Haptic Feedback in Remote Pointing

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Abstract
We investigate the use of haptic feedback for enhancing user performance with remote pointing devices. We present a number of concepts that use haptic feedback on such devices and the results of the first user study, in which we have compared the effects of different feedback types on users' performance and preference in remote pointing tasks. The study showed that the addition of haptic feedback significantly improves the performance, while it has also revealed a seemingly low user acceptance of haptic feedback. We discuss the implications of our findings and outline the future work.

Keywords
Remote pointing, haptic feedback, target acquisition

ACM Classification Keywords
H5.2. Information interfaces and presentation (e.g., HCI): Input devices and strategies, Interaction styles, Haptic I/O.

Introduction
New developments, most notably the rapid increase of the number and capacity of broadband Internet connections, have enabled the TV to grow beyond one-way communication of media. IPTV (Internet Protocol Television) provides functionality such as video-on-demand, an electronic program guide, integrated or networked recording possibilities, personal media

libraries, games, Internet browsing et cetera. This led to an increased complexity of the TV's interface, making it difficult to control with a conventional remote control that can only provide discrete manipulations. As the TV becomes much like a personal computer, a direct manipulation interaction style similar to that of the PC is preferred. Unlike the PC, a TV is usually operated from a distance, and often by a device that is held in mid-air. Therefore, standard interaction devices such as the mouse do not usually fit the traditional style of TV watching.

In the meantime, there is a growing number of remote pointing devices on the market, for example the Gyration GYR4101 Universal Remote Control, Logitech MX Air Mouse, Nintendo WiiMote, et cetera. It has been shown however, that on average remote pointing is slower than other types of pointing methods [7,8]. One possible way to improve the performance is by providing additional feedback. For example it has been shown that additional feedback in either aural form or tactile/haptic form can improve the users' performance when using a stylus [1,4]. Since no physical feedback is inherently present in remote pointing devices, testing haptic feedback on the remote device itself had our specific interest. We assumed that at least visual feedback would always be present in those applications we were interested in, so our initial question was whether or not the *addition* of haptic feedback would prove to be advantageous, and set out to compare this to the addition of aural feedback and to having only visual feedback.

Definition of Haptic Feedback

Several different definitions of haptic and tactile feedback can be found in the literature [12,13], but none seem to be conclusive or commonly accepted. The terms are used interchangeably. To avoid confusion we would like to propose the following definitions which have been adapted from a similar definition proposed by Subramanian et al. [12].

HAPTIC: We speak of haptic feedback when the kinesthetic sense, the sense generated by receptors in muscles, tendons and joints, plays the primary role in the perception of the feedback. Haptic feedback would be the kind that actively displaces body parts, tries to displace them, or prevents them from being displaced as for example force feedback can. In effect, the felt sensations come from internal stimuli, only indirectly caused by external stimuli – the device's haptic feedback.

TACTILE: We define tactile feedback as the kind that is sensed only or primarily by the exteroceptive (generated by external stimuli) sense *touch*. This feedback is generally less forceful and restricted to the surface of the skin.

Related Work

A large number of pointing interaction techniques and devices has been developed for remote interaction with large displays. For example, TractorBeam [10] is a hybrid point-touch technique that allows users to reach distant objects on tabletop displays. Soap [3] is a pointing device that is based on an optical mouse but can be operated in a mid-air. Another example is Laser pointing introduced in [9]. There are also a number of commercially available pointing devices. Only a limited amount of these employ tactile or haptic feedback [5,6,13] for improving the interaction, usually relying only on visual feedback on the display.

Tactile and haptic feedback in general has been extensively explored in order to improve the interaction in different situations [1,2,4-6,11,12,14]. One notable example is the Haptic Pen introduced in [6] which is a pressure-sensitive stylus combined with a small solenoid to generate a wide range of haptic sensations. The study reported in [4] showed that simple pointing tasks can be performed faster with haptic feedback than with only visual feedback. Poupyrev et al. [11] describe similar findings. Positive results have also been found using the wUbi-Pen [5], which is capable of providing feedback in the form of vibration, impact, texture and sound. In all these cases however, the stylus needed to either touch or be in a close proximity to the display surface.

The Nintendo WiiMote can serve as a remote pointer, and comes equipped with tactile feedback capabilities provided by a vibration motor. Unfortunately, the motor has a slow startup time (estimated through pilot studies to be 70ms in model RVL-003) and has limited feedback capability. A vibration motor is only capable of providing one single type of feedback, as opposed to a solenoid, that [6] showed to be capable of mimicking a number of different actions.

Haptic Feedback in Remote Pointing

Haptic feedback in remote pointing is an as of yet unexplored area which we believe may have the potential to both enhance current interaction styles as well as create entirely new ones. To achieve this, careful research and design is needed as haptic feedback could also cause a decrease in performance, for example by increasing the device's jitter and thus affecting its precision.

