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Liquid-based tactile sensing array with adjustable sensing range and sensitivity by using dielectric liquid

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ABSTRACT

This paper presents a novel tactile sensing array with adjustable sensing range and sensitivity. The sensing array consists of a deformable PDMS spacer layer, two Al glass substrates, and two dielectric liquids. The two dielectric liquids form a composite dielectric material, which is a low-dielectric-constant (ε_r) droplet covered with a high-ε_r liquid. The composite dielectric material is sandwiched between the upper and lower electrodes. By adjusting the electric flux passing through the electrodes, the contact angle of the droplet can be controlled. The sensing range and sensitivity were adjusted by varying the droplet shape. The results show that the device's sensing range can be adjusted in the ranges 0.05–0.29 N and 0.42–1.12 N. Compared with other devices, which are often used in a large force range, this device can be used in a smaller force range and provides 1.88 times greater sensitivity. Besides, the sensitivity can be adjusted during the sensing process.

1. Introduction

Making physical contact with the environment is important for robots. Tactile sensors are necessary for robots to mimic the human touch sensing ability. These sensors provide tactile or touch information to robots to enable them to perceive the environment [1–3]. The tactile information, such as weight and stiffness, would help robots to understand their surroundings. To perform different jobs requires different sensing ranges. For example, to grab different objects, such as eggs and rocks, robots require different sensing ranges to prevent possible damage to the grasped objects. An inappropriate grabbing or grasping force could cause damage if the force is too large. If the force is inadequate, the objects may fall [4]. Like human beings, robots have to move their arms and fingers appropriately to handle or grab objects. For example, during a contacting process, the robot should instantaneously analyze the situation and adjust the force or pressure it applies on objects. The dynamic sensing information is very important for controlling the applying force or pressure so as to prevent cracking and other damage [5]. Hence, tunable tactile sensors with a fast tuning ability are required. However, most studies on tactile sensing technology focus on sensor development. Further, the sensing range is usually fixed after fabrication.

Several sensing mechanisms are used in the field of tactile sensors, such as resistive [6], capacitive [7], piezoelectric [8], optical [9], and magnetorheological [10] mechanisms. Capacitive tactile sensors with highly linear and repeatable responses and low temperature drift have been intensively studied. The sensitivity of the capacitive tactile sensor is usually increased by sandwiching high-dielectric-coefficient material between the electrodes [11,12]. Fang et al. developed a capacitive CMOS-MEMS tactile sensor whose material can be changed during fabrication [13]. The sensing range can be tuned by ink-jetting deformable polymer with different stiffness values. Takahashi et al. changed the percentage of the inflowing dielectric oil between two parallel electrodes to adjust the sensitivity [14]. Pan et al. developed the droplet-based pressure sensor [15]. The sensing ranges can be changed by ink-jetting different volumes of droplets. These sensors' sensing ranges were fixed after fabrication. Besides, a readout circuit for adjusting the sensing range is required. Yang et al. dispersed comprising carbon nanotubes in liquid crystals composites to form sensing material [16]. Applying different external fields to change the conduction of the sensing element can dynamically tune the sensing range without readout circuitry. However, the sensor's sensitivity is not high enough for small force sensing.

To improve the aforementioned drawbacks, a dielectric-liquid-based tactile sensing array with an adjustable sensing range was

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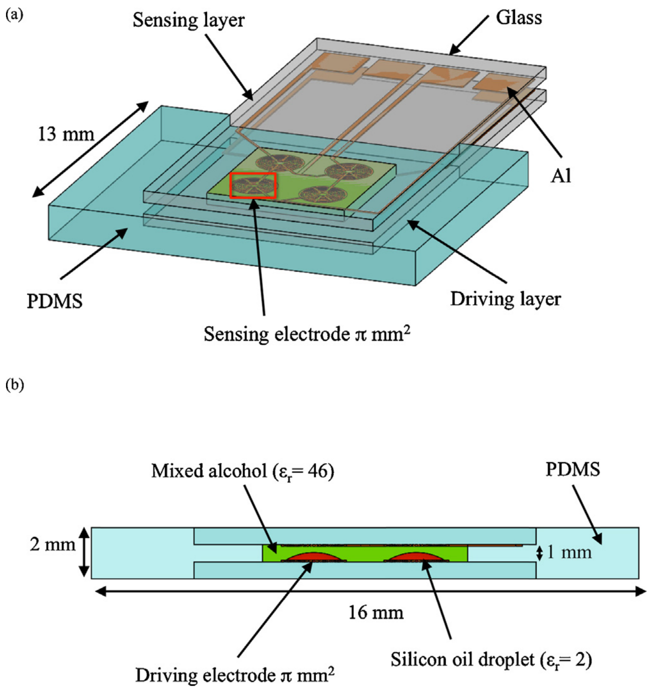

Fig. 1. (a) Schematic of the sensing array, (b) detailed dimensions of the sensing array.

