AmbiGlasses – Information in the Periphery of the Visual Field

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Abstract

While more and more digital information becomes available, the demand to access information whenever and wherever increases. However, ubiquitous information provision often interferes with the user's primary tasks such as walking, driving, or reading. In this paper we present a mobile device called AmbiGlasses, a pair of glasses with 12 LEDs that illuminate the periphery of the user's field of view. A conducted user study shows that participants are able to locate the correct LED with 71% accuracy and estimate the rough location of the LED with 92% accuracy. Participants were further asked to exemplary design visualization configurations for four directions. Consistent results show that different participants encode directions with similar patterns. We argue that the AmbiGlasses can therefore be used to convey clear and intuitive navigation instructions.

1 Motivation and Background

As the digital revolution is still in progress, the amount of information which is available steadily increases. At the same time mobile phones are frequently used to access this information from anywhere. However, interacting with mobile devices demands the full attention of the user. In contrast to interacting with desktop computers, there are often other competing and more important tasks, such as walking or chatting with a friend, when interacting with a mobile device. This often causes the user to interact with fragmented attention (Oulasvirta et al. 2005). But many mobile applications, such as pedestrian navigation systems, force the user to fully concentrate on the display and thereby distract the user from the environment (Rukzio et al. 2009). To not interfere with the user's primary task a display is needed that is always perceivable and enables a seamless transition from paying no attention to full concentration.

Figure 1: A mannequin with AmbiGlasses. The glasses consist of 12 LEDs that can be switched on or off separately.

In this paper, we investigate information presentation via light which illuminates the periphery of a user's field of view. The aim is to convey information in a continuous but unobtrusive and ambient way. We built a prototype called AmbiGlasses: a lightweight, wearable display which augments the user's field of view with additional information (see Figure 1). It exploits humans' abilities to effectively direct visual attention, combined with a low information density. Thereby, users are enabled to pay attention only if desired and to get relevant information in a fraction of a second.

Continuous but ambient and unobtrusive information presentation has received much attention in previous work. Ambient information presentation is always available, thus it enables users to smoothly move the focus of attention to the display and back again (Pousman and Stasko 2006). Ambient displays are usually designed to present information which is important but not critical. Another important aspect of these displays is that they present information permanently and typically reduce the complexity of the presentation to a minimum. Until now, most research on ambient displays focuses on stationary devices. Most existing wearable ambient displays for mobile users which address the visual sense (e.g. Schmidt et al. 2006 and Williams et al. 2006) are not always in the user's field of view. Thus, these are only perceivable as long as the user is explicitly interacting with the device. However, Costanza et al. (2006) use a wearable peripheral display, composed of small LED arrays embedded at the left and right edge of ordinary eyeglasses to deliver subtle notification cues. They showed that the display is effective in notifying its user in a subtle way. Though, they don’t take advantage of the whole frame as a potential information display and use the display in a very limited way, that is for simple notification cues only.

Another prominent example for permanent information presentation to mobile users is augmented reality (Caudell and Mizell 1992). Augmented reality (AR) systems embed digital information in a real world scene by registering the visualization with the scene seen by the user. Despite major progress in the AR field robust systems that can be used on a daily basis by the average consumer are still out of reach. A disadvantage is that AR goggles or head-up displays present the information directly in the user's field of view. This augmentation in the centre of the visual field can hardly be ignored and may divert the user's attention from their primary task. AR on handheld devices (see e.g. Henze et al. 2011) recently received some public attention but only enables explicit interaction.

To overcome the limitations of existing visual displays, other modalities for unobtrusive information presentation have been studied. For example, Holland et al. (2002) proposed to continuously present the direction of a destination via spatial audio feedback for pedestrian navigation. Auditory displays, however, compete with environmental noise and it is difficult to find a balance between *being hard to notice* and *being annoying.* Therefore, they are not always suited (Hoggan et al. 2009).

Tactile displays have also been proposed for providing continuous but unobtrusive navigation information (e.g. van Erp et al. 2005). It has been shown that information presented by tactile displays can be processible even under cognitive load (Duistermaat et al. 2007). However, most of the investigated tactile displays are custom made, bulky, and strictly limited in their degrees of freedom. Thus, in some situations, neither tactile nor auditory interfaces are suitable.

In the remainder of this paper we present the design and implementation of the AmbiGlasses prototype (Section 2). We then report from a user study which aimed at finding the basic principles of information presentation with AmbiGlasses (Section 3). We close the paper with a conclusion and outlook to future work (Section 4).

2 Design

In the following, we describe the design of a wearable ambient display for visual information presentation. First, we outline the design space for the display. On this basis, the concept of AmbiGlasses is described. The implementation gives details on the integration of Light Emitting Diodes (LEDs) into off-the-shelf LED glasses.

2.1 Design Space

Visual displays are usually considered as graphical displays that are composed of arrays of pixels. Graphical displays, as we use today, can present a very high information density. However, numberless studies on auditory interfaces (e.g. Holland et al. 2002) and, in particular, tactile interfaces (e.g. Heuten et al. 2008) showed that using displays with a very low information density can already support a user effectively.

In order to develop a non-graphical visual interface, we analysed the design space by reconsidering the physical parameters of light. Light is electromagnetic radiation, which can be described with the parameters intensity, frequency, polarization, and phase. Not all four parameters can be used to present information. However, humans can easily discriminate different intensities (experienced as brightness) and frequencies (experienced as colour). Colour perception, i.a. also depends on the relative stimulation of three different types of cone cells in the retina of the human eye, which is called trichromacy. Only if all of these different types of cone cells work well, a human is able to perceive colours correctly (Goldstein, 2008). Different polarization cannot be perceived by all humans and often only after some training (Haidinger 1844). Using the phase of light for a display is out of question because of technical limitations and the limitations of the human perception.

As the aim is to present structured informational messages via light and not via graphical displays, the characteristics of the intended interface are more similar to current auditory and tactile displays than to complex graphical displays. With the Tactons framework, Brewster and Brown (2004) conceptualised the presentation of structured informational messages using tactile displays. The Tactons concept is similar to the concept of Icons (for graphical displays) and the Earcons concept for auditory displays introduced by Blattner et al. (1989). We assume that the seven degrees of freedom Brewster described for Tactons can also be applied to AmbiGlasses. The *frequency* or wavelength of light is experienced as monochromatic colours and the *amplitude* is experienced as brightness. By mixing multiple colours, different *waveforms* are generated which can be seen as less saturated colours such as pink or magenta. *Duration* and *rhythm* can be applied to light in the same way as for tactile interfaces. The (body) *location* and *spatiotemporal pattern* can also be used for light-based systems. In fact, the high resolution of the human eye to differentiate *locations* and *spatiotemporal pattern*s, compared to the auditory and tactile senses, makes graphical displays possible.

2.2 Concept

Since the real world should not be occluded, our visual information presentation needs to be ambient and therefore only slightly noticeable. As the visual feedback should always be perceivable, the display must remain in a fixed position in relation to the user’s eyes. This can be realized by integrating the display into glasses (see Figure 1). From a design perspective, this means that the *location* of the individual light sources should not be in the centre of a user's field of view. Instead, several spots should be located at the periphery of the visual field. They further should be arranged in an equidistant manner, to cover as much of the potential visible area as possible and to increase the ability to differ between two single spots.

The colour of light is an established degree of freedom in the design of interactive systems. It is often used as status indicator to, e.g. give feedback if a system is working properly (green colour) or not (red colour). However, it is known that the human’s perceptibility of colour decreases in the periphery of the visual field. Given this design constraint, it doesn’t make sense to use different colours for the light spots of the AmbiGlasses. Therefore, our concept only considers a single *frequency* (resulting in a single colour). For the same reasons, our concept doesn’t consider different *waveforms*, i.e. the colour saturation is not modifiable in our design.

Ultimately, these two design restrictions lead to the final concept of the AmbiGlasses. The AmbiGlasses illuminate the periphery of the visual field with one single colour (i.e., *frequency*). The light can be adjusted in *brightness,* and different *rhythms* and *durations* can be created. Given the fact that the AmbiGlasses have several light spot *locations*, also *spatiotemporal patterns* can be created.

2.3 Implementation

We bought off-the-shelf LED glasses, which are usually available at, e.g., party suppliers. As these glasses are only able to flash all of the integrated LEDs at the same time and the light is emitted to the outside and not towards the user, we removed the complete electronics. As a replacement we installed 12 orange SMD LEDs with a comparatively low intensity (224 mcd) in the frame of the glasses (see Figure 2). Unlike off-the-shelf LED glasses, the LEDs emit light towards the user's eyes. Each LED is connected with a thin enamelled copper wire to a custom electronics board. This board basically houses a LED driving stage, a Bluetooth chip, and a micro-controller.

In the current prototype, the electronics are located outside of the glasses, but could be easily integrated into the glasses with more state-of-the-art assembling techniques. However, the given prototype is already lightweight, portable, low power consuming, and therefore potentially mobile and ubiquitous.

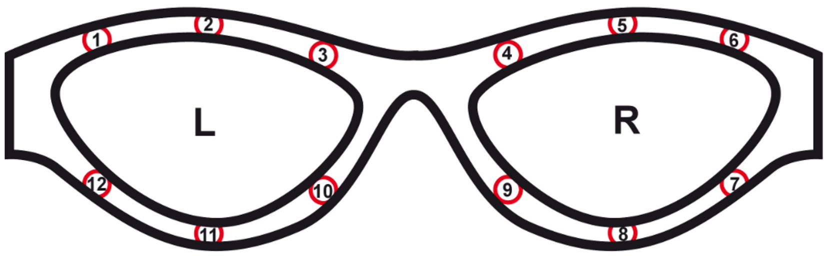

Figure 2: The ambient spots are arranged in an equidistant manner around the eyes. The figure shows the glasses from the perspective of a user looking through the glasses.

3 User Study

In this user study, we first want to investigate how exactly a user can locate a single illuminated LED. Second, we want to validate if users are able to process given information into a glasses illumination configuration, which we exemplary tried with directional information. Additionally, we are interested in further application fields which users could imagine using the glasses for.

3.1 Method

Nine volunteers participated in the study, whereby three of them were female. In average, the participants were 30.33 (SD 4.61) years old. Six participants usually wear glasses and one wears contact lenses. None of the participants had prior experiences in the use of AmbiGlasses. Prior to the study, every participant signed an informed consent. None of the volunteers was paid for participating in the study. The setup shown in Figure 3 was used in the study. The hardware included the glasses with the according electronic boards, a power supply, and a portable computer. The study was separated into two tasks, where a semi-structured interview was conducted in between. We placed the interview between the tasks as it otherwise could have been influenced by the results of the second task.

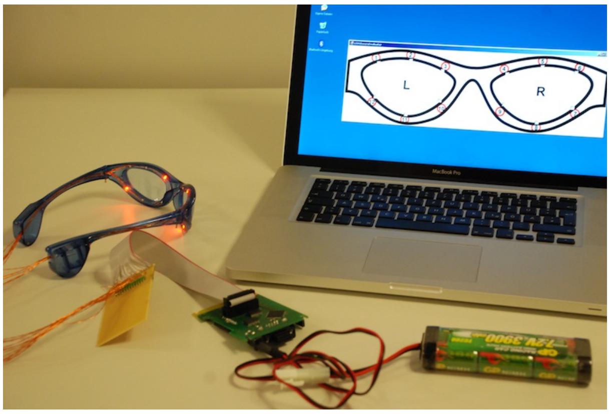

Figure 3: The setup of the user study consisted of the glasses with the according electronic boards, a power supply, and a portable computer.

In the first task, the participants were asked to identify a single activated LED at a time. Participants were given a sketch of the glasses, simplifying the identification with numbers and approximate locations of the diodes (see Figure 2). Each of the 12 available light emitting diodes was switched on in a random order. It was switched off again, if the participant clearly decided on a classification of the current appearance. After the first task had been finished, the participants were asked what they can imagine using the glasses for, and what technical aspects should be considered in future development to make them ready for daily use.

To determine light patterns for an exemplary application domain, we employed a guessability study methodology for the second task. The participants were given an interactive GUI to switch the LEDs on and off. The GUI looked like the sketch in Figure 2, extended with a checkbox next to each LED representation. Contrary to the first task, it was now possible to activate multiple LEDs simultaneously. Each participant was asked to get firm with the GUI and explore the potentials of multiple simultaneously activated LEDs. After having become familiar, the participants were asked to encode the four directions *ahead*, *behind*, *left*, and *right,* as they would feel how they have to be encoded by en- or disabling any LEDs. The order of the four directions was randomized. After configuring a direction, a portrait photo of the participant wearing the glasses was taken.

3.2 Results

For the first task, all participants had to identify each of the 12 LEDs. In total, participants tried to identify the correct LED 108 times. 77 of the given classifications (71.29 %) were correct and 31 classifications (28.70 %) were wrong. 22 of the 31 misclassifications were classified as an LED next to the activated LED. All the 9 misclassifications that are not next to the activated LED are located in the centre or upper part of the glasses (LEDs 2, 3, 4, 5, 9, 10). Furthermore, 24 of the 31 misclassifications are also in the centre or upper part of the glasses.

In the semi-structured interview, most of the participants imagined to use the glasses as a navigation aid. Some participants also mentioned that the glasses can be used to indicate events and objects outside of the field of view. Additionally, some participants stated that a possible use case is to show if new SMS messages, emails, or other messages are available. The participants also gave recommendation for further improvement of the AmbiGlasses. First of all, the glasses should fulfil the usual requirements for glasses: robust, lightweight, an appealing design, and a suitable dioptre adjustment. Furthermore, the participants stated that the glasses should be less obtrusive. The LEDs' light cone should not be visible to other persons. Some participants proposed a dimmable brightness or a dynamic adaption to the environmental brightness as a potential solution. Additionally, some participants could imagine using different colours to encode more information.

For the second task, every participant chose to switch on one or multiple LEDs on the according side of the glasses to encode the directions *left* and *right* (see leftmost images in Figure 4). Every participant enabled LED 12 to encode *left*, whereby in 8 cases additionally LEDs on the left side (LEDs 1, 2, 11) were enabled. LED 7 was enabled by every participant to encode *right*; again in 7 cases additional LEDs on the right (LEDs 5, 6, 8) were switched on. For the directions *ahead* and *behind*, every participant chose to switch on LEDs on both sides of the glasses at the same time (see rightmost images in Figure 4). Contrary to the other directions, here, all participants selected at least two LEDs. This is probably the case because of the non-unique assignment of the directions *ahead* or *behind* to the upper or lower LEDs. However, 5 participants (55.55%) clearly assigned *ahead* or *behind* exclusively to the upper (LEDs 1, 2, 3, 4, 5, 6) or lower LEDs (LEDs 8, 9, 10, 11).

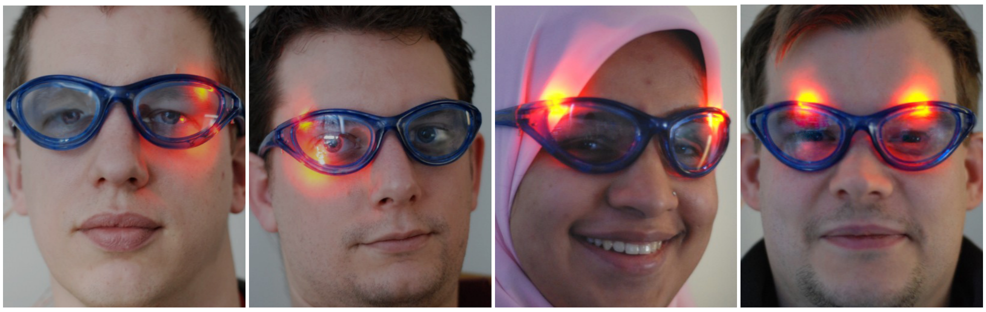

Figure 4: Two typical examples for encoding the directions left and right are shown in the two leftmost images. Every participant preferred to exclusively switch on LEDs on the according side of the glasses. Two almost equal-looking representations of behind and ahead are shown in the two rightmost images. Every participant switched on at least one LED per side to encode these two directions.

3.3 Discussion

In this study, we observed that 71.29% of the LED classifications were correct. 91.67% of the classifications were either correct or only one LED from the target away. Thus, 91.67% of the participants were able to indicate the rough direction. The participants preferred to indicate the directions *right* and *left* by only illuminating one eye, while the directions *ahead* and *behind* were mostly represented by illuminating either the upper or lower LEDs.

It is relevant that especially the LEDs in the centre and in the centred top of the glasses are more susceptible for misclassification than the other LEDs. During the second task, the participants more often did not use these affected LEDs for their encodings of the given information. Instead, the participants preferred the usage of LEDs which have a higher recognition rate (LEDs 1, 6, 7, 12).

The results of the second task show that participants often selected oppositely LEDs or LED areas for contrary directions (*left*/*right*, *ahead*/*behind*), even though they did not know about all the directions before starting the individual subtasks. Additionally, the participants did always choose symmetrical encodings.

The differences between a set of four directions could be distinguished certainly. For example, there were only 9 misclassifications (8.33%) for differencing between the upper and lower LEDs. Also, there were 9 misclassifications for differencing between each side of the glasses. None of the participants confused the leftmost or rightmost LEDs (1, 12, and 6, 7). The encodings which were figured out by the participants support this, as per each user they are consistent and do not overlap. In addition, most of the participants seemed to be certain in creating their distinct set of encodings. Taking into account the most popular encoding patterns and the LEDs which were more often misclassified, we propose the AmbiGlasses configuration for conveying directional information shown in Figure 5.

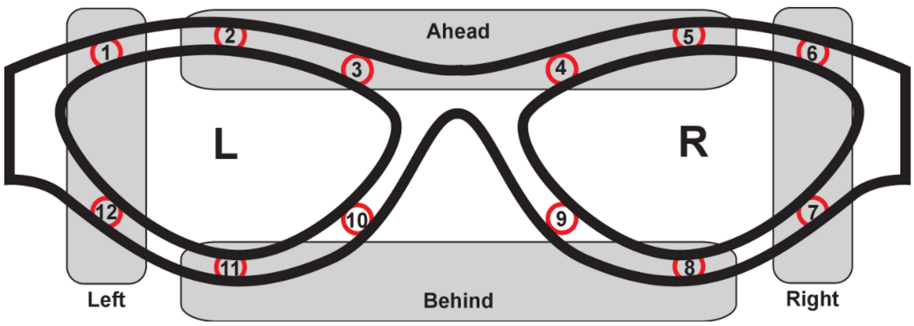

Figure 5: Based on our study we propose the shown AmbiGlasses configuration to convey directional information.

In the derived light design, the leftmost LEDs (1, 12) and the rightmost LEDs (6, 7) are mapped to the direction *Left* and respectively *Right.* The four central, upper LEDs (2, 3, 4, 5) encode the direction *Ahead*, whereas the four central, lower LEDs (11, 10, 9, 8) define the direction *Behind.*

4 Conclusion and Future Work

In this paper, we presented AmbiGlasses, a visual, ambient, and mobile information presentation device. The conducted study shows that information in the periphery of the visual field can be perceived with reasonably good recognition rates. We found that the left, right, and bottom light spots of the glasses can be detected very accurate, while misclassifications mainly occur in the centre of the glasses.

Using a participatory design approach, we figured out that participants are able to encode information by combining multiple light spots around the eyes. Analysis of the encodings showed that there exists a preferred encoding set, suitable for most of the participants. We identified that the less accurate detectable light spots were used less often in the users' information encodings. The participatory approach was particularly helpful, as it not only showed that consistent light patterns for directions exist, but also ensured an intuitive information presentation. The consistency of the user-defined encodings also shows that the influence of the individual perception is low. Thus, a common perception of the ambient information is given. Therefore, we argue that the AmbiGlasses can be used as navigation aid without any prior training.

This paper serves as a foundation and proof-of-concept that ambient information presentation in the periphery of the visual field is possible. The major advantage is that the information is always visually present and the AmbiGlasses do not force users to switch between modalities, as it would be required when using e.g. audio. In our future work, we will investigate how the identified patterns perform in an outdoor pedestrian navigation scenario, focussing learnability, differentiation, and how ambient the information presentation feels in daily use. Furthermore, we want to study if light patterns for other application domains can be found using a participatory approach. Technically, we plan to shrink the electronics and make use of dynamic LED brightness adjustments to reduce conspicuousness.

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