An Investigation of the Relationship between Texture and Human Performance in Steering Tasks

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ABSTRACT

Steering law is a fundamental model for steering tasks. Many researchers have investigated it according to different input devices, difficulty of task, subjective bias and scale effect etc. However, there is little study about the effect of surface environments especially on the texture of the interaction surface. In this paper, we experimentally investigated users' performances with various surface textures in steering tasks. Five common but different materials were used to supply different textures. Several potential factors of friction are considered in this study. The results showed that texture has no significant effect on movement time. Users naturally and dynamically adjust their force to suit different textures. In a limited range, the smoother the surface is, the more trajectory errors were performed. Our evaluation also proved that different textures can affect user satisfaction significantly.

Author Keywords: Texture, haptic interface, steering task, friction coefficient, human performance.

ACM Classification Keywords:
H.5.2. Information interfaces and presentation: User interfaces.

INTRODUCTION

With the development of complex computer rendering technologies, widgets and user interfaces are now often featured as multi-dimensional objects with sophisticated textures and physical properties. However, the manipulation of those objects is still constrained by the same user interfaces, making it hard for users to feel the physical features of widgets in the real world. Texture is passive haptic feedback, as described in [1, 12], with many unique properties, (e.g., roughness, hardness, stickiness, thermal conductivity). Nowadays, Input devices are changing from traditional computer mouse to pen-based devices, such as tablet PCs, PDAs, mobile phones, and touch-based devices, such as Microsoft Surface, Apple IPhone. Many users complain that a tablet or display is too slippery for writing characters or drawing pictures on. In order to avoid such discomfort, some users put a sheet of paper on the surface of the tablet. With this additional media, users can simulate the touch of normal writing or drawing on paper. On the other hand, users may have different performances with different textures on various devices. Imagine that you walk from one place to another. Compare the movement times when you walk on ice to when you walk on an asphalt road. Obviously, the time taken to walk on ice is much longer than the time taken to walk the same distance on an asphalt road. People walk more comfortably with ground friction. However, when people walk on ice, they tend to slip since the coefficient of friction is very small, maybe even as low as zero.

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Different displays or surfaces (even human skin [10]) have different textures. We can imagine that high-resolution texture displays will be designed and widely used in the near future. There are many researchers [4, 8, 9, 15, 17, 18] trying to combine the gap between the physical and digital worlds with their material qualities. Harrison and Hudson [9] used actuator to adjust the textures of six materials and proposed different texture displays. Results showed that users could recognize 2-4 different textures. Robles and Wiberg [15] applied the texture property to tangible user interface design with a case study of Icehotel. Jung and Stolterman [8] proposed preliminary studies to investigate how the subject probed and perceived the material qualities of objects and discussed how to apply user preferences to the design of interaction techniques.

In this study, we asked how texture affects steering task performance. Although pen gestures [2, 3, 13, 14] have long been investigated by researchers and users had different experiences writing characters with different texture surfaces, no study reports an investigation into the relationship between texture and user performance and satisfaction. In this paper, we try to provide insight into this question and design an experimental study to investigate this relationship.

RELATED WORK

Steering law is derived from crossing law whose recursion is the same as the Fitts' Law [7], that is $MT=a+b\log_2(A/W+1)$, where MT is the movement time to cross through the tunnel, a and b are constants depending on devices, A is the path amplitude and W is the path width. Accot and Zhai [1] divided a tunnel into N parts. The steering task is composed of N parts of crossing tasks when N tends to infinity. Steering law $MT=a+ b\ (A/W)$ was proposed in that study.

There are several studies that include force factors into the steering law. Yang et al. [19] proposed a new haptic-steering model $MT=a+ b\ (A/(W+\eta \times S))$, where η is a constant determined by the intensity of guiding force, to predict movement time for steering tasks with guiding force. Results showed that the model was more accurate than the traditional one for predicting performance times with force. The effects of stiffness and control gain on user performance were investigated for elastic devices by Casiez and Vogel [5]. Results showed that control gain affected error rate and movement time significantly but there was no significant effect for stiffness on user performance. There has not been any study that investigated texture effect in steering tasks.