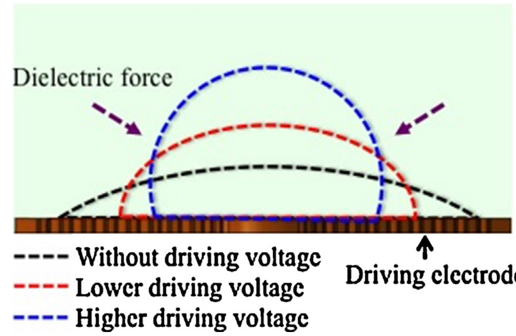

Fig. 2. Operating principle of the designed tactile sensor.

developed. In this paper, we proposed a novel tactile sensing array with an adjustable sensing range [17]. Each sensing element contains a low-dielectric-constant droplet covered with high-dielectric-constant liquid. The sensing range and sensitivity could both be adjusted by varying the droplet shape. In the following sections, the sensing mechanism, design, results, and conclusion will be described.

2. Design and operational principle

2.1. Design

Fig. 1 shows the schematic and detailed dimensions of the sensing array. The 2 × 2 sensing array consists of a dielectric layer

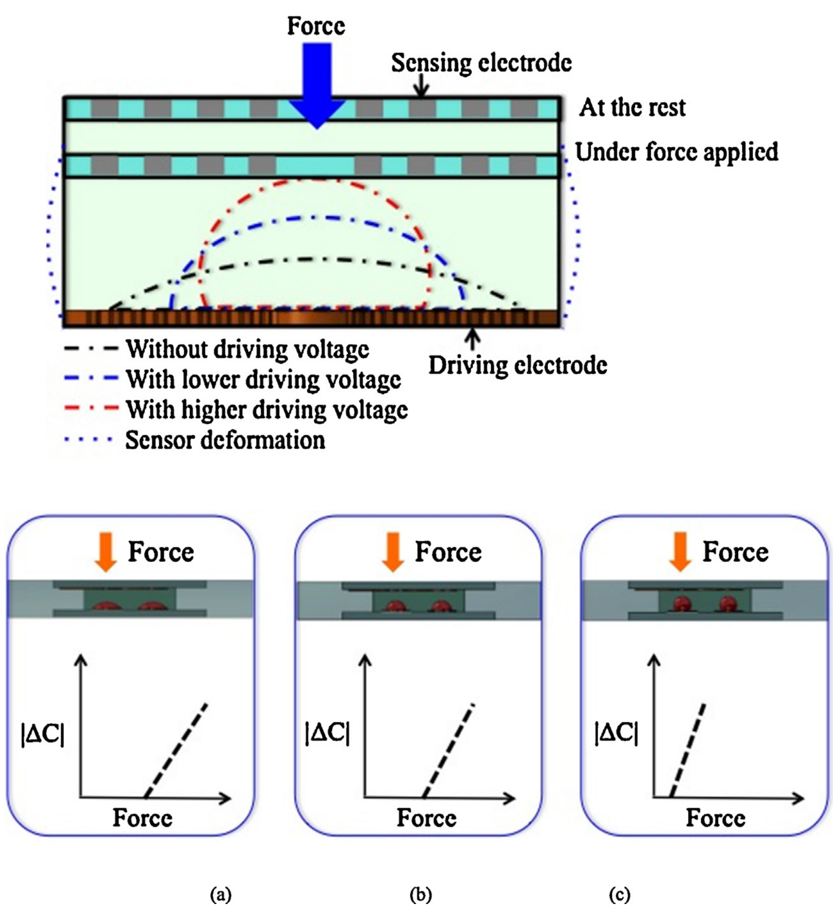

Fig. 3. Operating principles of the sensing array. (a) Without driving voltage on the driving electrode, (b) with lower driving voltage, (c) with higher driving voltage.