PressTact: Side Pressure-Based Input for Smartwatch Interaction

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CHI'16 Extended Abstracts, May 7–12, 2016, San Jose, CA, USA.
ACM 978-1-4503-4082-3/16/05.
http://dx.doi.org/10.1145/2851581.2892436

Abstract
Smartwatches have gained a lot of public interest as one of the most popular wearable devices in recent times, but their diminutive touch screens mar the user experiences. The small screen of watch suffers from visual occlusion and the fat finger problem. To address these issues, we present *PressTact* that extends interaction space beyond the watch surface to the sides of the device. It augments smartwatches with four pressure sensors - two sensors on the left side of a watch and another two on the right side. It enables users to input different levels of pressure that can be used for bi-directional navigation (zooming, scrolling, rotation) on smartwatches. In this paper, we explore the pressure event based input vocabulary set. Our preliminary user study shows that participants can input different pressure levels (light press, medium press, and strong press) in discrete and continuous mode with an acceptable accuracy. Finally, we develop several example applications to illustrate the potential of the proposed technique.

Author Keywords
Smartwatch; pressure input; interaction techniques; display occlusion; wearable computing.

ACM Classification Keywords
H.5.2 [Interaction styles (e.g., commands, menus, forms, direct manipulation)]: User Interfaces.

Introduction

Over the past few years, smartwatches have become increasingly popular particularly at the consumer level as an emerging computational form factor due to the unprecedented success of miniaturization technology. The primary input methods for the commercially available smartwatches are touchscreen and physical buttons. However, its small touchscreen limits available interactive surface and lacks tactile feedback. Just making smartwatches larger to provide more space for interaction is not a feasible option as this would make them more obtrusive.

In this context, our paper presents *PressTact* that extends interaction area beyond the watch surface to the sides of the device. It augments smartwatches with four pressure sensors - two sensors each on the left and right sides of a watch. This provision supports users to input different levels of pressure in discrete and continuous mode, which can be mapped to different actions in a variety of applications such as zoom-in and zoom-out a picture, rotating an image, scrolling a list at variable speed, select and edit text. *PressTact* is a finger-based pressure input modality for smartwatches that provides higher input expressiveness and broader interaction area without cluttering the screen.

This paper describes the details of hardware implementation, design, and evaluation of pressure event based input vocabulary set and shows the immediate feasibility of our approach by developing several example applications.

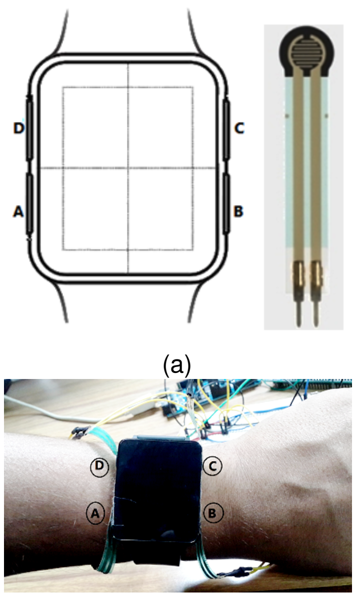
Related Work

Touchscreen interaction has become a fundamental means of controlling smartwatches. The small form factor of a smartwatch limits the available interactive surface area. Fingers obscure on-screen contents and user interface elements during the interaction. To enable rich interactions on wristwatches, researchers have investigated several techniques which are discussed below.

Baudisch et al. [1] presented touch enabled backside of the device for occlusion free interaction. However, a rear surface of a wristwatch is inaccessible to users. *TouchSense* prototype [2] expanded watch's touchscreen input bandwidth by augmenting different areas of a human finger with an IMU sensor. Oakley et al. [3] developed beating gestures composed of a rapid pair of simultaneous or overlapping screen taps made by the index and middle finger of one hand. In [4] Xia et al. presented a finger-mounted finetip stylus, called *NanoStylus*, that supports high precision pointing on a smartwatch with almost no occlusion.

Utilizing watch's bezel and strap instead of its touchscreen face is another way of efficient interaction. Oakley et al. [5] placed an array of touch sensors on the bevel of a watch to provide high-resolution capacitive input. Similarly, the haptic wristwatch [6] made up of a rotatable bezel and touchscreen with haptic feedback, allows for detection of simple, eye-free gestures such as covering the watch, turning the bezel, or swipe over the watch. Xiao et al. [7] moved away from a static bezel and introduced a proof-of-concept interface to provide mechanical input (such as pan, twist, tilt and click) by moving the movable display on a smartwatch. In [8], Perrault et al. presented *WatchIt* that uses wristband surface as an input area for occlusion-free selection and scrolling task. Likewise, *BandSense* [9] allows pressure sensitive multi-touch interaction on a wristband.

