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# Plex: Finger-Worn Textile Sensor for Mobile Interaction during Activities

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**Figure 1:** Plex enables eyes-free interaction during activities

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## Abstract

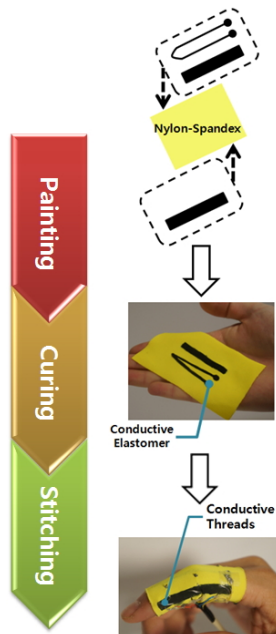
We present Plex, a finger-worn textile sensor for eyes-free mobile interaction during daily activities. Although existing products like a data glove possess multiple sensing capabilities, they are not designed for environments where body and finger motion are dynamic. Usually an interaction with fingers couples bending and pressing. In Plex, we separate bending and pressing by placing each sensing element in discrete faces of a finger. Our proposed simple and low-cost fabrication process using conductive elastomers and threads transforms an elastic fabric into a finger-worn interaction tool. Plex preserves an inter-finger natural tactile feedback and proprioception. We also explore the interaction design and implement applications allowing users to interact with existing mobile and wearable devices using Plex.

## Author Keywords

Wearable Input Device; Tactile; Mobile Interaction; Piezoresistive; Eyes-free Interaction.

## ACM Classification Keywords

H.5.2. [Information interfaces and presentation]: User Interfaces Input devices and strategies; User centered design.



**Figure 2:** Plex composite configuration and fabrication process

## Introduction

Modern smartphones and eye-wear devices have laid the foundation for Ubicomp in various environments. However, the conventional tactile input limits users from interacting with devices during daily activities such as walking or exercising. A typical eyes-on interaction with the mobile device exposes users to dangerous circumstances including falling, bumping, or traffic accident [9].

The hand is a key to demonstrate the mobile interactions and the most frequent interaction areas in hand are thumb and index finger [3]. There are various commercial products<sup>1,2</sup> as well as state-of-art research using fingers for precise mobile interaction [2]. However, previous products as well as research are designed to work under steady environments. Thus, it is not possible to use these devices during activities such as jogging, driving, or walking that cause high motion artifacts.

Plex is a textile finger-worn sensor for eyes-free mobile interaction. It is capable of sensing both strain and pressure discretely under dynamic working environments. In particular, mapping different sensing elements to existing smart devices brings out an innovative interaction technique. Although many types of textile sensors have been studied, we are not aware of a smart textile enabled small-size and robust finger-worn input device.

## Related Work

Conductive elastomers are known for piezoresistive characteristics and widely applied to strain and pressure sensors [8] A recent study successfully merged pressure and strain sensing on a flexible substrate [7].

<sup>1</sup>FIN: <http://www.wearfin.com>

<sup>2</sup>RING:<http://logbar.jp>

Nevertheless, the flexible substrate like PDMS typically provides an unusual texture to users and it requires time consuming nanofabrication to insert conductive materials. We design Plex to physically decouple each sensing element on the index finger: strain sensing on top and pressure sensing on the side.

Ashbrook et al. shows that always available input provides significantly faster access time to mobile devices [1]. With a wireless communication, it becomes easier to connect wearable accessories with mobile devices. Previous research achieved eyes-free interactions using smart clothing or wristband [6]. However, users have to follow an extra gestural process to move the hand to a specific location. Thus, the wearable input device requiring a minimal motion has a high potential to improve the usability for the daily mobile interactions.

## Plex: Design Approach

In the design of Plex, the main goal was to achieve a finger-worn device that can perform rich and stable mobile interaction regardless of the activity type. To attain these goals with a single finger-worn sensor, it should provide multiple forms of input method as well as guarantee a stable fixation to the human body. Based on the advantages of the index finger including digit-wise independence and maximum pinch strength, it is selected as a candidate to apply Plex [4, 5].

Several design factors including width and shape were considered. For strain sensing, we tested several design candidates in terms of width and shape. Although we assumed that high density of carbon composite benefits the resistance variation, we observed decrease in fabric's elasticity with extensive carbon elastomer stacking. A 2mm width was found to be most efficient to measure the

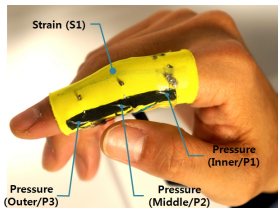


Figure 3: Plex prototype

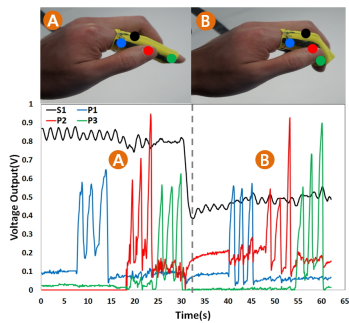


Figure 4: Sensor outputs during two phases: (a)  $0^\circ$  finger bending + pressing at 3 different locations (b)  $60^\circ$  finger bending + pressing at 3 different locations