Remote pointing tasks can be enriched by providing a haptic or tactile cue in certain situations. As a diverse range of such cues is available, it can cater to many different situations: confirmation on completion, warning on error, continuous analog feedback on a certain value, et cetera. A combination of these can lead to a primarily haptics-based interface.

In two dimensions, a system could aid people in performing complex in-air gestures for example by giving cues when they are off-course and/or have reached a node (and need to change pattern, shape or direction). It is not hard to imagine this idea being extended into three dimensions, enabling people to sense virtual objects in thin air. Such implementations may be particularly attractive to blind people or to the realm of ubiquitous computing.

Haptic feedback can also have a negative effect on performance. For example, since the device is operated in the air, haptic feedback could displace the device which would lead to an increased number of errors. Therefore, the force and timing of the feedback should be carefully considered. Another challenge is power consumption, which needs to be addressed by finding an optimal amount of force that would create a perceivable sensation with minimal power consumption.

As a first step in exploring the effects of haptic feedback on remote pointing, we have performed a user study with a basic pointing task.

Study: Comparison of Visual, Aural and Haptic Feedbacks

The main goal of this study was to compare the effects of different feedback combinations on the users'

figure 1. Modified uWand. The arrow shows the direction of the haptic feedback as perceived by the user.

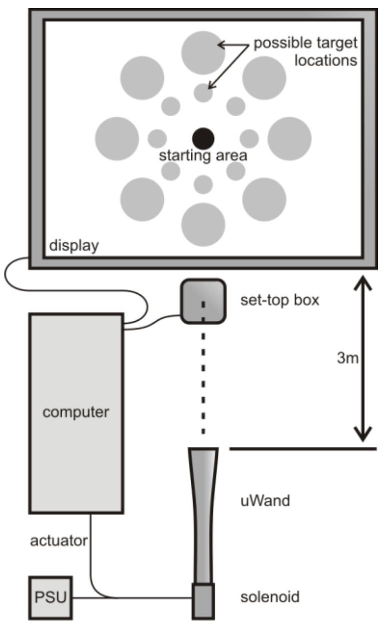

figure 2. Experimental setup.

performance and preference in a simple remote pointing task. Three different combinations of feedback types were tested in the experiment: visual only, visual with aural feedback and visual with haptic feedback.

Apparatus
The design of the remote pointing device was similar to the one described in [6]. Instead of a stylus, we used the uWand (www.uwand.com), to which we attached a solenoid (model BLP 68-121-710-721) in a small casing as shown in figure 1. The uWand is a novel pointing device for interactive TV. It is an absolute pointing device that uses LED technology to calculate where it is pointing at. As described in [6], different sensations can be simulated with the solenoid. We implemented only one type based on a single, 25ms, 18V impulse that creates a sensation of moving through a thin raised border by accelerating the solenoid's mass that then thrusts the uWand slightly towards the participant. Since the mass of the solenoid and uWand were comparable, the thrusting force (uWand acceleration) could be clearly felt.

The experiment was carried out using a display (size 64x48 cm, resolution 1024x768 px) connected to a PC. The modified uWand was used as an absolute pointing device taking control of the cursor. The distance between screen and the participant was fixed to 3 meters (figure 2). Participants were sitting down.

Tasks and stimuli
Figure 2 shows the experimental setup: a two-dimensional Fitts' law experiment using circular targets. Each task began with the starting area visible at the center of the screen, and a target area displayed semi-transparently. The participant needed to position the cursor inside the starting area and click the button on the uWand to start the trial. Once started, the target area became brighter while the starting area was reduced to an outline. When the target was acquired, the next task started. The distance to and size of the targets were varied, as was the required direction of movement. In case of an erroneous click outside the target area, the task had to be repeated. The visual feedback was provided in all conditions, and consisted of the moving cursor and the highlighting of the target area when the cursor was inside. Aural feedback (a short click) was provided through external speakers when the cursor crossed an area's border. The haptic feedback was provided on the same occasion: when crossing a border.

The experimental software recorded task completion time (movement time, MT), time on target (TT) and number of errors as dependent variables. The MT counter begins at the moment the user clicks on the starting position and stops when the user clicks inside the target area. TT is the time interval between the crossing of the target border and the click to acquire the target.

