Occlusion Management Techniques for Everyday Glanceable AR Interfaces

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Abstract

To maintain safety and awareness of the real world while using head-worn AR glasses, it is essential for the system to manage occlusions involving virtual content that blocks the user's view of the real world. We study this issue in the context of Glanceable AR interfaces, which involve presenting virtual information that the user can quickly access as a secondary task while performing other tasks in the real or virtual worlds. We propose eight different techniques to resolve these occlusions. The techniques differ in their content prioritization, automation level, and adaptation mechanism for resolving occlusion. We designed an experiment to understand the user experience with the techniques in a scenario that required both awareness of the real world and information access with the digital content. We measured task performance and user preference. The results show that techniques that prioritize real world viewing and those that automatically resolve occlusions result in better task performance. These techniques are also preferred by users, particularly when translucency is used to resolve occlusions. Despite the ease of information access, techniques that prioritize viewing of the virtual content were seen as less desirable by participants.

Index Terms: Human-centered computing—Mixed / augmented reality; Human-centered computing—Interaction techniques; Human-centered computing—User interface design

1 Introduction

Augmented Reality (AR) Head Worn Displays(HWDs) are becoming more and more lightweight and powerful. In addition to their usefulness for augmenting the real world with virtual three-dimensional objects, they also have the potential to become a major personal computing device in the near future.

Future AR HWDs will be able to be worn all-day to assist our acquisition of information, arrangements of activities and executions of daily tasks. They make possible "Glanceable AR Interfaces" in which virtual content can be displayed anywhere and anytime without the need of physical displays, and information acquisition could be as effortless as a glance. We believe multi-tasking consumption of information will become one of the primary uses of these devices. In such systems, users can have easy and quick access to information such as news, weather, email, social media feeds, etc while doing some other primary task.

Previously, Lages and Bowman introduced an adaptive walking interface for AR HWDs [10]. In this work, multiple pieces of information follow the user and adapt themselves to the environment. This work enables everyday information access for AR HWDs in a mobile scenario. A next step can be to present such information to the users in an unobtrusive manner that does not disturb the tasks at hand but also maintains awareness of the real world.

In this research, we propose eight different techniques for handling occlusion in Glanceable AR. These techniques vary in content prioritization, adaptation mechanism, and automation level. Understanding the effectiveness of such technique is crucial to the development of future all-day AR HWD Interfaces. This work makes the following contributions: (1) it establishes different criteria for classifying AR Interfaces and uses them to introduce Glanceable AR Interfaces; (2) it introduces three design dimensions for occlusion management interfaces; (3) it introduces eight occlusion management techniques for AR HWDs through a simulated AR experience in Virtual Reality (VR); (4) it reports on an in-depth evaluation of these techniques and design dimensions in a dual-task scenario.

2 Related Work

AR has been long considered as a future way of obtaining everyday information. In 2002, Feiner envisioned the future of AR displays as "much like telephone and PCs...displaying information that we expect to see both at work and at play" [8]. Previous research has extensively explored the possibility of placing virtual information around the users, especially in the format of 2D. Feiner et al. developed Windows on the World, a system that overlays virtual information as 2D windows in the real-world [7]. ARWin, proposed by DiVerdi et al., is a desktop workspace augmented by 2D applications such as weather, calendar and web browsers [5]. Lages and Bowman explored different adaptation strategies that contribute towards the design of augmented reality interfaces that support the fluid way we move and interact in the physical world [11]. However, surrounding the user with multiple virtual windows can cause information overload, in which different pieces of virtual information compete for the user's cognitive resources (i.e., make locating the required pieces of information difficult). Occlusion is one of the strongest depth cues in understanding the spatial relationships between different objects in the same space [4]. In the environment that real-world and virtual content co-exist, detecting and handling the occlusions between them become critical.

