# TIMMi: Finger-worn Textile Input Device with Multimodal Sensing in Mobile Interaction

**Sang Ho Yoon, Ke Huo, Vinh P. Nguyen and Karthik Ramani**
C-Design Lab, School of Mechanical Engineering
Purdue University, West Lafayette, IN 47907, USA
{yoon87,khuo,nguye131,ramani}@purdue.edu

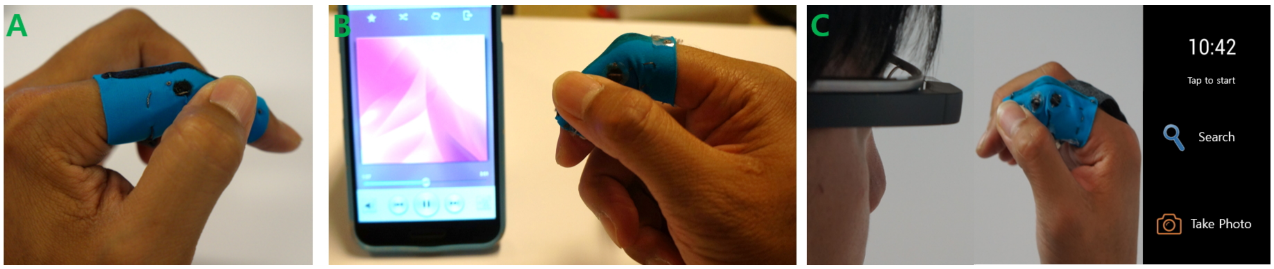


Figure 1: (a) TIMMi provides multimodal sensing through a single layer of textile (b) Controlling music player in smartphone (c) Navigating user interface in smartglasses

## ABSTRACT

We introduce TIMMi, a textile input device for mobile interactions. TIMMi is worn on the index finger to provide a multimodal sensing input metaphor. The prototype is fabricated on a single layer of textile where the conductive silicone rubber is painted and the conductive threads are stitched. The sensing area comprises of three equally spaced dots and a separate wide line. Strain and pressure values are extracted from the line and three dots, respectively via voltage dividers. Regression analysis is performed to model the relationship between sensing values and finger pressure and bending. A multi-level thresholding is applied to capture different levels of finger bending and pressure. A temporal position tracking algorithm is implemented to capture the swipe gesture. In this preliminary study, we demonstrate TIMMi as a finger-worn input device with two applications: controlling music player and interacting with smartglasses.

### Author Keywords

Tangible and wearable interface; mobile interaction; sensing; smart textile; finger; prototyping

### ACM Classification Keywords

H.5.2. [Information interfaces and presentation]: User Interfaces - *Input devices and strategies; Interaction styles*.


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## INTRODUCTION AND RELATED WORK

Mobile interaction with various sensing techniques has been drawing interest from researchers and developers [8]. Weiser metaphorically suggested the smart textiles as a next generation of the human computer interface with his vision of computers that “weave themselves into the fabric of everyday life” [14]. However, the sensing techniques in the smart textiles are more focused on a single modal sensing [2]. Recent works including Teleglove [9] and Beartek Glove[1] provide sufficient numbers of input trigger for the mobile interaction. These devices still require embedding sensors in multiple layers of the fabric which diminish the tactile feedback due to the stacked layer thickness. FIN[2] and FingerPad [3] provide rich interactions while maintaining a small form factor using optical and magnetic sensing. Inspired from these works, we use the smart textile for an interaction medium to achieve softness and thinness with a small form factor. We present TIMMi, a textile interface which utilizes finger pressing, bending, and swiping as input metaphors for the mobile interaction.

