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Precise Manipulation of GUI on a Touch Screen with Haptic Cues

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ABSTRACT

In this work, we designed a haptic stylus interface interacting with a touch screen. The stylus has functions of providing vibration, impact, and sound and it is a stand-alone system including its own battery and wireless communication module. We present a new interaction scheme on the Windows graphical user interface based on haptic feedback events for clicking, drag & drop, moving, scrolling, highlighting, and other things. From conducting experiments, we evaluated its performance that the haptic stylus improved precise control of GUI elements. A simple interactive digital sketchbook has been also implemented, which is providing haptic and auditory feedback while drawing and touching objects.

KEYWORDS: Haptic, pen, stylus, GUI, windows, image, tactile.

INDEX TERMS: H.5.1 [Information Interface and Presentation]: User Interfaces; H.1.2 [Models and Principles]: User/Machine Systems.

1 INTRODUCTION

Touch screen has been widely adopted as visual display and input device for mobile devices, kiosks, etc. Application of touch screen reduces the need for additional input devices or simply input interfaces of a system. However, the most common complaint of users when they manipulate user interface on a touch screen is uncertainty. For example, they are not sure whether they pressed a button or not although there was a visual feedback. Lack of high-precision interaction on touch screen has been a common problem and a challenge [1].

In order to make up for this uncertainty, there have been efforts to provide haptic feedback in the use of touch screen. One of the simplest ways is installing a vibrator in a mobile device, and this technology is already used in a commercial product [8]. A tactile display for handheld devices, "TouchEngine", has been suggested [9][10]. It creates an instantaneous force when the user presses a button. However, it could be applied only to small screen devices, since magnitude of the output force was not enough to be human-noticeable in a heavy system. There was another trial to provide tactile feedback for a mobile device [6]. Array of shear stimulator conveys pattern information to users. However, it still requires considerable effort to apply electronics to a mobile device. More practically, tactile feedback actuators were installed at the corners between touch panel and display screen [3]. When we install actuators inside the device, actuator usually requires strong output power to create recognizable haptic response. If we increase power of actuators, electronics problem should be solved in advance for mobile devices. If we decrease power of actuators, a system does not provide available haptic feedback output.

The pen-like interface is the most familiar tool to humans, and the worldwide used haptic device "PHANTOM" has a stylus type handle [7]. Also, the styli are now the most commonly adopted input interface of a touch screen. There have been researches for separate haptic input interfaces in the form of stylus. Lee et al. [4] achieved initial work for a haptic stylus. They installed a pressure sensor at the tip and a solenoid inside the body of the pen. It provides button clicking and buzzing sense. Recently, another approach adopted a similar device for a different application [5]. More recently, a pen-like haptic interface providing vibrotactile feedback and texture feedback was suggested [2]. All researches shows haptic styli are useful for manipulation of graphical user interface. However, miniaturization of their mechanism and electronics is required for realizing an interface to mobile devices. For more practical use, our work has been focused on a mobile and wireless stylus termed Ubi-Pen providing various combinations of haptic stimuli. It provides vibration, bilateral impacts and sound feedback in accordance with manipulation events. We introduce a Windows graphical user interface interacting with haptic feedback stylus. The interaction deals with button click, icon/file pick-up, drag-and-drop, window resize and scroll, object manipulation, text highlighting, and menu movement/selection. Several experiments have been conducted to prove that the proposed system guarantees precise control of GUI on a touch screen. Survey results are quoted with 95% confidence, unless otherwise noted.

2 WIRELESS HAPTIC STYLUS

Our main focus on designing a haptic stylus is miniaturization to practical size, weight, and power consumption. In addition, the stylus should provide sufficient output haptic stimuli.

2.1 Specifications

Figure 1 shows a prototype version of our haptic stylus, called 'Ubi-Pen Series'. As shown in the figure, we installed a vibrator, an impact generator, a speaker, and a microphone in the stylus. When we use the stylus as a pointing device on a touch screen, events occurring in computing device are transmitted to the stylus through Bluetooth wireless communication.

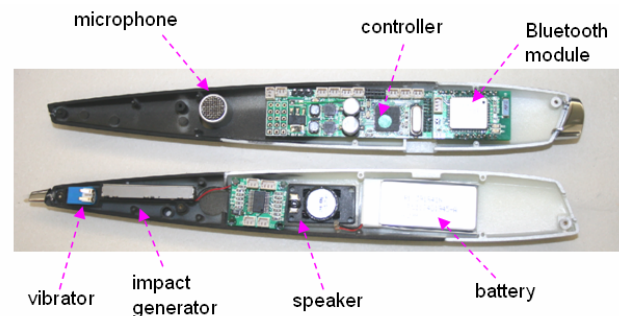


Figure 1. Appearance and Inside Structure of Haptic Stylus.