EXPERIMENT

Participants

12 right-handed university volunteers (9 males, 3 females, aged from 23 to 34 years) participated in the experiment. All participants had normal or corrected to normal vision. All of them had previous experience using a stylus and had medium to expert level computer experience.

Apparatus

The purpose of the experiment was to simulate how the texture affects the trajectory, movement time and error rate when subjects performed the task. Hollins et al. [11] chose 17 tactile stimuli to show how subjects mapped their judgments of texture into the perceptual dimension. According to that paper and also the input requirement, we selected several materials. Furthermore, even for the same material, different objects may have different textures. In this study, we compared five materials, A4 paper on top of the Wacom tablet (Paper), a hard plastic cover on top of the Wacom tablet (Hard cover), sandwiching several A4 papers between a soft plastic sheet and the Wacom tablet (Soft plastic), a thin plastic sheet on top of the Wacom tablet (Plastic), and a bare Wacom tablet surface (Tablet) (See Figure1).

The experiment was conducted on a 2.13GHz Intel Core2 CPU PC with Windows XP. A 17-inch 1024×768 monitor and Wacom inuos3 PTZ-431W connected to the PC. This Wacom tablet can detect the pressure (by force) with 1024 different levels corresponding to 0 - 4 Newton. The experimental software was developed with Java 6.0. In order to evaluate whether these five materials affected the accuracy and response time on the Wacom tablet, we did a pilot study before the experiment. In this pilot study, a tracing task was designed to evaluate accuracy and a pointing task was used to test response time. Results showed that both accuracy and response time were not affected by these materials.

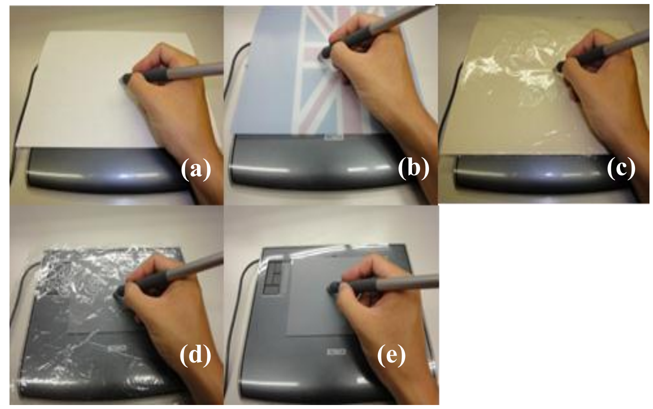

Figure 1. (a) Paper (b) Hard cover (c) Soft plastic (d) Plastic (e) Tablet.

Measurement of Coefficients of Friction

Since dynamic friction played a major role in the whole process of the steering task, we used the weight ratio method, which is the normal method used to measure the dynamic friction of all materials. The coefficients of dynamic friction are shown in Table 1.

Materials	Hard cover	Plastic	Tablet	Soft plastic	Paper
Coefficient of friction	0.081	0.126	0.153	0.233	0.295

Table 1. The coefficients of dynamic friction

Subjective Evaluation before the Experiment

There are also several factors which affect friction such as softness, pressure, speed, subjective factors and so on. The purpose of this measurement is to explore whether subjects can distinguish different textures among these five materials with a stylus. Participants with normal touch sense were seated in front of a desk. The subjects were asked to complete the experiment with their hand in a box to prevent participants using visual feedback to distinguish the different materials. Each subject estimated the roughness and smoothness of five surfaces with the stylus. We used the Thurstone paired comparison method [16] and designed the experiment to compare pairs of materials in each trial. There were 10 trials in this experiment.

After each trial, each participant was asked, “Which material was smoother?” and “Which material was softer?” If they could not distinguish the materials from each other, they were to answer, “Same”. The results produced a sequence from the smoothest to the roughest as follows: plastic, tablet, hard cover, soft plastic and paper. The sequence from the softest to the hardest was: soft plastic, paper, plastic, hard cover and tablet. The sequence of actual smoothness was not the same as in the subjective evaluation. The reason for this may be that the difference is too small and the coefficient value is not significant enough to the user, thus causing them to consistently perceive it differently.

