AlphaFabric: A Wearable Textile Sensor for Continuous Touch Tracking and Gestural Input

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Abstract
AlphaFabric is a wearable textile sensor capable of continuous touch tracking and gesture detection. It is made of two layers of conductive striped fabric separated by a layer of non-conductive foam. AlphaFabric uses resistive technology to determine the X and Y position of the touch on the fabric. The sensor can be worn directly on the skin or integrated into clothes and still retain consistent measuring properties even during continuous movement. We describe the construction of our sensor and outline its benefits compared to other textile sensing techniques. We implemented a set of applications to demonstrate the applicability and versatility of our sensor.

Author Keywords
Wearable computing; smart textiles; touch; gesture input.

ACM Classification Keywords
H.5.2. [Information Interfaces and Presentation (e.g. HCI)]: Input devices and strategies (e.g., mouse, touchscreen)

Introduction
In recent years, many researchers have investigated how to appropriate textiles as large and potentially unobtrusive wearable interactive surfaces. Different touch sensing fabrics have been proposed [3, 7, 4]. These fabrics are capable of detecting taps and simple stroke gestures while re-
The AlphaFabric sensor uses resistive touch technology to continuously detect the finger position on the fabric. Maintaining the physical characteristics of regular textiles. However, when placed near the skin [5] or during continuous movement [3, 7], these sensors can become quite noisy making it harder to detect touch accurately and reliably.

In this demonstration, we present AlphaFabric, a wearable multilayer fabric sensor capable of detecting touch and freeform gestures (Fig. 1). It uses resistive touch technology to avoid the common noise sources (e.g., the capacitive field of the body and continuous body motion) which affect most textile sensors. We show how AlphaFabric enables a large input vocabulary, which opens a range of new input techniques and novel use cases for wearable textile sensors.

**Sensor Design**

The sensor is composed of three layers of textile: two layers of conductive striped fabric placed perpendicular to each other forming a matrix, and a foam spacer in between (Fig. 2). The conductive layers are made by weaving conductive yarn into parallel stripes of 3 mm width with 3 mm spacing. These dimensions are based on the yarn’s physical properties and electrical conductivity. They are necessary to create reliable conductive electrodes and to avoid accidental connections between parallel stripes caused by yarn flyaways. Our sensor has a resolution of 4 ppi.

We used a foam spacer of 3mm thickness to separate the conductive layers. Foam is light, flexible, and very elastic: it concedes easily with applied pressure and resumes its normal shape spontaneously after being compressed. The thickness of the spacer increases the sensor’s resistance to accidental pressure especially during continuous movement. To create a touch contact on our sensor, one needs to exert force equal to 1.2 N. We used a laser cutter to cut holes into the spacer corresponding to the intersection points of the conductive stripes.

AlphaFabric scales easily. We built two sensors of different sizes: 80 × 80 mm and 120 × 120 mm. But one should note that the number of electrical traces which connect the fabric to the sensing controller increases linearly with sensor size.

In our prototype we used copper wires to connect the multilayer fabric to the sensing controller. These can be replaced with conductive thread. Our prototype works wirelessly using a Bluetooth unit and a power pack.

**Sensing Technology**

We use resistive touch technology to determine the X and Y position of the touch on the fabric. A touch is created when a contact is made between the layers by pressing on the fabric. A microcontroller (TI EK-TM4C1294XL) measures the resistance at the intersections of the conductive stripes to determine the coordinates of the contacts. Typically, a single touch results in registering several adjacent contacts. We compute the center of gravity of the contacts to determine the coordinates of the touch. The sensor can track the finger’s position continuously at a rate of 16.8Hz.
**Gesture Detection**

To demonstrate AlphaFabric’s capacity to detect gestures, we implemented two types of the most common path-based gestures in the literature: mark-based gestures and free-form gestures (see Fig. 3). We implemented a simple algorithm to detect mark-based gestures based on directional strokes. For detecting free-form gestures we used the $1$ gesture recognizer [8] and encoded the templates of the gestures. The recognizer compares user input to the templates using the proportional shape matching approach and provides an euclidean score. Our sensor is capable of detecting $25$ unique gestures, including tapping, at any scale and in any orientation.

