Grabrics: A Foldable Two-Dimensional Textile Input Controller

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Abstract

Textile interfaces can be ubiquitously integrated into the fabrics that already surround us. So far, existing interfaces transfer concepts, such as buttons and sliders, to the textile domain without leveraging the affordances and qualities of fabric. This paper presents Grabrics, a two-dimensional textile sensor that is manipulated by grabbing a fold and moving it between your fingers. Grabrics can be integrated invisibly into everyday clothing or into textile objects, like a living room sofa, while minimizing accidental activation. We describe the construction and the fold-based interaction technique of our Grabrics sensor. A preliminary study shows that Grabrics can be folded and manipulated from any arbitrary position, and it can detect 2D stroke gestures.

Author Keywords

Electronic textile; fabric; ubiquitous interface; wearable; foldable user interface; input controller.

ACM Classification Keywords

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

Introduction

Textile sensors can be integrated ubiquitously into fabrics that surround us, such as clothes, furniture, and automobile interiors. Fabric materials have specific affordances that can be leveraged to enable natural interaction with textile interfaces. For example, when we pick up a piece of fabric, we explore it with our hands to determine its properties by folding, crumpling, and caressing it. Researchers have explored some of these affordances (stretch, squeeze, drape, touch, pinch, and peel) in textile interfaces to enable intuitive interaction [4, 7].

Most textile interfaces transfer concepts such as buttons, sliders, and trackpads to the textile domain. While not making use of the textile's affordances, these interfaces also origin from a more static context. A major problem of integrating these sensors into fabric is accidental activation of the electronics. For example, a sofa pillow that integrates textile buttons to control a smart TV can be involuntarily activated when used as a back cushion. Instead, in this paper we propose fold-based interaction as a natural input technique to activate and interact with textile interfaces. We developed Grabrics, a two-dimensional textile sensor that is made of conductive thread and is capable of detecting the user fold axis and 2D stroke gestures. The sensor's sheer textile nature allows it to be seamlessly embedded into everyday fabrics, e.g., in a sofa pillow. Touching the Grabrics sensor will not immediately generate input signals, allowing users to use the pillow as usual. The user interacts with Grabrics by grabbing a fold in the sensor, e.g., integrated in the pillow face, and moving the fabric between her thumb and the surface that is defined by the remaining fingers of her hand.

In the following, we will describe our initial exploration of the interaction with this sensor. The contributions of this work are: (1) sensor construction technique and an algorithm to enable Grabrics input, (2) Grabrics interaction design and usage scenarios, (3) a preliminary evaluation of a Grabrics sensor prototype.

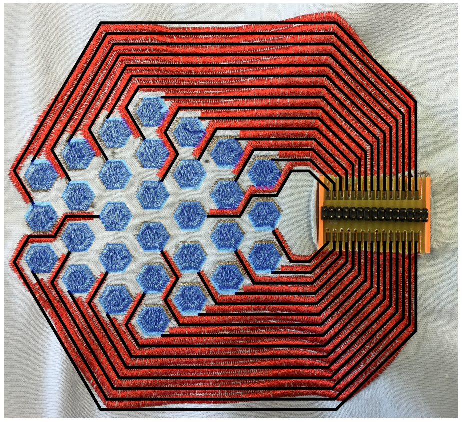

Figure 1: The Grabrics sensor consists of 30 pads of conductive thread embroidered onto a piece of cloth. When the user grabs a fold of the sensor, the interconnections are sensed by a microcontroller and mapped to relative 2D output.

Related Work

Basically, any of the textile manufacturing techniques, such as sewing [4], weaving, embroidery, or crocheting [10], can be used to build textile sensors. Perner-Wilson et al. [9] developed an electronic textiles kit and demonstrated the construction of textile sensors using craft techniques and material, focusing on the DIY community. Alternatively, Schmeder and Freed [11] describe the construction of a textile 2D touch and pressure sensor from two sheets of piezoresistive foil separated by a standoff layer. Designed as an electronic drum, the construction was mounted onto a rigid surface. Fabritouch [2] uses the same construction principle based on piezoresistive foil to construct a two-dimensional wearable touchpad. In Fabritouch, the surface supporting the touchpad (rigid table or soft body) was found to have a large impact on the precision and continuity of the input gestures, reducing the set of reliably recognizable

Figure 2: The conductive pads are embroidered in a circular manner, such that movement is not restricted by threads snagging onto each other.

gestures to simple horizontal and vertical strokes. While this sensor can easily be integrated into clothing, it does not solve the problem of involuntary activation.

iSkin [13] extends the metaphor of textiles and tattoos and uses biocompatible material to overlay the human skin with 2D sensing areas. While this technology allows you to place interactive surfaces nearly everywhere on the body, it faces the same problems of involuntary activation and does not provide haptic cues like textile interfaces do.