Based on our review, previous studies about occlusion management in AR can generally be divided into two categories: (1) handling the occlusion between real-world objects and virtual content to ensure credibility of registering virtual information [3,12,14,15]; and (2) handling the occlusion between one piece of virtual content and other pieces to ensure good visibility [1, 2, 9, 13]. However, limited work was found regarding how to handle the issue of virtual information preventing users from being aware of what us happening in the real-world. Lages and Bowman emphasized the importance of developing strategies to prevent virtual content from occluding the real-world, because users may desire to prioritize real-world over the virtual content in everyday activities such as walking [10]. When being overwhelmed by virtual information, users might not become aware of important real-world objects, people or events promptly. Ens et al. suggest placing information on surfaces to overcome the problem of occlusion in AR [6]. However, one of the benefits that AR offers is the ability to position informa-

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978-1-7281-6532-5/20/$31.00 ©2020 IEEE
DOI 10.1109/VRW50115.2020.00069

tion anywhere in the 3D world. Having access to empty surfaces is not likely to always be possible. How to manage occlusion in order to maintain awareness of the real-world while also providing access to virtual content remains an open question.

3 Glanceable AR Interfaces

In this study, we mainly focus on glanceable interfaces, a case of all-day AR interfaces that enables display and access of virtual information anywhere and anytime with a quick glance, along with or to aid the user's primary task. In this section, we introduce different criteria for classifying AR interfaces that present digital content on virtual displays. We then define glanceable interfaces using this criteria.

We suggest that AR interfaces can be classified using the following criteria.

Accessibility
Temporary interfaces are accessible upon the activation of a specific trigger. This trigger can be in form of an action (glancing, summoning, etc.) performed by the user or the occurrence of a change in the state of the system (notification).
Persistent interfaces are always accessible to the user, needless of any actions or triggers. Heads-up display interfaces in which the digital content resides at the edge of the user's field of view, and are always visible is an example of such interfaces.

Number of Tasks
Single-task interfaces are those in which the user is immersed. Such interfaces, are not necessarily virtual environments, but the user solely interacts with them and not any other virtual or real-world content.
Multi-tasking interfaces are used and interacted with, simultaneous with other cooperative XR interfaces or real-world tasks.

Level of Focus
Primary interfaces present the user's primary task and central focus. Such interfaces interpret all user interactions as inputs.
Secondary interfaces are available for access while the user is performing another primary task.

Level of Information Detail
Concise interfaces eliminate details and provide to-the-point presentation of data to decrease the required time and focus for grasping information.
Verbose interfaces present thorough and detailed information, while requiring more of the user's time and focus.

Placement
World-fixed interfaces are placed in a fixed position relative to the real world [7]. They can be *fixed to an object* and move with that object, or *fixed to a global location*.
User-fixed interfaces are placed relative to the user and follow them [7]. Such interfaces can be *body-fixed* and follow the user while maintaining a fixed orientation, or they can be *head-fixed* and follow the user's position and head orientation.

Glanceable AR interfaces
Based on the classification above, we define Glanceable interfaces as *secondary*, *concise* and *Multi-tasking* AR interfaces that are *user-fixed* and *temporary*. In other words, Glanceable AR interfaces present information/content that is designed to be accessed and understood with a quick glance while performing another primary task either in the real world or with virtual content. Many such information display interfaces can be available at once (different "apps"), and they follow the user so that they are available at any time and place. Using a Glanceable AR interface is analogous to using a smartwatch to quickly check information such as time, date, weather, or upcoming calendar events while doing some other primary task.

4 Technique Design

Occlusion of important parts of the real world is a critical issue for Glanceable AR interfaces. To address real-world occlusion by virtual content, we introduce eight techniques. In this section, we first introduce our technique design dimensions and then introduce our techniques in more detail.

4.1 Technique Design Dimensions

Our technique design dimensions are delineated in the following.

Content Prioritization
Based on the context and the user's primary task, an interface can prioritize the real world content over the virtual or vice versa. Here, when *prioritizing the real world* content of importance, no virtual content will occlude it. When *prioritizing the virtual content*, all of the glanceable content are initially accessible, even if they occlude the real-world objects of interest.

Adaptation Mechanism for Resolving Occlusion
There are many possible mechanisms that could be used to resolve occlusion. We focus on two such mechanisms: adapting the translucency level, or adapting the position of occluding virtual content [2]. From now on, these two intuitive adaptation mechanisms will be referred to as translucency mechanism and reposition mechanism.

