HapTick: Highly Accessible Gestures Using Tactile Cues

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ABSTRACT

While high-resolution and miniature gesture sensing technology has been widely explored, the interaction space is still limited due to the nature of low-resolution human proprioceptive sense. To better utilize the control space, we introduce HapTick, a method that discretizes one-dimensional swiping gestures with prompt tactile cues. By counting the tactile stimuli on the path of swiping, the user could effectively select numeric target in one typical swipe. We first derived the effective interval between modes. The results showed that with more-than-3mm distance between ticks, the overall accuracy of 95% can be achieved. In the second study, we compared two methods for selecting a digit ranging from 1 to 10. While there's no differences in completion time between multiple swiping selection and HapTick (3.2 sec vs 3.4 sec), HapTick outperforms in both physical demands (5 vs. 2*) and overall preference (2.41 vs. 4.41*). Lastly, we confirm the feasibility of applying HapTick to other interaction domain, *e.g.*, on-screen swiping, in-air gesture and input on 2D surface, in an explorative study. Two application scenarios were also proposed based on our findings.

ACM Classification Keywords

H.5.2. Information Interfaces and Presentation: User Interfaces — Haptic I/O, Input devices and strategies.

Author Keywords

Swipe; Touch; Vibrotactile Feedback; Numerosity Perception; Haptically-augmented Input; Input Modality; Finger; Experiment.

INTRODUCTION

Swiping gesture is a well-known one-dimensional input method for mode switching, commonly found in touchscreen and physical media controller. There are two broad types of swiping gestures: *Discrete* and *Continuous* input. With *Discrete* input, the user may finger-swipes on the interface toward a certain direction, and the next item will be activated[10]. In order to select a numeric item, say the third target on the right, the user needs to perform multiple rightward swipes individually. This type of swipe is commonly seen on touchscreen to flick to the next page or item. *Continuous* swipe, on the other hand, is another interaction designed for choosing a target in a sequence with only one single swiping[1], such as controlling the volume in a music player.

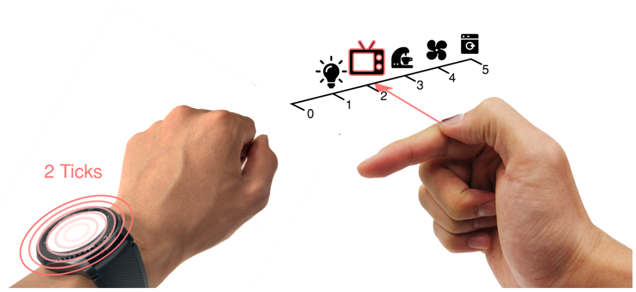

Figure 1. An example interaction of controlling smart home appliances using HapTick eyes-freely: when the user performs swiping with right hand to switch modes, vibrotactile ticks are given on the left hand to indicate the arrival of the mode.

Past works have introduced different approaches for extending the interaction space of swipe, *e.g.*, using camera to capture users' motions[17, 20], applying wireless signals to extend the application space[19, 24] and radar-based sensor[16]. Such research shed lights on using swipe gestures on various interfaces, *e.g.*, 2D surfaces[12], in-air gestures and on-body interfaces. Even more importantly, as the sensing resolution is far enhanced recently, the miniature gestural input become feasible. Take the application proposed in Project Soli for an example, a thumb-to-finger swiping can used for controlling any smart device in an eyes-free manner.

However, even the sensing techniques are already robust and with fine-resolution, the interaction capability is constrained by the limited human's proprioceptive control. Without the aid of graphical interface for confirming the selection, efficient continuous swiping is not feasible. For example, using thumb-to-finger gestures to manipulate the temperature of air-conditioner would require a continuous selection, which is difficult to perform without visual feedback. Therefore, the user is forced to perform series of discrete input instead, that

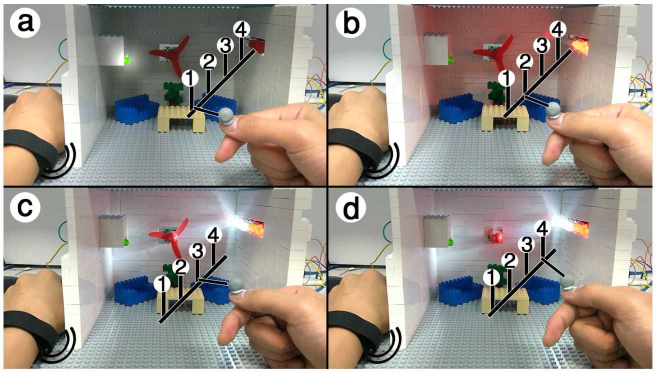

Figure 2. The 4-mode switch of manipulating IoT appliances: (a) mode 1 turns on the air conditioner, (b) mode 2 turns on red bulbs, (c) mode 3 turns on white bulbs, and (d) mode 4 turns on the fans.

