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Lightweight flexible keyboard with a conductive polymer-based touch sensor fabric

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ABSTRACT

We developed a lightweight flexible keyboard with a touch sensor fabric that consists of conductive polymer-coated fibers. In our sensor fabric, the conductive polymer-coated fibers, which are sensing electrodes, are woven at a 2-cm pitch and the rest of the fabric is filled with pristine polyester fibers. The sensing principle for human touch detection is the measurement of the capacitance between the conductive polymer-coated sensing fibers and human fingers. The keyboard system consists of the touch sensor fabric, a capacitance measurement circuit, a signal processing circuit and software for entering characters into a personal computer (PC). The fabricated fabric has a large area, 20.5 cm × 12.5 cm, and weighs only 9 g, making it large enough for touch input and light enough to carry. In addition, the sensing electrode is bendable to a diameter of 1 mm because the sensor electrode is not inorganic material but rather polymer. When the sensor is touched, the capacitance between fiber and finger is increased by 2 pF, which is large enough to be detected with conventional capacitance measurement circuits. Finally, the keyboard input is demonstrated with our fabricated fabric sensors. This technology will lead to the development of keyboards that are especially well suited for wearable and portable electronic devices.

1. Introduction

Recently, mobile information electronic devices, such as smart phones and tablet PCs, have become increasingly important [1]. Wearable computers and other new information tools will be commercially available in the near future [2–6]. For these present and future mobile information electronic devices, human interface devices such as keyboards and touch screens will be key technologies. However, for these new applications, especially for future wearable applications [7–9], keyboards require new features: keyboards should be very lightweight and bendable, so that they can be carried by being folded and put in a pocket, but should be large enough to receive input by relatively large fingers more easily than the small displays and keys of cell phones.

The three requirements for wearable keyboards are as follows: (1) a large area, (2) light weight, and (3) high flexibility.

1. Large area: The area required for a wearable keyboard is 20 cm × 6 cm. Because the average human finger width is 2 cm, the standard keyboard key is 2 cm in width [10]. In a keyboard with 2-cm-square keys, if the keys are 2 cm square and arrayed in 10 columns and 3 rows, the width and height of the keyboard are 20 cm and 6 cm, respectively. These dimensions are larger than those of a conventional cell phone keyboard (e.g., 5.08 cm × 7.62 cm for the iPhone) [11].
2. Light weight: The weight of the keyboard should be ten times less than 100 g for ease of carrying because the conventional mobile phones range in weight from 100 to 200 g [11].
3. High flexibility: Wearable keyboards should be able to bend to a radius of 3 mm so that the keyboard can be bent and put into a pocket for carrying or to be worn as a keyboard-stitched cloth. The bending radius of 3 mm is based on the standard bendability test for flexible electronic devices [12].

To provide these features, current keyboard or touch screen technologies should be improved, especially with respect to flexibility and light weight. Although existing capacitive and resistive types of touch screens are widely used because they are very easy to use to input information intuitively, these touch screens cannot sustain bending of the devices themselves. This is because the electrodes of touch sensors are indium tin oxide (ITO) and are brittle, owing to their sintered body of inorganic materials, and therefore are easily broken even under bending to a radius of 10 mm [13]. Thus, the use of such touch screens in flexible applications is impossible. On the other hand, existing keyboards are very heavy, and

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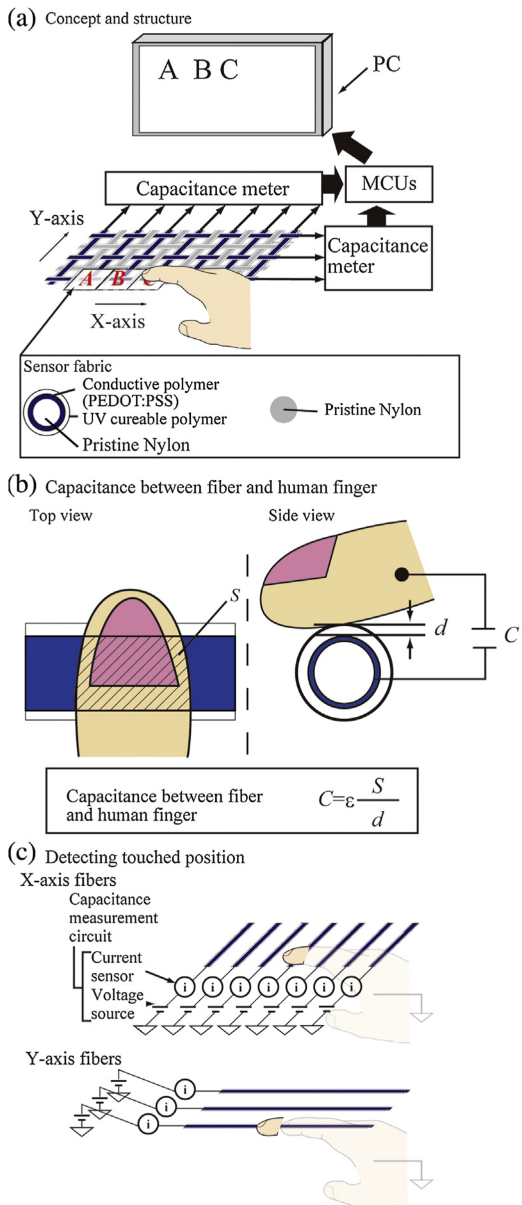