Schwarz et al. [12] augmented a piece of cord to create a multi-dimensional textile input controller. The cord is equipped with sensors to measure its rotation, applied pulling force and, using conductive thread, the touch position in one dimension. While the interaction with the device is simple, its integration into everyday clothing or furniture is limited.

Pinstripe [4] is a one-dimensional textile controller built from parallel lines of conductive thread sewn into everyday clothing. Users interact with Pinstripe by pinching a fold of cloth and sliding it between their fingers, which is picked up by the sensing textile and, e.g., mapped to a relative change of a continuous linear value. Furthermore, the size of the fold can be determined to vary the granularity of the value changes. Grabbing a fold requires an active gesture and does not happen by accident, making it an ideal sensor for everyday clothing. One limitation is that the fold in the sensor has to be picked up parallel to the sensing stripes, and it can only be rolled in one dimension.

Grabrics combines the flexible two-dimensional input of a touchpad with the robustness against involuntary activation of Pinstripe. We measure the relative displacement of a fold that the user grabs in arbitrary direction in 2D. The firm support surface defined by the user's fingers makes the sensor reading stable and reliable while requiring only little pressure.

Sensor

Construction

Grabrics is a 2D resistive textile sensor that, except for the sensing microcontroller, is entirely made of textile materials. The sensor consists of 30 pads of conductive thread embroidered onto a piece of cloth (cf. Fig. 1). In our prototype, the number of pads is constrained by the minimal distance required between two conductive threads to avoid unwanted connections from filament flyaways. Filament flyaways are a byproduct of the type of conductive thread and the manufacturing process. In our prototype, we used a thread that has good conductivity and is accessible to most users (Shieldex® 235/34, with a resistivity $< \ 600\Omega\ m$). After several iterations on the prototype, we found 3 mm spacing to be the lower bound needed to avoid unwanted connections. We insulated the lines leading from the pads to the landing zone of the microcontroller by stitching over them with non-conductive thread.

The pads are embroidered in a hexagonal shape from a thin conductive thread as an approximation of a circular shape. This allows the user to slide the sensor in all directions without the filaments hanging onto each other. The size and spacing of the pads were the result of iterative prototyping to create steady connections while moving the textile. The total size of the sensor is $180\ mm \times 200\ mm$. When folded, the effective operating range is reduced to $126\ mm \times 156\ mm$.

When a user pinches a fold in the sensor, some of the pads come in contact with each other, which can easily be sensed by a microcontroller (a Tiva C Series ARM Cortex-M4 in our prototype). Grabrics can sense continuous dis-

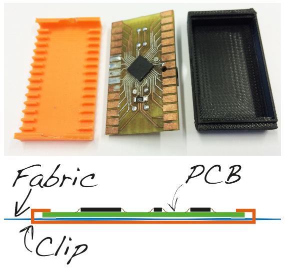

Figure 3: The orange clip provides bins for the endings of the conductive thread. The PCB just has simple contact areas on the bottom side and is pressed against the fabric by the orange plastic clip. The black part is the top case of the enclosure.

Figure 4: Grabrics can be integrated into textile objects in a less obtrusive way than other approaches, e.g., to recline an armchair. (Courtesy of Braunwagner GmbH.)

placement of the user's touch (pinch) over a fold at an update rate of 6.25 Hz (derived from informal testing to balance between signal fluctuation and update rate). The smallest incremental change in touch position that can be detected is about $4\ mm$.

We used the clipping mechanism introduced by Heller et al. [3] to interface between the textile components and the electronics (Fig. 3).

Fold Axis and Gesture Detection

In an informal study we observed users interact with a foldable textile placed on the non-dominant upper arm, the thigh, and held in the dominant hand. We noticed that users grab the textile at arbitrary positions, and with different hand orientations. A number of approaches have been proposed to detect the fold axis in paper-based interfaces [6, 15]. For the Grabrics sensor, we apply the following transformations on the connection matrix: First, we use the last two connection matrices (M_{t-1} and M_{t-2}) to filter out sensor jitter, mainly caused by applying different amounts of pressure on the fold, and apply the following formula: $M_t = (M_{t-2} \quad M_{t-1}) \quad M_t$. Second, we use a principal component analysis (PCA) on the sensor's connection matrix to determine the fold axis. We divide the connection matrix along the line of symmetry—fold axis—defined by the second PCA component (second eigenvector) followed by a calculation of the centroid of the active connection on one half of the matrix (Fig. 5).

