Properties Of A Peripheral Head-Mounted Display (PHMD)

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Abstract. In this paper we propose a definition for Peripheral Head-Mounted Display (PHMD) for Near Field Displays. This paper introduces a taxonomy for head-mounted displays that is based on the property of its functionality and the ability of our human eye to perceive peripheral information, instead of being technology-dependent. The aim of this paper is to help designers to understand the perception of the human eye, as well as to discuss the factors one needs to take into consideration when designing visual interfaces for PHMDs. We envision this term to help classifying devices such as Google Glass, which are often misclassified as a Head-Up Display (HUD) following NASA's definition.

Keywords: Peripheral Head-Mounted Display, PHMD, Optical HMD, Display Position, Peripheral Perception, Google Glass.

1 Introduction

Nowadays, it is designers who create purposes and needs for our daily usage of computers as they also create their own language and definitions (e.g. "smartphone", which is a multisensory touchscreen mobile phone).

Before introducing another new term for Head Mounted Displays (HMD), we look into the various technologies they are based on. There are two commonly used techniques: (1) optical lens projection, which projects an image onto our eye by using a mirror-lens system and LCD, LCos, OLED or CRT technology and (2) retinal projection (RP) also called virtual retina display (VRD), which projects a picture directly onto the user's retina of the eye [4]. Because the actual built-in technology of HMDs is often unknown to the user, it is hard to classify them correctly after this scheme.

Another way to differentiate HMD's can also be determined whether the image is being displayed in either monocular (to one eye) or binocular (to both eyes) fashion. Additionally, the display can also be transparent (ST-HMD), which is usually achieved optically, with a transparent mirror-projection (OHMD), or by showing the image recorded with a video camera in front (VHMD), as shown in *Figure 1*.

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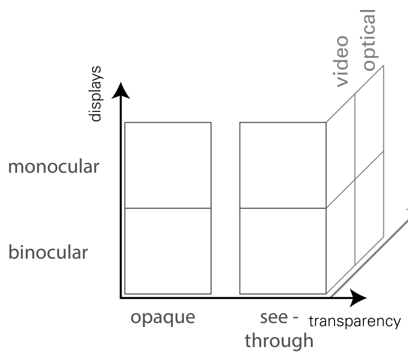

Fig. 1. Current classification based on physical and technology aspects [8]

A recently very famous HMD is Google Glass, which is denoted as a Head-Up Display (HUD) by Thad Starner [13]. Even though it sounds obvious, this definition might not adhere to the actual definition of HUD. While NASA defined this term over centuries of space flight research [11], it actually describes a display that addresses the eyes-free problem, by absolving the user from the need to angle down their head. Furthermore, it provides augmented information in the user's forward Field-of-View (FOV), which is commonly projected on a windshield. In contrast, the Head-Down Display (HDD) is located at the instrument control panel [11]. Also, a HUD is mainly used to augment additional information into reality, which is technically not feasible yet for products such as Google Glass (lens focus on the display causes a blurred environment – *see Figure 2*). Since the number of HMDs is increasing and yet the classification is still not so clear for designers, it is justifiable to reclassify them. Regardless of the implemented technology, a new taxonomy that is based on the devices' functionality would be possible to classify the groups in a more precise manner. We think that a PHMD would belong to a new sub-category of HMD, which is based on their functionality, such as the smartphone is a sub-category of mobile phone.

2 Peripheral Head-Mounted Display (PHMD)

2.1 Definition

A Peripheral Head-Mounted Display (PHMD) describes a visual display (monocular or binocular) mounted to the user's head that is in the peripheral of the user's Field-of-View (FOV). Whereby the actual position of the mounting (as the display technology) is irrelevant as long as it does not cover the entire field of view. A PHMD is considered to provide an additional, always-available visual output channel, which does not limit the user performing real world tasks.

2.2 Characteristics

The most important uniqueness is that the user's FOV is not being fully covered, allowing the user to perform real world tasks without limitations, while not having the pretension to raise or create immersion, such as HMDs usually aim for. For current display technologies, while projecting image onto the eye, the screen needs to be focused by the pupil to enable a clear reading of the screen, thus the environment becomes blurred and out-of-focus. So a PHMD such as Google Glass is capable of displaying (*Figure 2*) detailed information, when the pupil is focusing the display itself, as it also allows for (*Figure 2*) peripheral information when the eye focuses on the real world. Still, simple information such as notifications are perceivable when focusing on the real world instead of the display.

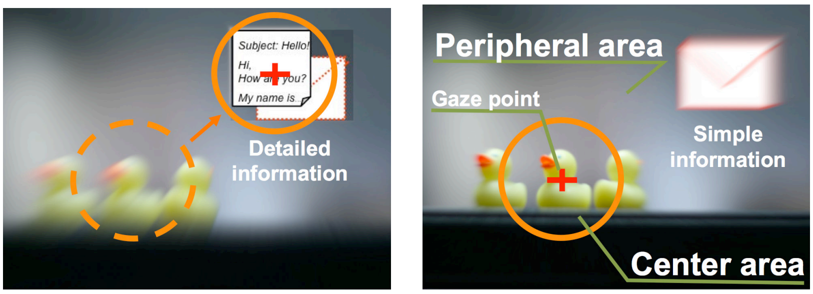

Fig. 2. Difference between detailed and peripheral information [7]

2.3 Peripheral Interaction

Since the PHMD is resting in the peripheral of the user's FOV, it has a high availability and can be quickly demanded by focusing it. Furthermore, significant changes - depending on the stimuli - of the screen content is still perceivable without focusing the display [3]. We envision this effect to be used to design peripheral information (e.g. such as visual notifications for incoming emails, approaching appointments, warnings). An efficient response to such perceived information could be accomplished in quick peripheral input described by Hausen [5] - *Peripheral Interaction*. This way, the user is not being greatly interrupted while completing real world tasks.

Notwithstanding, suitable input modalities for PHMDs that are not socially awkward remain to be discovered. Negative or positive social effects by wearing a PHMD and devoting attention on the screen while taking part in a conversation might be present, but are not proven yet. In addition, taking part in traffic while focusing on a visual input modality can lead to a considerable decrease of attention to the road.

However, compared to smartphone interaction, a quick switch to real world tasks is attainable, because there is no need for getting the device out of a pocket or bag. Furthermore, a PHMD does not need to be held by the user's hands, which offers a fully hands-free interaction. Since it is always available, it can provide peripheral visual information at any time, whereas peripheral information on smartphone in a pocket is not at all or barely perceivable (e.g. in a club/discotheque, while walking).

3 Designing Peripheral Information

Designing an optimal visual output for Head-Mounted Displays is a complex issue, since there are human factors that significantly impact users' perception [9].

3.1 Human Factors

Depth of Focus / Field: switches permanently by refocusing on objects, which is different in distances to the user. A display mounted somehow to user's eye has fixed focal distance. Focusing information such as presented on a screen leads to a change in the depth of focus. This causes blurring of information presented at other layers, which especially degrades the perception of high spatial frequency information such as text.

Eye-Movements: are actually done at a specific angle of 10°. To focus an object out of this angle, head movements are used automatically for support. However, when wearing an HMD with eye-movements that exceed this angle, since head movements do not have any effect on the interface, a drop in comfort might occur due to tired eye muscle.

Field-Of-View: describes the viewing angle of the user. The User's eye has a viewing angle of 94° from the center and 62° on the nose side [7]. The vertical angle is about 60° upwards and 75° downwards. HMDs often do not cover the whole FOV, which is also a reason for increased cybersickness.

Binocular Rivalry: describes the phenomenon, which occurs when dissimilar images are presented to the human eye [1,2]. As the two images captured by each eye is incompatible for stereo processing, they fight for visual dominance over the other eye's side view, resulting in alternating views from the two eyes, where the non-dominant view is almost unseen. This effect often occurs when wearing a monocular HMD. In this setup, researchers [10] also observed objects that completely vanish for several seconds from user's attention.

Visual Interference: describes the phenomenon when both eyes perceive different images that are overlapping, but the brain is not able to distinguish between those. This phenomena is also known as the inability for visual separation.

Phoria: describes a muscle state of the eye, when the eyes are not focusing on a specific point. There are three different states, which can be distinguished: Esophoria, Exophoria, Orthophoria. While one eye is closed or being obstructed by a display, phoria can occur, which has the potential to cause vertigo and nausea as well [14].

Eye-Dominance: Although the user has two eyes, one eye is predominantly used. The other eye is used to make corrections and provide additional spatial information. It is recommended to wear a monocular HMD over the dominant eye [9].

3.2 Peripheral Perception

While most of these factors mentioned above become problematic when both eyes are covered with displays, a single display resting in the peripheral FOV can be considered to be unproblematic, since it does not permanently influence the perceived picture of the real world. So, when consciously focusing on the peripheral head mounted display we can perceive detailed information, as described earlier in *Figure 2*). However, besides perceiving detailed information, we can also perceive information through our visual peripheral perception.

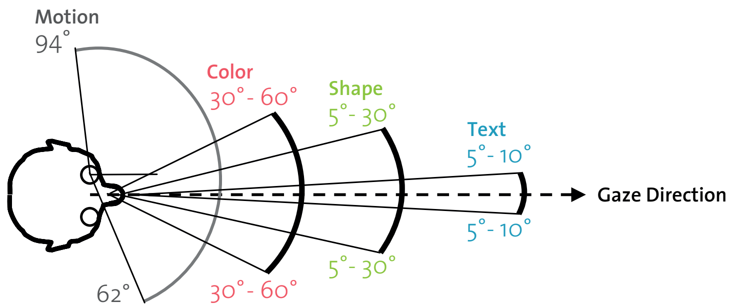

Fig. 3. Differentiable Areas and Angels for Perception of Motion, Color, Shape & Text [7]

Most obvious changes are "motion", which can be perceived over the whole spectrum of the FOV. In a smaller angle, change in color is also quite well perceivable (*Figure 3*). In contrast, perceiving shapes and reading text requires very dedicated attention of the pupil. However, when being very focused on a dedicated task, rough changes in shapes are still perceivable in a peripheral way.

In the field of HCI, there have also being researchers who investigated this visual "peripheral channel", such as Costanza et al. [3], who evaluated color indications in the peripheral FOV with a peripheral LED glasses in 2006.

In 2011 Ishiguro and Rekimoto [7] presented a more complex way of displaying peripheral information on a PHMD, while the switching between the detailed and peripheral view has been demonstrated to work automatically with an eye-tracker.

Recently, Hau Chua et al. [6] evaluated the display position of an OST-HMD (Google Glass) and found that notifications presented at the middle and bottom areas of our human vision is more noticeable. However, top and middle positions are less distracting and more comfortable and preferred by the users. Among all the positions, the middle right position was found to strike the best balance between noticeability, comfort, and distraction.

4 Conclusion

In this paper we presented a definition of a Peripheral Head-Mounded Display (PHMD) and discussed its uniqueness and properties. We also briefly discussed human factors designers need to understand in order to create thoughtful visual interfaces for HMDs. In summary, most HMD suffer badly of the effects of Binocular Rivalry, Depth of Field and Phoria. While a PHMD is not totally covering the FOV and also not augmenting information on real objects, it is not affected by known problems monocular HMDs usually suffer from, such as the effect of attention switching between reality and projection. Such problems have been figured out over centuries of airspace research and usually occur when trying to augment reality [12]. These potential dangers, when operating in critical situations, such as taking part in traffic, are less pronounced for PHMDs.

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