MonoculAR: A Radial Light Display to Point Towards Out-of-View Objects on Augmented Reality Devices

Uwe Gruenefeld
OFFIS - Institute for IT
Oldenburg, Germany
uwe.gruenefeld@offis.de

Lars Prädel
OFFIS - Institute for IT
Oldenburg, Germany
lars.praedel@offis.de

Tim Claudius Stratmann
OFFIS - Institute for IT
Oldenburg, Germany
tim.stratmann@offis.de

Wilko Heuten
OFFIS - Institute for IT
Oldenburg, Germany
wilko.heuten@offis.de

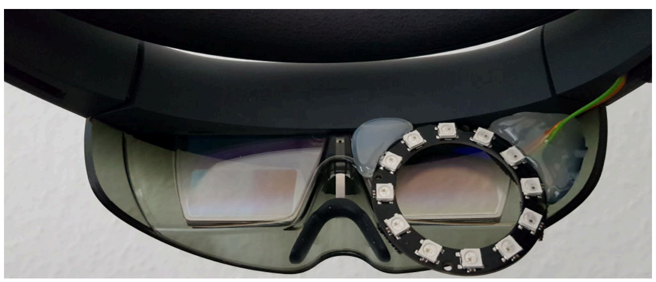

Figure 1: MonoculAR attached to Microsoft HoloLens.

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Abstract
Present head-mounted displays (HMDs) for Augmented Reality (AR) devices have narrow fields-of-view (FOV). The narrow FOV further decreases the already limited human visual range and worsens the problem of objects going out of view. Therefore, we explore the utility of augmenting head-mounted AR devices with *MonoculAR*, a peripheral light display comprised of twelve radially positioned light cues, to point towards out-of-view objects. In this work, we present two implementations of *MonoculAR*: (1) On-screen virtual light cues and (2) Off-screen LEDs. In a controlled user study we compare both approaches and evaluate search time performance for locating out-of-view objects in AR on the Microsoft Hololens. Key results show that participants find out-of-view objects faster when the light cues are presented on the screen. Furthermore, we provide implications for building peripheral HMDs.

Author Keywords
Head-mounted displays; Augmented reality; out-of-view; small field-of-view; peripheral display

ACM Classification Keywords
H.5.1. [Information interfaces and presentation (e.g. HCI): Multimedia information systems: Artificial, augmented, and virtual realities.]

Introduction

Current Augmented Reality (AR) devices suffer from having limited fields-of-view (FOV). Compared to the human visual system, which has a FOV exceeding 180° horizontally [7], current head-mounted Augmented Reality (AR) devices have fields-of-view that are several times smaller. For example the Microsoft Hololens[1] is limited to a 40° horizontal view. This is partly due to technical limitations, where extending the FOV of such devices requires more pixels to calculate, emits higher heat radiation, and results in lower wearing comfort due to increased weight. Importantly, this restricted FOV limits the immersive potential of these systems. This is especially true for AR scenarios, which often rely on users' awareness of the positions of out-of-view objects that lie outside of the restricted FOV (e.g., opponents in a multi-player game). This leaves visual information-processing capabilities of users underutilized. Furthermore, the experience of users is less immersive because of the abruptly ending display.

In this work, we explore the utility of augmenting head-mounted AR devices with *MonoculAR*, a peripheral light display, to point towards out-of-view objects. *MonoculAR* is designed as twelve radially positioned light cues with two implementations: (1) On-screen virtual light cues and (2) Off-screen LEDs attached around the device's display. We evaluate the performance of both implementations in a controlled user study with two different tasks. In both tasks, users have to search for specific out-of-view objects, but in one task only one out-of-view object is presented at a time, while in the other task multiple out-of-view objects are visible simultaneously.

We provide the following contributions: (1) Two implementations of radially positioned light cues and (2) a comparative evaluation of these two implementations for pointing towards out-of-view objects on Augmented Reality devices.

[1] https://www.microsoft.com/en-us/hololens, July 2, 2018

Related Work

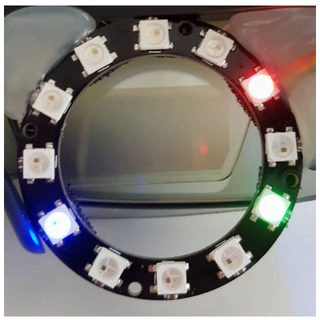
Our related work section builds upon two pillars: (1) previous work on visualization of out-of-view objects and (2) peripheral light displays.