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The vibrator is a rotary vibrator typical in mobile devices. The impact generator (L-type ForceReactor, ALPS Electric Co.) is a kind of linear vibrator which produces a click-like sensation with bilateral collision of a mass. The generator is arranged along a longitudinal axis of the stylus housing. Particularly, we place it at a position closest to user's finger grasping the stylus. Battery and Bluetooth module enable the stylus to operate as a stand-alone system. For multi-modality, two profiles of serial protocol and headset have been installed in a Bluetooth module.

When we operate the vibrator and the impact generator continuously at maximum power through wireless communication, the whole system consumes less than 0.5W. However, since the actuators operate when certain event signal occurs, average power consumption is far less than 0.1W. The capacity of the rechargeable battery is 3.7V and 270mAh. The system has a length of 21cm and a weight of 45g. The size of this prototype will be that of a pencil if it is customized. Especially, electronic controller, wireless communication chip and battery will be miniaturized. Our target is to insert the haptic stylus in the computing device such as PDA and mobile phone.

2.2 Principles

Here we describe the working principles of the impact generator. Figure 2 shows a very simplified model of the linear vibrator operation. There is a mass inside the generator and electromagnetic force induced by electric signal makes the mass move along a longitudinal axis of the case.

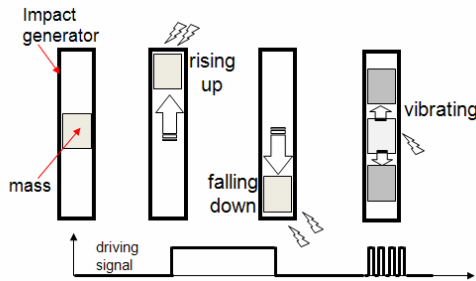


Figure 2. Operation of a Linear Vibrator.

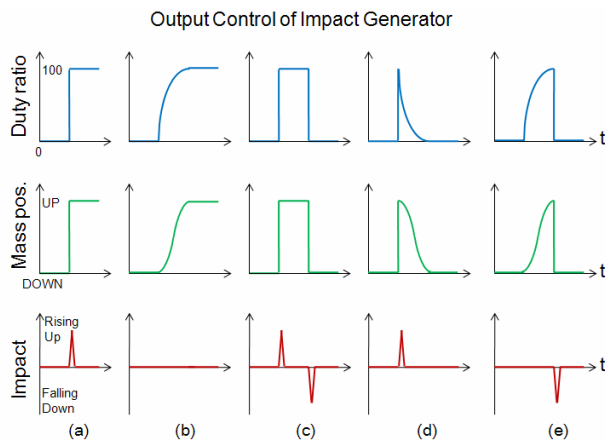


Figure 3. Various Feature of Outputs.

When a rising signal is applied to the generator, the mass moves up fast and it collides with the upper end. When a falling signal is applied to the generator, the mass moves down fast and it collides with the bottom end. The response time of the mass movement is on the order of milliseconds. However, if we apply square wave signal with a frequency of hundreds of hertz, the actuator vibrates.

This generator is generally used as a kind of linear vibrator with short vibration settling time and we otherwise use it as an impact generator.

Based on the operational characteristics mentioned above, we can use a variation of PWM (Pulse Width Modulation) duty ratio for the very rough acceleration control of the mass. This scheme is sometimes necessary. For example, when we need to set the initial position of the mass without any impact, the mass should move gently in a short time. Figure 3 shows our scheme for the output control of the impact generator. This scheme is also necessary when the same directional impacts are required repeatedly.

3 GUI MANIPULATION WITH HAPTIC CUES

We designed a new Windows interface interacting with haptic stylus. When we use a touch screen device, precise manipulations are extremely limited. A touch screen reduces complexity of input interfaces, but it also reduces usability. Lack of 'touch' interaction on a touch screen disturbs user's confidence in manipulations. The proposed stylus enables the touch interaction on a touch screen. As shown in Figure 4, there are typically several manipulation tasks such as clicking, selecting, dragging and dropping. In order to realize more precise control with haptic cues, system architecture and implementation methods have been investigated.

