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Flexible and stretchable fabric-based tactile sensor

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HIGHLIGHTS

- A flexible and stretchable durable fabric-based tactile sensor capable of capturing typical human interaction forces was developed.
- We present elaborate measurement results of the sensor.
- A process of creating multiple sensor areas in a single fabric patch was developed.
- The measures against performance degradation due to moisture are presented.
- Using the developed technology, a tactile dataglove with 54 pressure sensitive regions was built.

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ABSTRACT

We introduce a novel, fabric-based, flexible, and stretchable tactile sensor, which is capable of seamlessly covering natural shapes. As humans and robots have curved body parts that move with respect to each other, the practical usage of traditional rigid tactile sensor arrays is limited. Rather, a flexible tactile skin is required. Our design allows for several tactile cells to be embedded in a single sensor patch. It can have an arbitrary perimeter and can cover free-form surfaces. In this article we discuss the construction of the sensor and evaluate its performance. Our flexible tactile sensor remains operational on top of soft padding such as a gel cushion, enabling the construction of a human-like soft tactile skin. The sensor allows pressure measurements to be read from a subtle less than 1 kPa up to high pressures of more than 500 kPa, which easily covers the common range for everyday human manual interactions. Due to a layered construction, the sensor is very robust and can withstand normal forces multiple magnitudes higher than what could be achieved by a human without sustaining damage.

As an exciting application for the sensor, we describe the construction of a wearable tactile dataglove with 54 tactile cells and embedded data acquisition electronics. We also discuss the necessary implementation details to maintain long term sensor performance in the presence of moisture.

1. Introduction

The sense of touch allows humans and higher animals to perform coordinated and efficient interactions within their environment. An early experiment [1] demonstrated the importance of tactile feedback for manual interactions. It showed that when the sense of touch was eliminated, subjects had severe difficulties in maintaining stable grasp. Similarly, the lack of tactile feedback in today's industrial robots restricts their use to highly structured environments and contact with unknown objects and humans has to be avoided. Operating robots in open environments calls for a much higher degree of sensory data. We believe that robots can strongly benefit from force sensing capabilities when employed in unconstrained environments. An immediate benefit is the increased safety brought about by having contact detection. But, also important is the improved capability to manipulate objects under non-deterministic conditions that a sense of touch can facilitate [2–4].

In psycho-physiology, tactile sensors that can measure interaction forces at the human skin will allow for studies of human motor-control processes at a new level of precision. To date, much of the work done in this field concentrates on joint angle and positional information, such as given by posture datagloves or vision-based tracking systems [5]. Studying tactile feedback in human interaction experiments will provide valuable insights into the design of manipulation algorithms, which heretofore could not be obtained from only postural sensor technologies. In previous studies

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Fig. 1. Wearable dataglove with 54 tactile cells and embedded data acquisition electronics. It utilizes novel fabric based tactile sensors.

we already used instrumented tactile objects to measure grasp forces [6,7]. However, these experiments were restricted to specific objects that were fitted with tactile sensors.

The fact that humans and many robots have curved body parts restricts the practical usage of rigid tactile sensors. In an effort to overcome the limitation of such sensors we introduce a novel, flexible, tactile sensor with multiple sensitive regions integrated into a fabric composite. The resulting sensor has a thickness of ≈1.5 mm and can be cut and sewn in the same way as a common fabric, which means that a wide variety of shapes can be produced. As a consequence, wearable haptic sensing garments, such as shirts, trousers, hats or force sensitive datagloves (Fig. 1) can be produced. It allows anthropomorphic robots to be covered with touch sensitive material and thus endowed with a sense of touch. Furthermore, the field of Ambient Intelligence can greatly benefit from our sensor, as it allows for the augmentation of rooms and furniture with tactile sensing material, thus making them responsive to the presence of people and pets. For example, sensitive bed-linen and pillows could allow for less obtrusive monitoring of patients in hospitals.