TIMMi brings both strain and pressure sensing capabilities from a single layer of textile. We employ a two-phase and a polynomial regression analysis to model the relationship between magnitudes of pressure and strain against applied finger pressing and bending. By using a multi-level thresholding, we differentiate input signals from the pressure and strain sensing. The swipe gestures are captured via implementing the temporal position tracking algorithm. TIMMi only requires a single layer with stitched conductive threads which alleviates sensitivity issues due to the thickness of the device [1]. The prototype consists of soft materials to pre-

[1]Beartek Glove: `http://www.beartekgloves.com/`
[2]FIN: `http://www.wearfin.com`

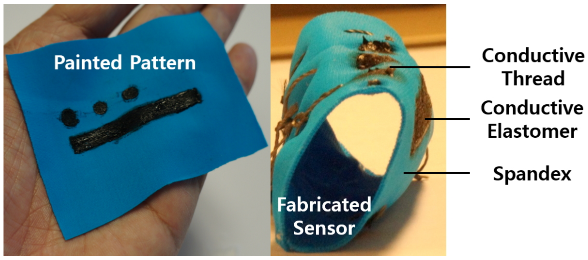


Figure 2: TIMMi prototype composition

serve the tactile sensing and improve the wearability compared to attaching hard and rigid sensors. We intend to explore: 1) A smart textile with multimodal sensing capability for mobile interaction, 2) Utilizing multimodal sensing for capturing user intent from finger bending, pressing, and swiping, and 3) Implementing applications including music player and smartglasses as applications.

## DESIGN RATIONALE

- *Input Metaphor*: The thumb and index finger possess the most frequent interaction area, the greatest range of pinch strength in the hand, and are most digit-wise independent [7, 10, 11]. These fingers support pressing, rubbing, and bending as input modalities for mobile interaction. Thus, we decided to adopt interactions between thumb and the index finger.
- *Multimodal Sensing & Wearability*: Smart textiles provide various sensing metaphors based on different compositions and structure [4]. Moreover, a thin layer of fabric and conductive thread provide sensory comfort [1]. In our prototype, the discrete distribution of carbon elastomer allows capturing bending and pressing concurrently.
- *Understanding multimodal inputs*: We utilize a time-based algorithm due to its ability to differentiate finger pressing and swipe gesture. Two-phase and polynomial regression models have been used for estimating magnitudes of pressure and strain [5, 6]. These regression models in combination with the temporal tracking algorithm allow TIMMi to support numerous input modalities.

## SYSTEM DESIGN

Our system design aims for three goals: 1) achieving a simultaneous pressure and strain sensing, 2) capturing different levels of finger pressing and bending as well as swipe gesture, and 3) fabricating thin, soft, and small form factor prototype. We apply flexible and soft materials to form the entire system.

### Sensor Fabrication

TIMMi consists of elastic fabric painted with conductive carbon elastomer[3] and conductive threads stitched on the fabric (Figure 2). Nylon-Spandex fabric (80% Nylon and 20% Spandex) is selected due to the exceptional elasticity. The diluted conductive elastomer is painted using a stencil and a brush. We selected the conductive elastomer due to its rebound elasticity (52%). The painted fabric is cured at 120 °C

[3]Wacker LR3162: http://www.wacker.com/

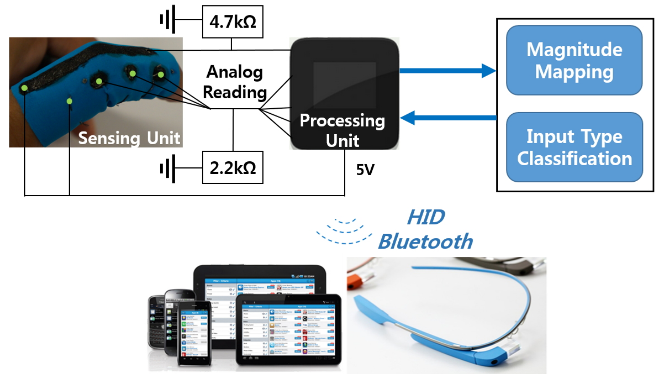


Figure 3: TIMMi schematic workflow

for 10 minutes. Combined Spandex and customized ink exhibits a good piezoresistive properties (0.15mm thick, resistance change of $50\Omega/in^2 \sim 40k\Omega/in^2$ due to pressure, gauge factor of 5). The design of two separate sensors allows detecting strain and pressure accordingly: a single line with 5mm width and three dots with 5mm diameter (Figure 2). While strain sensing is addressed with normal stitching, cross stitching into the front and back surfaces applies for pressure sensing [13].