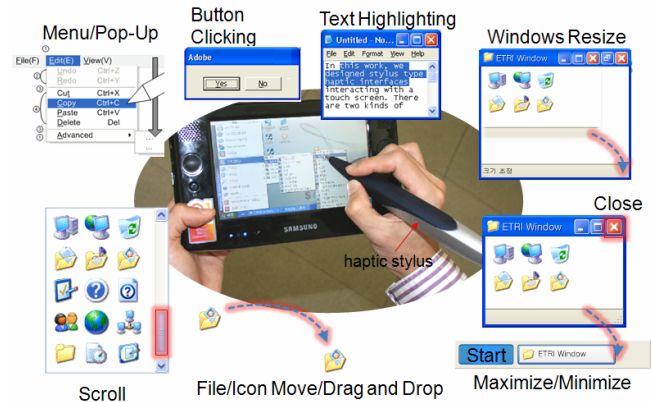


Figure 4. GUI Manipulation on a Touch Screen.

3.1 Architecture

Figure 5 shows the architecture of the whole system and interaction. The computing device itself like PDA, UMPC or mobile phone plays a main event processor.

When a user interacts with a stylus on a touch screen device, Windows Interface Message Filter detects event message notifying the current task, such as press button, scroll, and select icon. We developed a Haptic Information Provider playing the role of API (Application Programming Interface). The API provides function and library for the control of the haptic stylus. After decision of Haptic Information Provider, the command dataset according to protocol is transmitted to the haptic stylus through the wireless communication. And user is provided with additional sensory feedback like haptic cue. This feedback will help users manipulate GUI elements precisely. For usability, the API is developed for a computing device and the user does not have to set up the stylus. The current version of the API is optimized for the Microsoft Windows XP tablet version.

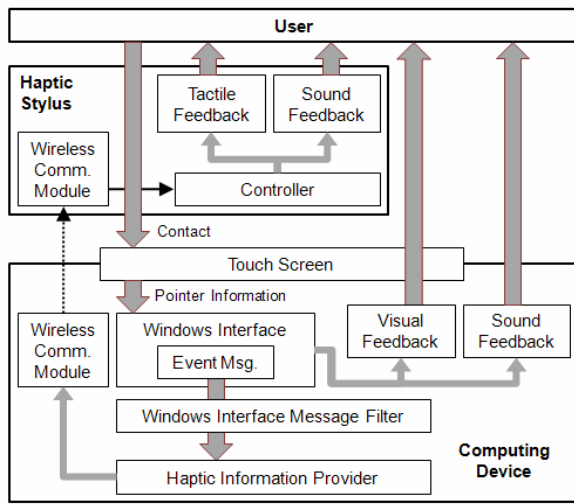


Figure 5. System Architecture.

3.2 Implementation

This section describes the actual implementation of GUI manipulation task.

Button Clicking: The button clicking stimulation is composed of a falling-down impact and a rising-up impact for pressing and releasing, respectively. As shown in Figure 6, button pressing is composed of 3 steps. The first step is increasing pressing force. The second step is button pressed state after sudden falling down when the pressing force is greater than a threshold. The third step is releasing the button with an abrupt rising up. We do not have to consider the first step since it naturally occurs on a touchscreen. The touchscreen itself provides a function of button pressing with a threshold pressure. And the keys of the second and the third steps are sudden change of movement. Because the sudden change is a kind of impact, we can simulate the second and the third steps with our haptic stylus including an impact generator. As shown in Figure 6, the falling down collision of the mass inside the generator gives effect of a button pressing. The rising up collision of the mass provides sense of a button releasing to users.

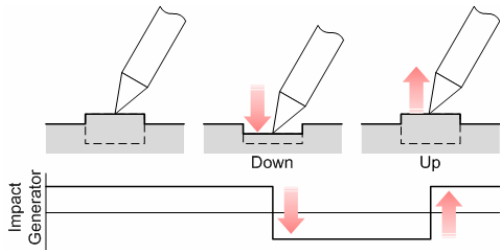


Figure 6. Haptic simulation of a mechanical button.

Menu: As shown in Figure 7, when a pop-up menu opens or closes, a short term vibration or impact occurs. When the pointer moves along the list, there is an impact cue notifying each item on the menu.