Task & Procedure

A circular steering task (Figure 2) was used in this study. The direction of the circular steering task was always clockwise. Each experimental trial started after the cursor crossed the start line and ended by crossing the end line. Both start line and end line must be successfully crossed otherwise the trial failed. Participants were asked to move the cursor inside the tunnel and to finish the task as quickly and accurately as possible. If the cursor was out of the tunnel, an error feedback via a color change in the trajectory was triggered to warn participants. *MT* (movement time taken to move from the start line to the end line), *SD* (standard deviation of the distances between trajectory points and the center of the circular tunnel) and average pressure from the stylus' tip (detected by Wacom stylus) were measured in each trial. Before the experiment, the task was explained to the participants and they were asked to perform some warm-up trials until they were familiar with both the steering task and the different material types. They were asked to have a rest between blocks.

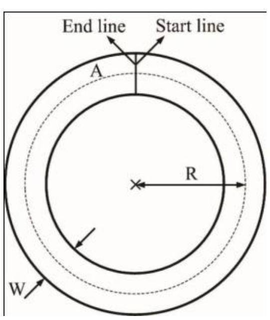

Figure 2. Experimental task

Design

We used a fully crossed within-subject factorial design. The independent variables were: *tunnel width W* (15, 30, 45 and 60 pixels), *tunnel amplitude A* (300, 450, 600, and 750 pixels), and *material type* (Paper, Hard cover, Plastic, Soft plastic and Tablet), 3 *blocks.* The presentation orders of the material types were counterbalanced across participants. The five different materials were taped on the top of Wacom tablet.

All participants conducted the experiment in sitting postures. Within each *material type*, the participants performed all combinations of *tunnel widths* and *tunnel amplitudes* presented in random order, each for 3 trials.

In summary, the experiment consisted of:

8 participants ×
5 material types ×
4 tunnel widths ×
3 trials ×
4 tunnel amplitudes ×
3 blocks
= 5760 times in total.

The experiment took approximately 40 minutes per participant. After the experiment, participants completed a questionnaire to rate their subjective preferences for the material types.

Hypotheses

H1. Different material type affects movement time significantly.

H2. Under the same amount of movement time in a steering task, the lower the coefficient of friction, the more errors users perform.

RESULTS

After analyzing the data, we found when the index of difficulty (*ID= A/W*) was higher, some participants could not finish the task correctly. Based on Accot and Zhai [1], if the cursor was out of the tunnel, the task was not considered to be the steering task any more. Therefore, we removed that part from the data. 88% of trials were successful. Finally, 8 participants' data were used for analysis in this study.

Movement Time (MT)

In contrast to H1, a repeated-measure ANOVA showed that there was no significant main effect for material types ($F_{4,28} = 2.296$, $p = 0.084$). This meant that the average speed that users took to perform the task was almost the same. As shown in Figure 3, the overall average movement time was 2051 ms.

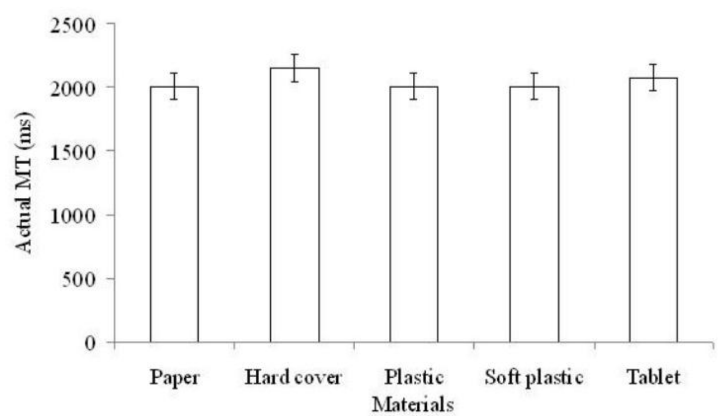

Figure 3. Mean MT by different material types (Error bars represent 95% confidence interval).

