FingerPad: Private and Subtle Interaction Under Fignertips

Submission #OOO

ABSTRACT

We present FingerPad, a nail-mounted device that turns the index fingertip into a touchpad, allowing for private and subtle interaction on the move. FingerPad enables touch input using magnetic tracking, by adding a hall sensor grid on the index fingernail, and a magnet on the thumbnail. Allowing for input through the pinch gesture, FingerPad supports private use, because the movements of the fingers in pinch are subtle and naturally occluded by the operation hand. Functionally, FingerPad is equivalent to a touchpad, and allows for eyes-free use. Additionally, by attaching the devices on the nails, FingerPad can preserve the natural haptic feedbacks without affecting the native functions of the fingertips. Through the user study, we analyze the three design factors, which are posture, commitment method and target size, to conclude the FingerPad's design insights. Though the results shows the trade-off among the factors, generally, participants achieve 93% accuracy for very small targets (1.2 mm) in the seated condition, and 92% accuracy for 2.5 mm-width target in the walking condition.

ACM Classification: H5.2 [Information interfaces and presentation]: User Interfaces. - Graphical user interfaces.

General terms: Design, Human Factors

Keywords: Always available, eye-free interaction, private input, subtle interaction, nail device, finger-mounted device.

INTRODUCTION

Recent development in mobile computing proposes glass-mounted displays. Though similar to head-mounted displays, glass-mounted displays (e.g., Google Glass) are specially designed to be light-weighted, attachable, nonobstructive to natural vision, and with increased social acceptance.

Although displays of this kind allow for personal and private visual outputs, their input methods may not keep the same level of privacy. Voice input, for example, is commonly used for glass-mounted displays because it is expressive and effective. However, voice input can be problematic in loud environment, and inappropriate in public space when privacy is required (e.g., password input) [11]. Gesture input receives the similar privacy concern, because the input behaviors are easily observable.

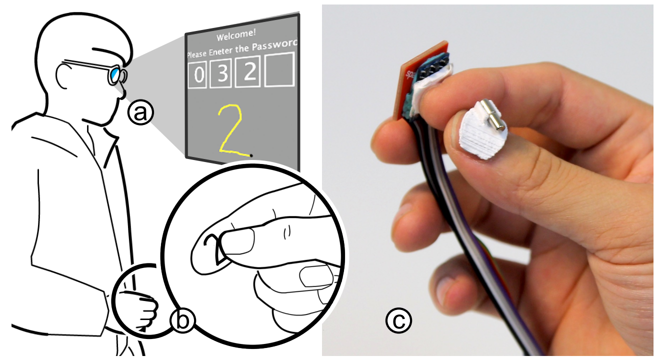

Figure 1: FingerPad enables touchpad function through the pinched fingertips using magnetic tracking, by adding a magnet and hall sensors on the fingernails, allowing for private and rich subtle interactions. Here, the user enters passwords to the (a) private glass display by (b) drawing numbers with the thumb tip on the index fingertip.

To allow for private input, recent research proposes subtle interactions [2][10][15], which looks upon implicit movements and are generally considered socially acceptable. For example, muscle interface [10] allows to input through unobservable muscle movement. Foot gesture [12] detects subtle foot motions. Ring devices [9, 1] and fabrics [6] are developed to support tapping, spin, and slider inputs. Although these methods allow subtle inputs (thus, private and socially acceptable), they generally suffered from limited input space.

We present FingerPad, a nail-mounted device that turns pinched fingertips into a touchpad, allowing for private and rich subtle interactions. As illustrated in Figure 1, the user treats the index fingertip as the touchpad, and the thumb as the touch stylus. FingerPad enables the touchpad function using magnetic tracking, by adding a magnet and hall sensors on the fingernails. Functionally, FingerPad is equivalent to a touchpad that users can learn with minimal effort. Allowing for 2D touch inputs, FingerPad is ready for rich interactions including pointing, marking menu, and stroke input.