The *translucency mechanism* adapts the translucency level of the occluding glanceable content to enable the user to see the real world behind it, but also retains enough visibility to enable the user to recognize its content and boundaries. The *reposition mechanism* raises the occluding glanceable content above the user's eye-level to reveal the real-world content that was behind the glanceable content.

It is important to note that in our implementation of these mechanisms, we made sure that users would not be able to read the required virtual information unless the glanceable content was opaque and in its initial position. This was to keep conditions similar between the two adaptation mechanism, different glanceable content, and users. We did not want users' vision to determine when glanceable content was readable. Also, the background, content, lighting, and colors of different glanceable windows are all different. Therefore, a single user might be able to read from specific windows even when they are translucent/repositioned and not from others.

Level of Automation
Occlusion management can be performed using one of the following automation levels:

Full Automation detects the occlusion of the real world by glanceable content and uses an adaptation mechanism to resolve occlusion. *Automatic Detection* detects the occlusion of the real world by glanceable content and provides a visual cue (we use a blinking red outline) on the occluding virtual content to notify the user about the occlusion. However, this interface gives the user control to choose whether they want to resolve the occlusion or continue to access the virtual content. *Fully Manual* interfaces neither detect nor react to the occurrence of the real-world content occlusion. This base-line level of automation does not introduce any distraction and gives the user absolute control at the expense of reducing their awareness of the surrounding real world.

4.2 Proposed Techniques

Considering the technique design dimensions, our design space includes 12 (2*2*3) unique techniques. However, four of these techniques are not sensible and they were excluded from the experiment. These four are the non-manual techniques that prioritize the real world. The practicality of such fully automatic, context-aware interfaces requires further investigation.

Automatic-Reposition technique initially prioritizes the virtual content, but automatically moves any occluding glanceable content above the eye-level to allow the user to see the real-world object of interest.

Automatic-Translucency technique initially prioritizes the virtual content, but automatically increases the translucency level of occluding glanceable content to allow the user to see the real-world object of interest.

Detection-Reposition technique initially prioritizes the virtual content. This technique outlines any occluding glanceable content with blinking red lines but gives the user control to manually raise it when/if they desire to see the real-world object behind it.

Detection-Translucency technique initially prioritizes the virtual content. This technique outlines any occluding glanceable content with blinking red lines but gives the user control to manually increase its translucency level, if desired.

Reposition-VirtualPrioritized technique initially prioritizes the virtual content. This fully manual technique does not detect occlusion and allows the user to manually move the glanceable content up and find the real-world object of interest.

Translucency-VirtualPrioritized technique initially prioritizes the virtual content. This fully manual technique does not detect occlusion and allows the user to manually make the glanceable content translucent and find the real-world object of interest.

Reposition-RW[1]Prioritized technique initially prioritizes the real world, and starts with positioning all the glanceable content above eye-level. This technique allows the user to access the glanceable content by manually lowering it.

Translucency-RWPrioritized technique initially prioritizes the real world, and starts with setting all the glanceable content to translucent. This technique allows the user to access the glanceable content by manually making it opaque.

Regardless of the technique, the user is allowed to manually interact with virtual content and adjust its visual features based on the technique's adaptation mechanism. For detecting occlusion in non-manual techniques, we monitor the collisions between the glanceable content and a frustum drawn from the user's eye-center to the corners of the important real-world object (Kevin). Once a piece of glanceable content enters this frustum, occlusion is detected and the state of that piece of glanceable content will change according to the technique.

5 Experiment

We designed a within-subjects experiment to evaluate our eight techniques. To evaluate these techniques in a controlled manner, we ran an AR simulation experiment in which users were asked to pay attention to the real world and virtual content simultaneously in a dual-task scenario.

5.1 Scenario and Context

We simulate a future world in which smartphones are replaced by always-on wearable AR eyeglasses **(Figure 1)**. The participant, a babysitter, is placed in a virtual room, watching TV while six pieces of glanceable content, namely: Instagram, Fitbit, Weather, Email, Snapchat, and News apps, are arranged around her. She is asked to perform the following two tasks:

Maintain awareness of the real world: The participant is required to watch Kevin, an autistic child, who occasionally seeks his babysitter's attention by waving at her **(Figure 1)**. Her primary task is to notice Kevin's wave and wave back at him immediately.

