Effective use of simulated force-feedback in a pointing task

A comparison of force-feedback, simulated force-feedback and standard feedback in a Fitts' type pointing task using a mouse-type device

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ABSTRACT
A method was developed to simulate force-feedback without taking resort to special feedback devices. In this paper, the effectiveness of this simulated force-feedback is measured. Three different feedback modalities are compared in a target acquisition task. The modalities are simulated force-feedback, actual force-feedback and no feedback. The functioning of force-feedback device is simulated with tiny displacements on the cursor position. This method exploits the domination of the visual over the haptic domain. Results show that simulated force-feedback can replace force-feedback in target acquisition tasks.

Keywords
Force-feedback, multi-modal, simulation, interactive animation, natural interfaces, haptics, multisensory perception.

INTRODUCTION
The vast majority of current graphical user interfaces involve manipulation of onscreen artefacts with a mouse controlled cursor [19]. The mouse is the dominant pointing and selecting device and has become the most frequently handled device in many people's daily lives. More frequent than cash, the steering wheel, doorknobs, pens, hammers, or screw drivers [25]. The most basic mouse task is the point/click action. A small improvement in this common task is a huge improvement in interaction design.
The efficiency of the target select operation can be described using Fitts law [14,15,18], that describes the influence of the size and distance of the target on the selection time. Much research has been conducted using Fitts law [8,13,19].
In a previous paper [22] we presented a method to evoke tactile sensations like stickiness, touch, or mass in a user interface without taking resort to special haptic input/output devices. In the current experiment we will evaluate the effectiveness of our method in a Fitts' law based target-acquisition experiment. Simulated force-feedback is compared to actual force-feedback and to the condition without feedback.

FORCE-FEEDBACK Vs SIMULATED FEEDBACK
Touch can play a powerful role in communication. It can offer an immediacy and intimacy unparalleled by words or images.[6,7]. It has often been suggested that improvements in this domain could lead to more natural computer interfaces [4,5]. Research in human-computer interfaces has addressed this issue with the development and evaluation of several force-feedback devices [2,3,9,11,17,21,23]. These devices are used to simulate a wide rang of object dynamics such as elasticity, hardness, and stiffness. Although many force-feedback devices are commercially available, they are not part of the standard desktop set-up. Not much software is therefore developed that utilises direct haptic feedback as a primary communication channel.

Active Cursor
The active cursor method [22] evokes tactile sensations without taking resort to special haptic input/output devices. Interactive animations are used to simulate the functioning of force-feedback devices. We simulate the functioning of a force-feedback device with tiny displacements on the cursor position. This method exploits the domination of the visual over the haptic domain. The cursor displacements evoke tactile sensations like stickiness, touch, or mass. This system has a lot in common with existing force-feedback

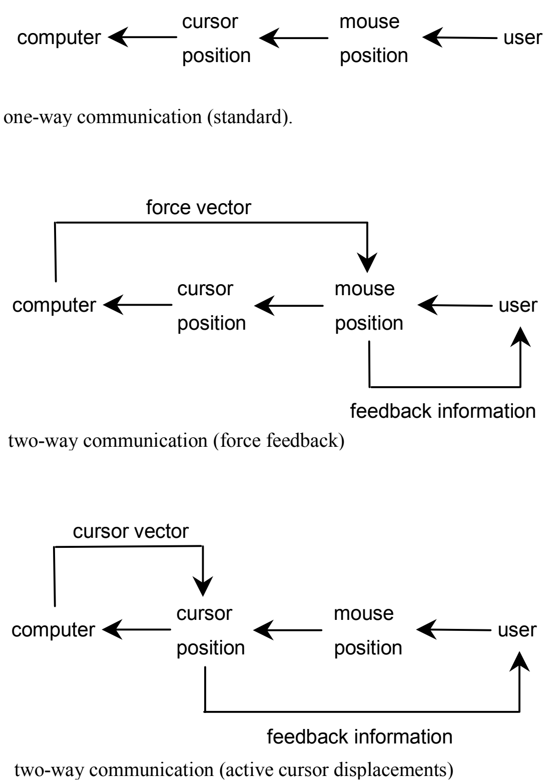

Figure 1 Communication dialog for standard setup, force-feedback setup and active cursor setup.