Benefits and limitations Allowing for touchpad functions through the fingers in pinch suggests several benefits. (1) Private: the movements of the fingers in pinch are subtle and naturally occluded by the operation hand. (2) Rich: the touchpad function allows input techniques, such as pointing, marking menu and stroke input. (3) Eyes-free: users can perform pinch gestures without visual support. (4) Natural haptic feedback: by attaching on the nails, we preserve the natural haptic feedbacks on the fingertips, not affecting native functions of fingertips (e.g., grip small objects). Addition-

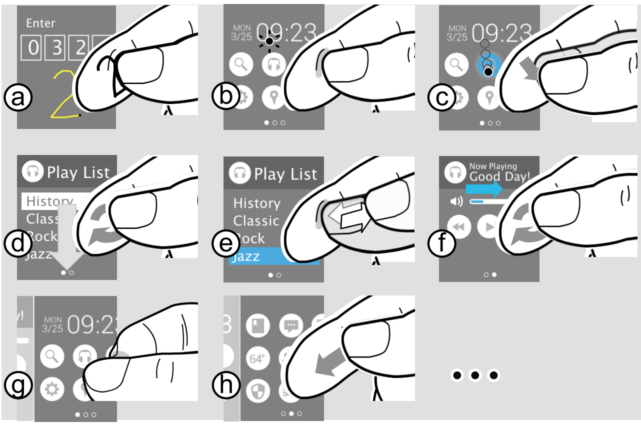

Figure 2: The walkthrough illustrates the use of FingerPad for glass displays. The graphics on the left-hand side of the subfigures are GUIs presented in the glass display view. The graphics on the right-hand side of the subfigures are the suggested gestures that can be enabled through our technique.

ally, by tracking through magnetism, FingerPad is occlusion free (i.e., can use with hand in pocket).

SCENARIO

Figure 2 illustrates a scenario of FingerPad for private visual outputs, such as the glass-mounted displays. On the train on his way to work, Robin puts on the glass display. On the screen, the glass asks Robin the password for authentication. Instead of using voice input, he chooses to use the FingerPad input for privacy concern. (a) He writes four numbers, one by one, on his index fingertip, to unlock the glass application. (b) Robin long presses on the index fingertip to enter the cursor mode, (c) moves the cursor over the music app, and takes off the thumb for selection. (d) In the music list, he circles on the fingertip to move to jazz category, and (e) clicks to enter the player page. (f) He circles again to tune up the volume. (g) To jump to home screen, he taps on the tip of the index finger. Now, he swipes the thumb leftward, moving to next app pages and plans to check the schedule of the day.

PROTOTYPE

FingerPad is a pair of nail-mounted devices comprising of a thin (1mm) magnetic sensing plate, and a plate of ferromagnet. The sensing plate includes a 3x3 Winson WSH138 Hall sensor grid (Figure 3a), and each sensor is separated to each other by 2mm, which suggests an area of 12(W) mm x 12(H) mm. Each sensor element detects both N- and S-polar magnetic field intensities in a range from 0 to 200 Gauss on a 1024-point scale. An Arduino board with an ATmega32U4 microprocessor is used to bridge the sensing plate with the computer. According to the magnetic strength captured by the plate, FingerPad approximates the magnet's position, transforms the position to the finger-pad coordinate defined through user calibration (see *Tracking* and *User calibration*), and sends to the applications.

To attach the sensor plate firmly on the nail, we use a 3D printer to craft a nail piece that suggests a nail-fit curve sur-

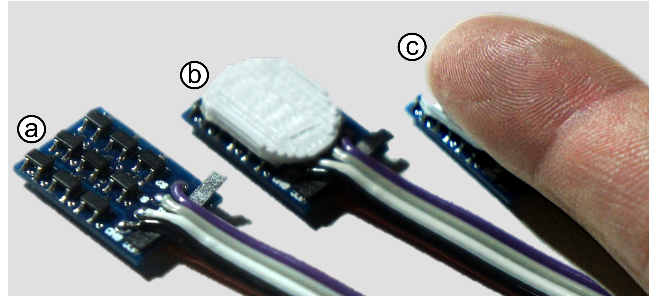

Figure 3: (a) The 3x3 hall sensor grid, and (b) a nail-shape plate with a curve surface (c) suggesting fitness to the natural nail.