[1]Real World

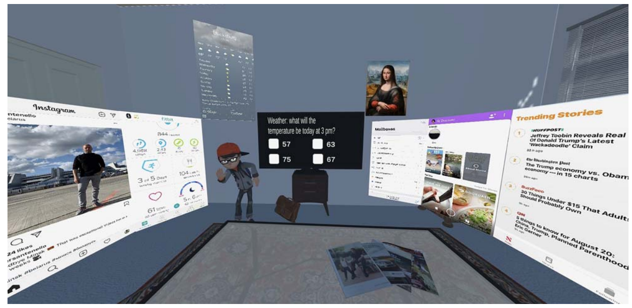

Figure 1: A screenshot of the virtual environment, showcasing the Automatic-Reposition technique. This figure shows a trial in which the user is required to answer a question from the virtual content (appearing on the TV) and react to the occurrence of a real-world event (the waving of the child).

To ensure that participant interact with the glanceable content using our techniques, Kevin moves to different locations and her view of him can get blocked by the glanceable content.

Access virtual information: Occasionally, a question (e.g. the temperature at a specific time of the day, number of unread emails, etc.) and four answer options appear on the TV **(Figure 1)**. The participant must access glanceable content to answer the question.

5.2 Procedure

This study was approved by the Institutional Review Board of the university (IRB). Upon arrival our participants were asked to carefully read and sign the consent form. Before starting the experiment we collected our participant's demographic information and prior experience with AR. After a brief introduction, participants completed a training session in which they familiarized themselves with the environment, glanceable content, their arrangement, and their tasks. Each participant then experienced eight sets of trials, one for each technique. Each trial set included ten trials. A trial required either a wave at Kevin, a question to be answered, or both, and participants did not know in advance which type of trial would occur. When questions were asked, some were from virtual content that would occlude Kevin, and others were from different pieces of virtual content.

All participant used the same eight trial sets in the same order, while the order of presentation of techniques was counterbalanced, to ensure that a particular trial set or the order of experiencing techniques did not bias the results. Before starting each trial set, the participant was trained on how to interact with that technique. After each trial set, the participant answered to a questionnaire about that technique. Finally, we interviewed each participant on their overall experience and their preferences.

5.3 Evaluation Metrics

We evaluate our proposed techniques and their design dimensions based on user performance and self-reported user experience. *Perceived Ease of information access* is evaluated through the participant responses to two post-technique survey questions that used five-point scales. Using that specific technique, we asked 1) how easy they found it to access information from the real world and 2) how easy they found it to access information from the glanceable content. *Preference* is evaluated through the participant responses to the final interview questions about their preferred technique dimensions and preferred technique overall.

We logged the user's interactions and used them to evaluate the user performance. The wrong answers to the questions and the excess wave-backs to Kevin in each trial were logged to measure

Accuracy. The participant's clicks on the glanceable content were logged and used to calculate the *Average operation count* for each technique. The start and end time of each task was logged and used to calculate *Task performance time*.

5.4 Hypotheses

Based on the five parameters we are exploring in this experiment, we developed and tested the following hypothesise:

Content Prioritization
Due to the nature of the primary task in this experiment and dependency of initial visibility of virtual content or the real-world object of interest on the content prioritization, we hypothesize that:
H1. Prioritizing the real world will be preferred.
H2. In terms of perceived easiness: **a)** Prioritizing the real world will be better than prioritizing virtual when accessing information from the real world. **b)** Prioritizing virtual content will be better than prioritizing the real world when accessing virtual information.
H3. In terms of task performance time: **a)** Prioritizing the real world will be faster than prioritizing virtual content when accessing information from the real world. **b)** Prioritizing virtual content will be faster than prioritizing the real world when accessing virtual information.

Adaptation Mechanism
H4. Reposition mechanism will be preferred, since this mechanism allows the user to have both virtual content and the real-world object of interest in their view.

Automation Level
Full automation systems always keep the real-world object of interest visible, and the lower the level of automation, the more interaction and manual operation is required from the user. For this reason we hypothesize that:
H5. In terms of preference: **a)** Full automation will be preferred to the other two level of automation. **b)** Automatic detect will be preferred to the full manual.
H6. In terms of perceived easiness: **a)** Full automation will be better than the other two automation levels for accessing information from the real world. **b)** Automatic detection will be better than fully manual for accessing information from the real world.
H7. In terms of task performance time: **a)** Full automation will be faster than the other two automation levels when accessing information from the real world. **b)** Automatic detect will be faster than fully manual when accessing information from the real world.
H8. Full automation will result in lower average operation count than the other two automation levels.

