Glasses with Haptic Feedback of Gaze Gestures

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Abstract
We introduce eyeglasses that present haptic feedback when using gaze gestures for input. The glasses utilize vibrotactile actuators to provide gentle stimulation to three locations on the user's head. We describe two initial user studies that were conducted to evaluate the easiness of recognizing feedback locations and participants' preferences for combining the feedback with gaze gestures. The results showed that feedback from a single actuator was the easiest to recognize and also preferred when used with gaze gestures. We conclude by presenting future use scenarios that could benefit from gaze gestures and haptic feedback.

Author Keywords
Wearable computing; gaze input; gaze gestures; haptics; vibrotactile feedback.

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

Introduction
Wearable computing devices are becoming increasingly popular. Currently, Google Glass[1] is perhaps the most well-known example of new technology that aims at

[1] https://www.google.com/glass/start/

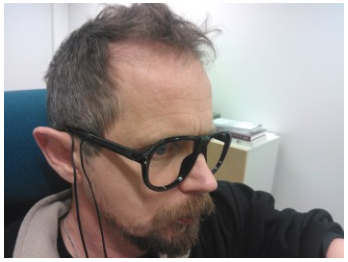

Figure 1. The prototype glasses.

shifting the focus of mobile computing from hand-held devices to wearable ones. However, wearable devices require new interaction methods to access information, and the usefulness of these methods is essential for broader acceptance of wearable devices.

We have started exploring the interaction space provided by smart eyewear worn in the head of a user. As the devices provide only limited space for sensing touch input, also other modalities are needed for control. One option is to use speech input via microphones in the device. However, speech input has an inherent limitation due to its public nature; people nearby can also hear the used commands.

An alternative to speech input is to use gaze. Gaze input has been used, for example, in text entry [11] and gaming [5]. Lately, there has been progress in incorporating gaze tracking technology to eyewear [7]. This could enable use scenarios where simply looking at objects either in real or in an augmented reality environment would be sufficient to interact with them.

While most prior work related to gaze input has used dwell time for selection (i.e., fixate the gaze to an object for a predefined duration), a better match for mobile interaction could be the use of gaze gestures. Executing commands by moving the gaze in a predefined manner is less accuracy-dependent as the gaze is not used for explicit pointing [3, 4]. In addition, gaze gestures are suitable for interacting with small objects [2] and they do not require a confirmation of selection via touch input [9].

One existing challenge in the use of gaze gestures is to provide sufficient feedback of the interaction. Using gaze for gesturing is quite abstract, and some form of assistance is required in order to learn the gestures and use them efficiently. Visual feedback is not optimal because it is difficult to perceive visual information during saccades (i.e., movement of eye). Further, auditory feedback may not be socially acceptable in some settings or not heard at all in a noisy environment.

To provide feedback of gaze gestures with smart eyewear, we have started studying the possibilities of haptics. Compared to other body locations such as the hand, the head has rarely been used as a stimulation site in haptic applications. This could partly be due to the touch sensitivity of the area [10]. However, some prior work does exist. Vibrotactile stimulation was studied in presenting information of nearby objects for deaf users [1] and soldiers [8]. The studies showed that while participants could perceive the information, careful feedback design is required when stimulating the user's head [8].

In this paper, we describe the motivation and design for a wearable prototype that provides haptic feedback of gaze gestures. We present the results of two preliminary user studies that were carried out to get early feedback of the prototype design. We conclude by presenting future use scenarios for utilizing the novel combination of gaze input and haptic output.

Design

Considerations

Our first study on combining gaze gestures and haptics indicated that gesture-based interaction tasks were completed faster when haptic feedback was provided to the user's hand with the built-in vibration motor of a

Figure 2. Prototype glasses with the locations of the three vibrotactile actuators illustrated with circles.

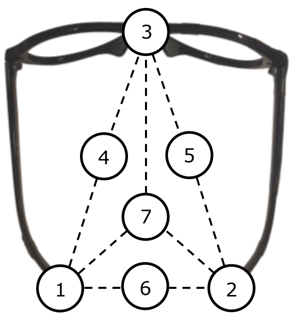

Figure 3. The used haptic stimuli set consisting of activations of one actuator (1-3), two actuators (4-6) and three actuators (7).

mobile device [6]. Also, earlier studies suggested that vibrotactile feedback is a feasible technology for head area haptics [1, 8]. Vibrotactile actuators are often small in size so it is relatively easy to embed them in devices. Also, they have low enough response time to be used with momentary gaze events. From the viewpoint of gaze interaction, several actuators would be needed to present feedback corresponding to the direction of gaze movement. For example, a horizontal gesture moving from left to right would require at least two spatially separated actuators. In earlier work [1], four actuators were attached to glasses so that two of them were stimulating the frontal and two the temporal (close to ears) region of the head. These areas are good for sensing vibrotactile stimulation [8], and they are also natural contact points when wearing glasses.