### Hardware

Analog readings are transmitted to a microprocessor through a customized fabric connector ($< 0.2\Omega/cm$). Instead of metallic wires, the customized fabric connector is used to keep the softness of the prototype. The processing unit comprises a chip sized microcontroller[4] (ATmega328, clock speed 16MHz), Bluetooth module (115200bps), and 3.3V lithium-ion battery. We select $2.2k\Omega$ and $4.7k\Omega$ resistors for pressure and strain sensor based on the voltage divider calculation(Figure 3). HID Bluetooth module passes input via standard communication protocol to the device. The total weight of the system is under 50g.

### Multimodal Sensing

The analog outputs from the piezoresistive fabric are processed with two different regression models. A multi-level thresholding and a temporal position tracking algorithm are used to create different input commands.

#### *Simultaneous Pressure and Bending Sensing*

We performed initial tests on pressing and bending with TIMMi which were investigated to confirm the capability of fabricated piezoresistive fabric in recognizing both finger pressing and bending discretely and simultaneously. The virtual manipulation illustrates real-time performance of the prototype (Figure 4).

#### *Magnitude Mapping*

The bending and pressing magnitudes levels are defined by the regression analysis. The resistance changes are plotted against applied pressure and finger bending angle. The zero-calibration is performed before each trial to compensate for

[4]Microview: `https://www.sparkfun.com/products/12923`

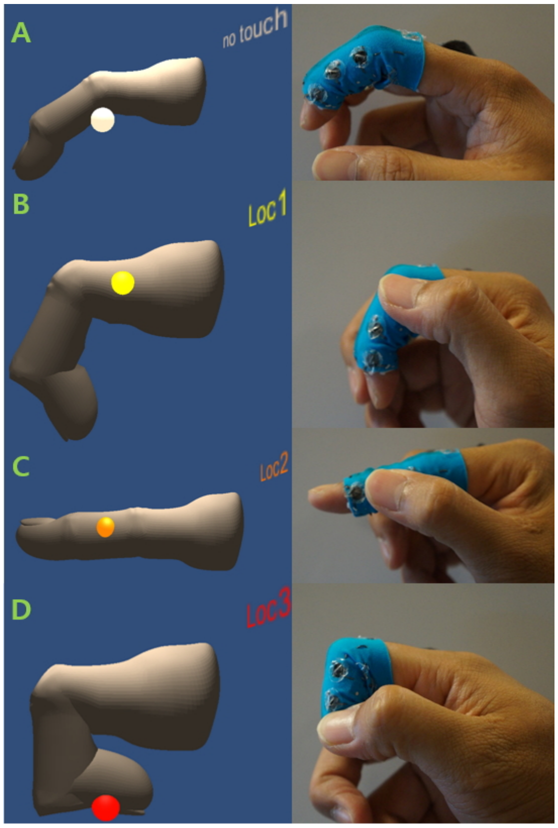


Figure 4: Real-time manipulation of virtual finger model with TIMMi (a) slight bending, (b) slight bending with tapping, (c) pressing gently, and (d) full bending with pressing firmly

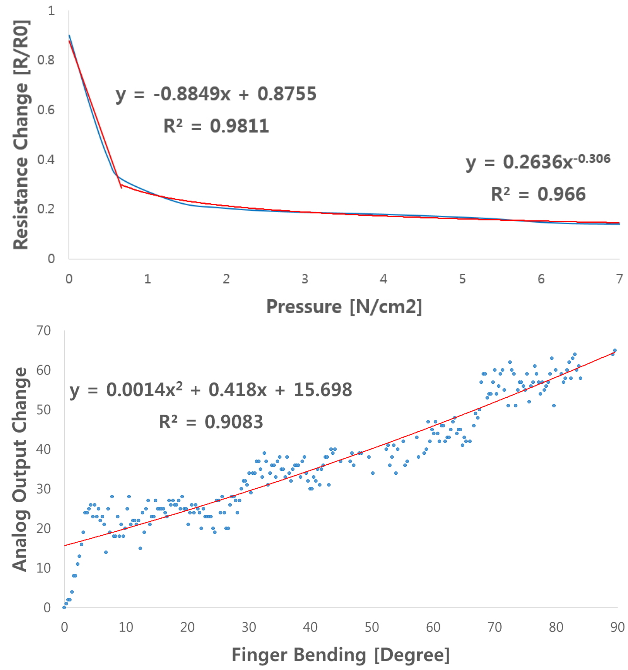


Figure 5: Magnitude model using two-phase regression model for finger pressing (Top) and polynomial regression model for finger bending (Bottom)