Technique:
H9. Automatic-Reposition will be the best technique in terms of user **a)** preference, **b)** perceived easiness, **c)** task performance time and **d)** average operation count. This is because this technique keeps both virtual content and the real-world object of interest visible at all time and is fully automatic, thus the user interaction for achieving their goals is minimized.

5.5 Apparatus

We used the Unity 2019.1.3f1 game engine to design a virtual environment that simulates our scenario. Users viewed the virtual environment with a Lenovo Mirage Solo standalone VR headset. We chose to simulate the AR scenario in VR in order to maintain experimental control, so that all participants experienced the experiment in exactly the same way. This approach has been used effectively in many prior studies of AR. Participants used the Mirage Solo's three-degree-of-freedom handheld controller to interact with the virtual content. We rendered a ray emerging from the front of the virtual controller, and users could "click on" a piece of virtual content by intersecting it with the ray and pressing the controller's touchpad button.

5.6 Participants

We gathered data from 36 participants. Data from four participants had to be discarded due to missing data. The participants were recruited from the student body of Virginia Tech. Of the 32 remaining participants, 20 had imperfect eye vision and used eyeglasses. 8 of the participants were female, and 8 of them were graduate students. One of the participants had never used any type of AR/VR before, 12 had limited experience and 6 of them expressed an expert-level of experience with AR/VR. Since we used eight technique orderings based on a Latin Square, we had four participants use each technique ordering.

6 Results

We conducted a series of analyses to test our hypotheses. For our ordinal data (i.e., perceived ease of information access) gathered from post-technique survey and interview, we performed Chi square approximations to the one-way Wilcoxon signed-rank tests.

For the quantitative data, we performed multiple two-way analyses of variance (ANOVAs) on task performance time, with *trial-type* as the first independent variable and *prioritization*, *adaptation mechanism*, *automation level* or *Technique* as the second one, and report the Least Squares Means(LSM) and Standard Error(SE). We also performed multiple one-way ANOVAs on operation count with *prioritization*, *adaptation mechanism*, *automation level* or *Technique* as the independent variable and report the Mean(M), and Standard Deviation(SD). We used an α level of 0.05 in all significance tests.

6.1 Preference

The majority (84.4%) of our participants prefer prioritizing the real-world content in this scenario, and translucency was also the choice of preferred adaptation mechanism for 84.4% of them. In terms of automation level, 93.8% of our participants consider full automation as the best and 56.3% of them preferred automatic detection over fully manual.

When asked which technique they preferred overall (**Figure.2**) all participants chose one of the four techniques in which the child is initially visible. Of these, 75% preferred one of the techniques that use the translucency mechanism, with 50% choosing Translucency-RWPrioritized technique as the best one.

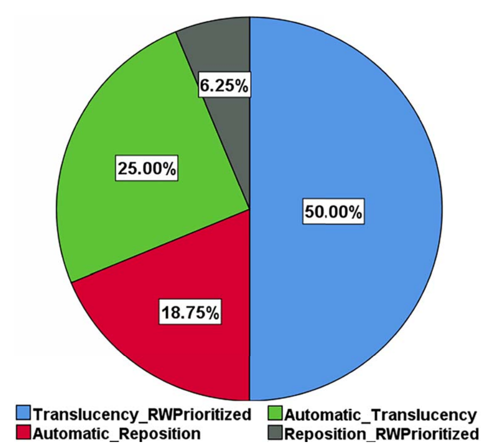

Figure 2: User's choice of best technique

6.2 Perceived Ease of Information Access

Figure 3 illustrates the effect of each technique dimension on the mean of perceived easiness when accessing information. More than

85% of participants ranked the level of ease for real-world information access (i.e., monitoring Kevin) when prioritizing the real world as 5(easiest). A Wilcoxon signed-rank test yields a significant effect (p=0.0001) of prioritization on ease of real-world information access. Prioritizing the real world increases ease of real-world information access (M: 4.81, SD: 0.47) than prioritizing virtual content (M: 3.78, SD: 1.16). However, we did not find any significant difference in ease of virtual information access caused by content prioritization.