Visualization of out-of-view objects

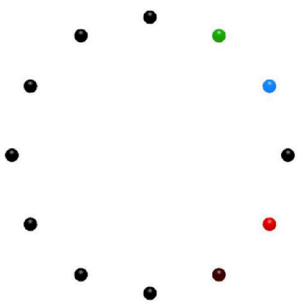
How to best perceive the locations of out-of-view objects is a problem related to the visualization of off-screen objects on small screen devices (e.g., smartphones). Many of the proposed techniques for visualizing off-screen objects rely on the Contextual views approach [2]. Contextual views mostly represent only objects of interest and do so using simple shapes (proxies) [5]. In our previous work [3], we adapted existing off-screen visualization techniques to head-mounted AR, where we mapped out-of-view objects onto a sphere to aid direction cueing using adapted Halo [1], Wedge [5] and Arrow [2, 6] implementations. We showed that Wedge and Halo outperform Arrow; however, these techniques perform worse with increasing angles towards out-of-view objects. Therefore, EyeSee360 was developed [4] to cue direction with an accuracy independent of the angle towards the visualized out-of-view object. However, the radar-like presentation in EyeSee360 uses a lot of space, and thus it visually clutters the user's field-of-view, especially on small field-of-view devices. To sum up, previous work proposed several techniques for visualizing out-of-view objects, but non of them takes small fields-of-view into account. However, especially small FOVs have the need for visualization of out-of-view objects.

Peripheral Displays and Wide FOV HMDs

Orlosky et al. [9] present a method to extend the limited FOV of HMDs by a fisheye view that compresses the pe-



(a) Off-screen LEDs.



(b) On-screen virtual light cues.

Figure 2: Implementations of *MonoculAR*. *Best seen in color.*

ripheral aspect. They found that users were able to detect 62.2% of objects distributed in 180°, while they could detect 89.7% with the naked eye. This, however, works for environments in 180° on a smaller FOV, and has a negative effect on perception of detected objects since smaller objects can disappear due to the compression. Yamada and Manabe [12] presented a method that uses two different lenses with different magnifications. While their prototype was usable for extending the FOV, two levels of magnification means the foveal FOV is clear while the periphery is blurry, and this lack of detail is not suitable for visualizing out-of-view objects. Nakuo and Kunze [8] present an initial peripheral vision glasses prototype, that can display patterns in the peripheral vision of the user. However, their prototype is limited in what can be shown in the left and right periphery and does not include different object positions, making it unsuitable for directional cueing.

Xiao et al. [11] presented SparseLight, introducing a matrix of LEDs placed in head-mounted VR and AR devices to create more immersive experiences. They showed SparseLight's usefulness in conveying peripheral information, improving situational awareness, and reducing motion sickness. While we use direction cues to indicate position of out-of-view objects, they use visual clones shown on multiple LEDs in an absolute mapping. This makes our approach more suitable for representing direction cues irrespective of how far they are in the 180° periphery view. Moreover, we encode out-of-view objects with a single LED on a radial LED ring instead of using multiple changing LEDs with varying distances to the eye, which ensures that objects can be perceived with equal accuracy and lower processing cost.

MonoculAR System

MonoculAR is inspired by SparseLight presented by Xiao et al. [11]. However, it differs in various aspects. Instead of augmenting both eyes, *MonoculAR* augments only one eye with twelve radially positioned light cues (see Figure 2(a)). This makes *MonoculAR* a low-cost solution that is easily attachable to existing hardware. Furthermore, we discuss a second implementation of our proposed system that uses on-screen virtual clones of the used light cues (see Figure 2(b)). Both implementations aim to help users locate out-of-view content on devices with small fields-of-view.

Directional cues

To cue directions towards out-of-view objects, *MonoculAR* maps out-of-view objects onto a sphere around the user's head onto a point *A* to remain with their direction information (based on [3]). Afterwards, the current user's head pose is also mapped to an according point *B* on that sphere. Then the shortest path[2] on the sphere between the user's head pose *B* and the out-of-view object *A* is drawn. The exit angle of that path at point *B* is then used to determine the LED on the ring that points towards that out-of-view object. Thereby, users can simply turn their heads to the direction of the illuminated LED to find the according out-of-view object. The color used was based on the color of the out-of-view object. If one visual cue needs to represent multiple out-of-view objects, then the objects' colors are combined.

Hardware implementation

The hardware of *MonoculAR* was built by combining a LED ring with a wifi-able microcontroller. We added 12 radially positioned and individually addressable RGB LEDs (WS2812B) around one eye to cue direction towards out-of-view objects. To control LEDs, we used a NodeMCU de-

[2] https://wikipedia.org/wiki/Great-circle_distance, July 2, 2018

veloper board[3] (ESP8266) with a low-cost Wi-Fi board attached, which serves as a Wi-Fi access point. The board is powered by a Li-Po battery (3.7V). We developed a REST-API to directly change LEDs over Wi-Fi via Web Requests. As such, *MonoculAR* is a standalone headset that does not require connection to any external device. The brightness of the LEDs was adjusted to match the brightness of the HoloLens display by matching the average brightness values of the colors.