will further leads to inefficiency and more efforts during the interaction. The aforementioned discussion leads to the research problem: *How could we successfully design the interaction that allows users to easily manipulate continuous miniature swipe gestures eyes-freely?*

To address the research problem, this paper introduces the interaction of HapTick, a multi-level continuous swipe method enabled by discreting the path of swipe with prompt haptic ticks. Whenever the position of the finger of the dominant hand exceeds a fixed distance of interval, one vibrotactile tick emitted from the wearable vibrotactile motor on the non-dominant hand will be produced to indicate the switch of modes. By counting the ticks, users are allowed to directly access a mode using a single swipe with different swiping distance.

Figure 2 demonstrates the activation of IoT device using HapTick. In this scenario, when user's right thumb touches index finger, the mechanism of HapTick would be activated and the camera starts detecting the finger gestures. During the process of swiping, when the thumb travels every 4mm interval, a vibration will be emitted on the user's left hand to inform users a new mode. After releasing the thumb from the index finger, the selected mode would be activated. For example, the user can turn up the fan after swiping four 4 intervals (4mm x 4times). Unlike discrete swipe selection which requires performing four individual swipe to reach the fourth mode, HapTick can accomplish the task within only one swipe.

To explore the design space of HapTick, the following factors were determined through a series of user studies: (1) the effective distance of interval between modes. (2) the subjective comparison between HapTick and multiple discrete swipes. (3) the potential of using HapTick onto other interfaces *on table*, *on forearm*, and *in air*. Our user studies revealed that 4mm interval between tick marks are long enough for multi-level, and can be easily applied to different scenario. The final design of HapTick is one finger moving with interval of 4mm and 70ms of vibration in another hand.

The contributions of this work are three-fold: (1) We proposed HapTick, a novel approach that enables multi-level continuous swipe selection by augmenting swiping with haptic ticks; (2) Design guidelines to support the use of HapTick; (3) A set of application scenarios to demonstrate the applicability of HapTick.

RELATED WORK

In this section, we review previous research on designing swipe interaction, enabling swipe sensing technology, and numerosity perception for touch input.

Designing Swipe Interaction

The gesture input methods can be categorized into discrete ones and continuous ones. In discrete gesture, users need to perform the same action multiple times to achieve the target. For example, multi-tap[8, 6, 18] and button need to presses each key or area one or more times to specify the desired target. In continuous ones, users usually perform the gesture once with other properties. For instance, wheel-like and clock-like designs use rotation[22]; slider use distance[21]; and pressure design use strength[9] as their level-adjusting properties.

In this paper, we focus on continuous swipe. HapTick take the distance into swipe and augmented it with vibrotactile feedback to make swipe gesture from discrete one to continuous one which is available in the multi-selection and eyes-free scenario.

Technique of sensing gesture

The technique of sensing gesture has been investigated greatly in previous works. Gupta et al.[7] exploited the Doppler effect to sense gestures in audio-based technology. Goc et al.[13] implemented a electric field sensing device, allowing for 3D finger and hand tracking. Cohn et al.[5] used the human body as an antenna for sensing whole-body gestures. The radio-frequency solutions are also well explored. such as using a portable smart radar sensor[23] to recognize human gestures and wireless signals to enable whole-home sensing[11]. Furthermore, Lien et al.[16] proposed Soli, which can resolve motion at a very fine level.

In this paper, we considered the minor moving of distance to make swipe gesture available in very tiny space onto these sensing techniques.

Numerosity Perception

Previous research has investigated the potential and limitation of numerosity perception. Brown et al.[3] explored perception of vibro-tactile and investigated into the effectiveness of tactons. Lechelt et al.[14] evaluated the numerosity perception on temporal dimension among visual, auditory and haptic channels. Cauchard et al.[4] designed a set of vibrotactile icons to represent the value 1 to 10. Brewster et al.[2] use various vibrotactile characteristic, such as frequency and amplitude, to structure tactile icons to deliver messages. Beside, Liao et al.[15] use dwell with vibrotactile to enhance the modality in minimum space.