Fig. 1. Concept and sensing mechanism of the flexible fabric keyboard: (a) conceptual sketch and configuration of the flexible fabric keyboard, (b) fabric keyboard structure consisting of conductive polymer-coated Nylon fibers, (c) touch sensing mechanism.

their mechanical flexibility is very low because they are composed of membrane switches, and the switches are on a rigid printed circuit board. Bending of membrane switches is difficult, and plastic keyboard structures are very heavy.

Therefore, a new type of flexible keyboard that is large in area (i.e., >20 cm in width), light in weight (i.e., < 100 g) and highly bendable (i.e., tolerant of bending to a radius of 3 mm) is required for use with wearable and mobile computers in the future. To meet these requirements, we developed a fabric type of keyboard in which the sensing electrodes are conductive polymer-coated fibers and the capacitance between the fibers and the fiber electrodes are measured for detection of touch input. Fig. 1(a) shows our proposed fabric keyboard, consisting of conductive polymer-coated fiber-woven fabric, capacitance meters in conventional microcontroller units (MCUs) and personal computers. In the sensor fabric (Fig. 1(b)), the conductive polymer and insulation film is coated on the Nylon fiber, and the resultant fiber is woven as wefts and warps at a pitch corresponding to the average human finger width (i.e., 2 cm) [10]. The rest of the conductive polymer-coated fibers are pristine polyester fibers. Fig. 1(c) shows the mechanism of capacitive measurement between fibers and human fingers. The human body is conductive and works as an electrode [14]. When a person touches conductive fibers, the capacitance between fiber and finger increases. By detecting this capacitance change, the character is input. The characteristics of the fabric keyboard system are based on the three requirements described above. Finally, the keyboard system was composed and demonstrated.

2. The sensing mechanism for touch input and the configuration of the fabric keyboard

Fig. 1(a) shows a whole sensor system, which consists of conductive polymer-coated fiber-based fabric, capacitance meters in MCUs and a PC. To form a capacitive type of sensor fabric, conductive polymer-coated fibers are woven as warps and wefts. The warps work as *X*-axis sensor electrode while the wefts work as *Y*-axis ones. Each sensor fiber is connected to each capacitance measurement circuit in conventional MCUs.

To detect the points of sensor fabric which is touched by a human finger, not the capacitances between crossing *X*-axis and *Y*-axis sensor fibers but the capacitances of each sensor fiber which formed between a sensor fiber and a finger are measured [14,16]. Fig. 1(b) shows the capacitance increase of each sensor fiber by touching a sensor fiber with a human finger. When a sensor fiber is not touched, the capacitance between a sensor fiber and a human finger is zero. But, if a sensor fiber is touched, the capacitor between a sensor fiber and a human finger is formed according to the contact area and gap between a sensor fiber and a finger. Because a human body is conductive and works as an electrode, the capacitance of conductive polymer electrodes on fibers increases under human touch [14].

Fig. 1(c) shows the measurement circuit to define the touched points. The touched *X*-axis fibers out of all *X*-axis fibers are detected by measuring the increase of the sensor fibers capacitances. This is because touch of a sensor fiber with a human finger lead to form a capacitor between the human finger and the sensor fibers. In the capacitance measurement circuit, a certain pulsed voltage is applied to each sensor fiber among *X*-axis fibers and the resultant transient current flows from the sensor fiber to the finger because a human body is large enough to flow small current for capacitance measurement circuit and to work as a ground. On the other side, no current flows to sensor fibers if the sensor fiber is not touched with a finger. The measured transient current is converted to capacitance because transient current depends on the capacitance. The *X*-axis sensor fibers which have large increase of the capacitance are the touched fibers. Then, the touched *Y*-axis fibers out of all *Y*-axis ones are detected in the same manner. The points where both the capacitances of *X*-axis fibers and the ones of *Y*-axis fibers are increased are finally defined as the resultant touched points [14].

Fig. 2 shows the fabrication process of conductive polymer fiber-based fabric structure. The details of its configuration are described as follows. The sensing electrode is the fiber, which is coated with conductive polymer and dielectric polymer of ultraviolet (UV)-curable adhesive as an insulating and passivation layer. A conductive polymer of poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) (H.C. Stark, Clevios PH1000) and a dielectric film of commercially available UV-curable adhesive (Tesk corp. A-1864) are coated onto the Nylon fiber through our proposed process of die-coating [15] (Fig. 2(1) and (2)). The Nylon fiber is conventional fishing fiber with a diameter of 485 μm, chosen because it has high tensile strength and a uniform diameter. The thickness of the PEDOT:PSS dry