systems, except for the fact that in force-feedback systems the location of the cursor is manipulated as a result of the force sent to the haptic display, whereas in our system the cursor location is directly manipulated (figure 1). Since direct two way communication through the pointing device has proved successful with haptic devices, it seems reasonable to expect benefits from direct communication through cursor positions.

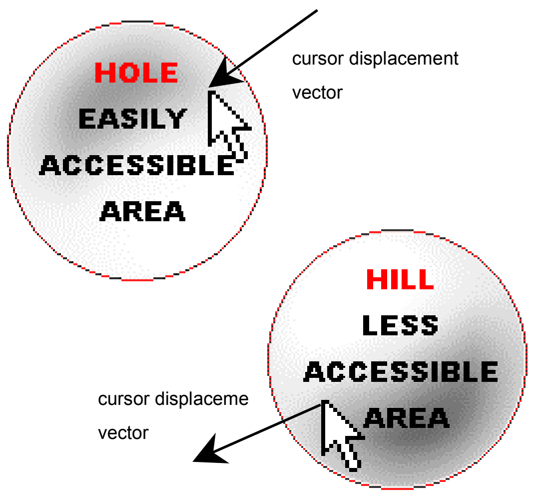

Figure 2 active cursor simulations of a hole and a hill

Among the virtual haptic objects we created are 'holes' and 'hills'. If the cursor rolls over a hole, it is dragged towards the centre. When rolling over a hill, the cursor is dragged away from the centre (figure 2). The active cursor can guide the user towards preferred positions or communicate properties of the interface to the user. Due to these cursor displacements a hole becomes an easily accessible part of the screen whereas a hill area is hard to access. This sort contextual feedback communicates in a very direct and intuitive way. Like with force-feedback devices, it is possible to create any 3d slope as well as dynamic slopes and textures. In the current experiment hole-typed shapes are placed underneath the targets to increase their accessibility. An interactive demo of the active cursor method is online at http://www.koert.com/work/activecursor/ (a shockwave plugin is required).

METHOD

Subjects

Thirty volunteer subjects participated in the experiment. The subjects were .. male and .. female., raging in age from 18 to 34. All subjects were regular users of mice in their daily work. None of the subjects had experience with force-feedback mice or active cursor feedback. The subjects were not informed about the goal of the experiments in advance.

Apparatus

The experiment was conducted using the Logitech Wingman force-feedback mouse. A mouse attached to a mouse pad that replaces the mouse mat and contains two motors used to provide force-feedback to the user [24]. This mouse was used in all conditions. The host computer was a pentium II class PC with a screen resolution of 1024x768 on a 17inch monitor. The data was collected with 1 pixel and 1ms resolution and saved in output files for subsequent analysis. Subjects sat in a special isolation room while the experimenter sat in an adjoining room.

Procedure

Subjects performed a simple target selection task. The experimental screen consisted of a start circle in the middle of the display. Once the start circle was clicked the first target appeared. The second target appeared after the first target was clicked. Movements were made in eight directions. Up, down, left, right and diagonal under an angles of 45 degrees. Subjects were instructed to move the cursor to the target and select the target by pressing the left mouse button. They were asked to do this in a normal tempo, as they would do in a normal desktop setting. They were not informed in advance about the different feedback modalities. After the experiment they were asked if they experienced different types of feedback and what ones they preferred.

