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Robust capacitive touch sensor using liquid metal droplets with large dynamic range

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ABSTRACT

In this paper, we introduce an interesting design for a capacitive touch sensing mechanism using liquid metal (LM) droplets to maintain the advantage of the floating electrode (robustness) and simultaneously improve the dynamic range of the device. LM has electric conductivity, thus it can be used as a floating electrode, and it simultaneously has the deformability of liquid, which does not suffer from fatigue. Therefore, the robustness of the device can be improved. The sensor uses changes in capacitance caused by the overlap area between the LM droplet and a pair of flat-bottom electrodes to improve its dynamic range. To verify the performance of the sensor, a total of 36 sensing elements with a spatial resolution of 2 mm and arranged in a 6 × 6 array were successfully fabricated using micromachining techniques. The performance of the fabricated device was analysed by one-cell and multi-touch tests. The device has a large dynamic range (∼40 pF). In addition, using the merits of the device, we applied our concept to an end-effector.

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1. Introduction

Force-measuring touch sensors are widely used in the fields of automotive, industrial, and medical applications [1]. Recently, capacitive touch sensors have attracted considerable attention in these fields because these sensors are well known to have low temperature sensitivity, low power consumption, and a robust structure [1,2]. Conventional capacitive touch sensors have a spacer between the two electrodes and measure changes in pressure by the deflection of a conducting diaphragm due to the applied force (interelectrode spacing) (Fig. 1(a)) [3–17]. Conventional sensors, however, have two issues awaiting solution. The first issue is poor dynamic range. These sensors usually induce several picofarad (∼10 pF), which usually necessitates the use of a sophisticated interface circuit to counteract the inherently poor resolution of the sensors [1]. If the device has a large dynamic range, its sensitivity can also increase because the device can have a wider capacitance variation as the specific force is applied. The second issue is the fatigue problem. These sensors typically have sensing electrodes including long thin metal traces, which are interconnected, on the deflection part (e.g. PDMS) where the force is applied [10,11]. The long thin metal traces on the deflection part easily undergo crack formation, which causes the fatigue problem. The fatigue problem causes frequent replacement of the device, which is not cost effective. The characteristics of conventional capacitive touch sensors are listed in Table 1.

In order to improve the poor dynamic range, our group developed a capacitive touch sensor that uses liquid metal (LM) droplets (Fig. 1(b)). It induces a capacitance change by the overlap area between the LM droplet and bottom electrode [18,19]. Because the distance between the LM and the bottom electrode can be reduced to a value equal to the thickness of the dielectric layer, the sensor can have more than approximately 10 times the dynamic range (∼100 pF) of conventional capacitive touch sensors. However, these sensors have long thin nickel tapes attached on the PDMS membrane which needs additional fabrication process. The nickel tapes can be detached from PDMS membrane when repeated load is applied to the sensor thus it can also causes fatigue problems.

To improve the robustness of the device, Cheng et al. developed a tactile sensing array using capacitive mechanisms with floating electrodes (Fig. 1(c)). Because this type of sensor does not have long thin metal traces on the deflection part, this approach effectively reduces the fatigue problem; nevertheless, this structure has only a quarter of the dynamic range (e.g. less than 1.5 pF) compared to a

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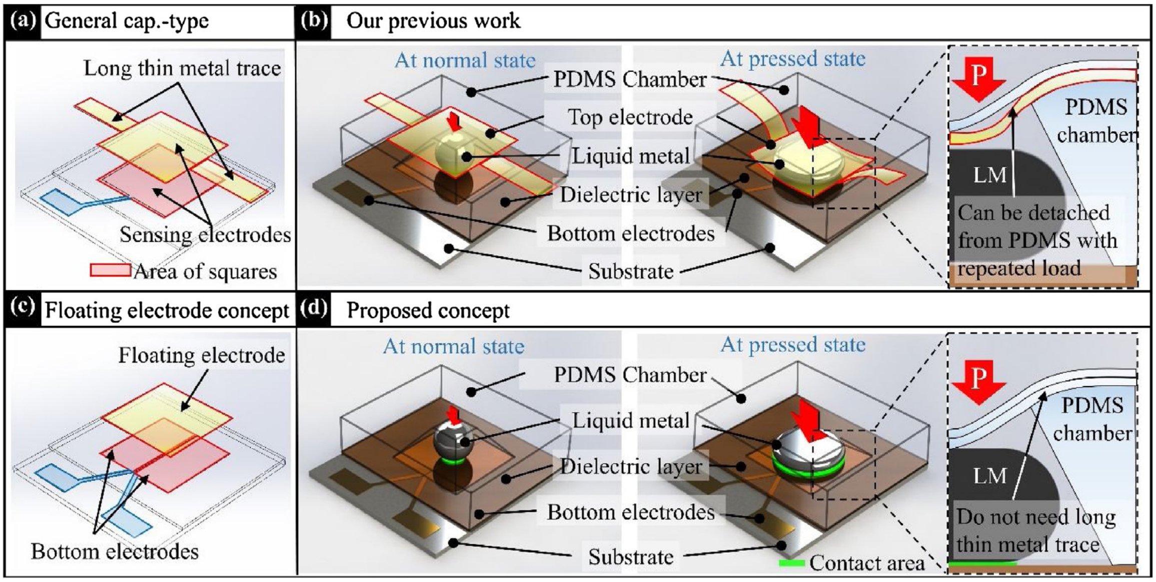

