HapticHead – 3D Guidance and Target Acquisition through a Vibrotactile Grid

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Figure 1: Oculus Rift and the HapticHead prototype.

Abstract

Current generation virtual reality (VR) and augmented reality (AR) head-mounted displays (HMDs) usually include no or only a single vibration motor for haptic feedback and do not use it for guidance. We present HapticHead, a system utilizing 20 vibration motors distributed in three concentric ellipses around the head to give intuitive haptic guidance hints and to increase immersion for VR and AR applications.

Our user study indicates that HapticHead is both faster (mean=3.7s, SD=2.3s vs. mean=7.8s, SD=5.0s) and more precise (92.7% vs. 44.9% hit rate) than auditory

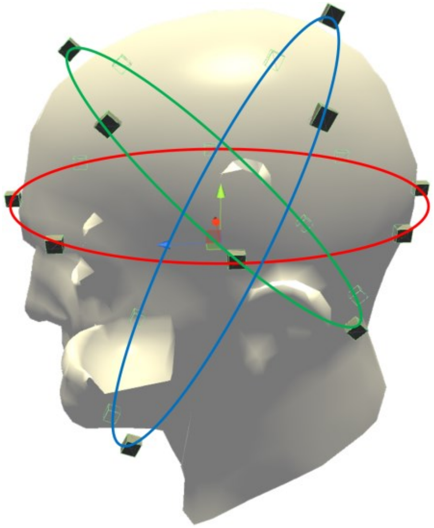

Figure 2: HapticHead modeled in Unity [13], side view. Note the three concentric ellipses around the user's head and no motor close to the ear's opening. The red ellipse contains 8 equidistant actuators, the green and blue ellipses each contain 6 actuators.

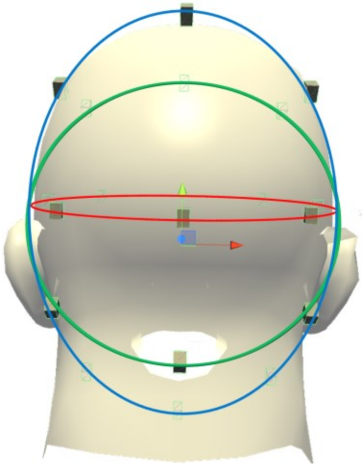

Figure 3: HapticHead modeled in Unity [13], rear view.

feedback for the purpose of finding virtual objects in 3D space around the user. The baseline of visual feedback is – as expected – more precise (99.9% hit rate) and faster (mean=1.5s, SD=0.6s) in comparison but there are many applications in which visual feedback is not desirable or available due to lighting conditions, visual overload, or visual impairments.

Introduction

Guidance and navigation systems use a large variety of different technologies to stimulate the visual, auditory, or haptic channels. The visual channel is usually the channel of choice as it typically has a higher bandwidth than the other channels. However, sometimes the visual channel is not the desired primary channel to be used for some kinds of feedback or in special situations such as when driving a car. The visual channel might be overloaded with information and important feedback can be overlooked or lighting conditions may prevent the user from seeing the feedback at all. Consider a VR or AR game with an already overloaded HUD due to lots of important data. HapticHead can be used to show or amplify important directional information such as the direction of enemy fire or increase immersion by making users feel the environment like explosion shockwaves, snowflakes on their head or virtual walls.

Another reason to use the tactile instead of the visual or auditory feedback channels are faster initial reaction times, as shown in numerous studies such as [9]. Note that this does not affect search tasks that much, as the initial reaction time is negligible. However, it does provide certain benefits in other use cases such as tactile warnings or attention focus applications, which are also possible with the proposed concept.

Related Work

In the area of vibrotactile feedback for guidance and navigation or spatial awareness there have been numerous works on haptic belts [5,6], shoes [7,8], the wrist [11], and also the head [1,3,4]. All of them have in common that they do not guide intuitively in three dimensions as they only use a single ring of vibration motors or less and thus can only map signals on a 1D ring or 2D plane with distance related vibration patterns. Conceptually, Cassinelli et al. [3] discussed extensions of their ring-prototype and proposed to place modules anywhere on the body but they did not implement or test this.