DESIGN

The experiment was a 3x4x3x3 fully within subjects repeated measures design. The factors and levels were as follows:

TARGET DISTANCE	72,144,288 pixels
TARGET SIZE	10,20,40,80 pixels
TARGET DIRECTION	horizontal (2x), vertical (2x), diagonal(4x)
FEEDBACK	force-feedback, simulated, normal

These conditions create a range of task difficulties typical of point-select tasks. A common metric for task difficulty is Fitts' index of difficulty (ID) measured in bits [14,15]. A model of human movement based on rapid, aimed movement. It makes sense that response time would be affected by the distance moved and the precision demanded by the size of the target to which one is moving. According to Fitts' law, the time (MT) to move to and select a target of width W which lies at distance (or amplitude) A is

$$MT = a + b\log_2\left(\frac{2A}{W}\right) \qquad [\mathrm{sec}] \quad (1)$$

where a and b are constants determined through linear regression. W corresponds to *accuracy*. The log term is the index of difficulty and carries the unit bits. In the current experiment, we use the Shannon formulation [18,20], as follows.

$$ID = \log_2\left(\frac{A}{W}+1\right) \quad [bits] \quad (2)$$

with ID=Index of Difficulty [Bits]
A=distance of target or amplitude [pixels]
W=width of target [pixels]

Using Equation 2, the task ranged from

$$ID = \log_2\left(\frac{72}{80}+1\right) = 0{,}93 \quad [bits] \qquad (3)$$

for the easiest task with a target size of 80 and a distance of 72 pixels. And an index of difficulty

$$ID = \log_2\left(\frac{288}{10}+1\right) = 4{,}09 \quad [bits] \qquad (4)$$

for the hardest task with a target of size 10 at a distance of 288 pixels. The relation between the index of difficulty and the actual movement time gives a measure for the performance of a user.

$$IP = \left(\frac{ID}{MT}\right) \quad [{}^{bits}\!/_{sec}] \quad (5)$$

For the normal feedback condition, target entry was indicated only through the displayed image of the cursors path. No additional feedback was provided. For the force-feedback condition, the motors in the Logitech Wingman force-feedback mouse were used to create a hole-shaped force-field above the target, pushing the cursor towards the centre of the target. In the simulated feedback modality the same force-field was simulated with cursor displacements. The size of the force-field was the same as the target icon size (figure 2). Each subject participated in three groups of three sessions. Each group consisted of one session for each feedback condition. The first group (three sessions) served to familiarize the subjects with the experiment. Only the data from the second and third group (six sessions) were analysed. All six possible orders of the three feedback conditions were used to counterbalance order and learning effects. Subjects were assigned randomly to two orders, performing one order in the second group of sessions and one in the third group. In each session the subjects received, in random order, the three feedback modalities.

Experiment 648 target clicks (216 learning, 432 used in analysis)								
Group 0 (216 targets, 3 modalities, learning)			Group 1 (216 targets, 3 modalities)			Group 2 (216 targets, 3 modalities		
Ses. 1 Force 72targ.	Ses. 2 None 72targ.	Ses. 3 Visual 72targ.	Ses. 1 None 72targ	Ses. 2 Visual 72targ.	Ses. 3 Force 72targ.	Ses. 1 Visual 72targ.	Ses. 2 Force 72targ	Ses. 3 None 72targ
3 dist 4 size 3 dir. 2 rep.	3 dist 4 size 3 dir. 2 rep.	3 dist 4 size 3 dir. 2 rep.	3 dist 4 size 3 dir. 2 rep.	3 dist 4 size 3 dir. 2 rep.	3 dist 4 size 3 dir. 2 rep.	3 dist 4 size 3 dir. 2 rep.	3 dist 4 size 3 dir. 2 rep.	3 dist 4 size 3 dir. 2 rep.

figure 3 Experiment structure, example of a possible experiment. In each session 72 targets were presented at 3 distances, 4 sizes, 3 directions and 2 repetitions.

