Haptic Feedback of Gaze Gestures with Glasses: Localization Accuracy and Effectiveness

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Abstract

Wearable devices including smart eyewear require new interaction methods between the device and the user. In this paper, we describe our work on the combined use of eye tracking for input and haptic (touch) stimulation for output with eyewear. Input with eyes can be achieved by utilizing gaze gestures which are predefined patterns of gaze movements identified as commands. The frame of the eyeglasses offers three natural contact points with the wearer's skin for haptic stimulation. The results of two user studies reported in this paper showed that stimulation moving between the contact points was easy for users to localize, and that the stimulation has potential to make the use of gaze gestures more efficient.

Author Keywords

Pervasive computing; wearable computing; gaze tracking; gaze gestures; haptics; haptic stimulation; smart eyewear; smart glasses.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction

The way we interact with computers will change in the near future due to the growing popularity of wearable devices such as smart eyeglasses. Glasses have only limited space for touch controls, and using speech for input hinders the privacy of interaction. This is why gaze could prove useful as an input channel with glasses. Gaze offers a more private path of communication, and eye movements can nowadays be tracked even in mobile use contexts. This is due to the recent introduction of wearable eye tracking devices by multiple manufacturers (e.g., Tobii and SMI).

Under ideal conditions head-worn gaze trackers can provide accurate estimations of the user's gaze point. The user can simply look at objects in real or augmented reality environment to select them. If the user looks at an object for longer than a predefined dwell time, the use of gaze can be interpreted as intentional and the object is selected and becomes gaze-operable. In practice, however, the accuracy of gaze data from mobile trackers tends to degrade, making it difficult to point at an object long enough. Recalibration of the tracker is a temporary fix but not always possible or desired.

An alternative to dwell-based selection is to use gaze gestures. Gaze gestures are based on relative eye movements that are less prone to difficulties caused by tracking inaccuracy [3]. With gaze gestures, the user can perform actions on an object by moving her gaze in a manner that can be separated from normal gaze movement. For example, a quick glance from an object to the left and then back at the object could lead to object selection. The complexity of gaze gestures is partly dependent on the number of strokes. A more

complex gesture could consist of shifting one's gaze around the corners of a square which results in a gesture with four strokes. If the number of strokes is high, separating the gesture from normal gaze movement is easier and fewer false positives can be expected. On the other hand, because performing gaze gestures consisting of several strokes is difficult especially for novice users, a small number of strokes could be preferred. Gaze gestures could also reduce the likelihood of unwanted selections that can take place with dwell time if the user looks at the object without an intention to select it.

While potentially effective, gaze gestures must be accompanied with sufficient feedback so that the user can perform them successfully. Giving visual feedback during a gesture may be distracting or difficult to perceive [4, 5]. In addition, visual feedback requires a screen which is not always available in a mobile condition. Hearing auditory feedback can also be problematic due to environmental noise. Therefore, we chose haptics as a feedback modality. Glasses that are worn on the user's body offer a convenient platform to incorporate technology for stimulating the skin. The human head is a touch sensitive body part that has to date been utilized scarcely as a haptic stimulation site. However, with careful design of vibrations, it is possible to provide information to a user by stimulating different areas of the head [1, 2, 8, 10].

In this paper, we study how gaze gestures can be combined with haptic feedback presented via glasses. We will start by introducing related work and then present results of two user studies. The first study was conducted to find out how accurately participants can localize haptic stimulation that moves between different

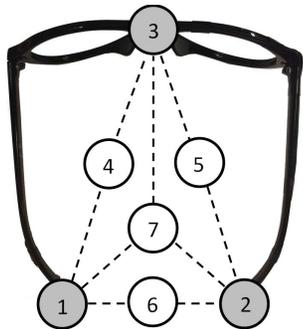**Figure 1**: The prototype glasses worn by a user.

Figure 2: The glasses shown from above to illustrate the three actuator locations in grey and the different stimuli used by Rantala et al. [8].

areas of the head. The second study combined this moving stimulation with two-stroke gaze gestures, and the goal was to evaluate whether participants can perform gestures more efficiently when they get haptic feedback during gaze movement. We conclude the paper by discussing our findings, possible use cases for this interaction technique, and our future research.