We found a significant effect (p=0.0069) of adaptation mechanism on ease of virtual information access. Translucency mechanism results in higher ease of virtual information access (M: 4.36, SD: 0.73) than reposition mechanism (M: 4.07, SD: 0.86).

We also found a significant effect of automation on ease of real-world information access, with significant differences between full automation and fully manual($p < 0.0001$), and between full automation and automatic detection ($p < 0.0001$). Full automation results in higher ease of real-world information access (M: 4.66, SD: 0.57) compared to automatic detection (M:3.9, SD: 0.9) and full manual (M: 3.8, SD: 1.3). However, no significant difference was found for this measure when comparing automatic detection with fully manual.

No significant difference was found for ease of virtual information access when comparing different techniques. However, we found a significant effect ($p < 0.0001$) of technique on ease of real-world information access. Techniques that made the child initially visible were ranked consistently higher than the other techniques for this measure.

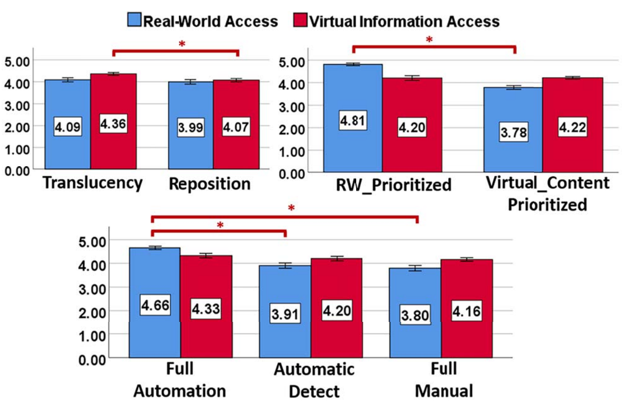

Figure 3: Mean of perceived ease of accessing information from the real world and from virtual content based on technique dimensions

6.3 Task Performance Time

We found a significant effect ($p < 0.0001$) of trial type on task performance time, with trials that only required the user to wave back at Kevin being significantly faster than all other trials. However, we did not find any significant interactions of trial type with any of the technique dimensions.

We did not find any significant effect of prioritization or automation on task performance time. In terms of adaptation mechanism, however, translucency (LSM: 6.28, SE: 0.1) was significantly faster (p = 0.0432) than reposition (LSM:6.56) for tasks that involved accessing information from virtual content.

We observed a significant effect (p= 0.0089) of technique on task performance time when accessing information from virtual content **(Figure 4)**. Pairwise comparisons showed that Reposition-VirtualPrioritized (M: 7.12, SE: 0.198) was significantly slower than six of the other techniques, and it was the least-efficient in terms of task performance time on virtual information access.

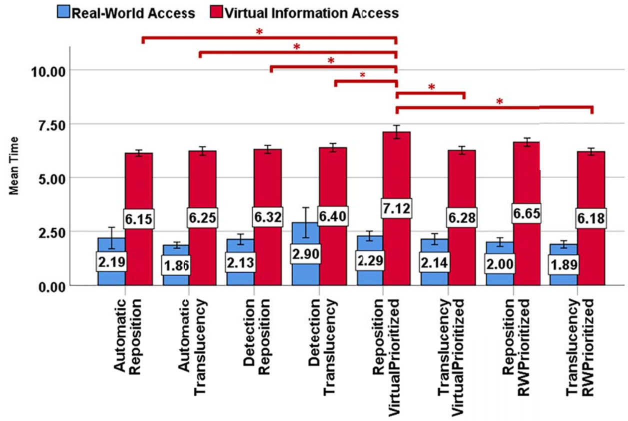

Figure 4: Time for accessing information from the real world and from the virtual content based on technique

6.4 Operation Count

We found a significant effect ($p < 0.0001$) of prioritization on the average operation count. Prioritizing the real world results in a significantly lower average operation count (M: 1.67, SD: 1.05) than prioritizing virtual content (M: 2.87, SD: 2.29). When prioritizing the real world the average operation count for accessing information from the real world is approximately zero. No statistically significant difference between the average operation count using translucency (M: 2.62, SD: 2.09) or repositioning (M: 0.53, SD: 2.15) was found. As expected, the average operation count of full automation (M: 1.46, SD: 1.84) is significantly different than that of automatic detection (M: 2.81, SD: 1.56, $p < 0.0001$) and full manual(M: 3.01, SD: 2.28, $p < 0.0001$). The average operation count also varies significantly ($p < 0.001$) among all techniques(**Figure 5**).

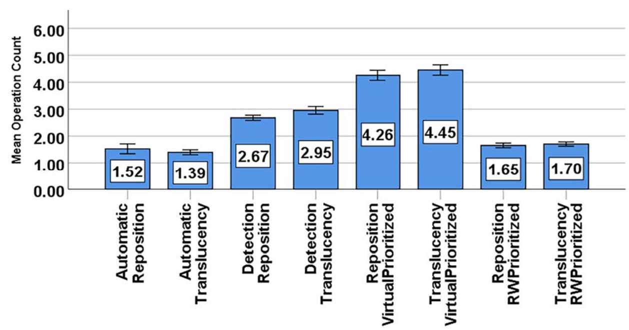

Figure 5: Average operation count based on technique. Most pairwise comparisons are significant; they are not shown in the figure to avoid visual clutter.

7 Discussion

We hypothesized that since in the context of this scenario the user is primarily required to monitor the real world, prioritizing real world would be preferred (**H1**), and would also facilitate (**H2.a**) and accelerate (**H3.a**) the performance of this task. Both hypotheses **H1** and **H2.a** were supported. However, it is noteworthy that based on the interview, this result is not merely due to the primary task and context of this experiment. Many of the participants expressed that, no matter the context, they would not prefer prioritizing virtual content since it introduces unwanted visual clutter in the periphery, which feels cumbersome and distracting, and reduces the feeling of awareness, security and control. This also may explain why **H2.b** was not supported: the participants did not perceive accessing virtual information when prioritizing virtual content as easier.

None of the parameters caused any significant difference in the task performance time when accessing information from the real world, and thus **H3.a**, **H7** and **H9.c** were rejected. A likely reason for this result is that the primary task in this scenario is focused on the real world and most of the participants preferred prioritizing the real-world object of interest. Our observations and the interview showed that most of the participants prioritized the real world manually if necessary once the trial started, even before they were required to access any information from the real world. For example, with the Translucency-VirtualPrioritized technique, participants would typically click on every window right at the beginning of the trial to make them translucent, so that they could see Kevin no matter where he was. Thus, all the techniques had similar performance results when responding to Kevin's waves. We speculate that it was for the same reason that the techniques with virtual content prioritized had no performance advantage over the other techniques when accessing virtual content and **H3.b** was not supported.

Based on our results, the majority of participants prefer the translucency mechanism, so we reject **H4**. We suggest that this was partially because we designed the reposition mechanism in such a way that the answers to questions were not readable when content was in the raised position. It may also be related to the fact that translucency was immediate, while repositioning took some time. The interview revealed two additional reasons for this preference. First, when using the reposition mechanism, the virtual content is not all at eye level. This required the user to tilt their head, and point up when interacting and accessing information from the virtual content. Second, translucency resolves visual clutter and distractions, which decreases user's cognitive task-load and information overload.

As we anticipated in **H5.a**, **H6.a**, and **H8**, full automation was superior in several ways to the other two automation levels. 93.8% of participants preferred full automation, accessing information from the real world was perceived easier with full automation, and the average operation count was smaller when using full automation compared to the other two. Unless manually specified otherwise, full automation always makes the important real-world object visible which lowers the physical task load. However, the interview results revealed another explanation for some of these results. Automatically changing the visual appearance (translucency/position) of the occluding virtual content draws the user's attention towards the visually different glanceable content and thus the real-world object of interest. This increases the user's awareness of important real-world events and facilitates their task.