RESULTS AND DISCUSION

Movement time

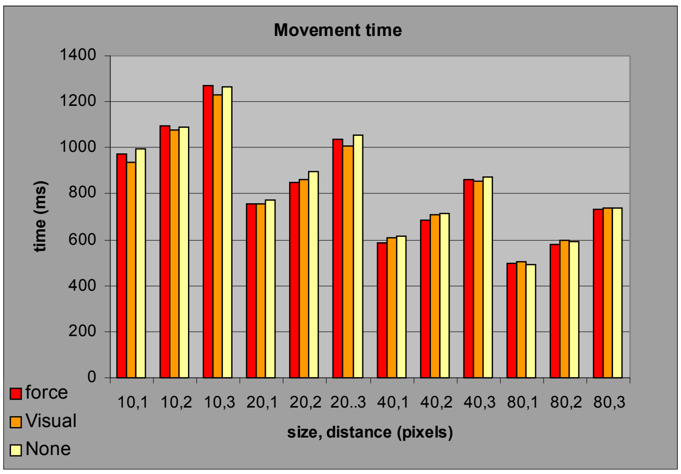

figure 4 movement time for all conditions.

The effect of the three feedback modalities on the movement time can be derived from figure 4. As expected, the movement times are highest for the condition without feedback. They are smaller for the force-feedback condition and the simulated condition without feedback. For smaller targets the movement times of the simulated feedback are the lowest whereas in bigger targets the force-feedback condition was clicked slightly faster.

Index of performance

The index of performance is calculated from the movement time. In figure 5 the IP is shown for the three modalities and three target sizes. Distances are omitted here.

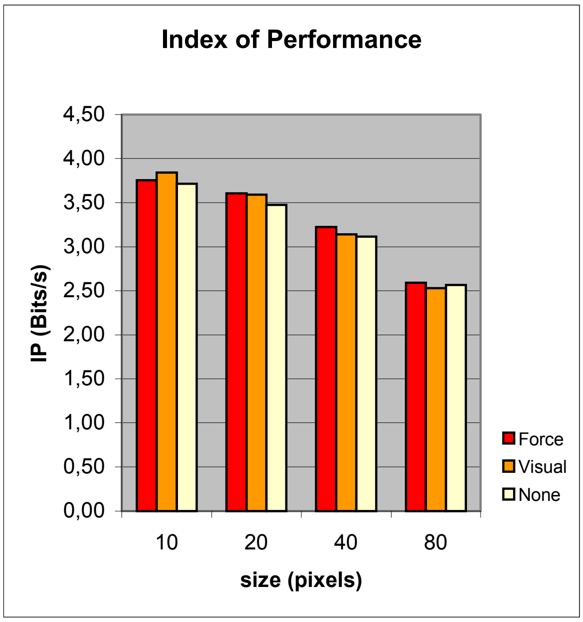

figure 5 index of performance for different sizes

Error rate

Error rate is defined as the percentage of mouse clicks that misses the target. Error rates are the lowest for the simulated condition 3.07%. With the force-feedback the subjects had an error rate of 3.37% whereas the error rate in the condition without feedback is the highest: 3,94%. We did not expect error rates to be lower for the simulated feedback than for force-feedback. The performance regarding error rate of simulated feedback is significantly better than real force feedback.

User Preference

The majority of the subjects preferred simulated force-feedback before force-feedback and the condition without feedback. Some of the subjects could not specify the difference between the three modalities that were in the experiment. There were no correlations found between preference and movement times.

