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A layered sensor for simultaneous, spatially coincident softness and moisture measurements

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ABSTRACT

This paper proposes a layered sensor for the simultaneous measurement of the softness and surface moisture of an object, at the same position. In the proposed sensor, a thin stainless steel film is pasted on a polyvinylidene difluoride (PVDF) film. The voltages in the stainless steel and PVDF films are generated because of electrostatic and piezoelectric effects, and the resulting waveforms can be measured while the proposed sensor repeatedly contacts and releases the object. The voltages in the films depend on the softness and surface moisture conditions of the object. The proposed sensor therefore makes it possible to measure the softness and surface moisture of the object using the voltage waveforms. Here, we present the relationship between the measured voltages obtained using the proposed sensor and the volume of distilled water infiltrated into the filter paper on the surface of the object, and the relationship between the voltages and the softness of the object. In addition, the potential of the proposed sensor for applications is discussed.

1. Introduction

Research on the sensations and functions of human skin has been performed in several fields. Many tactile sensors that mimic the haptic sensations and functions of the human skin have been developed as primary techniques in the field of robotics [1–4]. In recent years, many tactile sensors have been investigated as important components in medical instrumentation, for applications such as endoscopic surgery [5]. In addition, the sensations of human skin have also been investigated. Measurements have been made of skin conditions such as the adhesion, friction and wear [6], roughness and hardness [7], skin moisture (water content) [8–10], viscoelasticity [11], and softness [12,13]. In addition, sensors for the measurement of transepidermal water loss [14], and artificial finger tips for tactile measurements and feeling studies [15] have been developed.

The purpose of our study was to develop a simple tactile sensor for the material identification and measurement of skin conditions and properties. Previously, we proposed a tactile sensor based on piezoelectric ceramics that measures the electrical and ultrasonic properties of an object [16]. In addition, a technique based on the measurement of electrostatic charge was developed for the identification of objects [17]. A novel, simple tactile sensor based on a PVDF film, which is capable of measuring vibrations, electrostatic charge, and capacitance, was also proposed for the identification of materials [18].

In this paper, a novel layered sensor based on a PVDF film was developed for applications in measuring skin conditions, in robot fingertips and other related applications; this sensor enabled the softness and moisture to be measured simultaneously, at the same position. We determined the relationship between the voltages measured by the proposed sensor and the softness of the object, and the relationship between the voltages and the volume of distilled water infiltrated into the filter paper on surface of the object (which represented different moisture conditions). The potential of the proposed sensor for applications is discussed here.

2. Method

Fig. 1 shows a schematic diagram of the proposed sensing method. The layered sensor consisted of a PVDF film covered with thin insulator and stainless steel films. Voltage waveforms were generated in the stainless steel and PVDF films when the proposed sensor repeatedly contacted and released the object. The voltage in the stainless steel film was caused by the electrostatic effect [17,18]. The voltage waveform depended on the moisture of the object. The voltage in the PVDF film was induced by the piezoelectric effect, and changed depending on the softness. Therefore, two types of voltage waveforms were simultaneously obtained at the same position using the proposed sensor. The softness and moisture of the object were determined from the characteristics of the measured voltage waveforms.

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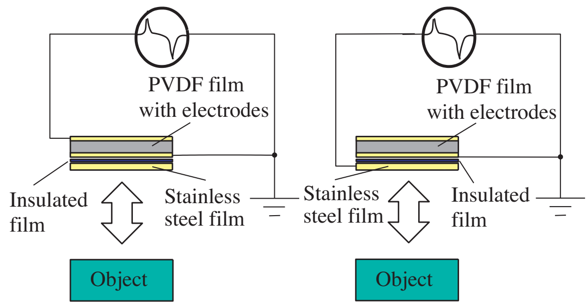

Fig. 1. Schematic diagram of the sensor structure and the sensing method.

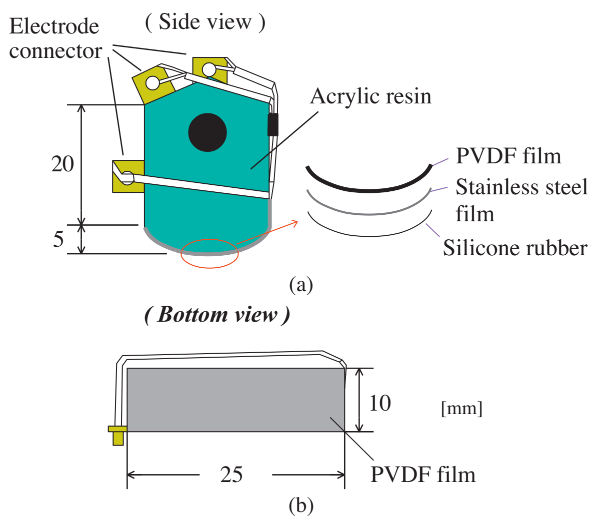

Fig. 2. Schematic diagram of the proposed sensor. (a) Side view, and (b) bottom view.