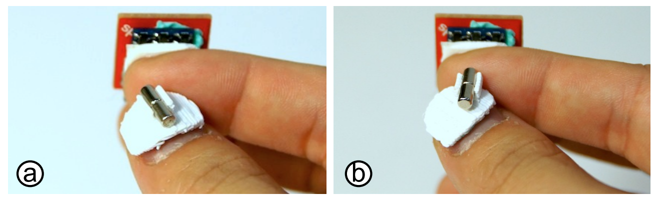

Figure 4: The magnet holder grips the magnet at certain orientation. (a) The first design of the magnet holder. (b) we push the magnet orientation 30 degree to the right, accommodating to the bio-mechanism of the index and thumb fingers.

face. As shown in Figure 3b, the sensor plate, gluing with the nail piece, is further glued on the user's nail using a twin adhesive tape. By gluing, we help users envision the future nail devices akin to the use of the artificial nails. We put on the prototype on the user's index fingernail in a way that the wires would not affect the finger motor space.

We create another nail piece that holds the magnet and fixates the magnet orientation. The principle to place the magnet is to allow the polar orientation of the magnet in parallel with the normal of the sensor grid when users placing the thumb on the center of the index fingertip. Figure 4a shows our first design. To adapt the bio-mechanism of the thumb and index finger, we improve the design by moving the magnet orientation 30 degree to the right (Figure 4b).

The magnet we used is a 2mm disk x 8mm strong ferromagnet, which allows for effectively sensing within 2.1cm by our sensor plate. Note that this effective distance can be further extended by using more sensitive magnetism sensors, such as magnetometers [1].

Tracking

We define a cartesian coordinate for the sensor-grid coordinate. For the 3 by 3 sensor grid, the sensor at the lower left corner is set as the coordinate origin. We approximate the magnet position in the sensor-grid coordinate using bilinear weighting according to the magnetic strength read by each hall sensor. Because the read magnetic field strength is in fact a mix of quadratic and cubic attenuation, this approach can only approximate the magnet position. We further regulate the positioning result in the *User Calibration* section.

Figure 5: To guide the calibration process, we stick a translucent dot pattern on the index fingertip, that helps to obtain good homographic transformations.

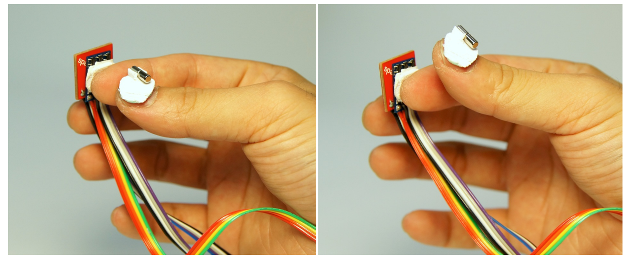

Figure 6: The user commits a selection by flicking the thumb up.

To improve the positioning, two strategies are applied. First, the polar of the magnet is placed in parallel with the normal of the sensor grid as shown in Figure 4b. Second, we exclude the opposite polar values read by the sensors. When users tap on the edges of the index fingertip (e.g., the tip or bottom areas), the magnet orientation may deviate from the normals of the sensors, which causes some sensors read the opposite polar values.

User calibration

The purpose of user calibration is to regulate the 2D positions computed in *Tracking*, to the finger-pad coordinate in the index fingertip. To account for the non-linear mappings between the sensor-grid and the finger-pad coordinates, we divide the finger-pad coordinate into multiple sub-coordinates, and approximate the nonlinearity by computing homographic transformation between each sub-coordinate and the sensor-grid coordinate.

Typically, a homographic transformation can be determined by more than 4 pairwise correspondent points. To guide the calibration process, we stick a translucent dot pattern on the index fingertip. The dots are separated by 4mm in a Cartesian coordinate, and the 3 by 3 dot pattern suggests a normal size of the fingertip. We stick the pattern on the index fingertip area, as shown in Figure 5. The 9 pairs of the correspondent points from calibration process are then used to compute the homographic transformation for each of the four sub-coordinates. As long as the magnet orientation correctly positioned, the calibration configuration can adapt well to fingers with different sizes and thickness.