There exist many attempts to develop flexible tactile sensors. A common technology employs flexible printed circuit boards (PCBs) [8–10], which can be bent in one dimension at a time. Cutting the film carrier, tactile sensors capable of covering two dimensional curvatures have been demonstrated too [11,12]. Stretchable materials can much better adapt to arbitrary, even dynamically changing surfaces. A sensor using gold-plated copper wire interwoven into conductive rubber was presented in [13]. Although simple in construction, it was not very robust due to exposed fragile wiring on the outside surface of the sensor. A mechanically simpler sensor based on a sheet of pressure sensitive conductive rubber that was used as the sensor material was introduced in [14]. It used a technology called electrical impedance tomography to gather the tactile data from connectors that were only attached to the boundary of a uniform sheet. Although simple in mechanical design, the electronics required to sample the values was relatively complicated and the output signal exhibited negative effects such as ghosting and mirroring (presenting tactile output on locations that in reality have none). An interesting approach to produce a complete wearable tactile suit employed a conductive fabric, but suffered from an almost binary output [15]. Very high spatial resolution was demonstrated in [16] in which a glove made from sprayed-on silicone elastomer was introduced, but it was unfortunately not removable from the hand without destroying the sensor and thus not reusable. Finally, micro-machined strain gauges on kapton film [17] allow for a high spatial resolution, but are unfortunately not very robust due to exposed miniature mechanical components.

Our design overcomes all the mentioned drawbacks: it is flexible, stretchable and robust, and allows independent sampling of multiple tactile pixels (taxels) in a relatively high spatial resolution with taxel spacing of less than 10 mm possible.

In the next section we will introduce the construction of the fabric tactile sensor in detail. In Section 3 the sensor performance is evaluated and measurement results are given. Section 4 introduces an innovative application for the developed flexible tactile sensor in the form of a tactile dataglove. Finally, Section 5 summarizes the article and discusses future work.

2. Fabric based tactile sensor

The specifications we set out for the required sensor were that it should be sensitive and robust enough to discriminate and withstand the forces occurring in everyday grasping and manipulation and that it should provide numerous taxels to acquire distinguished spatio-temporal tactile patterns. To the best of our knowledge, and after an exhaustive search for such a device, no single, flexible, tactile sensor design was found which fits all these specifications.

After evaluating numerous compositions of various conductive fabrics, we decided on a design that uses 4 layers of different plain and conductive fabrics, which ensured good elasticity of the compound sensor (Fig. 2). The sensor is based on the piezoresistive effect, where the electrical resistance of a material changes under mechanical pressure. Our sensor uses a piezoresistive, stretchable knitted fabric (72% nylon, 28% spandex) and is manufactured by Eeonyx.[1] The individual fibers within the fabric are coated on a nano-scale with inherently-conductive polymers. The material is available at different resistances, determined by the thickness of the applied coating. During experimental testing, we found a material with a volume resistivity of ≈20 kΩ ·m to be most suitable for our application.[2]

By placing the piezoresistive fabric between two highly conductive materials, we can observe a change in the resistance measured at the two outer layers when pressure is applied to the compound. These outer layers constitute the low impedance electrodes that transport current into and out of the sensor with minimal losses. A low impedance of less than 2 Ω/sq. is achieved by plating nylon knitted fabric (78% polyamide, 22% elastomer) with pure silver particles.[3]

Our experiments exhibited a higher signal repeatability, especially in the subtle pressure range of 0–50 kPa, when an additional non-conductive meshed layer was added between the middle piezoresistive layer and one of the electrode layers. Sensor sensitivity was found to depend on the thickness of the meshed layer and on the size of the mesh openings, with larger openings and thinner layers producing better sensitivity to first touch (determined by the smallest detectable force). We evaluated meshes with openings in the range of 0.2–5 mm. The final design is a 0.23 mm thick meshed fabric with a honeycomb structure (Fig. 2) and mesh openings (size ≈2 mm) accounting for ≈70% of the surface.

With this additional mesh layer, the sensor has a very high resistivity (in the range of GΩ for a 50 × 50 mm sample) when not acted upon, which is achieved by the introduced gap between the

1 http://www.eeonyx.com/.

2 Measured with an ETS 803B resistivity probe, weighing 5 lb.

3 Unit Ω per square as used by the manufacturer. This means that the given resistance applies to arbitrary sized square specimen.

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