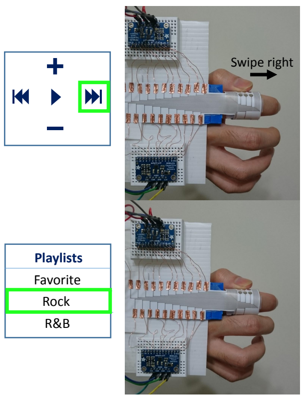

Figure 1: Control music player on smart glass using TouchRing. Thumb swipe with the middle finger touched to change songs and volume. Thumb swipe with the middle finger untouched to switch playlists.

TouchRing: Subtle and Always-Available Input Using a Multi-touch Ring

Hsin-Ruey Tsai
National Taiwan University
Taipei, Taiwan
hsnuhrt@gmail.com

Lee-Ting Huang
National Yang-Ming University
Taipei, Taiwan
himitsu320@gmail.com

Min-Chieh Hsiu
National Taiwan University
Taipei, Taiwan
r03922073@ntu.edu.tw

Mike Chen
National Taiwan University
Taipei, Taiwan
mikechen@csie.ntu.edu.tw

Jui-Chun Hsiao
National Taiwan University
Taipei, Taiwan
r04922115@ntu.edu.tw

Yi-Ping Hung
National Taiwan University
Taipei, Taiwan
hung@csie.ntu.edu.tw

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Abstract

We propose a finger-worn touch device TouchRing to provide subtle and multi-touch input. TouchRing leverages printed electrodes and the capacitive sensing technique to detect touch input. It allows users to perform multi-touch gestures in one hand to increase input modality. TouchRing worn on the index finger allows multi-touch using the thumb and middle finger. Ten multi-touch gestures are designed in this paper. We also propose touch detection and gesture recognition approaches in TouchRing. Gesture Recognition accuracy is evaluated in the user study. Applications for TouchRing are also proposed to make controlling smart glasses more convenient.

Author Keywords

Subtle; multi-touch; always-available; capacitive touch; printed electronics; wearable device; touch input; gesture recognition.

ACM Classification Keywords

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

Introduction

Subtlety and privacy are important for users when using mobile devices in public spaces. A lot of studies have proposed various subtle interactions using wearable devices such as finger-worn devices [1, 3] and wrist-worn devices [5, 6, 9, 17]. Wrist-worn devices detect wrist muscles changes when performing gestures using signals such as electromyography (EMG), pressure or capacitance. They are able to detect gestures from the whole hand; however, they suffer from environmental noise. Different wearing positions or sleeve covers can also influence the device accuracy. Finger-worn devices usually detect certain finger gestures; nevertheless, they can avoid more interference.

The ring form factor is socially acceptable finger-worn device for users. Based on the interaction method, the ring form factor devices can be categorized into two types: *finger motion detection* and *interactions on the ring* devices. *Finger motion detection* devices allow users to move the finger wearing the ring or the fingers around the ring to perform the input gestures [2, 3, 4, 7, 8, 10, 13]. However, they are vulnerable to environmental noise such body motion or magnetic fields. *Interactions on the ring* devices allow users to directly interact with the ring, such as touching, pressing and spining the ring [1, 15, 18]. Nevertheless, small input area of the ring limits the input modality. In this paper, we propose TouchRing to increase input modality of a ring using multi-touch input.

TouchRing is a ring with printed electrodes on the surface to detect touch input by leveraging the capacitive sensing technique. TouchRing is worn on the index finger so that the dexterous thumb can perform touch gestures easily. Combining the middle finger around the ring, the fingers are able to perform multi-touch gestures. Combining five gestures, including up/down/left/right swipe and tap, performed by the thumb and a touch gesture performed by the middle finger, ten gestures are recognized and examined in this paper. The contributions of TouchRing are in the following. (1) Increasing input modality for *interactions on the ring* devices using multi-touch input in one hand. (2) Subtle and private interactions when performing touch gestures on the ring. (3) High mobility and always-available input because touch input is not interfered when walking or other body motion. Furthermore, touch input for the ring wearing on the index finger can be easily performed even when both hands are occupied, such as grasping or holding something. (4) Low-cost and easy implementation using printed circuits for prototyping. Finally, we propose some scenarios and applications requiring subtle and multi-touch input using TouchRing, as illustrated in Figure 1.