Based on previous works, HapTick explores a combination of tactile numerosity perception and hand swipe motion. Besides, it uses numerosity perception, i.e., counting vibrations, to enable active, invisible and efficient mode selection.

STUDY OVERVIEW

In the User Study 1, we first proved the feasibility of HapTick interaction where the participants have to coordinate of skin perceptions and motor controls to perform continuous swipe selection. Moreover, the other equally important goal of the study is to determine the effective distance between intervals. Single 70ms haptic tick is delivered from the wrist-worn vibration motor on the left hand, which is so short that it is nearly impossible for visual or audio observation. Four candidate intervals (3mm, 4mm, 5mm, 6mm) were included. The result showed that with more-than-3mm intervals, the 95% of accuracy could be achieved.

In User Study 2, we attempted to prove that HapTick are more preferable than doing a series discrete swipe. A comparison that require the participants to select a numeric target ranging from 1 to 10 in both HapTick and discrete swipe ways. The evaluation of subjective ratings reveals that even though the HapTick has approximate completion time, the physical demand are lower than the other and the preference level are significantly higher.

Finally, User Study 3 examined whether the derived design could be used in different interfaces. Thus we used 4 mm interval to conducted similar experiments onto on table, on forearm and in air. The results showed that the similar mechanism can easily be adopted and used in various interaction space.

USER STUDY 1: BASELINE PERFORMANCE OF HAPTICK ON HAND

The goal of study 1 was to measure the effectiveness of HapTick on hand configured with four intervals of tick (3mm, 4mm, 5mm, 6mm) and 70ms vibration for 10-level selection on hand. The four candidate intervals were determined from an 8-participant pilot test on the touchscreen of a smartphone. The result of the pilot test showed that the overall accuracy is 81.5%, 91.8%, 94.1%, and 94.25% for the 1mm, 2mm, 3mm, and 4mm intervals between ticks.

Study Design

The experiment was a four interval within-subjects design. The independent variables were INTERVAL BETWEEN TICK(3mm, 4mm, 5mm, 6mm) and TARGET (selecting a target of vibration 1 to 10). To eliminate the learning effect, we counterbalance conditions using a Latin Square. There were 50 random swipe-selection trials (5 rounds of 1 to10 vibrations). For each trial, A digit between is displayed onscreen to indicate the TARGET of the current trial. In order to simulate the scenario that the dominant hand performs operation and the non-dominant hand wears watch, we gave vibration on non-dominant hand. Liao *et al.* [15] also proved that there is no significant difference no matter the vibration given on the performing hand or not.

In summary, the experimental design is: 4 intervals×12 participants×50 trials = 2,400 data points. For every trial, we record the ***CompletionTime***, ***CorrectAnswer***, and ***UserAnswer*** for later analyzing.

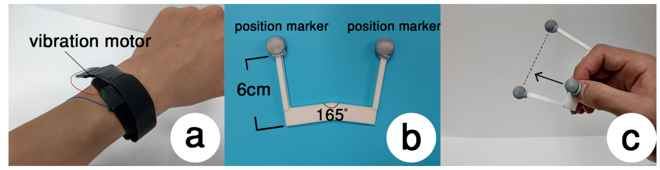

Figure 3. (a) The vibratactile feedback is provided by a vibration motor, which is fixed on the wrist of left hand (the position of display of watch) with a nylon belt. (b) The mold which was used to expand the distance between markers. (c) The operation of HapTick on hand.

Participants and Apparatus

In this study, we recruited 12 paid participants (6 male), 24 to 30 years old (average 24.8) for this study from our university. The study was implemented on OptiTrack V120: Trio (frame Rate is 120FPS and resolution is 640×480), which can detect the 3-D position of reflective markers. We use three reflective markers in this study. Two reflective markers were for positioning, and one reflective marker was stuck on participant's thumb with clay. The actual moving distance detected was the vertical projection of the point of the reflective marker of thumb on the two positioning markers. Because of the limitation of resolution of the device, we used 3D printer to make a mold to expand the length between two positioning makers.(Figure 3b)

The vibration feedback is a 70ms vibration provided by a vibration motor, which is fixed on the wrist (the position of display of watch) with a nylon belt (Figure 3a) and is controlled by Arduino.