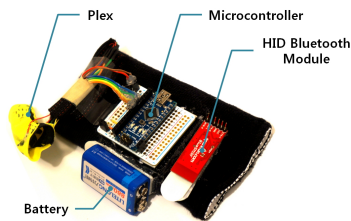


Figure 5: System configuration

strain. Furthermore, we preferred a V-shape due to easy wiring connection. Subsequent experiments on comparing V-shape and straight line exhibited similar performance using the same width. Thus, we chose 2mm width V-shape line for measuring strain. Meanwhile the pressure sensing comprises a 6mm width straight line since it can cover most of areas on the side of a finger.

We transform normal fabrics into piezoresistive fabrics by painting the diluted conductive elastomer<sup>3</sup>. Spandex fabric (80% Nylon and 20% Spandex) is selected as a basis fabric due to its known exceptional elasticity. Figure 2 describes the composite configuration and the fabrication process of the prototype sensor:

- toluene diluted conductive elastomer is smeared onto fabrics using a stencil and a brush to create a V-shaped line (strain sensing) on the top surface and straight line (pressure sensing) on both surfaces,
- the painted fabric is cured by putting it into the oven at  $120^\circ\text{C}$  for 10 minutes, and
- conductive threads are stitched/cross-stitched to the controlled fabric.

Figure 3 illustrates the different sensing elements of Plex. With proposed textile based sensor, Plex enables finger touch/pressure/bending as an input method. We assumed that each sensing element works without physical crosstalk if we isolate them to discrete faces of a finger. In order to verify the assumption, we conducted a small test to check whether all sensing elements work independently. In Figure 4, the independent relationship between strain and pressure sensing elements continues regardless of finger bending and/or pressing. It is also noticeable that pressure sensors do not trigger each other during operation.

<sup>3</sup>ELASTOSIL from Wacker Ltd.

The system comprises Arduino Nano microcontroller, BlueSMiRF Human Interface Device (HID) Bluetooth module, resistors and lithium-ion battery (Figure 5), which are attached to the wrist band for the fixation. The total weight of the hardware device is under 100g. Optimal resistors are selected based on the voltage divider calculation. Then, the microcontroller processes analog readings from the piezoresistive fabric and sends standard input signals wirelessly to mobile devices through the HID Bluetooth module.

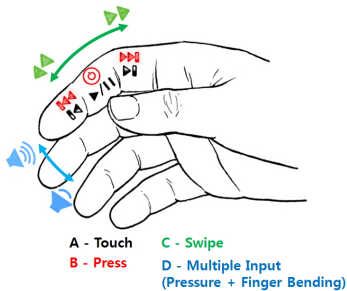
## Implementation

### Interaction Design

We explore an interaction design of Plex with generalized smart device functions. Plex allows the following input methods: touch, press, finger bend, and swipe. These interaction methods are typically inherent to everyday used mobile device and computers. Thus, they can be easily mapped to conventional functions such as selection, left/right action related function, and intensity control mechanism. For different users, the default sensor values vary due to the finger size. We compensate it with the zero calibration whenever the user wears Plex. As shown in Figure 6, touch/pressing, swiping/bending, and combining multiple input methods are utilized to form a complete input set for an application.

### Eyes-free & Private Interaction Applications

We develop two prototypical applications for leveraging the use of Plex: eyes-free mobile interaction and private interaction with smart eyewear (Figure 7). In our application, we directly pair it to an existing device without any software or hardware modifications. This guarantees the compatibility as an input device. Our applications envision that existing products get benefits in terms of richer and more private interactions using Plex.



**Figure 6:** Conceptual Interaction Mapping for mobile music player



**Figure 7:** User interacts with existing smartphone and smart-eyewear using Plex

For eyes-free mobile interaction, Plex provides rich enough interactions to control default music player's most functions including initiate/exit music player, play/pause, fast forward/rewind, scan previous/next song, and volume up/down. Based on user's proprioception and tactile feedback, they can control without looking at Plex.

Currently people interact with smart eyewear using an embedded track pad on the frame which accompanies a noticeable arm movement to nearby people. Using Plex to control the device provides much more private interaction where user's intent to use the device is hardly noticeable by others. In addition, Plex provides plenty of mapped functions to control the general GUI.

### Future Work

Further design iteration will improve Plex in terms of accuracy and usability. We can replace the metallic wires with textile craft materials. Currently, the manual painting process causes low reproducibility due to the density variance. By adopting ink-jet printing technology, we can obtain uniform density on the fabric regardless of reproduction.

User studies based on both qualitative and quantitative aspect can bring out greater insight from end users. The exemplary types of future user study include false-positive test, Fitts task, finger-centric task, NASA-TLX, and Likert scale based questionnaires. These evaluations could support the internal and ecological validity of Plex as an input device for Ubicomp under various environments.

### Acknowledgments

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