Related Work

A lot of wearable devices are proposed. In this paper, we focus on the devices which is worn on a finger, provides subtle interaction and touch input.

Finger-worn Devices

Magnet motion tracking was a common approach applied on finger-worn devices to perform 1D [1, 8], 2D [3, 10] or even 3D [4] input. Abracadabra[8] leveraged the magnetometer in the smartwatch to track the magnet worn on the finger of the other hand. Nonetheless, the two-handed interaction was the restriction. uTrack [4] provided precise pointing in the 3D space by using a permanent magnet and a magnetometer worn on different fingers of the hand. However, no commitment approach was mentioned. Both approaches had lower social acceptance due to a magnet worn on a finger tip. In addition, two wearable devices demanded was the limitation of magnet motion tracking. LightRing [13] provided 2D input on any surface. A gyroscope and a proximity sensor detected left/right and up/down of the finger, separately. Nevertheless, when walking the gyroscope was interfered. Consequently, LightRing was improper in mobile condition.

Subtle Interaction on Wearable Devices
Using magnet motion tracking Nenya [1], FingerPad [3] and DigitSpace [10] provided subtle 1D and 2D input. In Nenya [1], users spun it to select items shown on the smartwatch or in eyes-free. Although the unpowered ring was the contribution of Nenya, the two-handed interaction commitment and 1D input were limitations. In FingerPad, users performed 2D input using the pinch gesture to move the thumb on the index finger tip. FingerPad provided a small 2D touchpad with tactile feedback for the thumb. DigitSpace extended the concept of FingerPad and provided a larger 2D touchpad on index and middle finger tips. Other segments in the fingers were also leveraged as 1D input area to control smartwatches. However, nail-mounted devices reduced social acceptance and multi-touch was not provided. Besides, Nenya, FingerPad and DigitSpace required two or more wearable devices for magnet motion tracking.

Touch Input on Wearable Devices
To consider single/multi touch and one/two -handed input, we categorized touch input wearable devices into four classes. In single touch and one-handed input, PinchWatch [14] and NailO [11] allowed users to touch on the finger segments and the nail, respectively. PinchWatch tracked the thumb using an infrared (IR) camera, but it suffered from the occlusion problem. NailO was a customizable nail-mounted device. It recognized the swipe and press gestures through electrodes and the capacitive sensing technique. Although NailO was fashionable and fascinating female users, it was hard to get high social acceptance from male users compared with rings. In single touch and two-handed input, iRing [15] recognized the rotation angle, finger bending level and touch or more precisely press direction using different skin IR reflectance. However, three finger gestures were not allowed to be performed at the same time due to complicated reflectance relationship also mentioned. In multi- touch and two-handed input, WatchIt [16] allowed users to interact with the smartwatch by touching the wristband. The resistive sensing technology was leveraged to detect the touch gestures, including pointing, slide and scrolling, on the wristband. Nevertheless, two-handed interaction was required. We found that multi-touch and one-handed input was not provided currently.

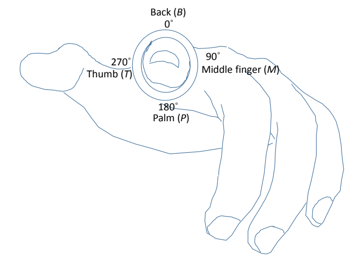

Figure 2: Four parts of TouchRing, including thumb (*T*), palm (*P*), middle finger (*M*) and back (*B*).