**Sensor Evaluation**

We performed informal in-lab tests to observe how the sensor behaves under three wearable conditions. Participants were asked to wear the sensor on their arms and perform the set of gestures in Figure 3. The participants were free to move their arms as they wanted. We then asked the participants to repeat the same gesturing task but this time we controlled three variables: the STIFFNESS of the material underlying the sensor (ranging from a stiff hard surface to soft foams), the ROUGHNESS of the material overlaying the sensor (synthetic silk, cotton, jeans, and rib knit cotton), and the RADIUS to which the sensor can be bent ($180^\circ$—$20^\circ$). We manipulated these variables to simulate the expected wearing conditions of a textile sensor when placed on the body or integrated into clothes.

AlphaFabric created no accidental contacts when placed on the body. The success rate of our sensor was $84\%$. Some gestures were registered by the hardware but not detected by the recognizer, while other gestures failed to register. The authors of this work score $92\%$ success rate indicating learning effects. Following, we summarize our observations.

The sensor’s performance was independent of the stiffness of the underlying material or the roughness of the overlying material. Only when the sensor was bent to a radius below $26\,$ mm, the foam spacer started to make creases along its surface creating permanent electrical connections between the conductive layers. In practice, these contacts can be detected by software and filtered out but this would cause the input resolution of the sensor to decrease.

Interaction with the sensor was perceived more pleasing when the underlying material was softer, despite the fact that more pressure was needed to create a contact.

Smooth overlying materials such as silk improved the user experience. In contrast, rough overlying materials such as rib knit cotton made it challenging to sustain a continuous contact between the finger and the fabric, which resulted in premature gesture detection (false positives). A quick fix would be to increase the time threshold before a gesture is detected to, e.g., $2\,\text{sec}$, enough time to resume contact and continue the gesture. However, this solution potentially reduces the responsiveness of the sensor.

**Prototype Applications**

To demonstrate the versatility of AlphaFabric, we implemented prototypes based on two input modalities: continuous finger tracking and free-form gestures (Fig. 4). The first prototype is a doodling application. The user draws on a computer display by moving her finger continuously over the surface of the textile sensor. We implemented a marking menu interface to enable the user to access and navigate hierarchical menus using simple mark-based gestures. This interaction also allows users to interact with menus on small and mobile devices eyes-free [1].

![Figure 3: Mark gestures (top), free-form gestures (below) [2].](image-url)
As a possible usage example of continuous touch tracking, we envision implementing handwriting recognition to convert doodling strokes to digital text, similar to [6], creating a relatively large and quickly accessible textile notepad. The same input modality can be used to control a cursor or manipulate objects in a head-mounted display.

The second prototype uses gestures to control other applications. We implemented a set of gestures to control a keynote presentation (directional swipes to navigate the slides, and two gestures to enter and exit the presentation mode). The sensor can be operated while attached on the user’s body, e.g., upper thigh (see Video Figure).

**Summary and Future Work**

We built AlphaFabric, a simple textile sensor that enables continuous touch tracking and gesture recognition on fabric. The sensor can be worn on any location on the body and can be easily integrated into everyday garments.

Resistive touch technology brings accurate and reliable control to wearable textile sensors, and because it responds to pressure, it can detect a contact with a finger or through layers of fabric. However, during long interaction intervals, resistive sensors can become cumbersome to use. We are looking into new types of flexible, elastic and abrasion resistant textile spacers (e.g., 3D fabrics) that can further reduce the pressure needed to register touches.

We intend to increase the resolution of our sensor by increasing the number of conductive stripes per fabric inch. This requires testing new types of conductive yarns that can be woven into narrower closer pins.

Further studies will be needed to investigate how the sensor reacts in-the-wild, e.g., in crowded areas and while doing physical activities such as walking and running. This work provides a step towards the development of wearable touch sensors with large gesture vocabularies and new input modalities.

**References**