variations in finger-worn conditions. For pressure, we use a two phase regression model which encompass linear and exponential characteristics of the sensor output. For finger bending, we employ a polynomial regression model which could predict magnitudes between 0∼90° of proximal interphalangeal joint bending. Magnitude mappings are primarily carried out since mapped values are used as a reference in recognizing different levels of the input signal.

Two-phase Regression Model:

$$y_i = mx_i + b, \; for \; x \leq 0.7N/cm^2 \tag{1}$$

$$y_i = \alpha x_i^{\beta}, \; for \; x > 0.7N/cm^2 \tag{2}$$

Polynomial Regression Model:

$$y_j = \sum_{i=0}^{n} a_i x_j^i + \epsilon_j \tag{3}$$

These magnitude models show average accuracy of 97.3% (pressing) and 90.6% (bending). Plots illustrate the raw data and the developed regression models (Figure5).

### *Capturing Input Types*

TIMMi utilizes mapped magnitude models to capture input types. In this preliminary work, we dissect pressure and bending magnitudes into three regions which can distinguish more than an on/off status. The segmentation levels can be adjusted according to applications. We employ a temporal position tracking method to detect the swipe gesture and differentiate between discrete pressing and swiping. If users trigger two different painted dots with small amount of pressure, the algorithm counts the time gap between two events. The whole event is recognized as a swipe gesture only if the time gap falls within a specific constant for which we use 0.5 seconds.

We conducted a small pilot test to confirm the input classification performance of TIMMi. It involved 7 participants where we asked them to execute every input type designed in the prototype such as different levels of pressing and bending as well as swiping with both directions. The zero-calibration was carried out with a straight finger posture prior to each test. Figure 6 illustrates the confusion matrix of different input types. Pressing and bending magnitude detection exhibited average accuracy of 97% and 92% respectively while swipe gestures detection gave 80% accuracy. Less accuracy was observed in swipe gestures due to different swipe velocities among users.

## IMPLEMENTATION

In this study, TIMMi is implemented as a new input device for smartphone and smartglasses.

### Eyes-free Mobile Input Metaphor

Multimodal sensing provides intuitiveness in controlling the default music player application in Android OS. Our design focuses on providing comfort for wearing in order to not restrict natural finger motion. In general, the eyes-free interaction is motivated to enhance the controllability while visually

Selected

| Presented / class | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **67** | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 |
| 2 | 2 | **66** | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| 3 | 1 | 0 | **69** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| 4 | 0 | 0 | 0 | **68** | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 5 | 0 | 0 | 0 | 2 | **66** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 1 | **70** | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | **68** | 0 | 0 | 0 | 0 | 0 | 3 | 2 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | **68** | 1 | 0 | 0 | 0 | 1 | 1 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | **69** | 0 | 0 | 0 | 6 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **70** | 2 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **63** | 9 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | **61** | 0 | 0 |
| 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **54** | 0 |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **58** |

**(1) Tap (2) Press gently (3) Press firmly on outer pressure dot**
**(4) Tap (5) Press gently (6) Press firmly on middle pressure dot**
**(7) Tap (8) Press gently (9) Press firmly on inner pressure dot**
**(10) 0°(11) 45° (12) 90° finger bending**
**(13) Inner direction (14) Outer direction swiping**

Figure 6: Confusion matrix of different input types. Rows indicate presented inputs and columns refer to selected inputs.

distracted from mobile devices [15]. Our approach is to suggest a wearable device with passive haptic experience where users utilize somatosensory tactility for mobile interaction.