Tasks and Procedures

There are four interval testing per participants, and every interval contained 50 trials. In every trial, participant first see a task number on screen, and were asked to input the given task number with HapTick on hand (swiping their thumb on index finger and he/she would receive vibrotactile feedback that indicate a mode arriving in every given interval arrived).

Before starting every trial, participants were asked to press a button to represent the start sign, and after performing HapTick operation, he/she had to press button again to represent the finish sign. The system recorded the time between two pressing as ***CompletionTime***.

Besides, Participants were allowed to perform reverse swipe if they felt they exceeded the given task number.

To familiarize participants with the testing procedure, a training block was provided. Each interval testing took about 6 minutes, and there were 3-minute breaks between blocks. In total, each participant took about 40 minutes to complete the study. To prevent participants from receiving vibrations by counting the vibration sounds, they were asked to wear a headset emitting pink noise.

Results

The overall accuracy are 93.2% (s=5.2%), 96.8% (s=3.23%), 97% (s=3.27%), and 96.3% (s=3.92%) for the 3mm, 4mm, 5mm, and 6mm intervals between ticks, respectively.

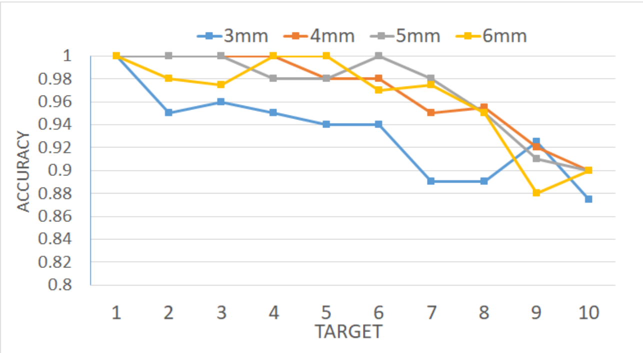

Figure 4. The accuracy of HapTick of User Study 1

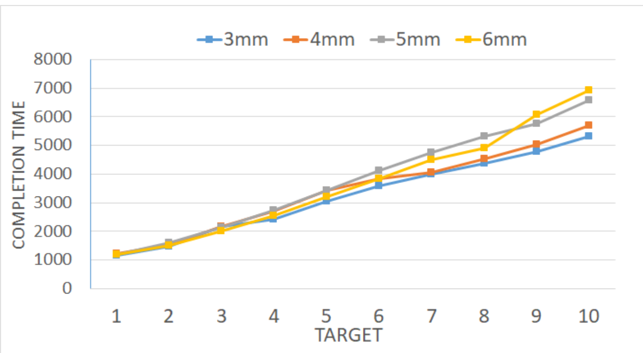

Figure 5. The completion time of HapTick of User Study 1

The overall completion time are 3230 ms (s=303 ms), 3424 ms (s=589 ms), 3763 ms (s=678 ms), and 3666 ms (s=551 ms) for the 3mm, 4mm, 5mm, and 6mm intervals between ticks respectively.

We conducted two two-way repeated measures ANOVA to compare the effects of INTERVAL and TARGET on accuracy and completion time.

Figure 4 showed the trend of accuracy in User Study 1. The results revealed no significant interaction between INTERVAL and TARGET ($F_{27,297} = 1.02$, p=0.445), and no significant difference between INTERVAL on accuracy ($F_{3,33} = 2.33$, p=0.092). There was a significant difference between TARGET on accuracy ($F_{9,99} = 4.74$, p <0.001). The result of pairwise comparisons showed that the accuracy decreases with higher TARGET.

Figure 5 showed the trend of completion time in User Study 1. The results revealed no significant interaction between INTERVAL and TARGET ($F_{2.600,28.6} = 1.214$, p=0.312) after Greenhouse-Geisser correction, and no significant difference between INTERVAL on completion time ($F_{1.338,14.71} = 0.854$, p=0.371). There was a significant difference between TARGET on accuracy ($F_{1.86,20.46} = 87.07$, p <0.001). The result of pairwise comparisons showed that the completion time increases with higher TARGET.

Discussion

The results showed that the accuracy is high at every interval. With more than 3mm HapTick, participants can even achieve the accuracy higher than 95%. Besides, we also proved the learnability of HapTick via that with only a few minutes training, participants could quickly finish the task and achieve high accuracy.