In-air gestures-based interaction mechanisms utilize the space around the watch for input with minimal screen occlusion. For example, *Gesture Watch* [10] augments a watch face with an array of proximity sensors to detect swipe gestures above and around the watch. *Abracadabra* [11] supports around the watch interaction using magne-



(a)

(b)

Figure 1: (a) Interlink Electronics 400FSR pressure sensor positions around a smartwatch. The positions are marked as ‘A’, ‘B’, ‘C’ and ‘D’. (b) The experimental *PressTact* prototype with LG W100 smartwatch.

tometer sensor. In [12], *Transture* overcomes the spatial constraints of touch gestures on small watch screen by allowing them to continue in the hover state. Knibbe et al. [13] extended the interactive surface of a smartwatch by enabling users to perform single finger, multi-finger, and whole arm gestures to the back of the hand. They used a combination of infra-red sensors, ultrasound sensors and a piezoelectric sensor to recognize six different distinct gestures. In *Skin Buttons* prototype [14], a user can select the icons projected on the skin by pushing his or her finger on those icons. It is a projected interface that enables button inputs using laser light and photo sensing techniques.

There existing other work which utilizes skin, hand, blow, eye-gaze, etc. to expand the interaction space of a smartwatch. For instance, *SkinWatch* [15], an embodied interaction modality, supports gesture input (like pinch, rotation and scroll) by sensing deformation of the skin under wristwatch via photo-reflective sensors. Akkil D. et al. [16] presented gaze-gesture based single-handed interaction on smartwatches for menu navigation, selecting an item and notification task. *Blowatch* [17] provides blowing as an input for one handed smartwatch interaction. Kerber F. et al. [18] proposed one-handed, eyes-free smartwatch interactions using an EMG armband and compared its task completion time with respect to touch interactions.

In this paper, we use pressure sensors to extend the smartwatch's interaction space beyond its tiny touchscreen. Our approach is related to the work done by Spelmezan et al. [19], where they installed two continuous pressure sensors on one side of a smartphone to detect squeeze based inputs. In our case, we are particularly interested in exploring this side pressure sensors based interaction for smartwatches as this kind of wearable device has a fixed position on the wrist and it is less likely to be misplaced.

Here, we report initial results from a study on how users can comfortably input different levels of single sided (pointing type) pressure and two-sided (grasping type) pressure in wristwatch context. Further, the pressure sensor has several advantages - it requires very less power to operate, it provides inexpensive input interface, users can rapidly switch between different pressure modes and it is thin enough for wearable devices. Because of its thin size, pressure sensors can be easily integrated into the smartwatches without significantly changing device's form-factor.

PressTact Prototype

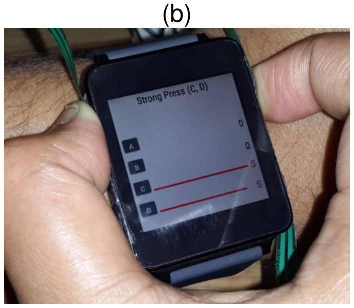
Figure 1 represents the experimental prototype of *PressTact*. It allows users to apply pressure onto the bottom-left sensor (A), the bottom-right sensor (B), the top-right sensor (C) and the top-left sensor (D) individually or in a combination of any two sensors simultaneously. The prototype has four primary components: LG W100 smartwatch running on Android Wear, Moto G Android smartphone, four force-sensing resistors (Interlink Electronics FSR 400), and Arduino Mega ADK. The FSRs are attached to the body of a smartwatch in the configuration shown in Fig.1. Each FSR has a round sensing area of 7.62 mm diameter and works like a variable resistor whose resistance changes when a force or pressure is applied. The FSRs don't have a linear resistance vs. force characteristic. In order to linearize pressure input, an op-amp based current-to-voltage converter circuit is used as recommended in [20]. The pressure sensors are connected to the Arduino micro-controller via an electrical circuit. The Arduino samples pressure sensor data at 50 Hz and 10-bit resolution and sends it to Moto G phone using a HC-05 serial port Bluetooth module. The phone processes the sensor data, runs an algorithm for recognizing different pressure events, and transfers the detected pressure input to a paired smartwatch.

Table 1: *PressTact* input vocabulary consisting of 30 pressure-events

Pressure Levels	Combination of Force-Sensing Resistors									
	A	B	C	D	AB	CD	AC	BD	AD	BC
Light Press	#1	#4	#7	#10	#13	#16	#19	#22	#25	#28
Medium Press	#2	#5	#8	#11	#14	#17	#20	#23	#26	#29
Strong Press	#3	#6	#9	#12	#15	#18	#21	#24	#27	#30

(a)

(b)



(c)

Figure 2: User study application interface: (a) light pressure on sensor B (b) simultaneous medium pressure on sensors B and C (c) strong pressure on both C and D at the same time.