Prototype

We developed a prototype device based on sunglass frame with lenses removed (Figures 1 and 2). Three vibrotactile actuators (LVM8, Matsushita Electric Industrial Co., Japan) with a diameter of 0.8 cm were attached to the frame. We chose three actuators over four [1] because three was enough for presenting spatial feedback. Two of the actuators were glued to the ends of the bows to stimulate the temporal region of the head. We chose to fix the actuators to the bows instead of using an adjustable mounting so that the glasses would fit all users without having to change the actuator positions. Also, as the vibration travels through the bows, the feedback can still be perceived without direct skin contact with the actuators. To stimulate the frontal region of the head, the top bar of the frame was removed so that the third actuator could be attached on top of the bridge using soft foam and electric tape.

User Study 1: Feedback Locations

Objective

Our goal was to find out how accurately users can distinguish stimulation from the three actuators. This information is important in further interaction design because the feedback should be easy for users to perceive. Because our focus in this first study was only on the haptic stimulation, no gaze gestures were used.

Participants

A total of 12 participants took part in the study (mean age 22, range 18-36 years). We recruited only people with normal vision because the current prototype cannot be used on top of regular glasses.

Stimuli & technical setup

We used a set of 7 different stimuli (see Figure 3). The stimuli were activations of a single actuator (1-3), combinations of two actuators at the same time (4-6) or a combination of all three (7). The actuators were driven using a 150 Hz sine wave that should not cause user discomfort [8]. Also, the duration was set to 20 milliseconds so that the perceived sensation would resemble a short "tap" rather than constant buzzing that could be irritating. The audio signals were fed to the actuators using a PC running Pure Data (PD) audio synthesis software and a Gigaport HD USB sound card.

Procedure

The study was conducted in a laboratory setting. After putting the glasses on, the participant could try each of the stimuli by using a graphical interface similar to Figure 3. The participant used a computer mouse for initiating the stimuli, and the training took approximately 2 minutes. The training was followed by a test where the participant was presented with stimuli

Stimulus #	Stimulus Location	Mean recognition rate
1	Left	100.0%
2	Right	100.0%
3	Front	85.0%
4	Left & Front	56.7%
5	Right & Front	65.0%
6	Left & Right	56.7%
7	All	51.7%

Table 1. The mean recognition rates for the stimuli (see Figure 2 for locations) in Study 1.

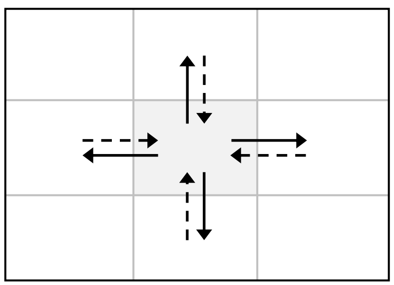

Figure 4. The used four gaze gestures in Study 2. Each gesture consisted of two strokes: out (solid arrows) and in (dashed arrows). Haptic feedback was presented in the end of a stroke (head of the arrows).

one at a time, and the task was to use the mouse for indicating which stimulus was felt. One of the answer options had to be chosen for the test to proceed. Each stimulus was presented 5 times in a random order. Thus, the total number of trials per participant was 35.

Results

The results are shown in Table 1. The main finding was that stimuli with only one actuator were the easiest to recognize (85.0-100.0%), whereas stimulation from all three actuators was the most difficult to recognize (51.7%). In all cases the mean recognition rates were well above chance level (14.3%). The overall recognition rates between participants varied between 51 and 91%.

User Study 2: Feedback Preferences

Objective

The goal of the second study was to see what haptic feedback locations participants would prefer to use with gaze gestures. For this purpose, a gaze tracker was used that detected gaze gestures based on eye movements. Haptic feedback was presented during gaze gestures with the prototype glasses.

Participants

The same 12 participants from Study 1 took part in this follow-up study. All participants had already completed Study 1 and were therefore familiar with the prototype.

Stimuli & technical setup

The stimuli from Study 1 were used (see Figure 3). A desktop Tobii T60 tracker was used for tracking the participant's gaze. This was chosen because the current prototype glasses were built mainly for studying the use of haptics and therefore did not have built-in gaze tracking capability (see [7] for an example). The participant was seated in front of the Tobii display at a distance of approximately 60 cm.