There is no significant difference between intervals on completion time. However, the completion is a little high in the mid-level target (4,5,6), which takes more than three sec., and high-level (7,8,9,10), which makes more than 4 sec. Besides, some participants reported the swipe space is a little narrow while performing the high-level task, especially in the interval of 5mm and 6mm.

USER STUDY 2 : SUBJECTIVE ANALYSIS BETWEEN MULTIPLE SWIPING SELECTION AND HAPTICK

The experiment was to evaluate the subjective individual experiences about multiple swiping selection and HapTick.

Study Design

The study was a two gesture within-subjects design. In this study, every participant was asked to perform multiple swipe and HapTick to finish 50 random selection trials (5 rounds of 1 to 10 vibrations) respectively. The result of User Study 1 suggested there is no difference between interval on accuracy and completion time, so we selected 4mm HapTick as the representative in this study. Finally, participants were asked to answer the four questions of subjective feeling about this experiment.

Participants and Apparatus

We recruited 12 participants (six female, age from 20 to 25) for this study from our university. The apparatus are the same with User Study 1.

Tasks and Procedures

Every participant started from multiple swipe or HapTick testing (four from multiple swipe). After first testing, there was a 3-minute break and then started another one. In every trial of multiple swipe testing, participants were asked to perform swipe with reasonable and comfortable speed. After the two testing, participants were asked to answer the questions about subjective feeling.

Subjective Rating Analysis

We modified some NASA-TLX questions to fit this study. During the 4-question post-study questionnaire, the participants were asked to give their subjective rating, as a score between 1 (the least) and 7 (the most), on two gesture. Thus, the subjective rating analysis design is: 12 participants×2 gesture×4 questions = 96 data points. The results have been further analyzed with Wilcoxon signed rank test. The four questions are as follow:

- Q1: The physical demand to perform the gesture
- Q2: The mental demand to perform the gesture
- Q3: The temporal demand to perform the gesture
- Q4: The overall preference level of the gesture

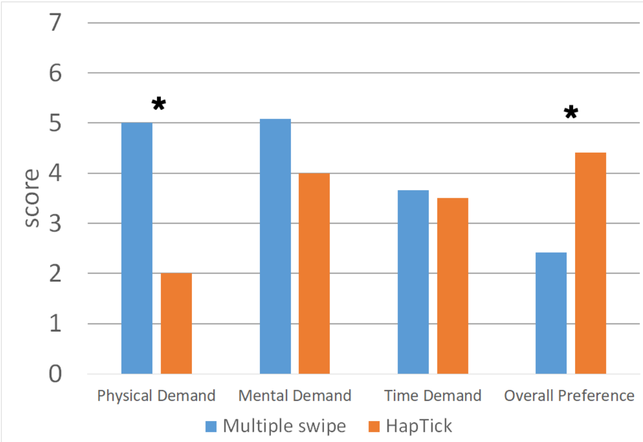

Figure 6. The result of subjective rating analysis of multiple swipe and HapTick

Results

The overall completion time are 3271 ms (s=333 ms) and 3472 ms (s=647 ms) for the multiple swipe and HapTick in this study. We compared the completion time of multiple swipe condition and HapTick condition by 2ÃŮ10 (condition-sÃŮtarget vibrations) two-way ANOVAs. The result showed there is no significant difference on completion time between two condition($F_{1,11} = 0.062$, p=0.80).

Figure 6 show the result of subjective rating analysis. The average scores of multiple swipe are 5 (s=1.53), 5.08(s=1.08), 3.66 (s=1.77) and 2.41 (s=0.79) for the Q1, Q2, Q3, and Q4 respectively; The average scores of HapTick are 2 (s=1.12), 4 (s=1.27), 3.5 (s=1.56) and 4.41 (s=1.08) for the Q1, Q2, Q3, and Q4 respectively.

We conducted four Wilcoxon signed rank test on every question between multiple swipe and HapTick. The result showed that physical demand ($z_{2.113}$,p=0.035) and overall preference ($z_{2.081}$,p=0.037) had significant difference between multiple swipe and HapTick.

Discussion

In this section, we discuss the questions separately and analyze the potential reasons.

Physical Demand: There is a significant difference in physical demand. Some participants even reported his/her thumb was aching after the testing of multiple swipe because of performing a great number of swipes, whereas in HapTick participants need to perform one swipe in every trial.