Pressure Event Vocabulary for Interaction

Our objective is to propose different pressure events that could be combined to support a richer interaction and at the same time, they should be unambiguous to recognize. We thus consider that users can apply pressure on each sensor individually or in a combination of any two sensors simultaneously. It results in total ten types of FSR combinations - Press (A), Press (B), Press (C), Press (D), Press (A, B), Press (C, D), Press (A, C), Press (B, D), Press (A, D) and Press (B, C). Further, users can actuate FSRs at different levels - light press, medium press, and strong press. To recognize three discrete pressure levels, we take the average of 500 msec sensor data (F_{avg}) each time and check the following conditions:

- Light press if 0.5 $\leq F_{avg} <$ 3
- Medium press if 3 $\leq F_{avg} <$ 5.5
- Strong press if 5.5 $\leq F_{avg} <$ 10

Here, we measure input force in Newton, and a user can apply approximate 10N force at the maximum. We use 0.5N thresholding to avoid unintended pressure input. Ultimately our input vocabulary consists of 30 (10 combinations of FSRs $\times$ 3 pressure levels) different pressure events which are represented in Table 1.

User Study of PressTact Input Vocabulary

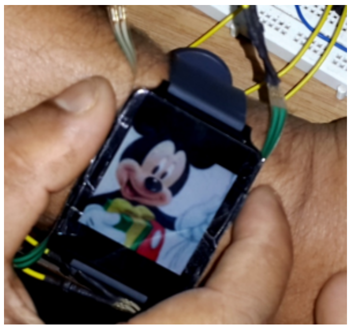
In order to evaluate the user's ability to trigger each of the thirty pressure events, we performed a pilot study in which the participants were asked to selectively input different levels of pressure on demand.

Method

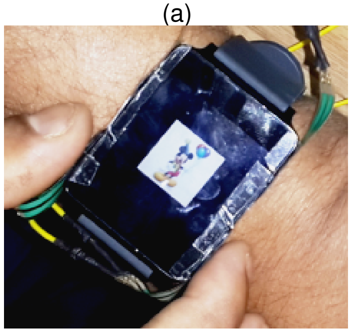
We developed one Android application where users have to input target pressure according to the instruction, and they can visualize the corresponding sensor's pressure level through a progress-bar and a text-box situated at the right most side as shown in Fig.2. Further, our system provides light, medium, and strong intensity of vibration feedback based on the different levels of input pressure. We designed targeting test in two modes: discrete and continuous. For the discrete mode test, the participants were asked to achieve the target pressure at the first press and then release the sensor(s). For the continuous mode test, after attaining the target pressure at the first press, they have to maintain that target pressure for three seconds and then release the sensor(s). They will feel 500 msec of vibration for the discrete mode and 3 sec of vibration for the continuous mode, as soon as they achieved the target pressure. When a user successfully completes a trial, a new target task is randomly generated in the application interface, and we also logged the test type, trial number, correctness of the trials, completion time etc. for each trial.

Table 2: Users' success rate(%) for performing different levels of pressure in discrete and continuous conditions.

FSRs	Light Press		Medium Press		Strong Press	
	Discrete	Continuous	Discrete	Continuous	Discrete	Continuous
A	86.42	81.29	85.94	78.63	77.12	75.36
B	91.88	88.29	90.18	87.38	86.44	83.56
C	91.54	89.61	92.04	89.59	88.23	85.33
D	83.74	82.88	82.58	82.11	76.51	75.81
AB	98.46	98.54	97.89	96.53	98.12	96.75
CD	97.83	98.06	98.24	95.49	96.82	95.22
AC	85.93	82.27	81.41	76.61	78.13	72.85
BD	83.81	82.66	82.93	82.06	77.08	71.01
BC	88.84	88.03	85.63	84.93	80.31	77.72
AD	78.61	74.34	75.08	72.66	73.81	72.96



(a)



(b)

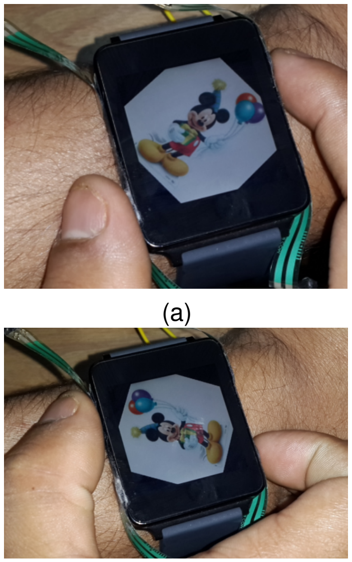
Figure 3: Photo gallery app: (a) zoom-in an image by pressing CD simultaneously (b) zoom-out an image by pressing AB simultaneously.