TouchRing Hardware Prototype
TouchRing is worn on the index finger for multi-touch input. We divide the TouchRing surface into four parts, including thumb (*T*), palm (*P*), middle finger (*M*) and back (*B*), as illustrated in Figure 2. The thumb and middle finger around the ring are able to touch the ring. The thumb input area, including (*T + P*), embraces approximately 180 degrees. The middle finger is less dexterous than the thumb so the input area only includes (*M*). We observe that the part (*B*) is the improper input area for one-handed input.

Capacitive sensing technology is leveraged to sense touch input. TouchRing consists of electrodes, capacitive sensors and a ring. 1) Electrodes: A total of 21 electrodes are printed on the ring surface. 9 electrodes (3×3) are both ar-

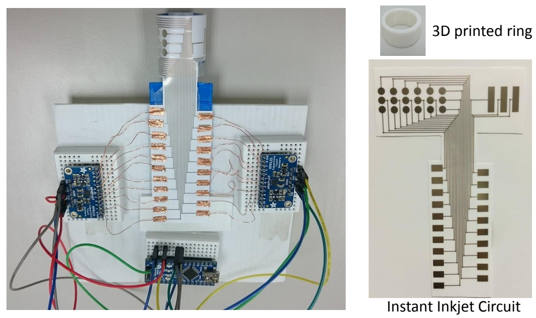

Figure 3: (a) TouchRing hardware prototype. (b) 3D printed ring. (c) Printed circuit.

ranged in part (*T*) and (*P*) to detect thumb touch and only 3 electrodes in (*M*) to detect the less dexterous middle finger touch. We use the Instant Inkjet Circuit technique in [12] to print the electrodes and wires on a white PET film with silver nanoparticle ink from Mitsubishi Paper Mill. The printed wires width is 0.3 mm to prevent a broken circuit. The width between the printed wires is 0.5 mm to prevent a short circuit, as illustrated in Figure 3 (c). 2) Capacitive sensors: we connect the electrodes with the capacitive sensors to sense touch signals. Two Adafruit MPR121 capacitive touch controllers are used and each provides 12 individual capacitive sensing pins. An Arduino Nano receives data from the controllers. 3) A ring: it is printed by a 3D printer with thickness 2.5 mm to prevent the ring fragile and noise from the finger, as shown in Figure 3 (b). We attach the film to the ring and connect it with the capacitive sensors to fabricate a TouchRing prototype, as illustrated in Figure 3 (a).

When touch gestures are performed or the index finger worn the ring moves, the index finger may be pressed by parts of the inside of the ring, and this produces some

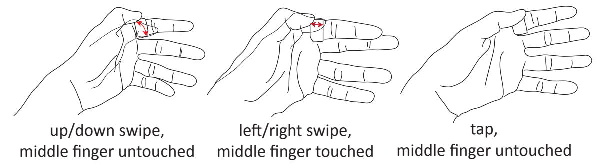

Figure 4: Gestures defined in TouchRing

noise. Besides, printed wires also produce some unwanted touched signals when they are touched. Therefore, the noise and unwanted touched signals are handled by the proposed detection algorithm. Certainly, more sophisticated capacitive sensing techniques can improve TouchRing in the future. In addition, although our prototype is wired, it is practical to make TouchRing wireless by using a bluetooth chip and battery as in NailO [11].

Touch on a Ring

Users wear TouchRing on the index finger and use the thumb with better dexterity as the major input and the middle finger as the minor input.

Gesture Definition

The thumb is more dexterous designed to perform five gestures, including up/down/left/right swipe and tap. On the contrary, the middle finger is more awkward to perform various gestures. Thus, we design the touched and untouched gestures for the middle finger (Figure 4). For the gestures which demand for both fingers, the middle finger touches the ring at first, and the thumb touches and performs the gestures. Combining five thumb gestures and two middle finger gestures, ten gestures are allowed to be performed on the multi-touch device TouchRing.

Touch Detection
The fingers touching the ring triggers the electrodes to send touched signals. TouchRing distinguishes which finger touches the ring by recognizing which part of the ring the touched electrodes belong. By averaging all touched electrodes in each part of the ring, TouchRing find the center position of the touch.

