fStrip: A Malleable Shape-Retaining Wearable Strip for Interface On-Demand

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Abstract
This paper presents *fStrip*, a wearable device, which enables the use of tangible-and-deformable interface on-demand for mobile tasks. *fStrip* consists of an array of strain gauges for shape reconstruction, a 9 degrees-of-freedom inertial motion unit (IMU) for motion input, and an optional strip display for visual output. We present the prototype and an algorithm for shape reconstruction based on NURBS approximation. Our experiment reported that, from a set of six primitives collected from 9 participants, *fStrip* achieved 88% recognition rate using SVM classifier.

Author Keywords
Malleable user interface; organic user interface; wearable devices.

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

Introduction
We present *fStrip*, a malleable shape-retaining strip as a mobile and wearable device. Like a flexible curve, users can bend *fStrip* into different shapes by hands. Owning to its native mild stiffness resembling to flexible curves, *fStrip* can retain a newly created shape for users to perform manipulational operations upon the physical affordance al-

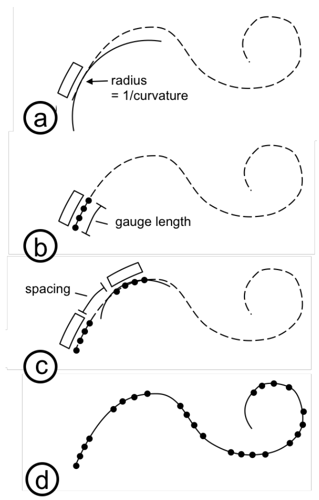

Figure 1: The procedure of turning 16 curvature points reported by the strain gauges into a smooth curve using spline interpolation.

lowed. Users wrap *fStrip* around their wrists as wearable accessories. For tasks where physical affordances are preferable, *fStrip* allows form creation for physical interactions.

In terms of form creation, curves and clays describe a shape in different ways. A piece of clay fills a shape, and a flexible curve traces it. *fStrip* is thereby more effective in creating symbolic shapes. For example, making a letter 'M', users make three turns on the flexible curve. Making a circle shape simply connects two ends of the curve.

Related Work

A strip interface allows physical manipulations other than touches. For example, cordInput [3] explored touch, pulling, and twisting interaction and their combination for menu controls on the cord-based interface. The cordInput, however, dose not detect shape. Deformable touch strip [5] allows detecting a created shape, but they did not focus on physical affordance. MetaSkin [4] can detect stretching interaction. But the stretched material cannot memorize the newly created shape. In this paper, we explore a malleable shape-changing interface using *fStrip*. We are interested in a malleable strip that users can create new shape according to the usage context, and further utilize the newly created affordance for interaction.

ShapeTape [1] allowed users to create and modify 3D curve and models by bending and twisting the curve tape. Grossman et al. [2] further exploited the interface to facilitate function inputs while modeling. While also using strip interface, our work differentiates from the previous works twofold. First, our strip interface allows uses to retain a created form by manipulating the malleability of the strip. Second, we focus on using the strip as a wearable device, which enables deformable-and-tangible-interface on-demand.

Figure 2: *fStrip* prototype. (a) NinjaFlex substrate, (b) *fStrip* with iron wires, (c) *fStrip* with 9DOF IMU and LED strip, (d) strain gauge breakout board, (e) main board (f) stacking main board and breakout board.

Hardware Prototype

Figure 2 demonstrates our hardware prototype, which consists of 16 resistive strain gauges mounted on a flexible strip made by NinjaFlex (Figure 2a). The local bending causes the resistance of the strain gauge to increase or decrease according to the bending direction. To reduce the background noise, we secure one of a strain gauge from deformation and choose it as a reference to the noise, named dummy gauge. Together, an array of the other 15 strain gauges allows accumulating local bends for shape reconstruction.

The electronic components are integrated on two compact customized circuit boards, the main board (Figure 2e) and the strain gauge breakout board (Figure 2d). The main board contains a microcontroller (Atmel ATMEGA328P), which controls two low-ohmic 8-channel multiplexers (NXP

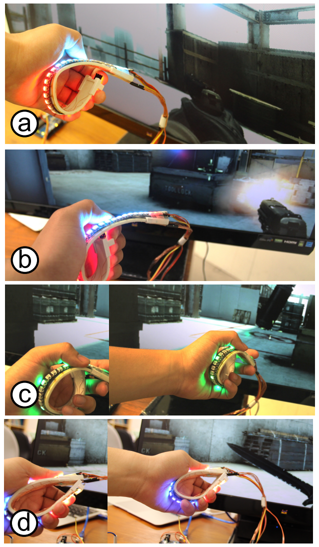

Figure 3: Playing FPS games with *fStrip*.

NX3L4051) to retrieve readings from sensor chips, and a 16-bit analog-to-digital convertor (TI ADS1115) for signal amplification. The two compact boards are stacked (Figure 2f) and then connected to the *fStrip*. The readings of 16 strain gauges are collected consistently over 45 fps, allowing for deformation of the *fStrip* in real-time. To allow for motion input and visual output, a 9DOF motion sensor and a NeoPixel[1] LED strip are integrated (Figure 2c).