Land-on detection

Although the hall sensor plate can detect hover state (e.g., the thumb is in the proximity to the index fingertip) according to the strength of the magnetic field, it is hard to determine when the user's thumb landing-on the index fingertip. To detect land-on, we add an accelerometer to the hall sensor plate to detect the impact of the finger contacts. For the detail, we compute the derivative in the X, Y, and Z-axes, respectively, by using a sliding window. Through monitoring the values in the sliding window, a candidate for land-on can be found when a positive derivate is followed by a negative derivative. A land-on action is only reported, when the thumb is found within the hover range at the same time. After land-on, touch interactions performed by the user can be recognized, until the thumb is out of the hover range.

Flick selection

We propose the flick selection, as shown in Figure 6. Moving the cursor over a target, the user commits a selection by taking off the thumb up. Upon exit of the hover state, we remove the cursor movement in the last 180 milliseconds (determined from a pilot testing) to eliminate the unwanted cursor movement. The last cursor position is used to determine the selection. The side effect of the flick selection is that the user may see the unwanted cursor movement before the thumb exits the hover state. Nevertheless, the users can understand it and it won't affect users' performance.

APPLICATION

Based on the touchpad functions provided by our prototype, we implement the touch cursor, gesture input, and stroke input functions to prove the capability of the FingerPad. The implemented application is the same as described in the *SCENARIO* section. In the touch cursor function, a user can perform a long press to enter the cursor mode which reveals the cursor on the display (e.g., glass interface). By moving the thumb on the index fingertip, the user can freely move the cursor. Through the flick selection, the user can commit a selection on the menu. For the gesture input, we also provide swipe and circling gestures. In a page view, the user can swipe to left or right to enter the next or previous page. In a list view, the user can perform clockwise or counter-clockwise circling gesture to scroll down or up through the list. In stroke input, we adapt the unistroke recognizer [14] for our numeric input, which allows users to write the password or phone numbers.

USER STUDY

The purpose of the study is to determine users' ability to provide precise cursor control through the fingertips in pinch. Because the subtle interactions are designed for mobile usage, therefore, the seated and walking conditions are considered. The walking condition allows us to see the level of influence while using the FingerPad technique on the move with glass displays. Moreover, the committed methods may also affect users' performance. Therefore, we not only tested flick method, but also tested bi-manual clicker method. Finally, we also want to know how small the target that the users can point at to know the limitation.

Task and Conditions

The participants need to move the cursor over the target shown in the screen and commit the selection by using single-

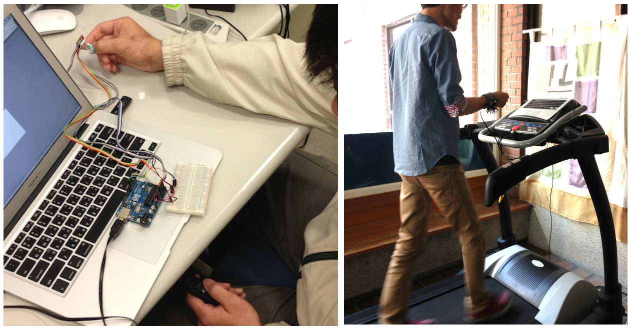

Figure 7: The study setup for the seated (left) and walking conditions (right).

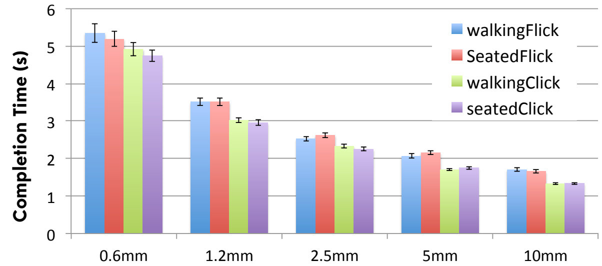

Figure 8: The study completion times, with 95% confidence intervals, of different target sizes in two commitment methods under seated and walking conditions.

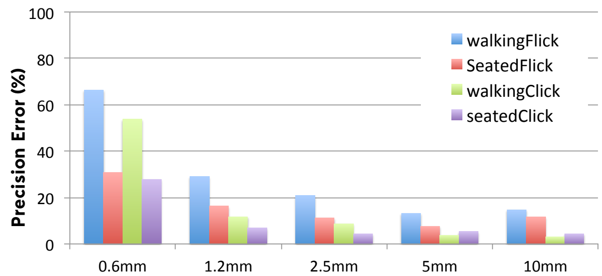

Figure 9: The study error rates of different target sizes in two commitment methods under seated and walking conditions.

handed flick selection method or the bimanual clicker method with the non-pointing hand depending on the conditions. The target's color will be changed when the cursor is entered into the target square. Upon successful selection, the target will disappear and next target will be showed up on the screen. We measured task time and error rate for the target sizes of 10mm, 5mm, 2.5mm, 1.2mm and 0.6mm separately. The 0.6mm case is included to test the users' limitation.