Recently, a Seattle-based startup called OmniWear Haptics [12] emerged, trying to commercialize an idea similar to HapticHead. No detailed information on their prototype is available publicly, except for a few pictures. Obvious differences to HapticHead are the missing chin belt and that the OmniWear cap does not go that far down to the neck. Due to this, their prototype only covers the upper part of the head and cannot be used to intuitively guide to objects below the user.

Concept

Common haptic 2D navigation and guidance approaches use a single ring of haptic actuators around different parts of the body such as the waist, feet, or head. For a 3D approach it makes sense to place actuators on the head as a user can intuitively turn his head in the direction of a stimulus.

We chose to place actuators on three concentric ellipses around the head (as shown in Figure 2 and Figure 3) for a good and equal coverage of all possible directions.

Welcome! First study part will be
Auditory only

Focus blue box to start.

Figure 4: User study: Participant's view with red crosshair.

Figure 5: Participant of the user study trying to locate a target behind him via vibrotactile guidance.

The chosen positions make sense from an anatomic perspective as they leave important parts of the face uncovered. We decided not to place actuators close to the ear openings, because vibration noise through bone conduction increases dramatically in close proximity to the ears. The motors above and behind the ear are both about 4-5 cm away from the ear opening, depending on head size.

Prototype

Our prototype (Figure 1) consists of a bathing cap with vibration motors (12 mm coin type, 3.3 V, 70 mA, 9000 rpm) attached as explained above (Figures 2 and 3). The chin strap hosts three of the vibration motors and can be removed and adjusted to different head sizes.

The vibration motors are controlled by PWM signals of four Arduino Nanos on a switchboard, connected to a stationary PC through USB and an external USB hub. Future versions of our prototype will feature a custom circuit and a Raspberry Pi instead of multiple Arduinos.

On the software side, vibration motors are modeled at their corresponding position in a Unity [13] scene. This allows easy spatial activation of selected motors, depending on the task.

For the 3D Object guidance task, we activate the three motors that are closest to the target with an interpolated intensity that represents closeness. The closest motor is running at highest intensity. Motor intensities are not static and are rather adjusted with head rotation, so if a user turns the head towards the target, the signal also travels along the trajectory towards the front of the head.

User Study

We designed a user study to evaluate the performance of our prototype. We chose to evaluate 3D object guidance performance as a first step and plan to evaluate immersion and other factors in future work.

The study includes visual feedback as a baseline because AR and VR applications are usually designed around giving visual feedback. We also decided to compare our haptic feedback to auditory feedback, as this is the kind of feedback that is typically used when applications aim not to overload the user's visual sense.

In the visual feedback condition guidance towards objects is achieved through the concept of attention funnels as in [2]. We implemented this concept and made sure it also works with targets behind users.

For auditory feedback, we used white noise in combination with Unity 5.2's included spatial sound system with "spatial blend" set to 1 (full 3D) and Bose QC25 stereo noise cancellation headphones (NC off).

For the purpose of this study, we built a simple VR environment in Unity 5.2 that spawns 20 equidistant spheres as targets on the surface of a larger, invisible sphere with the viewer in its center as shown in Figure 4 and Figure 6. The spheres were distributed with pack.3.20 coordinates from [10].

In each trial, participants have to focus a "start box" for half a second in order to start the test. Feedback is turned on and the participants' task is to find the feedback source "as fast and precisely" as possible. Once the participant is sure of finding the source, he or she focuses the suspected sphere and presses a hand-

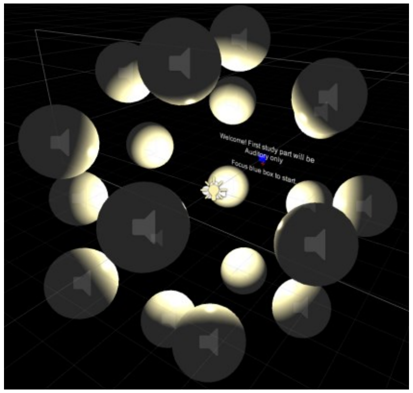

Figure 6: User study: Unity [13] scene view from the outside. The user's camera is in the center.