Movement along the fold axis is mapped to output on the X-axis while a perpendicular movement to the axis results in changes of the Y-axis. The centroid determines the coordinates of the user's touch location. Finally, we apply a first order low-pass filter ($\alpha = .3$) on these coordinates, and the relative change in the user's displacement and direction is then communicated to the host.

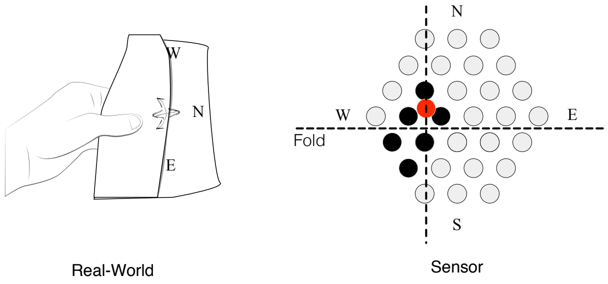

Figure 5: The user grabs a fold in the Grabrics sensor, we apply PCA on the connection matrix to determine the fold axis (dotted horizontal line), then we calculate the centroid of the active connections (black dots) on one half of the matrix. The centroid (red dot) represents the user's touch.

Fold-based Interaction and Mapping Function

Fold-based interaction has been investigated in many interfaces: displays [5], paper [14, 1], and printed electronics [8]. In the domain of electronic textiles, folding is leveraged as a natural and regular way for interacting with fabric [7, 4].

The ability to embed textile sensors ubiquitously into existing textile objects has the advantage of providing simple control interfaces that are less intrusive than other approaches. For example, instead of placing plastic buttons on the side of a recline armchair, the Grabrics sensor can be integrated into the chair's fabric (Fig. 4). However, one consequence of such textile interfaces is involuntary activation, e.g., by accidentally pressing on the side of the chair, the chair could recline undesirably. Grabrics mediates this problem by using folding (pinching) the textile sensor between the users fingers as an explicit activation gesture. Consequent pinch and slide gestures are then translated as control commands. This interaction technique also allows

Grabrics to be integrated into textile objects and perform reliably, independent of the underlying support surface, e.g., in wearables or furniture A practical consideration when designing fold-based textile interfaces is to be able to detect the arbitrary fold axis, the position, and the orientation of the fold [4]. This feature allows for a faster acquisition time, and does not require the user's continuous attention when grabbing the interface.

To determine an appropriate input-output mapping function for our sensor, we captured a user sliding her thumb from left to right over Grabrics using a Vicon optical tracking system. We compared the tracked thumb motion (ground truth) with Grabrics sensor readings (see Fig. 7), and noticed that compared to the Vicon, fine movements on the textile are not captured by the sensor. This is due to two physical constraints of the textile sensor: (a) limited input resolution, because of the low number of conductive pads; and (b) limited effective operating range, defined by the area of the user's fingers when performing a fold [2].

Due to this low resolution, applying a mapping function that controls the output displacement based on the input displacement, such as with the mouse, trackball, and trackpad, is inappropriate, as it would result in jumping output values. Alternatively, we opted for a displacement-to-velocity mapping function, such as in an isometric joystick. This mapping requires less resolution to detect directional displacement and is appropriate for devices with limited operating range. Within the operating range of Grabrics (when folded), we recognized 10 mm to be the displacement threshold that the user can distinguish and control. We mapped this threshold to a discrete two-level acceleration function, which controls the gain (velocity) of the output.

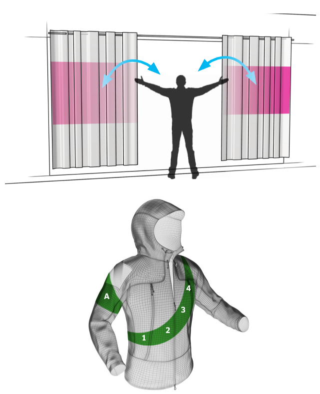

Figure 6: Grabrics example usage scenario, providing a transparent and flexible textile interface to everyday objects. (Courtesy of Braunwagner GmbH.)