In the *seated condition*, the participants sat on the chair in front of the table where the screen was positioned toward the them. They were instructed to adjust the chair height such that they could rest their dominant hands on the table for support (Figure 7a). The participants ensured that they could see the smallest 0.6mm target clearly. Otherwise we moved the screen closer to the participants. In the *walking condition*, they performed the tasks on the treadmill. The screen was placed on top of the treadmill control platform, as shown in Figure 7b. The treadmill was set to normal walking speed (3.5 km/hour).

Interface and apparatus

The participants wore the sensor part of the finger pad device on the index fingernail, and the magnet part on the thumbnail. Because the nail sizes and the way participants move their thumbs on the index finger pads are bio-mechanically different, we helped participants put on the device, and adjusted the magnet holder orientation in order to accommodate interpersonal tapping habits. In the pilot testing, we found the thick fingers from some male participants could degrade the tracking performance with the original magnet setting. To avoid the tracking errors in the study, we replace the magnet with a wider magnet (4mm disk * 8mm height) that ensures the tracking performance in the study.

Experimental design

The study design was 2 x 2 x 5 x 12 (Condition x Commitment method x Target Size x Target Position) with 3 repetitions for each cell. The Condition was the between-subject variable. The target sizes were 10mm, 5mm, 2.5mm, 1.2mm and 0.6mm separately, and the target positions were the 12 centroids of a regular 4 x 3 grid. For each trial, we recorded the task completion time and error. The different commit methods were counterbalanced. The target sizes and positions were randomized.

Participants

22 participants (10 female) with mean age of 26.9 (std: 3.9), between ages of 22 and 38, were recruited from the university. Each was rewarded a small gift for their participating. The task took about 30 minutes. All participants have the experience of touching input, because they all have touch-input smart phones. All are right-handed.

Results and discussion

With the same target size, the same commitment method, but different postures To analyze the obtained data, we ran the t-test pairwisely to know whether the different postures will affect the users' performance. The statistics shows that no matter the condition is walking or seated, the completion time has no significant difference. However, for error rate, when the target size is below 2.5mm, it shows the significant difference between the two different postures. For the design insight, if the system can detect users' postures, it can provide different UI layouts when users are in different postures. For example, while users are seated, the system can provide tight layout and compact information, and while users are walking, the system can provide loose layout and abstract information. However, if the users want the consistent user experience, the target size should be above 2.5 mm.

With the same target size, the same posture, but different commitment methods To analyze the obtained data, we ran the t-test pairwisely to know whether the different commitment methods will affect the users' performance. For the completion time, the statistics shows that there is a significant difference only in the condition while the posture is walking and the target size is 10mm. Therefore, we can say that generally the two different commitment postures don't affect the performance of the completion time. On the contrary, for the error rate, except the 0.6mm case, while in the walking condition, the statistics shows significant difference between flick and clicker methods. For the design insight, we can conclude that if we want to improve the performance, we can choose the different commitment methods. However, there is a trade-off between the two methods. Though the clicker method can achieve better performance, it requires bimanual interaction. Compared to clicker method, users can performance the task with only one hand, which provides more freedom to the other hand.

With the same commitment method, the same posture, but different target sizes To analyze the obtained data, we ran the t-test pairwisely to know whether the different target sizes will affect the users' performance. No matter in completion time or error rate, the statistics shows that 0.6mm has significant difference compared to all the other target sizes while the posture is walking or seated. For the completion time, it further shows that 1.2mm has significant difference compared to 5mm and 10mm while the posture is walking or seated. Hence, for the design insight, we suggest the button size should be larger than 1.2mm for better user experience. Though the different commitment methods can achieve different performance, we doubt that it is hard to improve the performance in any commitment method while the button's size is under 0.6mm.

