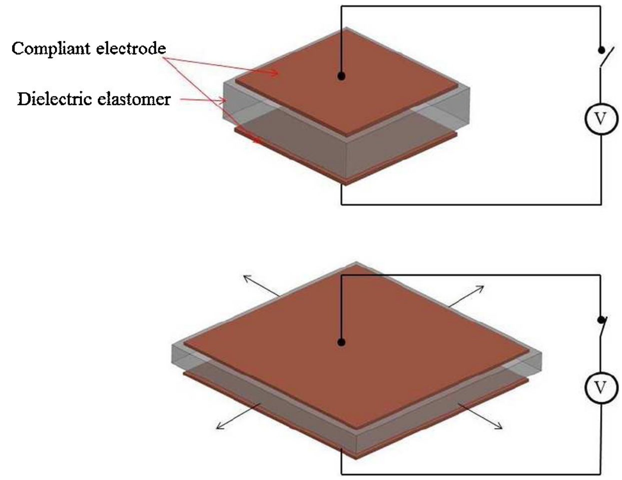

Fig. 2. Basic principle of dielectric elastomer actuator.

$$\sigma = \epsilon\epsilon_o\left(\frac{V}{t}\right)^2 \quad (1)$$

where σ, called Maxwell stress, is compressive pressure from charge on the surface. And ϵ_o and ϵ are free-space dielectric permittivity ($\epsilon_o = 8.85 \times 10^{-12}$ F/m) and relative permittivity of the dielectric material, respectively. V and t represent the supplied voltage and the thickness between the electrodes, respectively. Depending on the design and fabrication technique, the dielectric elastomer actuator can be implemented in various forms and generate a wide range of motions from micro to macro scale.

Fig. 3 depicts the proposed design of the tactile display. The design is primarily based on Pascal's principle [18]. A frame is rigid, and fluid is filled up with pressure inside the cavity. Thus, at "Voltage OFF" state, a touch layer is bumped up by the pressurized liquid. When a driving voltage is supplied to the actuator, that is "Voltage ON" state, the actuator is contracted toward thickness direction and expanded along the radial direction by Mexwell stress. Thus, the actuator is moving down, and the touch layer moves down by

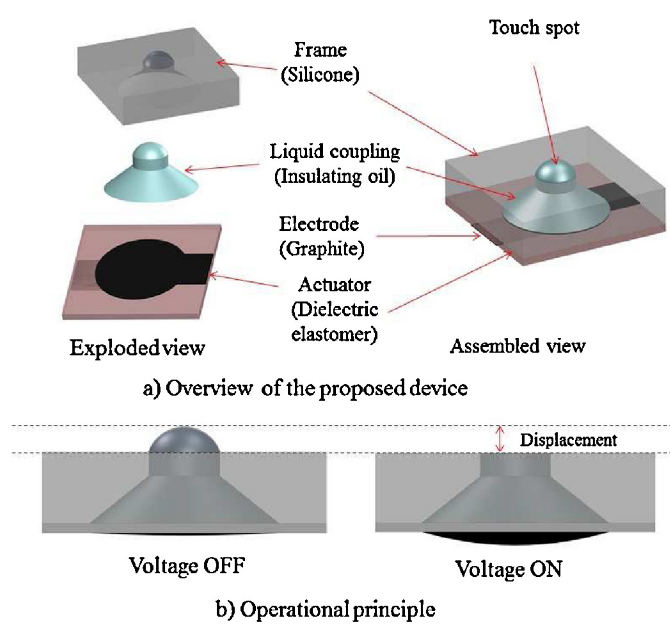

Fig. 3. Idea of liquid coupling tactile display.