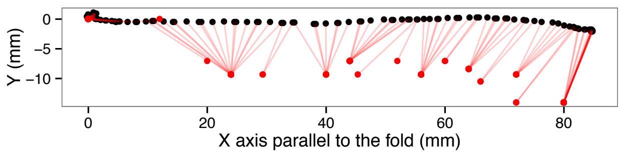

Figure 7: Motion trace from Vicon (black) and Grabrics (red) in the input space. Each line connects the trace from the same timestamp.

Use Scenarios

The textile nature of Grabrics enable it to be integrated seamlessly into our furniture and clothes (Figure 6). A Grabrics sensor can serve as a simple, hand-held remote controller. For example, it can be used to control the volume or switch channels on a TV, or serve as simple game controller in the living room. Integrating Grabrics into home curtains, for example, provides transparency between the form and function of the sensor [10].

Our sensor's ability to detect the user's fold axis makes it especially appealing for becoming part of our clothes. For example, a user can grab an arbitrary fold in her sports jacket and navigate the menus of an MP3 player using the 2D sensor. Textile designers can integrate Grabrics in any orientation and users will be allowed to interact with the controller quickly, and eyes-free.

Preliminary User Study

We conducted a preliminary user study to investigate the capability of our prototype in terms of pointing accuracy. The task was a reciprocal pointing task, requiring participants to select 7 targets that appeared on the screen in a circular arrangement. A factorial within-subject design was used. The independent variables were Device (Grabrics and a touchscreen), distance between targets D ($D_S = 512$ mm, $D_L = 650$ mm), and target width W ($W_S = 42$ mm, $W_L = 96$ mm). D-W combinations were fully crossed. We recruited 5 volunteers (all male) with a mean age of 32.6 (SD $= 8.6$), one left-handed. The users handled the Grabrics prototype in their dominant hand.

Axis Angle (°)	Users' Deviation (°) Mean	SD
0	1.62	1.43
51	1.24	0.94
102	1.78	1.18
154	1.57	1.16
205	1.64	1.06
257	1.29	0.96
308	1.89	1.58

Table 1: The captured angular resolution of the Grabrics. Axis angle describes the ideal movement direction. The actually performed gestures did not significantly deviate from this axis.

Results and Discussion:

Table 1 shows how much the users deviated from the task axis. Applying factorial ANOVA, we found no significant effect for the task axis angle on the actual angle of movement ($F(1,11) = 9.57$, $p < .09$) or the overall error rate ($F(1,11) = 1.7$, $p < .14$), which could indicate that users had a similar level of control in all possible directions.

To determine how well users were able to control pinch displacement, we used Welch's t-test to compare the overshoot count in our prototype to the touch screen condition. There was no significant effect of device on the overshoot count (Welch $t(485.60) = 1.07$, $p = 0.284$). Users overshoot on the touch screen (M = 0.49 , SD = 0.68) as often as on Grabrics sensor (M = 0.66 , SD = 3.28). This indicates a comparable control over displacement. We did not observe any ordering effects (fatigue or practice).

During the study, we observed that the continuous handling of the textile causes the fabric to shift in the hand of the participant and makes it harder for the thumb to make connections between the pads. In this case, the participants released, re-grabbed, and re-centered the textile in their hands.

Limitations and & Future Work

Our current prototype is limited in terms of physical (input) resolution. Many parameters contribute to this limitation: the type of conductive thread, the manufacturing and embroidery process, and the electrical connections around the sensor. While these problems can be solved using production-scale manufacturing processes, we will explore more accessible ways, for example, other stitching techniques and patterns to achieve higher sensor resolution. We will also explore other fabrics to reduce the friction of the fold. In this paper we used a clipping mechanism to rapidly prototype textile sensors. One limitation of this mechanism is that it becomes bulky very quickly as we increase the number of connections. We are currently exploring a time-multiplexing approach in a grid-style connection. This will allow Grabrics to become more scalable.

Conclusion

We described the design and implementation of Grabrics, a 2D foldable textile sensor that, aside form the microcontroller, is made totally out of textile material. Grabrics is activated by an explicit fold gesture and manipulated continuously by a pinch and slide gesture over the fold. Our observations suggest that a practical consideration for foldable interfaces is their ability to operate independent of the fold axis. This allows Grabrics to have a low device acquisition time, and to support eyes-free interaction. While we did not expect Grabrics to outperform the touchscreen in terms of movement speed and accuracy, we found that 2D control over pinch direction and displacement is comparable to high-resolution touchscreens. Both of these parameters are the strength of Grabrics. The resultant angular resolution of Grabrics suggests that circular interfaces, e.g., marking menus, can be potential interfaces for fold-based input.

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