Software implementation
We implemented *MonoculAR* in the 3D game engine Unity[4]. The on-screen virtual light cues are implemented as emitting spheres that are black when no direction is cued. The refresh rate of these on-screen virtual lights is synced with the refresh rate of the hardware LEDs to make them comparable. Furthermore, the virtual light cues are placed towards the border of the HoloLens display.

Experiment
To compare both implementations of *MonoculAR* we conducted a controlled user study.

Study design
To evaluate the performance of both implementations of *MonoculAR*, we conducted a within-subjects controlled laboratory study in Augmented Reality with the Microsoft Hololens. Our study's only independent variable was implementation with two levels (On-screen vs. Off-screen). We used quantitative methods to evaluate user performance taking search time and search error as our dependent variables. Search time is measured as the time a user needs to locate and select an out-of-view object in the scene, while search error is specified as the number of objects a user wrongly selected.

[3]https://wikipedia.org/wiki/NodeMCU, July 2, 2018
[4]http://www.unity3d.com, July 2, 2018

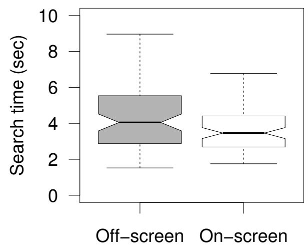
For this study, we asked: Does the off-screen implementation of *MonoculAR* perform better than the on-screen implementation on a small field-of-view Augmented Reality device with respect to search time and search error **(RQ1)** and perceived usability **(RQ2)**?

H_1 We expect the on-screen implementation to result in lower search time than the off-screen implementation *(because the on-screen visualization is closer to the user's focus and therefore, more perceivable [7]).*

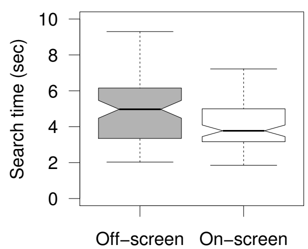
H_2 We expect the off-screen implementation to be subjectively perceived best *(because the user's screen does not become visually cluttered by the light cues).*

Procedure
The within subjects study was divided into two search tasks. Both tasks were divided into two blocks, with each block testing one implementation (*MonoculAR (Off-screen)*, *MonoculAR (On-screen)*). We counter-balanced the two tasks and two blocks across all participants. The out-of-view objects were randomly distributed in 3D space. However, we avoided spawning objects visible on-screen at the start position. We stored the seeds of the position generation for each task to test the same positions for each implementation. However, by choosing the order at random, we ensured that participants would not recognize a previous pattern of positions from the foregoing implementation.

Task A: Search task (single object) In this task the user had to search for an out-of-view object that was the only existing object in the environment. The object was a white colored cube. Therefore, the cues shown to the user were



(a) Task A: Single object.



(b) Task B: Multiple objects.

Figure 3: Comparison of search times (in seconds) of both implementations (off-screen vs. on-screen). Showing minimum, maximum, second quantile, third quantile and median.

also white. To start a trial of this task, the user had to focus on a point directly before him/her. Then, when the user clicked to indicate that he/she was ready, a virtual out-of-view object (cube) appeared in the 360° around the user, and a white LED cued the relevant direction. When the user found the out-of-view object, he/she had to select it with the cursor. The time was then stopped. Each implementation was tested in ten trials plus one additional trial in the beginning for training, which is excluded from the results.

Task B: Search task (multiple objects) In this task, the user had to search for an out-of-view object that was presented with two other objects in the environment. In each trial there were three cubes (one red, one blue, and one green). To start a trial of this task, the user had to focus on a point directly before him/her. Then, when the user clicked to indicate that he/she was ready, three virtual out-of-view objects (cubes) appeared in the 360° around the user. Afterwards, a random color was chosen from the three options and the user was asked to locate the cube of that color. All three cubes were visualized on *MonoculAR* during this task (see Figure 2). When the user found the out-of-view object, he/she had to select it with his/her cursor. The time was then stopped. Each implementation was tested in ten trials plus one additional trial in the beginning for training, which is excluded from the results.

After all blocks, we asked participants to fill out our individual subjective questionnaire and a demographic questionnaire. Overall, each participant took approximately 30 minutes to finish the experiment.