Standard Deviation (SD)

A repeated-measure ANOVA showed there was a significant main effect for material types ($F_{4, 28} = 8.859$, $p = <0.001$). As Figure 4 illustrated, the sequence from the biggest *SD* to shortest *SD* was plastic, tablet, hard cover, paper and Soft plastic, thus confirming hypothesis H2. An interesting phenomenon was that the subjective smoothness sequence was almost the same as this *SD* sequence (except the soft plastic). It showed that, within the range of coefficients of friction, the smoother the surface is, the more error trajectory user performs.

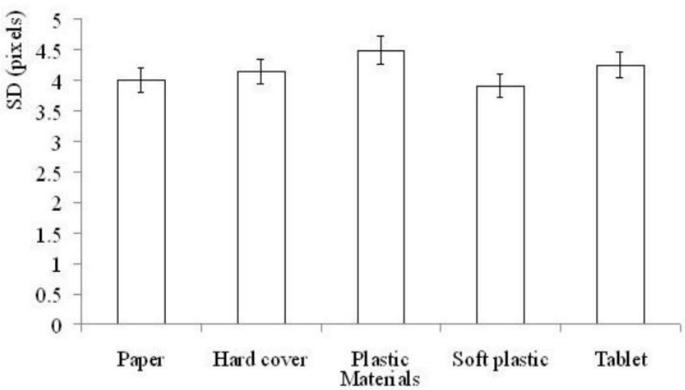

Figure 4. Mean SD by different material types (Error bars represent 95% confidence interval).

Pressure

A repeated-measure ANOVA showed there was a significant main effect for material types ($F_{4, 28} = 3.681$, p=.016). As Figure 5 illustrated, the sequence from the biggest pressure to lightest pressure was hard cover, paper, tablet, soft plastic and plastic. This showed another interesting phenomenon that each participant may use different forces to do steering task. It can be explained as such: each participant has a different comprehension of the task demand [21] which they should finish task as fast and accurately as possible. When there were several different textures, participants tried to keep the speed and accuracy as they thought. So they dynamically adjusted their behavior and their forces to suit the texture. Subjective bias played a role in it and covered the effect of texture. This also maybe the reason why there was no significant effect on from material types on *MT*.

Fitts' Law Analysis

A linear regression of *MT* by *ID* for each material was summarized in Table 2. The results of linear regression for each materials suggested the information capabilities (described by *1/b*) [20] of same devices with different texture surfaces were almost the same.

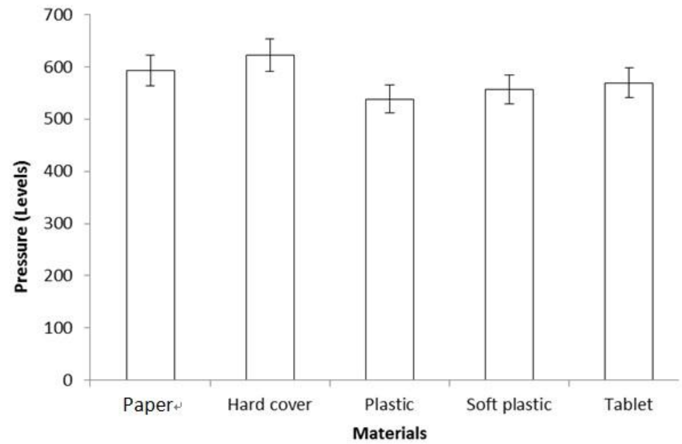

Figure 5. Mean pressure by different material types (Error bars represent 95% confidence interval).

Materials	a (ms)	b(ms/bit)	r^2
Paper	23.85	125.54	0.992
Hard cover	152.65	126.97	0.994
Plastic	132.23	125.37	0.996
Soft plastic	140.87	119.47	0.991
Tablet	123.27	128.58	0.997

Table 2. Steering Law regression values for material types.