Object Selection/Movement: When we select an object, an icon or a window, attaching-like stimulation is generated. When we move the selected object, instantaneous tactile bit (impact) is generated according to movement for every event. This cue guarantees precise movement of an object that the user is able to move the object one pixel at a time on a touch screen. Since precise position arrangement of windows, polygons or object on a touch screen is a very difficult task, people usually do not try this kind of task on the touch screen.

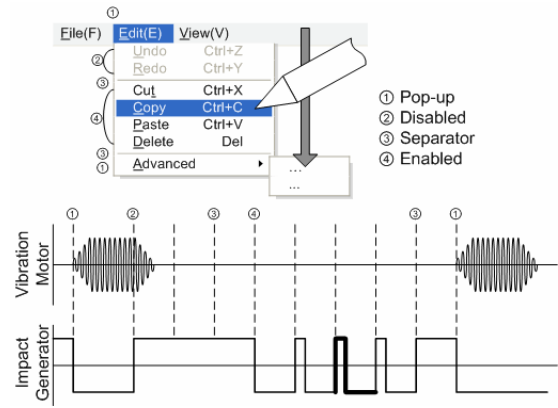


Figure 7. Menu Manipulation.

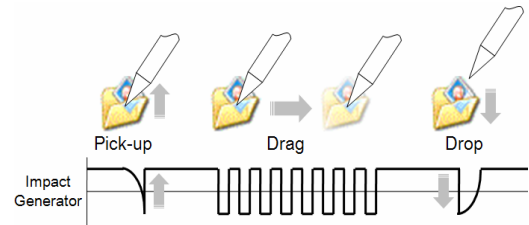


Figure 8. Object Selection and Movement.

Group Selection: When a user tries to select multiple icons by dragging the pointer, haptic stylus notifies the addition of icons into the selection. As an additional icon is selected into a group by user's dragging pointer, an impact occurs at each addition event. This helps your recognize grouping status intuitively.

Scroll & Window Size Control: In order to guide a precise control of scrolling and resizing of windows, tactile bit is generated in accordance with every event.

Close, Maximize & Minimize: There is short term vibration or varying vibration to indicate execution of command. 50 ms short-term strong vibration is provided for notifying windows closing. For 100msec, there are gradually strengthening vibration notifying maximization and gradually weakening vibration notifying minimization.

4 EVALUATIONS

In order to evaluate the performance of the proposed haptic stylus, we conducted four experiments and two field tests. 10 subjects participated in the experiments and their ages are from 24 to 38. A UMPC (Q1, SAMSUNG) has been used as a test-bed for the experiments.

4.1 Button Clicking

We tested the effectiveness of the haptic stylus. We presented subjects with a simple calculator interface on a touch screen. They had to enter each of the 6 equations (2,225,578 + 7,999,991; 3,333,666 + 1,112,222; 8,877,866 + 3,337,777; 4,333,322 + 8,882,122; 6,677,642 + 1,111,544; 4,273,333 + 5,544,333) shown on the right of the screen. The same equations have been used for our previous research [2]. Each equation was randomly presented and 2 kinds of haptic feedback were also randomly provided. Vibration is 50ms short-term vibration and the impact feedback is the method described in the Figure 6. Subjects had to calculate every equation twice until they obtained the correct answer to each. This calculator displayed only the results of calculations, not the figures entered. In this study we measured task completion time.

	Average Duration of Calculation	Standard Deviation
Without haptic feedback	12.96 (sec)	2.50
Vibration Feedback	11.44 (sec)	1.73
Impact Feedback	10.57 (sec)	2.30

Table 1. Task Completion Time for Button Clicking

	Standard Error	Margin of Error with 95% Confidence
Visual-Vibration	0.77 (sec)	1.41
Visual-Impact	0.72 (sec)	1.33
Vibration-Impact	0.53 (sec)	0.97

Table 2. Difference according to Modality

The experimental results in Table 1 show that the both haptic feedbacks of the stylus decreased the length of time to enter the calculations. A major consequence of the click sensation was to add self-confidence to users, and this contributed to fewer errors and a reduced duration in calculations. For more details, Table 2 shows difference analysis results. From the confidence level analysis for statistical significance, we are 95.9% and 99.5% confident, respectively, that Vibration Feedback and Impact Feedback improve task completion time for Button Clicking. We are 93.2% confident, respectively, that Impact Feedback improves task completion time over Vibration Feedback for Button Clicking. From the margin of error analysis compared to only visual feedback, we are 95% confident that Vibration Feedback improves task completion time by at least 0.1 sec for a equation and Impact Feedback improves task completion time by at least 1.06 sec for a equation. Since impact generation time is shorter than vibration time, impact feedback case was faster. We asked each participant about the effectiveness of clicking sense feedback and they all agreed that haptic feedback gives self-confidence. Additionally, we had a chance demonstrating the system IT exhibition shows and 145 of 160 visitors agreed that impact feedback scheme provide users with a perception of a real button. For vibration, most of them did not agree its reality but appreciated its effectiveness. From this test, the effectiveness of the system's button pressing feedback has been verified.