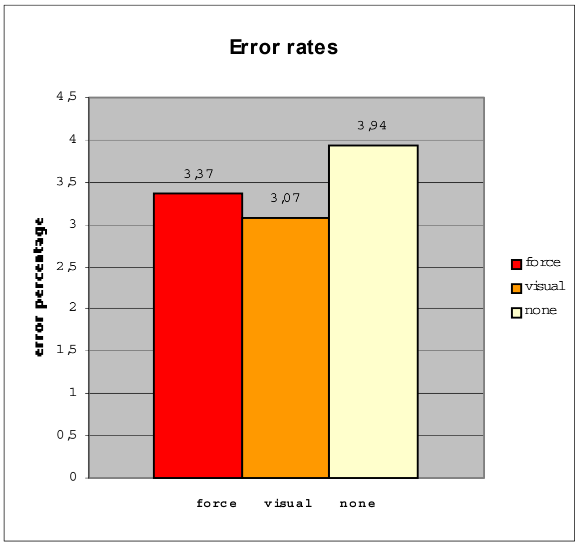

figure 6 Error rates

DISCUSSION

This research compared force-feedback with simulated force-feedback (tactile effects induced with cursor displacements). The effectiveness of the feedback modalities were compared in a target acquisition experiment. The condition without feedback was included for reference. The three feedback modalities were varied with target distance and size. Earlier research [1,11] pointed out that force-feedback can improve the effectiveness of a target selection tasks. This study points out that visually simulated feedback can replace force-feedback in target selection tasks. The effectiveness of simulated force-feedback is similar or even better than force feedback. In some situations we showed that simulated feedback is more effective. This appears to be the case especially for smaller targets. For bigger targets is it is somewhat less effective. We believe this to be a trade off between the activation of the haptic modality. The lower performance of force-feedback on smaller targets might be caused by the activation of the force modality. The performance regarding error rate of simulated feedback is significantly better then real force feedback. Error rates are significantly lower for the simulated condition (3.07%) than with the force-feedback (3.37%) and the condition without feedback (3.94%). We do not have a solid explanation for this effect. We expect that the higher error rate is an effect of the activation of the force modality. Further research is needed in on this effect. Current research shows the effectiveness of simulated force-feedback in a simple pointing task. It may seem remarkable that one can "see" the forces acting on a manipulated object and that feeling the forces can, for small objects, even be distracting. On the other hand, in common situations the forces on small objects can be really weak and, especially if one only looks at objects and does not touch them; one may derive the forces acting on an object from seeing its movements. Such a situation arises when the manipulations are carried out by a

person different from the observer. The observer may, in that case, infer the presence of forces from the movements by the objects causes by someone else. For these situations it is beneficial to have the facility to infer the presence of forces acting on an object from the movements only seen and not also felt.

Conclusion

We conclude that simulated force-feedback is a good alternative for force-feedback in target selection tasks. In some respects, e.g. for smaller targets, it works even better than force feedback. Simulated force-feedback results in lower error rates and a higher index of performance for smaller targets. For bigger targets, real force-feedback resulted in lower movement times. From our data we derive that the optimal feedback modality could be found in a combination of simulated and real force feedback. The lower performance of force-feedback on smaller targets might be caused by the activation of the force modality. Therefore, we expect simulated force-feedback can play a role in the smoothening of force-feedback effects. Although the majority of the subjects preferred simulated force-feedback over force-feedback and the condition without feedback, simulated feedback is not expected to replace haptic feedback in general. We have only measured the effectiveness, not involvement or presence. All these factors are omitted in the current experiment. In more complex haptic dialog the results of the haptic simulation might turn out less successful. The *communicative* role of haptic feedback in the current target selection task is very limited. Touch can play a powerful role in communication. It can offer an immediacy and intimacy unparalleled by words or images. The firm handshake, an encouraging pat on the back, a comforting hug, all speaks to the profound expressiveness of physical contact. In the real world, touch can further serve as a powerful mechanism for reinforcing trust and establishing group bonding [6,7]. Further research is needed to learn more about simulating force feedback. Frequent use of simulated force-feedback could lead to motion sickness. Future experiments need to be conducted to learn if there are drawbacks on the use of simulated force feedback. Some constraints are already clear. The effect of simulated touch can be applied only in combination with a visual display.

Future work

Further research into the potential of simulated force-feedback is needed. Current research only measured the *effectiveness* of the simulation. Future work deals with the evaluation of the *experience* of simulated haptic feedback. What force do users feel with there eyes and where in the sensation, perception, cognition path does this effect occur? This can be measured through perceptual tasks such as discrimination of force experiments. It is interesting to speculate what the role of sound might be in these situations. Another important research path is the *design* of interaction styles that use (simulated) force feedback.

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