Gesture Recognition
The gestures, swipe and tap, designed in this work can be recognized using relative touch positions between where the finger touches and where it lifts. Comparing the direction and slope from the beginning to the end of the touch can easily recognize the swipe direction. It is commonly used on touch screen. Nevertheless, some situations should be considered for ring input. First, due to the ring-style form factor, a ring provides larger input area for swipe up/down but smaller input area for swipe left/right. Therefore, swipe left/right are harder to be performed and recognized. Second, the ring curvature causes that swipe left/right slightly prone to swipe up/down, and vice versa. For instance, when swiping up and down, the thumb movement forms a curve and the thumb base is the center. Thus, if the ring is worn on the left hand, swipe up and down may be misclassified into swipe left and right, separately (Figure 4). Third, after performing the gesture, the thumb lifting usually slightly moves toward the thumb base and interferes the recognition. Consequently, we perform some improvements for the recognition.

Take the thumb lift problem into account. The swipe direction is defined as the direction from touch beginning position to the farthest position before the lift. Furthermore, distance thresholds are defined to distinguish whether a gesture is swipe up/down, swipe left/right or tap. If vertical distance between the touch beginning and the farthest position is over the threshold, it is recognized as swipe up/down depending on the direction. Otherwise, it can only be recognized as swipe left/right or tap. Furthermore, the tap distance threshold is shorter than swipe left/right in both vertical and horizontal. This approach reduces misclassification between swipe up/down and swipe left/right due to ring curvature and uneven size of the input area.

User study

A user study was performed to evaluate accuracy of the multi-touch gesture recognition on TouchRing.

Experiment Design and Procedure
Five gestures, including swipe up/down/left/right and tap, were performed by the thumb. Two gestures, involving touched and untouched gestures, performed by the middle finger. Combing the gestures from these fingers, ten multi-touch gestures could be performed on the TouchRing. A total of 5 (thumb gestures) x 2 (middle gestures) x 3 (repetitions) x 5 (blocks) = 150 trails were performed by each participant. The gestures were randomized.

The participants sat in front of the laptop and the worn the ring on the left index finger. The ring and the printed circuit were attached to the edge of the desk. Their elbow was allowed to lay on the leg to reduce fatigue. In the experiment, a gestures was shown on the screen in each trial. The participants pressed SPACE and performed the gesture after hearing a BEEP. When finishing the gesture, they pressed SPACE again. The font color on the screen then turned green or red if correct or incorrect gesture was recognized respectively and the next gesture was shown. During the period from first SPACE to the BEEP, the participants kept untouched the ring. Therefore, any electrode sending touched signals during this period would be excluded for the trial due to its corruption. It could also be achieved by sophisticated recalibration or more advanced capacitive sensing techniques. We leaved it in the future work. After the experiment, we interviewed the participants to obtain feedback and comments. The whole experiment took about an half hour.

Participants and Apparatus
8 participants (6 male) aged 22-30 (mean 25.13) were recruited for the experiment. All of them were right-handed and required wearing the on their left index finger. They received some incentive after the experiment.

Results and Discussion
Recognition accuracy was the number of gestures correctly recognized divided by the total number of gestures. Ten gestures were recognized in the experiment. The mean accuracy of the gestures was 81.77% (SD: 10.35%). The same thumb gestures got higher accuracy with the untouched middle finger gesture then with the touched middle finger gesture, as shown in Figure 5 (up). We observed that some participants sometimes did not touch with enough stress and time using the middle finger. Touching using the middle finger was not like using the thumb with the fingertip. It could be more unstable. Comparing Figure 5 (up) and (down) also showed that misclassification of the middle finger gesture reduced the accuracy. Especially, many touched gestures were recognized into the untouched gestures. We believed that it could be improved by adjusting the middle finger time threshold and touch sensitivity.