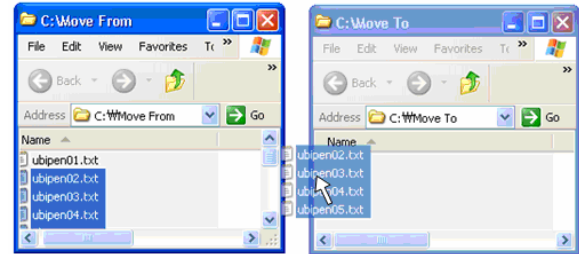
4.2 Icon/File Manipulation

We often move files or icons on a touch screen. In this task, exact grouping is sometimes necessary. As shown in Figure 9, for example, a user has to move 4 files from the left window to the right one. But unfortunately, the half of the last file is hidden by the frame. In this case, if a user is not careful he/she will often highlight less or more than 4 files. Even though the user grouped 4 files exactly, he/she sometime fails moving the group from left to right.

For the evaluation, subject moves 4 files 3 times from the left windows to right one. In case of mistake, the trial should be done again. When a subject try to select multiple files by dragging the pointer, haptic stylus notifies addition of a file. An impact occurs per addition. And when the user drags the group, there is discrete haptic cue mentioned in the Figure 8 of the previous section. We compared haptic feedback case with visual feedback-only case. As shown in the Table 3, haptic feedback remarkably decreases task completion time. It helps precise selection of the last files

placed in the border of the window. The standard error for difference is 0.67 and the margin of error with 95% confidence is 1.22. From the confidence level analysis for statistical significance, we are 98.5% confident that Haptic Feedback improves task completion time for File Manipulation. From the margin of error analysis, we are 95% confident that Haptic Feedback improves task completion time by at least 0.49 seconds for File Manipulation.

Figure 9. File Manipulation.



Highlighting/ Dragging and Dropping

	Average Duration	Standard Deviation
Without haptic feedback	7.20 (sec)	1.50
Haptic Feedback	5.48 (sec)	0.75

Table 3. Task Completion Time for File Manipulation

In the beginning actually, we have tried to compare vibration feedback with others. But we concluded it was not necessary since vibration was not effective in this task. When we drag the pointer slowly, the vibration is available cue. In this task, since a user is trying to achieve the task as quickly as possible, the dragging speed is fast. At the moment, the vibration does not provide discrete cue any more but the device generates continuous vibration.

4.3 Text Handling

Normally, people do not use a text editor on a touch screen device due to poor usability. For the first step of the use of a text editor on a touch screen, the proposed haptic stylus can be used for a more convenient copy & paste or a cut & paste. As shown in Figure 10, we presented a text movement task to subjects. Like a file grouping task, as a subject highlights the sentence letter by letter, there is impact cue notifying addition of a letter. And when the user drags the sentence to the end of the paragraph, there is discrete haptic cue described in the Figure 8 of the previous section. We designed a special text editor for this experiment. A subject repeated this task 5 times.

Table 4 shows experimental results ($p < 0.05$). Average duration for a task with haptic feedback is shorter than conventional case. The standard error for difference is 0.27 and the margin of error with 95% confidence is 0.50. From the confidence level analysis for statistical significance, we are 96.7% confident that Haptic Feedback improves task completion time for this Text Handling 1. From the margin of error analysis, we are 95% confident that Haptic Feedback improves task completion time by at least 0.07 seconds for this task. Contrary to our expectation, however, the results do not show significant improvement with haptic feedback. Although the subjects gave comments that haptic feedback was better, the difference does not remarkably appear on this result. We discuss this at general field test section. With the same reason mentioned above, vibration case does not compared here.

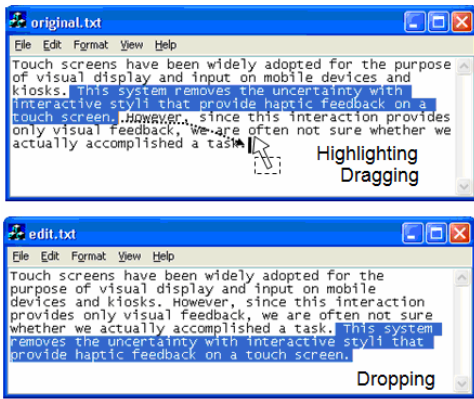


Figure 10. Sentence Highlighting and Dragging Task

	Average Duration	Standard Deviation
Without haptic feedback	5.44 (sec)	1.54
Haptic Feedback	4.87 (sec)	1.43

Table 4. Task Completion Time for Text Handling 1

For a more practical case, we conducted another experiment here. We sometimes need to copy a text or a word for filling out a blank like a search window or a spreadsheet. We often highlight a part of a word in a sentence for copying or searching task. This kind of task is usually very difficult on a normal desktop computer with mouse interface.

The subjects were presented with the following sentence: “Touch-sensitive screens are everywhere from car navigation systems and mobile phones to PDAs, UMPCs and MP3 players thanks to the rapid development of touch-screen technology.” They were told to highlight 10 words in the shadow and move them to other editor window. We measured task completion time. Table 5 shows experimental results that haptic feedback contributes to precise and quick manipulation on a touch screen. The standard error for difference is 2.13 and the margin of error with 95% confidence is 3.90. From the confidence level analysis for statistical significance, we are 100.0% confident that Haptic Feedback improves task completion time for this Text Handling 1. From the margin of error analysis, we are 95% confident that Haptic Feedback improves task completion time by at least 6.36 seconds for this task. It is clear that providing haptic cues contribute to better precision handling of text on a touch screen.

	Average Duration	Standard Deviation
Without haptic feedback	60.17 (sec)	9.35
Haptic Feedback	49.91 (sec)	6.44

Table 5. Task Completion Time for Text Handling 2

4.4 General Field Test

In order to get more general response, we demonstrated the system at two international exhibitions. We spent 3 days at the International Exhibition 2007 for Next Generation PC Industry and 5 days at ACM SIGGRAPH 2008. The system has been introduced more than 1,000 visitors and operated for longer than 50 hours. The stylus normally continuously operates for 3hours

after a time battery charging. This process naturally verified reliability and robustness of the developed system. At the demonstration, impact-based feedback has been used mainly, except in windows pop-up, maximization, and minimization.

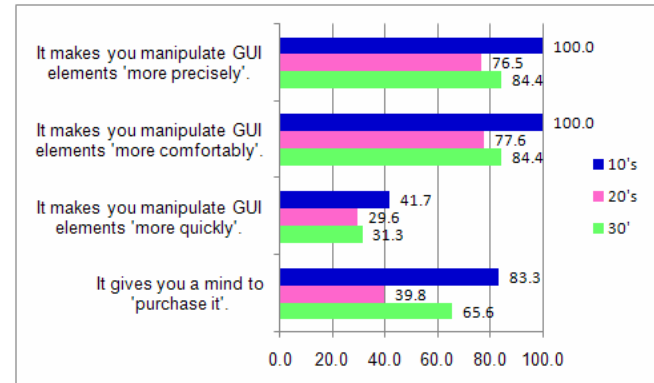


Figure 11. Contribution of Haptic Interaction.

During the demonstration, we received questionnaires from 162 people (99 males, 56 females, and 7 unmarked). The first questionnaire is about contribution of haptic feedback of the proposed stylus. As shown in Figure 11, users feel they can manipulate GUI precisely with haptic cue. In addition to this, they feel more comfortable. Contrary to focus of our previous experiments, only 30~40% people feel haptic feedback induces faster manipulation. It is true that haptic feedback contributes to improvement of manipulation speed in many tasks on a touch screen. But most people show their satisfaction in preciseness and comfort rather than in speed. It seems because they do not have to pay intensive visual attention to the small touch screen.

As shown in Figure 12, the second questionnaire is about preference to haptic feedback functions. More than 90±5% of people feel that button clicking feedback contributes to easy manipulation and more than 65±7% of people selected object manipulation. Particularly, teenagers show high positive interest for all functions. Although most visitors tried the system for less than 5 minutes, most visitors did not experience haptic interface, and many people were unfamiliar with touch screen, considerable amount of people agreed to the contribution of each haptic feedback function.