3. Experimental method

Fig. 2 shows a schematic diagram of the proposed sensor, and Fig. 3 shows a photograph of the sensor. In the proposed sensor, a stainless steel film with a thickness of 0.005 mm was attached to the PVDF film, which was already covered with a thin insulating film (KFP-110AS, Kureha Trading Co. Ltd., Tokyo, Japan,

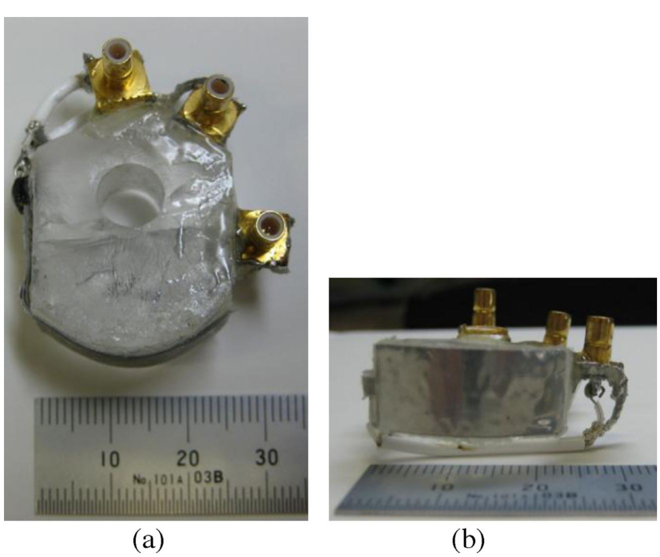

Fig. 3. Photographs of the proposed sensor. (a) Side view, and (b) top view.

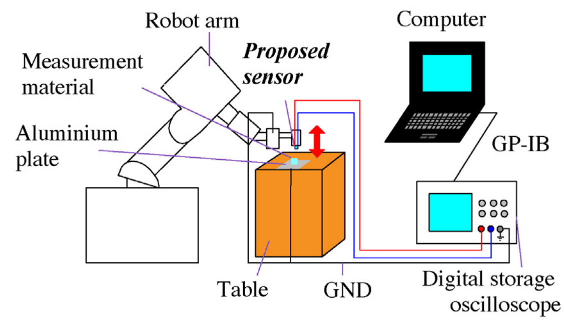

Fig. 4. Schematic diagram of the measurement system.

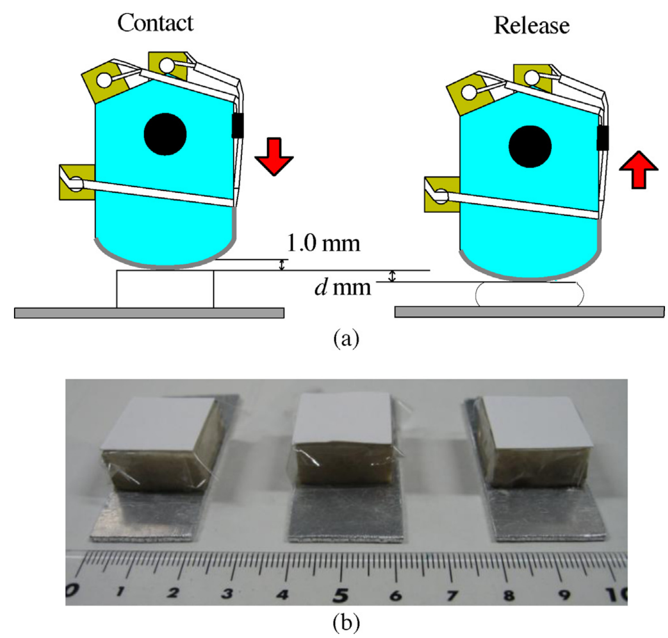

Fig. 5. Schematic diagram of the experimental method. (a) Movement of the sensor, and (b) photograph of the measurement material.

10 mm × 25 mm × 1 mm). In addition, a silicone rubber sheet with a thickness of 0.02 mm was attached to the surface of the stainless steel film, to protect the sensor. The proposed sensor was arranged along the semi-circular face of an acrylic block with a width of 10 mm. Fig. 4 shows the measurement system. The proposed sensor was attached to the front end of a robot arm (DENSO VS-6354DM). The proposed sensor was repeatedly contacted with and released from the measurement object with a constant speed; this was achieved by controlling the robot arm. In this experiment, the robot arm was moved at 50% of its maximum speed – i.e., the middle speed of the robot arm – because the voltages induced on the stainless and PVDF films became larger as the speed was increased. The voltage waveforms induced in the stainless steel film and the PVDF film were measured during the fifth contact-and-release cycles. The amplitude of the waveform from the stainless steel film was relatively stable; the waveform was measured using a digital storage scope with a sampling frequency of 2.5 kHz (Tektronix TDS 2014), and the measured data were stored in a personal computer using a general-purpose interface bus (GP-IB). Fig. 5 shows the experimental method and the sample materials. The sensor was moved from −1 mm to d mm, where the point at which contact between the sensor and material was achieved was defined as 0 mm. The measurement object was fixed on an aluminum plate with a thickness of 1 mm that was connected to ground. Urethane gel with three different softnesses (20 mm × 20 mm × 10 mm, hardness, 0, 5, 15: