Wearable Head-Mounted 3D Tactile Display Application Scenarios

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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. In a previous work, we presented HapticHead, a potentially mobile system utilizing 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. The purpose of this paper is to explore potential application scenarios and aesthetic possibilities of the proposed concept in order to create an active discussion amongst workshop participants.

Introduction
Guidance and navigation systems use a large variety of different technologies to stimulate the visual, auditory, or haptic channels. In a previous work we introduced the HapticHead concept and showed it to be an interesting solution to simple search tasks for virtual objects around the user if the visual sense should remain unoccupied [7]. However, our concept can be applied in many more use cases, which will be discussed in the following sections.

Common haptic 2D navigation and guidance approaches use a single ring of tactile actuators around different parts of the body such as the waist, feet, or

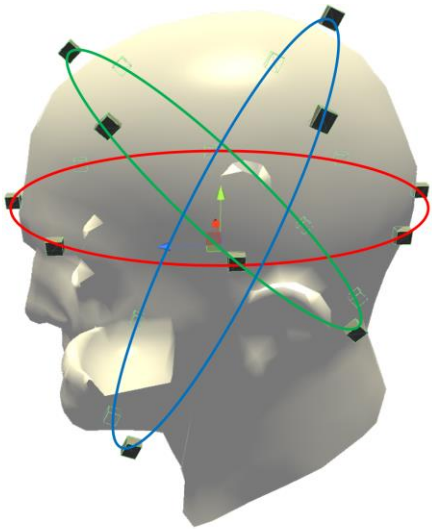

Figure 1: HapticHead concept modeled in Unity, side view. Note the three concentric ellipses around the user's head and no motor close to the ear's opening. The red ellipse contains 8 equidistant actuators, the green and blue ellipses each contain 6 actuators.

Figure 2: HapticHead prototype.

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 1) for a good and equal coverage of all possible directions. The chosen positions make sense from an anatomic perspective as they leave important parts of the face uncovered. This allows the user to act and navigate in the real world as usual. 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.

Our prototype consists of a bathing cap with vibration motors (12 mm coin type, 3.3 V, 70 mA, 9000 rpm) attached (see 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 Arduino Nanos on a breadboard.

Due to the placement of actuators around the head, our concept raises a number of interesting aesthetics design questions which will be discussed in a following section.

Related Work

In the area of vibrotactile feedback for guidance and navigation or spatial awareness there have been numerous works on haptic belts [4,6], shoes [8,9], the wrist [10], and also the head [1,2,3]. 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. [2] discussed extensions of their ring-prototype and proposed to place modules anywhere on the body but they did not implement or test this.

OmniWear Haptics [11] announced an idea similar to HapticHead. However, no detailed information on the prototype is available publicly, except for a few pictures and YouTube videos. Obvious differences to our concept are the missing chin belt and that the OmniWear cap does not go that far down to the neck.

Use cases

The following describes possible use cases that are not yet investigated except for the guidance aspect, which was partly investigated in our previous work.

Guidance to virtual or real positions / objects / humans

There is a wide variety of different guidance scenarios that HapticHead enables. For instance, in a botanic garden or a zoo our concept could guide a user's visual attention towards a particular plant or a tracked animal. In the Sistine Chapel it could guide users towards specific paintings on the ceiling and provide auditory explanations. In these scenarios the visual experience would not be distracted by graphical overlays.

Another possible application would be finding the orientation of one's own body while steering a quadcopter in first-person view or the quadcopter position relative to one's own body, using GPS as a tracking system. In such a scenario both is relevant:

Figure 3: HapticHead prototype combined with an Oculus Rift for a tactile virtual-object-search-task.

The user's position from the perspective of the quadcopter and the quadcopter's position from the perspective of the user. This is an unusual experience that we do not have in everyday life. We suspect that 3D vibrotactile feedback can simplify such a dual-perspective control task, as compared to purely visual feedback.

Combined with a suitable input system, our concept could provide guidance in rescue scenarios. In an area with thick smoke the system could alert users of possible collisions with objects that they cannot see or guide them safely to a casualty in need of medical attention. It might also be integrated into bike helmets to display obstacles in any direction or vehicles approaching from behind.

Guiding visually impaired people to objects in the real world would be an interesting application area for our concept as well. The challenge in this scenario is the noise generated by actuators. Visually impaired people usually substitute their visual by their auditory sense. If something generates a noise on the head, this might affect their situational awareness through their auditory sense. The HapticHead concept could still be used with either very quiet actuators or with a haptic feedback design that leaves the actuators off most of the time. Another possibility would be using small electrical muscle stimulation electrodes in order to generate a tickling sensation without generating any noise. However, this might be dangerous because of the possibility of small currents running through brain areas. In future work, we plan to investigate some of these possibilities and build a prototype specifically for visually impaired people.

Virtual walls / VR borders / collisions with virtual objects
HapticHead can be used to make users feel virtual walls – or just about any objects they try to interact with – on the head. People who experience VR might wonder why they do not feel anything when sticking their head through virtual walls. With our concept it should be possible to feel the position, orientation, and to some extend the smoothness of a surface of any virtual object with the head. Of course, it is not possible to stop the head in its movement but with sufficiently strong vibration motors the movement through a virtual wall can be made an uncomfortable experience. Virtual walls with haptic feedback might also be used in augmented reality scenarios to indicate boundaries of areas or physical objects. For example, at the side of a road with heavy traffic or at a pedestrian crossing a virtual wall could warn the user.

Tracking and presence of moving real or virtual objects
Just as in simple guidance applications, our concept can also be used as an output device for tracking moving virtual objects or display the presence of nearby real or virtual objects such as bees, mosquitos, or spiders. Another possible application scenario would be to head a virtual soccer ball and make a user feel its impact and position as it repeatedly bounces off the user's head.

Particles
Using particles in conventional VR or AR applications means that the user can move through those particles and see them flying through their head or landing near the eyes without feeling anything. Using HapticHead, a user can look up and play "catch the snowflake", feeling a small tactile impulse at the point of contact.

3D movies and 360° videos with haptic feedback
Imagine watching a 3D movie with lots of explosions and loud noise at home. A user can see and hear those explosions, but without any haptic feedback it is not possible to feel them – except for the kind of haptic feedback that very loud noise generates as a side effect. With our concept, it should be possible to emulate shockwaves moving through a user's head at different speeds and in sync with other visual and auditory content in 3D movies.

Aesthetics

Related work has already investigated how to make other devices such as smart glasses aesthetically pleasing on the head [5]. Implementing the HapticHead concept poses several design challenges due to its constraints. In our first iterations we focused merely on technical aspects and did not consider aesthetics at all. However, if such a device shall ever reach a broader audience, a lot of work has to be done in order to make it aesthetically pleasing and users comfortable while wearing it in public for certain use cases such as guiding visually impaired people. In the following sections we will discuss a number of possibilities in order to give such a headwear an acceptable look when wearing it in public.

Concealing under a hat or beanie
One of the most successful strategies in our opinion might be to hide the whole headwear under a beanie or hat in order to completely conceal its existence. Using a hat, the whole prototype could be integrated into the top of the hat, including all wires and battery. A beanie would have to go far down to the neck in order to hide the cables going down into a jacket / pullover where the rest of the prototype could sit in a pocket on the inside.

However, both, hat and beanie would not be able to conceal the chin strap, which is an essential part of the concept. This could only be concealed by using a helmet-like piece of garment which also serves another purpose at the same time. Helmets are commonly accepted to have chin straps in order to fix their position on the head. However, wearing helmets in public is unusual when the practiced application does not recommend wearing a helmet such as in a simple pedestrian navigation task.

Miniaturization and integration
Future implementations of our concept could further miniaturize components and even use different tactile actuators such as small electrical muscle stimulation electrodes for local, tactile stimulation. Cables could be concealed by using leading yarn woven into socially accepted headgear such as beanies.

Not concealing on purpose
Sometimes, wearing something really new and fancy can be a potential selling point of a new product, even on the head such as smart glasses. However, as implementations of HapticHead tend to look like EMG devices it remains a big challenge to optimize the aesthetics for social acceptability.

Conclusion

In this position paper we propose application scenarios for high-fidelity haptic 3D feedback on the head. Such feedback enables intuitive haptic guidance and immersion for VR and AR applications, and also holds potential for guiding visually impaired people. Through different categories of scenarios we show avenues of future research in this area. We also discussed potential ways to make our concept aesthetically pleasing by hiding actuators under – or integrating them into – a hat or beanie.

For mobile use it is important not to block the user's direct awareness of the environment. Several mobile application areas may benefit from haptic 3D feedback, including biking, pedestrian navigation, tourism, museum and sight visitors, and sports fans. We also think that there is significant further potential when combining haptic 3D feedback with augmented reality glasses, handheld devices, and smartwatches.

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