Mental Demand: There is no significant difference in mental demand; however, both of scores exceed 4. In both of condition, participants need to keep the mode (number) they are swiping in mind while performing a task, which would be a burden to them.

Temporal demand: There is no significant difference on temporal demand. It means participants did not think one of them is time-consuming than another. This matched the result of statistics.

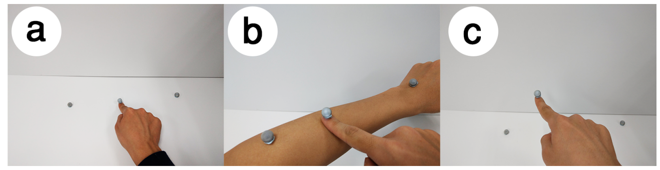

Figure 7. (a) HapTick on table. (b) HapTick on forearm. (c) HapTick in air.

Overall Preference: There is a significant difference in overall preference. After testing, some participants reported the key point is that HapTick just needed to perform gesture once, while multiple swipe needed to perform several times to finish the task.

USER STUDY 3 : HAPTICK: ON TABLE, ON FOREARM, IN AIR

The experiment was to evaluate the usability in the different scenario, on table, on forearm and in air.

Study Design

The study design were similar as User Study 1, and the only difference is that this is a three scenarios within-subjects design.The study is conducted in the different scenario, on table, on forearm, in air (Figure 7). In every study, we use two reflective markers for positioning, and one stuck on participant's nail of the index finger. Participants were asked to move their index finger between the two position markers. The result of User Study 1 suggested there is no difference between interval on accuracy and completion time, so we select 4mm HapTick as the representative in this study. To eliminate the learning effect, we counterbalance conditions using a Latin Square.

The experimental design was: 3 scenario$\times$8 participants per interval$\times$ 50 trials per scenario = 1,200 data points.

Participants and Apparatus

We recruited nine participants (four female, age from 23 to 25) for this study from our university. The apparatus are the same with User Study 1.

Tasks and Procedures

The tasks and were the same as User Study 1. Participants were asked to perform HapTick with the index finger of dominant hand in all studies. In on table scenario, participants were asked to perform HapTick with only index finger on table; In on forearm scenario, participants perform HapTick on the skin of upper forearm; In in air scenario, participants were asked to perform HapTick in air without leaning on other objects.

Results

The overall accuracy of are 97.75% (s=1.9%), 95.8% (s=3.4%), and 98% (s=1.5%) for the HapTick 4mm on table, on forearm, and in air respectively.

The overall completion time are 2789ms (s=494ms), 2618ms (s=539ms), and 2643ms (s=415ms) for the HapTick 4mm on table, on forearm, and in air respectively.

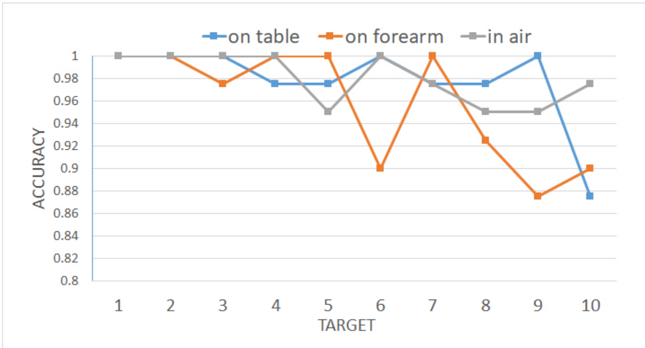

Figure 8. The accuracy of HapTick in various scenario

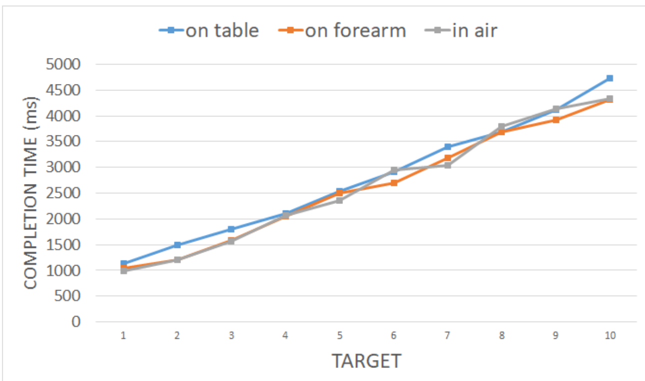

Figure 9. The completion time of HapTick in various scenario

Discussion

The results showed that the overall accuracy of the various scenario are high, and completion time is apparently less than the User Study 1 (on hand). We found the potential reason for this gap might be the use of different part of muscles; however, we do not intend to discuss the issue in this paper.