Six unpaid volunteers (2 females, average 28.6 years) from our Institution took part in this study. All participants were right-handed, and none of them had any p rior experience with the smartwatches. They wore our *PressTact* prototype on their left wrist and performed different pressure events with the right hand. As per our instruction, they used their index finger to apply pressure to the individual sensor (i.e. A, B, C, and D). They took the help of their index and middle fingers to press two sensors located at the same side (i.e. BC, AD) and used both the thumb and the index finger to press sensors on the opposite sides (i.e. AB, CD, AC, and BD). This user study was performed in a lab environment, and users were in seated positions. Before the beginning of the experiment, a demo session was conducted to make them familiar with the software interface and the interaction mechanism. They also practiced before starting the actual test. Each user performed 30 pressure-events $\times$ 10 repetitions $\times$ 2 test modes = 600 trials and took approximately 54 minutes (SD = 4.6) to complete the test. Lastly, we interviewed participants for informal feedback.

Results and Discussion

Table 2 represents users' average success rate to input different levels of pressure (light press, medium press and strong press) in discrete and continuous conditions. From this table, we observe that the pressure sensors A, B, C, and D provide 80.79%, 87.96%, 89.39% and 80.61% accuracy respectively. Users achieve significantly better performance from sensors B and C compare to sensors A and D while they are applying pressure on each FSR. The reason is that users have comfortable index finger position when they put pressure on B and C. If they want to input pressure on A and D, then they have to rotate index finger by 180° and it is quite difficult to maintain different pressure levels in this finger position.

While we consider any two FSRs jointly, then AB and CD combinations provide the best success rate, that is, overall above 96%. In both cases, the position of sensors is en-



(a)

(b)

Figure 4: Photo gallery app: (a) clockwise image rotation by pressing AC simultaneously (b) anti-clockwise image rotation by pressing BD simultaneously.

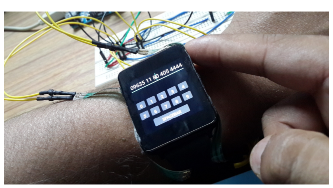


Figure 5: Number entry app: press C to move caret toward left.

tirely opposite to each other (i.e. left and right side); as a result users can easily maintain different pressure levels with their thumb and index fingers.

The combination BC gives the second best performance ($\sim$ 84.25%) because users are able to put pressure on B and C simultaneously just by placing their middle finger and index finger on the respective sensors. While users apply pressure from the right side, the placement of the watch body shifts toward left. Although this position shifting occurs in small scale, it has significant contribution in errors during the experiment.

The next best performance comes from the AC and BD combinations, and it is almost 79.51%. Here users face difficulty to input different pressures as the sensors are diagonally opposite to each other. Finally, we get the most erroneous performance in our study from AD combination and it is $\sim$74.57% on an average. The reason behind this poor performance is that users can't maintain balanced pressures on both the sensors from the left side using their index and middle fingers.

In our experiment, the average completion time for discrete trial was 1.42 sec (SD = 0.18) and it was 1.75 sec (SD = 0.26) for continuous trial.

In feedback session, most of the users mentioned that side pressure sensor based smartwatch input is easy to learn, easy to press, and it is a promising input modality for future smartwatches. They were able to control whole pressure event vocabulary in discrete and continuous mode with an average success rate of 85.16%. In fact, most of the participants felt more natural and pleasant with the discrete mode of pressure input.

Application Example

To show the feasibility of our proposed pressure event based input vocabulary, we developed two applications - photo gallery app and number entry app.

In the photo gallery app, users can zoom-in and zoom out an image by applying pressure on CD and AB, respectively (see Fig.3). They can control zoom-in/out rate by applying different levels of pressure. For example, light pressure corresponds to slower zoom-in/out, while strong pressure provides faster zoom-in/out. For continuous zoom-in/out, they have to apply a certain level of pressure continuously. Similarly, users have to press AC and BD for rotating an image in a clockwise and anti-clockwise direction respectively, and it is shown in Fig.4.

In number entry app, users can control the caret inside the text box quickly and precisely using the pressure event vocabulary set. To move the cursor one digit left, press C lightly, and to move one digit right, just light press D (see Fig.5). After fixing the caret at a particular position, they can perform 'delete' operation using AB combination.

Conclusion

In this paper, we investigated the use of side pressure sensors on smartwatch device for occlusion-free interactions. We presented a working prototype of *PressTact* and defined a rich vocabulary of pressure event that can be mapped to many different actions in a variety of applications. Through a preliminary user study, we showed that the idea is feasible to use. For the future work, we plan to conduct more extensive user studies in a real life setting. We will also compare this analog pressure input technique with the buttons and dials of the existing watches.

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