Procedure

The tracker was first calibrated to detect the participant's gaze. Then the used four gaze gestures were introduced (Figure 4). The gestures originating from a previous study [6] were chosen because they were easy to perform. Each gesture was started from a neutral area in the center of the display (grey region in Figure 4) and consisted of two strokes. To initiate a gesture, the gaze was moved from the center to one of the four directions, and then back to the center within 700 milliseconds from the start of the first stroke. This maximum duration was chosen to separate intentional gaze gestures from normal fixations.

The participant was instructed to try the four gaze gestures at his or her own pace and to select haptic stimuli (Figure 3) that were thought to be the best fit for each of the gestures. That is, there was no specific interaction task to complete. Separate feedback could be chosen for the two strokes of a gesture. Feedback was presented in the end of a stroke. The participants could also opt for no feedback in case they did not prefer haptics. The selections were made using the Tobii display and a mouse.

Results

The results are shown in Table 2. In general, the participants chose haptic feedback for the first stroke of all gestures but usually preferred not to use any feedback with the second stroke. The feedback choices were mostly in line with the recognition rates of Study 1. That is, the participants preferred stimuli that were

Gaze gesture		Mode of participants' preferences
Name	**Stroke**	
Left	←	Left (11)
	⇢	None (6)
Right	→	Right (11)
	⇠	None (6)
Up	↑	Front (10)
	⇣	None (8)
Down	↓	Left & Right (11)
	⇡	None (8)

Table 2. The rightmost column shows the preferred feedback choices (number of participants in parentheses) for the strokes of each gesture in Study 2.

easy to recognize, and for three out of four gestures a stimulus with only one actuator was the most preferred choice. Also, the spatial actuator locations were utilized when associating feedback with the gestures. For example, a stroke towards the left side of the screen was mostly associated with stimulation from the leftmost actuator.

Scenarios for Gaze Gestures and Haptics

We envision that the proposed interaction method of combining gaze gestures and haptic feedback could be used in a range of different use scenarios. Here, we present the three main types.

Interacting with objects in the physical environment without a visual display

Smart eyewear with embedded eye tracking and haptic technology could enable interaction with objects in the physical environment. Provided that the glasses would have a forward-facing environmental camera and recognition of different objects, a user could carry out tasks such as controlling lamps in the ceiling of a room by fixating the gaze at them and then performing a gaze gesture. Haptics would assist in completing the gestures successfully.

Interacting with a public display

Gaze gestures and haptics could also be used in interacting with public displays such as information walls. Because the displays are often expensive and therefore placed behind protective transparent glass, providing input using touch may not be possible. Smart eyewear and gaze gestures could enable access to the information. Haptics could provide immediate feedback even before the display information is updated. For example, in a train station or bus stop a user could browse timetables by using only gaze.

Interacting with a near-eye private display

In this scenario the user would have a near-eye display incorporated into the eyewear (e.g., Google Glass). Instead of using touch gestures or speech input, gaze gestures and haptics would allow for entirely private interaction. For example, the user could browse recent text messages from friends. This would leave one's hands free for other tasks.

Discussion and Future Work

In this paper, we have presented a design for a wearable haptic feedback device that can be combined with eye tracking and gaze gestures. The initial user studies showed that participants were able to recognize stimulation from a single actuator with a high accuracy (85.0-100.0%). However, combinations of several actuators were notably harder to distinguish. This indicates that for easy recognition, the number of different stimuli and simultaneous actuator locations should be kept low. The participants' preferences suggested that haptic feedback was useful mainly when combined with the first stroke of a gaze gesture. This is in line with the results of a previous study [6] where haptic feedback provided in the middle of a two stroke gesture made the interaction faster and improved the subjective experience of use.

As the results of the current study proved the prototype to be feasible, we are planning to continue this line of research. First, we aim to evaluate the prototype glasses in interaction tasks to measure whether the addition of haptic feedback provides practical benefit such as decrease the time required to complete interaction tasks [6]. Second, the current haptic feedback design may not have been optimal as it was difficult for users to distinguish which actuators were used if they were activated at the same time. One option to improve this could be to adjust the timing of stimulation from the different actuators. This would enable feedback that "travels" between the actuator locations. Also, while none of the participants commented that the used vibrotactile stimulation would have been unpleasant, we will also explore alternative actuation technologies that could function with lower frequencies. Finally, we are planning to replace the desktop gaze tracker with a mobile counterpart that would enable more realistic use scenarios and experiments.

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