Localizing Haptic Stimulation Presented via Glasses

Rantala et al. [9] designed a wearable haptic feedback prototype (see Figure 1) based on a sunglass frame with lenses removed. They attached three small vibrotactile actuators (LVM8, Matsushita Electric Industrial Co., Japan) to the glasses so that two of them were attached to the tips of the temples and one on top of the bridge (see Figure 2). The frontal and temporal regions of the head are sensitive to vibration [8] and also natural contact points when wearing glasses. A 20-millisecond sine wave with a frequency of 150Hz was used to drive the actuators. Because of the short duration, the stimulation resembled a short tap rather than constant buzzing that can be annoying [6].

To evaluate how accurately users could localize stimulation from the three actuators, Rantala et al. conducted an experiment where participants felt stimulation either from a single point (circles 1-3 in Figure 2), from two points at the same time (4-6), or from three points at the same time (7). After the participants had felt a randomly chosen stimulus, their task was to indicate which of the three points were activated. The results showed that stimulation from one point was easier to localize (85-100% mean accuracy) than simultaneous stimulation from two points (57-65%) or three points (52%). This finding was in line

with earlier work indicating that localizing simultaneous points of haptic stimulation is more difficult than a single point [2]. One possible way to improve the stimulus design would be to introduce delays between the actuators so that only one location is active at a given time [10].

Associating Gaze Gestures with Stimulation from Glasses

In the same study, Rantala et al. also investigated how participants would associate haptic feedback with gaze gestures [9]. They used four different two-stroke gestures that required gaze movement from the initial position in the center of a display to one of the four main directions (*left*, *right*, *up*, or *down*) and then back to the initial position.

In a user study participants were instructed to try the four gaze gestures one at a time and then select haptic feedback separately for both strokes of the gesture if they felt that the feedback was helpful. The feedback was presented using the glasses shown in Figure 1. The gaze gestures were detected using a remote eye tracker (Tobii T60) placed on a tabletop because the glasses did not provide gaze tracking functionality.

The results showed that the majority of participants selected feedback only for the first stroke towards the borders of the display. Out of 12 participants, 11 associated the *left* gesture with feedback from the left side of the glasses and the *right* gesture with the right side of the glasses. For the *up* gesture 10 participants chose the front actuator, and for the *down* gesture 9 participants chose simultaneous stimulation from the left and right sides. These feedback choices indicated

that the participants preferred feedback congruent with the direction of gaze movement.

Study 1: Localizing Moving Haptic Stimulation

The aim of this study was to improve the haptic feedback design compared to that of Rantala et al. [9] where it was shown that localizing simultaneous points of haptic stimulation is difficult. We added a short delay between stimulation from two actuators and conducted a user study to evaluate how this change affected user's capability to localize the stimulation.

Participants
A total of 16 volunteers (aged between 19 and 41 years, average 23 years) took part in the study. All participants were from the University community and reported having normal sense of touch. Only one of them was familiar with gaze tracking technology, while all had experience of haptic feedback. The prototype glasses could not be worn with regular glasses, so we only recruited participants who had good enough eyesight to see the display without difficulties.

Apparatus & Haptic Stimuli
The glasses used by Rantala et al. [9] were utilized also in this study. Two actuators attached to the temples of the glasses provided stimulation that was felt behind the ears. The third actuator stimulated the nose and forehead. The actuators presented six different patterns that consisted of subsequent stimuli from two actuators. A delay of 400 milliseconds was set between the onsets of the stimuli. With this approach, we created the following patterns: left → right, right → left, left → front, front → left, right → front, and front → right (see Figure 3).
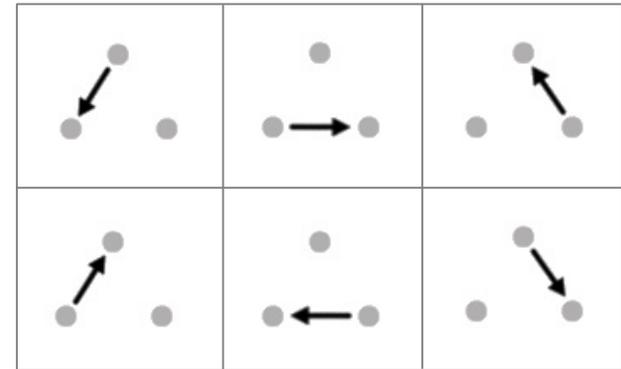

Figure 3: The six haptic patterns tested in Study 1. The patterns consisted of two subsequent stimuli. For example, the pattern shown in the top left corner was first felt on the nose/forehead and then behind the left ear.