Though the user study, we were also impressed by the users' ability in cursor control under walking condition, even though the cursor jittering was inevitable. When working on the smallest target, the participants reported that they reduced the jittering by pressing hard with the pinch gesture. For the details, they first moved the cursor to the target nearby, then added force between the fingertips, and slightly moved the cursor's position for fine control.

Generally, through the user studies, we can conclude three design insights. First, the different postures indeed affect the performance, but while the target size is larger enough, e.g., larger than 2.5mm, the influence is diminished significantly. Second, the different commitment methods can achieve different performance. By considering the comfortableness and convenience, the alternative designs of the single-handed commitment methods can also be considered. For example, hard pressing Figure 10a, moving the middle finger in the air Figure 10b, or slightly twisting the wrist Figure 10c can be the method. Third, the target size of the control buttons should not be too small, e.g., smaller than 0.6mm. Nevertheless, the system design should consider the trade-off among the three factors.

RELATED WORK

This work is related to private and subtle interaction, and finger-worn devices, and magnetic tracking.

Private and subtle interaction

Several subtle interaction technique had been proposed. Costanza et al. [2] had used electromyography for sensing subtle motionless gestures. Saponas et al. [10] used the similar technique for sensing different finger gestures. Scott et al. [12] proposed the idea of using mobile devices located in user's pocket to sense the foot gestures. PingStripe [6] allows users to perfrom subtle interactions by pinching and rolling a piece of their cloths. Other works [1, 9] used ring as the subtle input device. Still, these works can only support limited gesture input. FingerPad, on the other hand, is functionaly equivient to a the touchpad, which implies that providing more dimensions for the input space.

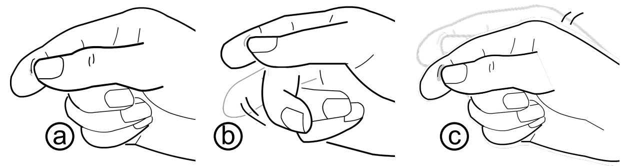

Figure 10: Other commitment methods described by the participants. (a) press (e.g., the mouse button), (b) move the middle finger, and (c) move the wrist.

Finger-worn input devices

Several works using the finger-worn devices for sensing gestures had been proposed. FingerRing [3] placed accelerometers on every finger of user's hand for sensing different chord gestures. UbiFinger [13] allows users to control house appliances using finger gestures by placing IR transmitter and bending/touch sensors on the index finger in combination with the accelerometer on the wrist. MagicFinger [16] extended the dimensions of touching gestures by mounting camera on the finger. Since FingerPad using finger pinch gestures as the input, it increases both privacy and subtlety in comparrison to these works.

Magnetic tracking

Maginetic tracking had been used to sense the gestures in a remote distance. For instance, Han et al. [4] tracked finger-mounted magnet for handwriting input. Similarly, Abracadabra [5] used finger-mounted magnet to control the watch device. Nenya [1], on the other hand, used the magnet mounted in the finger ring to control the device. Liang et al. [7] used magnetic mounted in the stylus and the hull sensor array for enabling input on arbitrary surface. In comparrison to these works, FingerPad provides more private and subtle input by mounting the hall sensors and magnet on the fingertips.

CONCLUSION

We have presented FingerPad, a nail-mounted device that enables touchpad functions on users index fingertips, allowing for private and subtle interaction on the move. Our studies show user ability in cursor control using the pinch gesture with FingerPad. The statistics shows that the users can achieve 93% accuracy for very small targets (1.2mm) in the seated condition, and 92% accuracy for 2.5 mm-width target in the walking condition, which is sufficient enough for the mobile usage. Through the user study, the design insights are also concluded through the explored three factors, which are the posture, commit method, and target size. Though there always has the trade-off among the factors, the study still shows that the FingerPad can work very well for the subtle interactions.

For the future, although the design of the FingerPad is for mobile glass display usage, the FingerPad might be also worked without visual supports. The different commit methods can also be explored in the future to create more different alternative gestures. For the devices designed for richer private output are invented, users have the need to use it privately with richer input device, and moreover, the method should be subtle enough to achieve the social acceptability, such like the FingerPad.

ACKNOWLEDGMENTS

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