### Socially Acceptable Interface

TIMMi works as an input device for the smartglasses. The tactile input interface for conventional smartglasses is located on the frame which requires publicly noticeable gestures. The social acceptance of the interaction can improve with less noticeable gesture [12]. We aim to enhance the social acceptability by utilizing a single finger interaction. This approach is expected to reduce the extra noticeable gesture since users can manipulate fingers accurately with a subtle motion.

## DISCUSSION

Implemented applications and conducted pilot test show that rich interactions can be accomplished in a single finger by broadening input modalities. A thin and soft layer of prototype provides the multimodal sensing without adversely affecting the user wearability. Incorporating a smart textile as a wearable device for mobile interaction illustrates that the embedded and embodied interactions can be merged into a single device. In TIMMi, the piezoresistive sensing technology is embedded while users interact using embodied gestures like finger pressing, bending, and rubbing (swiping). We hypothesize that exploiting these embodied gestures within a small embedded system improve the eyes-free performance and social acceptability. To explore this further, we intend to conduct physio-psychological user studies.

We only used conductive threads to provide a soft conductive path in our current design. It will be interesting if we imprint highly conductive ink over the conductive elastomer for future work. To improve a classification, we will consider Support Vector Machine (SVM) method. During follow-up user studies, we expect to figure out quantitative and qualitative results on eyes-free performance and social acceptability as well.

## CONCLUSION

We present TIMMi, a finger-worn textile input device with multimodal sensing capabilities for mobile interaction. By painting carbon elastomer and stitching conductive threads, we implemented pressure and strain sensor on a single layer of fabric. We employed multi-level thresholding for magnitude detection and temporal position tracking algorithm for capturing different finger gestures. A pilot test showed participants were able to effectively use TIMMi for triggering various inputs. The applications shown in this paper imply the potential enhancement of current mobile interaction. We expect that our work will be helpful in exploiting smart textiles as a multimodal input device.

## ACKNOWLEDGMENTS

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## REFERENCES

1. B. Behera et al. Comfort properties of fabrics woven from ring-, rotor-, and friction-spun yarns. *Journal of the Textile Institute*, 88(3):255–264, 1997.
2. L. M. Castano et al. Smart fabric sensors and e-textile technologies: a review. *Smart Materials and Structures*, 23(5):053001, 2014.
3. L. Chan et al. Fingerpad: private and subtle interaction using fingertips. In *Proc. of UIST*, pages 255–260. ACM, 2013.
4. G. Cho. *Smart clothing: technology and applications*, chapter 9. CRC Press, 2010.
5. C. Cochrane et al. Design and development of a flexible strain sensor for textile structures based on a conductive polymer composite. *Sensors*, 7(4):473–492, 2007.
6. Z. Del Prete et al. A novel pressure array sensor based on contact resistance variation: Metrological properties. *Review of Scientific Instruments*, 72(2):1548–1553, 2001.
7. F. Gonzalez et al. A framework for the classification of dexterous haptic interfaces based on the identification of the most frequently used hand contact areas. In *World Haptics Conference*, pages 461–466. IEEE, 2013.
8. K. Hinckley et al. Sensing techniques for mobile interaction. In *Proc. of UIST*, pages 91–100. ACM, 2000.
9. K. Huber et al. The making of the teleglove: crafting interactions for basic phone use in the cold. In *Proc. of TEI*, pages 241–244. ACM, 2014.
10. S. N. Imrhan. Trends in finger pinch strength in children, adults, and the elderly. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 31(6):689–701, 1989.
11. J. N. Ingram et al. The statistics of natural hand movements. *Experimental brain research*, 188(2):223–236, 2008.
12. C. S. Montero et al. Would you do that?: understanding social acceptance of gestural interfaces. In *Proc. of MobileHCI*, pages 275–278. ACM, 2010.
13. M. Shimojo et al. A tactile sensor sheet using pressure conductive rubber with electrical-wires stitched method. *Sensors Journal, IEEE*, 4(5):589–596, 2004.
14. M. Weiser. The computer for the 21st century. *Scientific american*, 265(3):94–104, 1991.
15. B. Yi et al. Exploring user motivations for eyes-free interaction on mobile devices. In *Proc. of CHI*, pages 2789–2792. ACM, 2012.