Procedure and Design
We carried out the experiment with 8 participants (3 females and 5 males, all right-handed) between the ages of 20 and 29. All subjects were tested individually. The experiment used a 3×2×2×8 within-factor design with a variety of planned comparisons. The independent variables were feedback: visual, visual + aural (also referred to as just *aural*) and visual + haptic (*haptic*), distance (10 and 16 cm / 160 and 256 px), target size (6 and 3 cm / 96 and 48 px), and movement direction (angles of 0, 45, 90, 135, 180, 225, 270 and 315

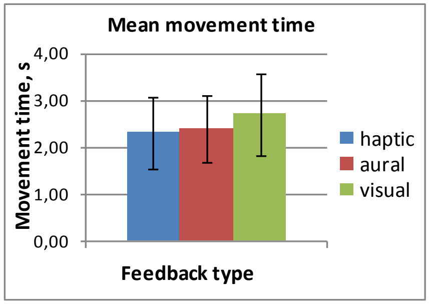

figure 3. Mean movement time and standard deviation

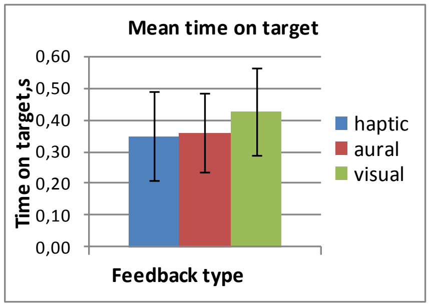

figure 4. Mean time on target and standard deviation.

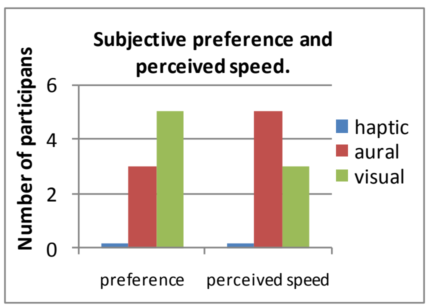

figure 5. Subjective preference and perceived speed.

degrees). The order of presentation of the different feedback combinations was balanced using a Latin-square design. The presentation of size, distance and angle was randomized, and each combination was presented four times per feedback type. We gathered a total of 384 trials per subject, taking each subject 30 minutes on average. In an exit questionnaire we asked participants to rank the different feedback combinations in order of preference and speed.

Results

We used the repeated measurement analysis of variance and Bonferroni post-hoc pair-wise tests for all our analyses.

MOVEMENT TIME: The average trial completion time was 2.48s (visual 2.71s, aural 2.39s, haptic 2.33s) with a standard deviation of 0.80s (figure 3). There was a difference in MT between the target distances, between the target sizes ($P<.001$) and between feedback types ($F(2,14)=8.265$, $P<0.01$). Pair-wise comparison showed that visual feedback was significantly slower than haptic, while we found no significant differences between aural & haptic pair and aural & visual pair. We found no significant differences between different movement directions (angles).

TIME ON TARGET: The average time on target was 0.38s (visual 0.43s, aural 0.36s, haptic 0.35) with a standard deviation of 0.14s (figure 4). Just like in MT there was a significant difference in TT between feedback types ($F(2,14)=10.745$, $P<0.01$). Pair-wise comparison showed that the visual feedback was significantly slower than both haptic and aural, while we found no significant differences between aural and haptic feedback. Further analysis of TT for small and large targets showed that for small targets the only significant difference was between aural and visual feedback, while for the large targets visual feedback was significantly slower than both haptic and aural.

ERROR RATE: The condition with visual feedback had the least average number of errors: ~24 errors per participant. Aural had ~40 errors per participant and haptic was the worst with ~47 errors per participant. The majority, 59%, of errors was done in trials with small targets.

USER PREFERENCE: Overall the participants preferred visual feedback (5/8). Aural was second (3/8) while haptic was never preferred (0/8). In terms of perceived speed users rated aural as fastest (5/8), then visual (3/8), and haptic as slowest (0/8).

Discussion and Future work

Results of the study have shown a discrepancy between the measured performance and the participants' preferences. In terms of time both aural and haptic feedback types performed better than visual, while in terms of user preference haptic feedback was rated last. Moreover, while haptic was actually the fastest technique, it was perceived as being the slowest. This may be because of a sensory overload as a result of a side-effect of the solenoid and its actuator (a relay): both made a sound when activated, in essence turning the visual + haptic combination into visual + haptic + aural. Some participants explicitly told us afterwards that this was too much, one mentioning he decided to pick one feedback type (visual) to focus on and discard the other stimuli. Another reason for low preference could be that the sensation from the haptic feedback was simply not pleasant.

In follow-up experiments we will better isolate the different types of feedbacks. We will also fine-tune the amplitude and duration of the impulse to create a more recognizable and pleasant haptic sensation.

Conclusions

In this paper we have outlined the first steps we have taken towards implementing haptic feedback in a remote pointing device. We have showed that haptic feedback can be beneficial in simple pointing tasks, but that more thorough design is required in order to improve users' acceptance and appreciation. We plan to perform a number of follow-up studies to more precisely measure the added value of the haptic feedback and to identify parameters that can improve both the performance and users' acceptance.

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