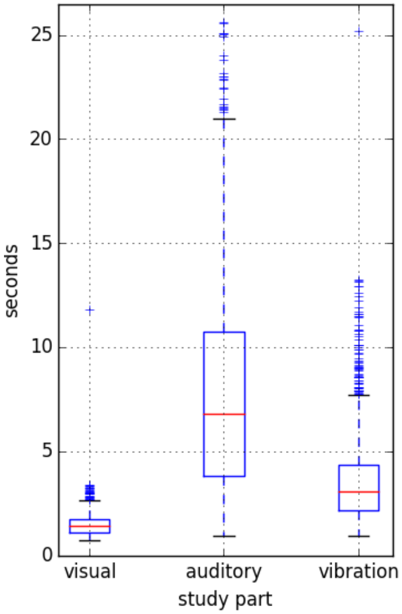

Figure 7: Boxplots of completion times for all conditions with merged data from all participants.

held button. The sphere visually highlights in green or red, depending on whether it was the right one. Instead of training trials, we chose this form of active highlighting feedback in order to measure how fast the participants would improve and "calibrate themselves" towards this new form of haptic feedback.

We invited a total of 7 participants, 1 of them female (mean age 24.9y, SD=4.6y). Only one had previous experience with VR HMDs.

Each participant had to do 160 trials (20 targets x 8 repetitions, randomly distributed with userId as seed) for each of the three feedback conditions (visual, auditory, and vibration). The order of the three feedback conditions was counterbalanced with a Latin square. We measured task completion time and error rate as dependent variables. Participants had the possibility to pause between each trial and had a forced pause when the feedback condition changed. The study took around one hour for each participant. As a reward for participation each participant received a bar of chocolate.

Results

Out of the 1120 total trials per feedback condition, 8 (0.7%) were excluded from the visual and 14 (1.3%) for each, the auditory and vibration part due to outliers (outside of mean ±3σ range of task completion speed).

Table 1 and Figure 7 show the measured dependent variables with merged data from all participants. The boxplots show data from all trials (not just successful ones). Boxplots of just the successful trials look very similar to the ones shown. Both, the vibration and auditory study parts have several trials where users really wanted to be sure of the correct target and took a long time to identify it.

Table 1: Task completion times and success rates for different feedback conditions

	Avg. task completion time	*Std. dev. of task completion time*	*Success rate*
visual	1.49s	0.58s	99.9%
auditory	7.83s	4.99s	44.9%
vibration	3.67s	2.25s	92.7%

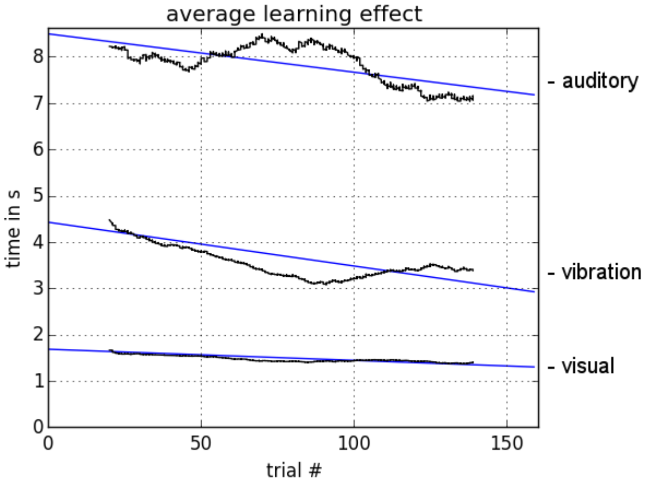

Figure 8: Average learning effect for each of the conditions with merged data from all participants. Blue line: Linear regression. Black curve: Moving average with a window size of 40 trials; border effects hidden.