Fig. 1. (a) Schematic of general capacitive touch sensor and (b) our previous work. (c) Schematic of floating electrode concept and (d) our proposed concept.

conventional capacitive touch sensor that does not have a floating electrode (poor dynamic range). Moreover, the floating electrodes deposited on the deflection part still can suffer from cracks when repeated loading is applied to the sensor [10,11].

In this paper, we introduce an interesting design for a capacitive touch sensing mechanism using LM droplets to maintain the advantage of a floating electrode (robustness) and simultaneously improve the dynamic range of the device (Fig. 1(d)). We used LM droplets (mercury) as a floating electrode. Mercury has electric conductivity, thus it can be used as an electrode, and it simultaneously has the deformability of liquid and does not suffer from fatigue [19]. With regard to the dynamic range issue, as mentioned in our previous work, a large capacitance change is induced by the overlap area controlled between the LM droplet and the bottom electrode because the distance between the LM and bottom electrode can be reduced to a value equal to the thickness of the dielectric layer. This principle applies identically to the device because the capacitance is induced by the overlap area between the LM droplet and two bottom electrodes in this study. Since it uses floating electrode concept, the device has only a quarter of the dynamic range compared to our previous work [19]. Nevertheless the device has a relatively larger dynamic range (~40 pF) than the touch sensors that have floating electrodes (~1.5 pF) and even larger than the conventional capacitive touch sensor using interelectrode spacing (~10 pF), at 2 mm of spatial resolution, as shown in Table 1. For a feasibility test, a total of 36 sensing elements having a spatial resolution of 2 mm and arranged in a 6 × 6 array were successfully fabricated using micromachining techniques. The performance of the fabricated device was analysed by one-cell and multi-touch tests. Moreover, the concept of the device was successfully applied to an end-effector.

2. Materials and methods

2.1. Measurement concept

In our capacitance measurement concept, an LM droplet, a dielectric layer, and a pair of bottom electrodes are necessary (Fig. 1(d)). The sensor measures the capacitance by making use of the overlap area between an LM droplet and a pair of flat-bottom electrodes, rather than using a variable interelectrode. The droplet maintains its spherical shape in the normal state because of the high surface tension of the LM; therefore, the overlap area between the LM and bottom electrodes is small. In contrast, in the pressed state, the LM droplet is squeezed on the dielectric layer; as a result, the overlap area increases.

Table 1
Comparison of this work's performance with that in the literature.

	Measurement mechanism/change	Spatial resolution (mm)	Dynamic range (pF)	Sensitivity (pF/N)	Note
H.-K. Lee et al. [4]	interelectrode spacing	2	~0.31	~2.5	Measuring shear force
M.Y. Cheng et al. [5]	interelectrode spacing	8	~1.32	~4.32	Measuring shear force
J.A. Dobrzynska et al. [6]	interelectrode spacing	6–10 (various types)	~1.7	~5.4	Measuring shear force
L. Viry et al. [8]	interelectrode spacing	~8 (side length of the device)	–	–	Measuring shear force
R.D. Ponce Wong et al. [9]	interelectrode spacing	~0.5	on the order of tenths of pF	–	Flexible device
M.Y. Cheng et al. [10]	interelectrode spacing	~4.5	~2.2	~1.2	Using floating electrode
H.-K. Kim et al. [12]	interelectrode spacing	2	~10.8	36	Touch screen application
Y.-C. Wang et al. [13]	interelectrode spacing	~2	~1.2	1.9	A mutual capacitive touch panel
D.-J. Won et al. [19],	overlap area	2	~100 (Chamber side length: 1.5 mm, thickness of dielectric layer: 4300 Å)	~147	Using liquid metal droplet
This work	overlap area	2	~40 (Chamber side length: 1.6 mm, thickness of dielectric layer: 4000 Å)	~26	Using liquid metal droplet

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