Each actuator was driven using a 150Hz sine wave with a duration of 20 milliseconds. The amplitude of stimulation was identical for all three actuators. Audio signals were created in Pure Data (PD) and then fed to the actuators through a Gigaport HD USB sound card. A custom Java application was used to record participant's responses. The PD and Java applications ran on a PC (Intel Core i5-2520M, 8GB, Windows 7).

Procedure
The participants were first seated in front of a computer display and instructed to wear the prototype glasses. Each stimulus pattern was presented four times in a random order (6 patterns × 4 repeats = 24 trials). After sensing a stimulus pattern, the participants' task was to select one of the response icons shown in Figure 3. The next pattern was presented after a 5-second delay. Once all the trials were completed, we asked the participants to rate how they perceived the haptic stimulation in terms of its pleasantness (unpleasant–

pleasant) and intensity (too low–too high). This was done separately for each actuator using bipolar rating scales ranging from −4 to +4.

Results
The results indicated that 15 out of 16 participants localized all sequences perfectly, and the mean localization accuracy was 99%. The single error was caused by the right → front pattern.

The mean ratings for perceived stimulus intensity and pleasantness are shown in Table 1. For the ratings of intensity, a Friedman test showed no statistically significant differences between the locations. For the ratings of pleasantness, a Friedman test showed a statistically significant effect of actuator location (X^2 = 17.4, p < 0.01). Pairwise comparisons performed with Wilcoxon signed-rank tests showed that the participants rated stimulation of the front actuator as significantly more unpleasant than stimulation of the left actuator (Z = 2.7, p < 0.01) and the right actuator (Z = 2.7, p < 0.01).

Actuator location	Intensity		Pleasantness	
	Mean	SD	Mean	SD
Left	0	0.7	1	1.2
Front	-0.5	1.8	-0.2	1.2
Right	0.3	0.9	1.1	1.3

Table 1. The mean ratings and standard deviations for perceived stimulus intensity and pleasantness for the three actuator locations.

Study 2: Effect of Haptic Feedback on Performing Gaze Gestures

In the second study our aim was to find out whether users can perform gaze gestures faster when they get haptic feedback during gaze movement.

Participants
A total of 12 volunteers (aged between 19 and 27 years, average 22 years) recruited from the University community took part in Study 2. Ten of the volunteers had also participated in Study 1.

Apparatus
Information of gaze movements was collected with a Tobii EyeX gaze tracker attached to the bottom frame of a 24″ computer display. A mobile gaze tracker incorporated into the glasses would have offered a more ecologically valid setup, but since we were mainly interested in the effect of haptic feedback, a remote gaze tracker and a stationary setup were sufficient. The prototype glasses, haptic stimulation parameters, and PD application were identical to Study 1. Gaze data was processed using a custom application written in C#.

Procedure
Participants were seated in front of the display at a distance of 50-60 cm. After putting the glasses on, the gaze tracker was calibrated for each participant. The participants' task was to perform two-stroke gaze gestures by first moving their gaze from the center of the display to a target sign (+) on the left or right side of the display and then back to the center (see Figure 4). The distance between the center position and the target signs was set to 17 cm. We chose only horizontal gestures because they could be associated with spatially congruent haptic feedback using the glasses.

Figure 4: The experimental interface consisting of three areas that were defined to recognize gaze gestures. It should be noted that the area borders were not visible to the participants during the study. Instead, the participants saw only the direction sign (<) and the two target signs (+).

The experiment consisted of two blocks of 25 trials. In each trial the task was to perform a randomly assigned *left* or *right* gesture. The gesture direction was shown to participants by a graphical arrowhead in the center of the display. To recognize gestures, we defined three areas that are visible in Figure 4 for illustration purposes. Gestures started when gaze left the center area and ended when it returned to the center area from either of the side areas. This was also how gesture completion time was defined. Once a gesture was completed, the next trial was initiated after a 3-second pause.

The participants were divided into two groups. In the first block both groups completed all 25 trials without feedback for training purpose. In the second block one group got haptic feedback while the other group did not. Feedback was given separately for both strokes so that for a *left* gesture feedback of the first stroke was felt behind the left ear and for a *right* gesture behind the right ear. Feedback of the second stroke was always felt on the nose/forehead. Feedback was triggered immediately when gaze moved to another

area. We analyzed gesture completion times of the second block. The first two trials were discarded from the analysis so a total of 23 trials were analyzed per participant. It should be noted that the full experiment consisted of four blocks, but the description and analysis of the last two blocks are beyond the scope of this paper.