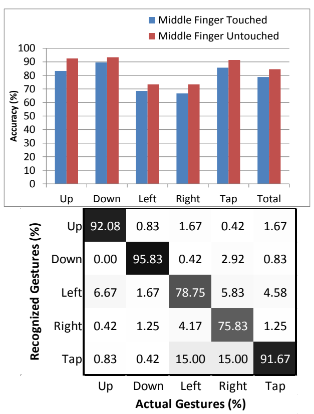

Figure 5: The results of the user study. Up: mean accruacy of each gesture. Down: confusion matrix of the thumb gesture accuracy regardless of the middle finger gesture.

We noticed that regardless of the middle finger gesture, swipe up/down had better accuracy than swipe left/right, as illustrated in Figure 5 (down). Some participants indicated that due to only three electrodes in a row in our prototype, they needed to move the thumb from one edge to the other carefully. Otherwise, it might be easily misrecognized. Especially, shrinking the thumb was not easy for everyone when swiping left. It was caused by uneven input area. Furthermore, swipe up was easily misclassified into swipe left. It was consistent with thumb movement forming a curve as described in gesture recognition section. However, comparing with swipe up, swipe down seemed not misclassified into swipe right. We supposed that swipe up gesture was similar to finger flick. Therefore, the participants' thumb left the ring quickly and it caused that the swipe distance was shorter in swipe up than in swipe down. Swipe down was not easily misclassified into swipe right and swipe left/right was not misclassified into swipe up/down either. It proved that the proposed gesture recognition algorithm successfully distinguished these two different kinds of swipe. Smaller input area for swipe left/right still resulted in misrecognition among swipe left, right and tap. It could be improved by increasing more electrodes in a ring product in the future.

Applications
TouchRing providing subtle and multi-touch input allows users to perform tasks more easily on smart glasses. For example, when looking at photos, users swipe the thumb with untouched middle finger to switch photos and with middle finger touched gesture to switch albums. Another instance is to control a music player panel. When listening to the music, users swipe left/right and up/down to switch songs and change volume with middle finger untouched. They can also switch playlists by swipe gestures with middle finger touched, as illustrated in Figure 1.

Limitations and Future work
The results of the user study show that recognition for swipe left/right was not robust enough. Therefore, we will increase the electrode number in each row to improve the recognition. Although the printed circuit is easy to fabricate a prototype, it seems not stable enough for capacitive sensing

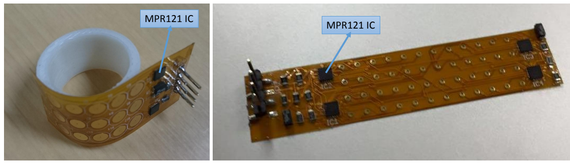

Figure 6: Advanced TouchRings fabracted by flexible PCB. Left: 18 electrodes (6 x 3). Right: 48 electrodes (12 x 4).

due to high resistance. To reduce the ring size and increase electrodes, an advanced prototype of TouchRing is fabricated using a flexible printed circuit board (PCB). We fabricate a ring with 18 electrodes (6 x 3) at first, as shown in Figure 6 (left), and observe that the touch signals are more stable. We further fabricate a ring with 48 electrodes (12 x 4) on the surface and wires are on the two layers of the flexible PCB as shown in Figure 6 (right). The three parts are not conductive. 4 MPR121QR2 capacitive sensors on the flexible PCB detect the touch signals from the electrodes. We will evaluate the performance of the advance TouchRing in the future.

TouchRing provides multi-touch input; however, only two middle finger gestures proposed in this paper. We suppose that the middle finger can perform more gestures (e.g., swipe up/down) to create more various multi-touch gestures. Furthermore, with more electrodes on the ring, users can use the ring as a touch pad. In this work, we focus on recognizing input gestures on the ring. However, TouchRing can be used to detect gestures in daily life in the future.

Conclusion

We propose subtle and always-available input using a multi-touch ring. Ten multi-touch gestures provided by combining the thumb and middle finger gestures. The touch detection and gesture recognition approaches are proposed. The gesture recognition accuracy is 81.77%. We believe that advanced capacitive sensing techniques and more electrodes arranged on the ring are able to improve the performance. Furthermore, more complicated gestures can be designed in the future.

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