The average learning effect is shown in Figure 8. Note the steep learning curve for vibration that flattens around trial 90 and the auditory learning curve with high variance that seems to jump down a bit after trial 100.

Figure 9: Development of the success rate (0 – 1) for each of the conditions with merged data from all participants. Smoothed by a moving average with a window size of 40 trials; border effects hidden.

As Figure 9 shows, the success rate of the visual and vibration modalities is more or less constant over the course of the experiment. The success rate for the auditory modality increases a bit after around trial 80.

Qualitative results

Qualitative results were measured through a post-questionnaire with Likert scales (1-5 / disagree-agree).

Participants agreed that the HapticHead vibration feedback is helpful for finding virtual objects (median 4, MAD=0). They strongly agreed that the feedback position around the head was appropriate (median 5, MAD=0) and that the vibration feedback itself was pleasant (median 4, MAD=1). Participants disagreed about hearing the vibration feedback too loudly (median 2, MAD=0).

When asked which feedback they would prefer, they strongly preferred visual over auditory feedback (median 5, MAD=0) but were unsure about visual vs. vibration feedback (median 3, MAD=0). They also clearly preferred vibration over auditory feedback (median 5, MAD=0).

Discussion

As expected, the baseline of visual feedback is not touched by the HapticHead prototype. It is 2.46 times slower and has an error rate of 7.3%, which is much higher than the negligible 0.1% of visual feedback. However, when compared to auditory feedback, the HapticHead prototype performed 2.13 times faster and much more precisely than auditory feedback, which has an error rate of 55.1%.

It is debatable, whether a more sophisticated audio system with true surround headphones and more complex software than Unity 5.2’s included audio system will improve the auditory results dramatically but we do not expect a large difference.

We decided not to include definite hints on having the right target in front of the user such as an auditory beep or a vibration pattern. Obviously, this would improve the results of both, vibration and auditory feedback. However, we wanted to focus on the pure intuitive guidance towards the object rather than letting the user just randomly sweep the environment for a definite hint on the right target.

Limitations

Giving feedback on the head implies some anatomy limitations such as the thickness of user's hair, which can weaken the stimulus received. In our user study, we had two participants with thick hair who indicated that they did not receive strong enough feedback on the top of their heads. These participants needed more time to find the correct targets but had a similar success rate as the others. We attribute this to the frontal vibration motors on the user's forehead, which are unimpeded by hair.

There is also the problem of vibration noise through bone conduction. Closer to the ears, this noise increases dramatically and can affect a user's enjoyment of this kind of feedback. For this reason, we did not place vibration motors close to the ears in our prototype. When asked whether they heard the vibration feedback too loudly, participants of our user study disagreed.

Conclusion

We proposed HapticHead, a concept for intuitive tactile 3D guidance and immersion and conducted a user study to show its usefulness in one exemplary use case. Limitations of our first prototype (vibration strength, hair thickness) were exposed and will be useful when building a new, more advanced prototype in future work.

Future Work

The proposed HapticHead concept can be applied to many use cases. Specifically:

- VR/AR applications
  - Guidance to virtual or real objects in 3D
  - Immersion: Feel shockwaves, particles, virtual walls or VR borders, moving virtual objects: "virtual bee", especially when combined with spatial audio
  - 360° videos with haptic feedback
- Precise guidance in 3D for the blind or elderly people as opposed to existing 2D solutions
- Collision feed-forward for future virtual or real collisions of the user's head
- Blind spot feedback and attention focus in a car

We already implemented a few VR immersion example applications and look forward to evaluate these in a qualitative user study. We will also do a more sophisticated user study with more participants on the 3D guidance aspect and consider encoding depth information through vibration patterns. We will investigate a possible use of HapticHead for guidance and navigation to real objects for the blind and elderly people.

On the hardware side, we will develop a more integrated, mobile version of our prototype, battery-powered and communicating wirelessly with a control device. Participants of our user study indicated that it would be a good idea to extend our prototype by another vibration motor directly between the eyes for a definite hint on the correct target in case it cannot or should not be visually marked. We will build the new version of our prototype with this extension in mind.

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