Results
The results showed that participants who did not receive haptic feedback in the second block completed a single gesture in a mean time of 510 milliseconds (see Figure 5). For participants who received haptic feedback the corresponding time was 415 milliseconds. This suggests that haptic feedback could potentially make the use of gaze gestures faster. However, an independent-samples t-test showed that the difference between gesture completion times was not statistically significant.
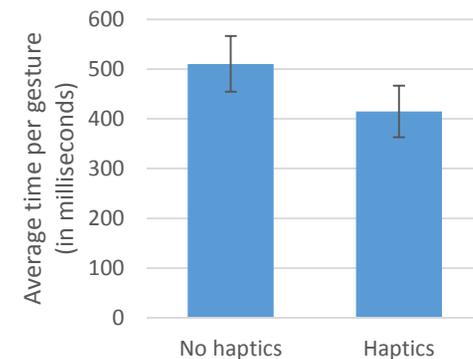

Figure 5: Mean completion times and standard deviations of two-stroke gaze gestures with and without haptics.

Discussion

The results of Study 1 indicated that localizing temporally separated haptic stimulation is easier than simultaneous stimulation that has been used earlier in some head haptics studies [2, 9]. Participants were able to distinguish between three locations with nearly perfect accuracy. Even though there were no differences between localization accuracies between the actuators, the subjective ratings indicated that haptic stimulation felt on the frontal part of the head was perceived as more unpleasant than stimulation behind the ears. This could be related to the fact that the front actuator was situated close to eyes that people naturally tend to protect from sudden touch stimuli. This finding indicates that it might be better to stimulate the more neutral areas close to ears.

The results of Study 2 showed no statistically significant benefit of using haptic feedback with gaze gestures even though the gesture completion times tended to be slightly faster with haptics. The small effect of haptics could partly be due to our simple two-stroke gaze gestures. We hypothesize that haptic feedback might make it easier for people to confirm that a stroke has been successfully recognized and that they could continue with the following stroke. In such a case the benefit of feedback could possibly accumulate as more strokes are performed. It has also been shown that haptic feedback is beneficial if the task requires multiple two-stroke gestures [7].

The main limitation of this work was the use of a static setup with a remote gaze tracker. However, we have started to explore more mobile setups. The vibrotactile actuators used in the prototype glasses are very small and therefore easy to attach also to mobile gaze trackers. This requires altering the driving parameters currently customized to lightweight, plastic glasses.

Our general goal with this line of research is to enable interaction with everyday objects and interfaces through gaze and haptics. Instead of using touch or speech input to control a device equipped with a near-eye display, the user could issue commands with gaze. For instance, when seeing a notification of a new message, the recipient could open it by using a gaze gesture. Haptic feedback would assist in performing the gesture successfully. Potential issues with more realistic use cases include avoiding false positives with haptic feedback. That is, users should not get haptic feedback if they move their gaze without an intention to perform a gesture. The likelihood of this could be mitigated by utilizing multi-stroke gestures that provide feedback only for the last strokes before recognition.

We see that the use of gaze and haptics with eyewear would be best suited to situations where the interaction needs are more occasional than continuous. This is true for pervasive and wearable computing in general because the aim typically is to provide quick access to information while possibly carrying out other simultaneous tasks. Gaze as an interaction modality is suitable in such situations since input can be given quickly and without having to reserve hands for the interaction. Further, the sense of touch offers a largely untapped channel for communicating information to wearable device users. Touch stimulation can usually be perceived reliably also when observing visual information or hearing auditory information is difficult.

This paper has discussed pervasive computing and eye tracking from the viewpoint of human-computer

interaction design, but progress is needed also in related fields such as gaze tracking technology and power management for the use scenarios to be realized. Power consumption, price, and frequent need to recalibrate commercial head-worn gaze trackers are currently not in line with expectations for consumer use. Fortunately, some of these barriers are being reduced. The price issue can be mitigated with off-the-shelf components for the electronics, open-source software, and 3D printing of the frames. For example, the Pupil tracker (http://pupil-labs.com/pupil/) could make it easier for developers and eventually also consumers to utilize gaze tracking while on the move. Further, most current trackers require wired connections for both data transfer and power. The power requirements could be reduced with purpose-built computing hardware and by intelligently processing the video data only when gaze is actually used for interaction.

Acknowledgements

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