What the surprise is that some participants reported that in air gesture was very difficult at training block, but they still got high accuracy result in the testing block. This proved that with easy vibrotactile feedback, a human could enhance their motor skills to perform fine gestures in small space. Besides, two participants reported that on forearm would be a little difficult because there was inconsistent tactile feedback while swiping on the soft skin. With the given result, we can prove the usability of HapTick in the different scenario.

INTERACTION SCENARIOS

Here we present two prototype interactions to demonstrate the possible usage of HapTick selection.

Controlling IoT Devices

Figure 2 showed the HapTick operation in IoT scenario. Within one simple swipe, the users may determine which device to be turned on or off. Since each mode has assigned a targeted digit, the users can memorize and perform the selection eyes-freely. For example, selecting mode 1 to turn on an air conditioner; mode 2 to open the media player. In the kitchen scenario, users can adjust the mode of microwave and activate the timer while cooking.

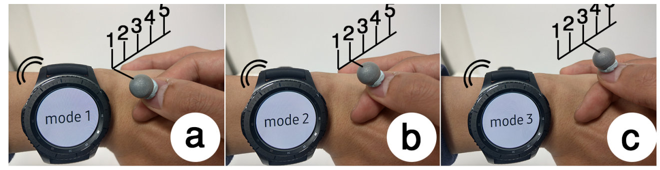

Figure 10. Mode-selection on smartwatches with HapTick (a) HapTick to mode 1. (b) HapTick to mode 2. (c) HapTick to mode 3.

Eyes-free Fast Selection on Wearables

Figure 10 showed the HapTick operation on wearables. Since wearables have limited input space, and some of them are lack of display, *e.g.*, smart earbuds and smart rings, we can use HapTick eyes-freely to manipulate them. For example, in a driving scenario, a driver can adjust the temperature of air conditioner or reject a call with HapTick. Besides, in a walking scenario, users can use HapTick to switch songs in playlists or tune the radio for better safety.

Private and subtle Scenario

With HapTick, a user can perform interaction precisely in a private and subtle scenario. An example is controlling the smart device in class or meeting, as it is considered impolite to avert eyes from presenters to devices. Through the operation of HapTick, a user can perform interaction with devices, such as sending predefined messages or turning the phone on silent.

DISCUSSION

Our studies are conducted under well-controlled lab environment. In real-world contexts; however, user performance to perceive haptic ticks from HapTick can be hindered when users at the same time perceive a different stimulus, such like visual, audio, or other haptic forms from the environment. This issue can be alleviated by extending the length of intervals and the strength of vibrations. We encourage future research to investigate the real-world performance and other improvements.

Our work focuses on enhancing one-dimensional swipe with tactile cues. However, HapTick can also be applied to two dimensional and three dimensional scenarios. We expect future researchers to further explored the design of higher dimensional HapTick.

Through studies, we proved HapTick can be applied to different parts of body efficiently, such as HapTick on hand and on forearm. The result showed high accuracy of HapTick in various scenarios; however, we did not in-depth explored the difference in multiple situations and interfaces in our study, such as from the perspectives of anthropotomy or ergonomics.

HapTick can potentially be integrated with any input interaction to expand its input space further and reduce the completion time. For example, through the direct touch, the different part of fingers, or pressure, we can activate different start mode (e.g., start from 5 or 10), and then perform HapTick gesture form this start point to reduce moving length and completion time.

CONCLUSION

This paper presents HapTick, a haptically-augmented swipe for multi-level mode selection. Three user studies were conducted to explore the usability and potential of HapTick. The results showed that with more than 3mm HapTick on hand, at least 95% rate of accuracy can be achieved for 10-level selection. The subjective analysis also showed that comparing to multiple swipe, users felt less physical demand and had overall preference while performing HapTick. Since results revealed that the accuracy was also high while conducting in the various scenario, HapTick can be extensively used for a wide range of interfaces by wearing actuators. Possible applications of HapTick include smartphones, smart wearable devices, laptops and IoT devices. For future work these researchers consider: a) exploring more scenario HapTick can apply for different usages, b) working with other input methods, and c) investigating real-world and expert performance.

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