Participants
We had 8 volunteer participants (4 females), aged between 23-31 years (M=26.25, SD=2.49). All participants had normal vision except one who had normal-corrected vision. None had color vision impairments. We asked participants to answer two 5-point Likert items to rate their experience with head-mounted devices and the Microsoft HoloLens. Participants stated that they had more experience with head-mounted devices (Md=4, IQR=1.25), while they had less experience with the HoloLens (Md=2.5, IQR=1.25).

Results

Task A: Search task (single object)
For the search task with a single object shown, we consider the effects of one factor (implementation) on search time. The mean search times for both implementations are: *MonoculAR (On-screen)*=3.78s and *MonoculAR (Off-screen)*=4.33s. The search times are compared in Figure 3(a). A Shapiro-Wilk-Test showed that our data is not normally distributed ($p < 0.001$). As we compare two matched groups within subjects, we directly performed a Wilcoxon Signed-rank test. Here we found only small evidence of a potential effect of implementation on search time ($W = 1230$, $Z = -1.87$, $p = 0.060$, $\phi = 0.15$).

Task B: Search task (multiple objects)
For the search task with multiple objects, we consider the effects of one factor (Implementation) on search time and object selection accuracy (where object selection accuracy means an object was selected wrong during a trial). The mean search times for the implementations are: *MonoculAR (On-screen)*=4.54s and *MonoculAR (Off-screen)*=5.06s. The total number of wrongly selected objects is zero for both implementations. The search times are compared in Figure 3(b). A Shapiro-Wilk-Test showed that our data is not normally distributed ($p < 0.001$). As we compare two matched groups within subjects, we directly performed a Wilcoxon Signed-rank test. Here we found a significant effect of implementation on search time ($W = 1114$, $Z = -2.43$, $p = 0.015$, $\phi = 0.19$).

Comparison between search tasks
To compare the two different tasks, we consider the effects of one factor (task) on search time. The mean search times for the tasks are: *Task A*=4.05s and *Task B*=4.80s. A Shapiro-Wilk-Test showed that our data is not normally distributed ($p < 0.001$). As we compare two matched groups within subjects, we directly performed a Wilcoxon Signed-rank test. Here we found a significant effect of implementation on search time (W = 4555, Z = -3.21, p $=$ 0.001, $\phi =$ 0.18).

Questionnaire
At the end of the study, we asked participants to answer four questions with 5-point Likert items. Participants stated that they were able to easily find the out-of-view object with *MonoculAR (On-screen)* when only one object was presented (Md=5, IQR=0.25), and the same for *MonoculAR (Off-screen)* (Md=4, IQR=1). Furthermore, they stated that they were able to easily find the out-of-view object with *MonoculAR (On-screen)* when several objects were presented (Md=4, IQR=1.25), while they were neutral for *MonoculAR (Off-screen)* (Md=3, IQR=0.5). Overall, seven participants preferred *MonoculAR (On-screen)* while one preferred *MonoculAR (Off-screen)*.

Discussion

On-screen vs. Off-screen implementation In both tasks the implementation that used on-screen virtual light cues performed better than the off-screen LEDs. While our results were only significant for one task (multiple objects), we believe that with more participants tested, on-screen visualization for a single object shown would also be significantly better than off-screen visualization. Here, we accept our hypothesis H_1. We argue that on-screen visualization outperformed off-screen visualization due to the proximity of these light cues to the user's focus. Thereby, the light cues of the on-screen visualization could be perceived better and human color perception was able to better distinguish between those colors [7, 10]. Participants subjectively rated the implementations in line with our quantitative results. Therefore, we can not accept our hypothesis H_2. In our hypothesis, we argued that the on-screen visualization would clutter the screen and therefore to be subjectively perceived as worse. However, our study was designed as a controlled lab study, so no other visual content was visible on the screen except the out-of-view objects. Therefore, visual clutter did not affect the results of our study. In future work, visual clutter should be added to the screen.

Multiple out-of-view objects Our results show that more out-of-view objects lead to higher search times. We think this is due to overlapping of cues (e.g., when one out of twelve LEDs has to indicate the direction towards two out-of-view objects). Furthermore, color perception may haves an effect here because some colors can be distinguished more easily than others [7]. We suggest, if possible, to only cue one out-of-view object at a time.

Conclusion

In this paper we presented *MonoculAR*, a technique to point to out-of-view objects on Augmented Reality devices. The technique supports two different implementations: (1) on-screen and (2) off-screen visualization. In a first study, we explored search time performance of both implementations. We showed that the on-screen variant is preferred by users and results in faster search times. Moreover, our results suggest visualizing only one out-of-view object at a time to improve search times. Future work is required to investigate additional influencing factors, such as visual clutter.

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