Subjective Evaluation

We used two dimensions which were ease-of-use and accuracy to evaluate the five materials subjectively. Participants were asked to rate these materials using a 7 – point Likert scale (7 for best, and 1 for worst). As shown in Figure 6, most participants liked paper and disliked plastic. Most of them reported "It is comfortable to steer on the paper" and it is the most "natural" material and most suitable for a stylus. One participant said that "plastic is too slippery for me and I can't have precise control over the stylus".

CONCLUSION & FUTURE WORK

Haptics is one of the people's modalities that has been investigated and exploited in human-computer interaction. Due to the limitation of hardware that produces haptic feedback, most haptic feedback is vibration (supplied by a motor) and force feedback (supplied by Phantom and CyberGlove). Texture reveals the status of the target and increases the interaction information. This factor plays a significant role in pen-based interfaces. This study is an initial contribution to the investigation of the effect of texture in steering tasks.

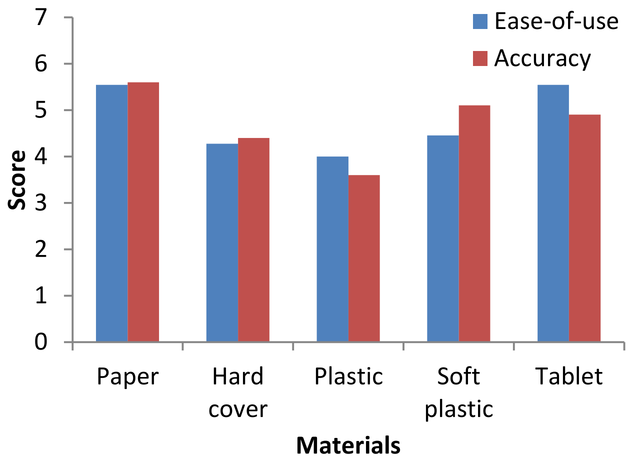

Figure 6. Subjective evaluation of ease-of-use and accuracy.

The movement time results indicated that texture did not affect the time significantly as expected in hypothesis 1. One of the potential reasons is that the circle steering task is not sensitive enough to detect the relationship between movement time and the friction of materials. In further work, we will use different tasks to explore the effect of texture. Another potential reason is that users dynamically changed the force they applied to suit the different textures according to the task demand that they should perform the task as quickly and accurately as possible. In order to get the larger anti-friction force to assist movement, users have to apply greater force to the tablet surface and therefore the delay of movement is overcome.

The accuracy results show that texture had a significant main effect on standard deviation which was a symbol of accuracy. Under the same amount of movement time in a steering task, the lower the coefficient of friction, the more errors users performed. Considering pressure and subjective evaluation together, the more the user applies force, the more accurately they performed. For the rough material, users controlled the pen actively applying greater force. However, for the slippery material, users had to reduce the force to reduce uncontrolled slippage. The movement of the pen was much more affected by rough the material than by the slippery material. Therefore, the trajectory achieved with the rough surface was much more accurate.

All results from the experiments show that the relationship between MT and ID obeyed the steering law. The changes of constant a and b revealed adjustments when using different materials. Subjective evaluation showed that most users preferred paper and disliked plastic. We observed that, in the pilot study of subjective evaluations, the sequence from the smoothest to the roughest was: plastic, tablet, hard cover, soft plastic and paper. This means that most users preferred rough material but disliked slippery material. It can be stated as follows: users can control the movement of a pen tip fluently with greater force on a rough surface. Another potential reason is that paper has long been familiar to users. This long experience and natural knowledge makes this result likely.

This research investigates the effect of texture in steering tasks. As information communicating between humans and computers increase, it is critical that we explore and apply different modalities of the human being into interactive interfaces. This work gives a basic understanding of this kind of haptic feedback. Our findings are the more significant because they demonstrate that the common glass surface of most tablet surfaces is not the best kind of surface for optimum accuracy or for user satisfaction. It suggests that user should change different textures to get natural and realistic haptic feedback according to the different tasks and personal preferences. In the future, we also want to use gesture tasks to investigate the effect of different textures.

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