Making Malleable Strip

We add iron wires to bring malleability to our flexible strip. As shown in Figure 2, two iron wires are added to two sides of a strip during fabrication and then serve for two purposes. First, iron wires are not stretchable. Enclosing the wire kills stretchability of the flexible strip, while greatly mitigates the degree of the strip being twisting. Second, iron wires are malleable, and more importantly, they can keep newly formed shapes. Adding the wires endows a flexible strip with the ability to keep its form.

Shape Reconstruction

We think of strain gauges as an arc segment in the length of strain gauge with specific radius, which is calculated from the voltage output of amplifier. Our strain gauge strip, thereby, composes 15 discrete segments of arc distributed uniformly across the strip.

Figure 1 illustrates the process to translate isolated arc segments, strain gauge segments, to a flexible curve representing shape. Starting from first arc segment, we replace it by four uniformly-distributed points, and at the end point, we append another arc segment, gap segment, whose length is the known spacing between strain gauges in the strip and whose radius is the interpolation of the adjacent strain gauge segments. Then, we append the next strain gauge segment, replace it by four points, and repeat the process until the last strain gauge segment is consumed. After the process, 60(15x4) points are used as pivots for guiding a NURBS curve.

Evaluation

To evaluate with actual performance metrics, we compared the reconstructed shapes with ground-truth shapes defined by laser cut acrylic shapes, in which 6 primitives (square, triangle, circle, V-shape, U-shape, M-shape, L-shape) were used. By fitting FlexiBend in each primitive, we could compute the average differences in angles (from curvatures) across corresponding sample points in the primitives (M=7.6°, SD=1.20).

To understand the feasibility of *fStrip* in the proposed applications, nine participants were recruited to deform *fStrip* into same primitive shape set. A total of 63 samples were collected. We conducted leave-one-person-out cross-validation with a SVM classifier to measure the accuracy of shape detection. The result shows the overall accuracy is 88.2%.

Application: Metaphorical Devices

Figure 3 demonstrates an example of using *fStrip* in a first-person shooting game. The user forms *fStrip* into different shapes to switch between weapons including pistol, grenade and saber. Making a '6' shape recalls a pistol. The circle on one end of the strip serves as the pistol grip and is colored dark brown, and the straight part on the other end serves as the pistol barrel and is colored dark gray.

Pressing the grip triggers a gun shoot with a red dot on the strip display, representing a bullet, fast moving from the grip, through the slide, and to the screen. This visual feedback bridges the *fStrip* and screen displays, which reinforce the perceived experience of the user. Owing to the

[1] http://www.adafruit.com/category/168

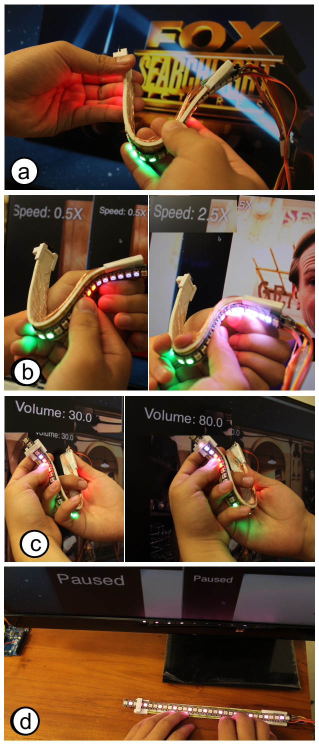

Figure 4: Using *fStrip* for uni-stroke recalls function.

mild stiffness of *fStrip*, the grip would push itself back such that the user could perceive force feedbacks on the grip on each trigger.

Turning the *fStrip* into a 'Q' shape switches to holding a grenade in hand. The motion sensor then detects throwing the grenade forward. Shaping the *fStrip* into a compressed 'U' shape recalls a saber, which the user can stab forward to attack the enemies. The interactions mentioned above all come with a corresponding visual appearances and effects on the strip display.

Application: Unistroke Recalls Function

The concept of shape-recalled functions is applied and demonstrated. To quickly access functions in the environment (e.g., control a television) or functions of mobile devices, users form *fStrip* into abstract shape icons or unistroke letters as instant interfaces. Abstract shapes and unistroke letters are symbolic icons, allowing for short-cut accesses and physical controls on the created forms.

Figure 4 demonstrates an example of symbolic shape input. To remotely control a video player, the user forms the FlexiBend into a 'V' shape, along with the strip display revealing where on the strip allows physical controls for the video player (Figure 4a). Pushing forward the newly formed FlexiBend towards the video player, the association is accepted. Bending the right-handed end of the V-shape adjusts the playback speed. The strip display therein reveals current speed by its illumination (Figure 4b). Bending the other end adjusts volume levels. The strip display therein reveals current volume by a progress indicator (Figure 4c). Setting the FlexiBend flat on the table pauses the video (Figure 4d).

Conclusion

We have presented *fStrip*, a malleable shape-retaining strip that allows users to create physical affordance according to the usage context. As future works, we would like to explore other manipulational interactions on a flexible strip such as stretching and twisting.

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