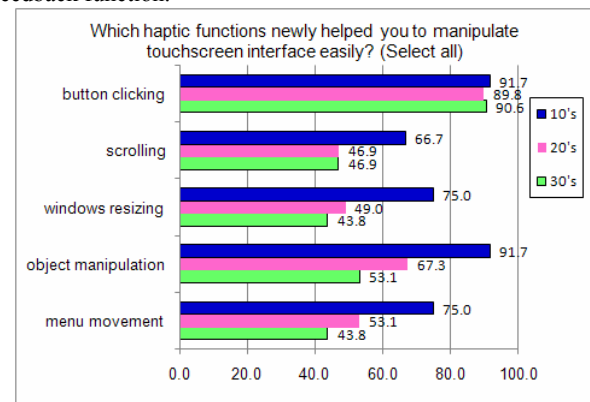


Figure 12. Effectiveness of Haptic Feedback Functions

5 APPLICATIONS

The application area of proposed methodology can be expanded to various systems beyond GUI manipulation. Our first trials are a haptic puzzle and an interactive digital sketchbook.

As an example to assess the performance of haptic stylus and touch-based graphical user interface, we designed a puzzle game. If we control graphical objects precisely on a touch screen with a stylus, it will spread the practical application area of touch screen devices. For example, this may show a possibility of dealing presentation software on a touch screen. As shown Figure 13, we specially designed a puzzle game. When we select, move, rotate and resize a polygon, haptic cues according to manipulation events help users to do the task precisely. Every specific amount of change of size, angle or position induces haptic cue. This handling task has been demonstrated at the field and results show (See Figure 11 and 12) almost most people feel more comfort and more than 65% people agree haptic stylus contributes to easy object manipulation.

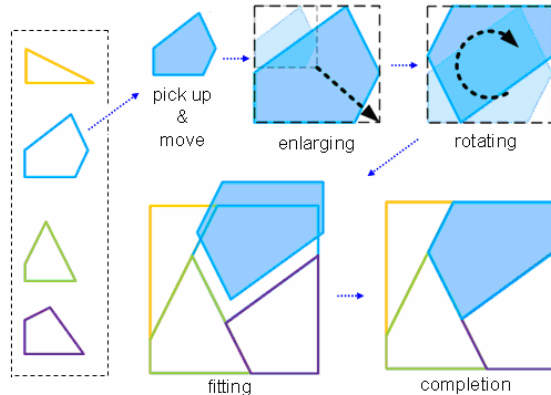


Figure 13. Haptic Puzzle.

In these days, digital book has become the new education or entertainment system for children. We add interactive functions to the digital book. The system provides different haptic feedback for *Free Drawing*, *Contour Drawing* and *Touching Object* respectively[11].

6 DISCUSSION

From the trials and errors in the experiments, subjects' comments and visitors' responses, we find several issues to be discussed. Many people point out that the impact generator has a weak output force. We may solve this problem by increasing supplying current or by installing a bigger actuator. But we think differently. When we grasp the actuator directly with naked finger, we feel strong impact. Therefore, miniaturization of the stylus will be a better solution. Miniaturization will increase transmitted energy to the user and decrease power consumption. Compared to vibration, impact has an advantage of controllability. Actually many haptic feedback interfaces adopt vibrators. Haptic feedback for button clicking and drag & drop has been realized using vibrators [8]. In general, typical vibrators operate for tens of milliseconds after turning off the input signal. It's called settling time. The settling time of vibrator is very long compared to the impact response. Therefore an impact actuator generates several tens discrete output signals per second and a vibrator does less than 10 per second.

7 CONCLUSION

The new stylus proving vibration, impact and sound feedback has been proposed. In this paper, we mainly focus on the effectiveness of haptic feedback including vibration and impact. For more systematic approach, we suggest a software architecture and API. And we present a new interaction scheme on the Windows graphical user interface based on haptic feedback events for

clicking, drag & drop, object handling, scrolling, highlighting, menu, etc. From conducting experiment, performance of the system has been assessed. And the field tests show supplementary point of view. The conclusion is that the haptic stylus improves usability of touch screen. It increases manipulation speed for some functions such as button clicking, file and text drag & drop, contributes to preciseness and makes user more comfortable. Productivity increase of at least 10% has been observed in some experiments. In addition, a simple interactive digital sketchbook has been implemented, which provides haptic and auditory feedback while drawing and touching objects. In the future, we will focus on miniaturization and psychophysical experiments.

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