A majority (56.3%) of participants preferred automatic detection over fully manual. This by itself is not strong support for **H5.b**. However, it is notable that during the interview, many of the participants who chose full manual over automatic detect acknowledged that automatic detect increased their awareness of the real world while giving them control over the system. Many expressed that a more appealing choice of interface design components for automatic detect techniques (i.e., less stress inducing colors, more noticeable blinking speed and highlight line thickness, or the ability to manually deactivate the highlights) would swing their vote towards it. This along with the fact that automatic detection still requires manual interaction when accessing information from the real world and is not easier to perform compared to full manual, may explain why **H6.b** was not supported.

As opposed to our expectation, only 18.8% chose the Automatic-Reposition technique as the best technique. In terms of perceived easiness, this technique was the second best when accessing information from the real world, and was not any different than the other techniques when accessing virtual information. It was also not significantly faster than other techniques, nor was it the best technique in terms of average operation count. These results lead us to reject **H9.a**, **H9.b**, **H9.c**, and **H9.d**.

Overall, the majority (75%) of participants were concerned about minimising visual clutter and distraction, which is possible by translucency, more than any other dimension of the occlusion management techniques. The Automatic-Translucency technique can lower the task load, decrease unwanted visual clutter and distraction, and even help increase user's awareness of important real-world events. Yet, the fact that 50% of the participants chose the Translucency-RWPrioritized technique along with their interview comments may indicate that the participants primarily care about the visibility of the real world and minimizing visual clutter and information overload, which feels more natural and gives the user a feeling of control.

During the interview, a technique that prioritizes the real world and automatically makes the required glanceable content available was frequently suggested by the participants. The practicality of such interfaces relies on the existence of an intelligent context-aware system that automatically detects the virtual content that user needs. Extensive research would need to be conducted to determine the feasibility of such a system.

8 Conclusions

Glanceable AR interfaces will allow future users or AR glasses to quickly access information when needed, while performing other tasks in the real world. We have introduced three different design dimensions of occlusion management techniques for Glanceable AR Interfaces: content prioritization, adaptation mechanism, and level of automation. Using these design dimensions we proposed eight different techniques and evaluated them in a specific scenario that requires the user's attention on both glanceable content and the real world. Our findings show that: **a)** full automation and RW prioritization are preferred and perceived as easier when monitoring the real world, **b)** translucency is perceived easier and performed faster when accessing information from virtual content, and is the preferred adaptation mechanism, and **c)** Users in our scenario primarily care about the visibility of the real world and minimizing visual clutter and information overload.

All-day wearable AR devices are likely to be successors to today's smartphones. Effortless and active virtual information access while maintaining awareness of the surrounding real world requires an adaptive interface. The design of occlusion management techniques and understanding their attributes is an important step towards the development of such adaptive interfaces.

Acknowledgements

The authors would like to thank Blair McIntyre, Wallace Lages, Daniel Monzel, and the other members of the 3D Interaction Group and the Center for Human-Computer Interaction for helpful discussions about this work.

References

[1] R. Azuma and C. Furmanski. Evaluating label placement for augmented reality view management. In *Proceedings of the 2nd IEEE/ACM international Symposium on Mixed and Augmented Reality*, page 66. IEEE Computer Society, 2003.

[2] B. Bell, S. Feiner, and T. Höllerer. View management for virtual and augmented reality. In *Proceedings of the 14th annual ACM symposium on User interface software and technology*, pages 101–110. ACM, 2001.

[3] M.-O. Berger. Resolving occlusion in augmented reality: a contour based approach without 3d reconstruction. In *Proceedings of IEEE Computer Society Conference on Computer Vision and Pattern Recognition*, pages 91–96. IEEE, 1997.

[4] J. E. Cutting and P. M. Vishton. Perceiving layout and knowing distances: The integration, relative potency, and contextual use of different information about depth. In *Perception of space and motion*, pages 69–117. Elsevier, 1995.

[5] S. Di Verdi, D. Nurmi, and T. Hollerer. Arwin-a desktop augmented reality window manager. In *The Second IEEE and ACM International Symposium on Mixed and Augmented Reality, 2003. Proceedings.*, pages 298–299. IEEE, 2003.

[6] B. Ens, E. Ofek, N. Bruce, and P. Irani. Spatial constancy of surface-embedded layouts across multiple environments. In *Proceedings of the 3rd ACM Symposium on Spatial User Interaction*, pages 65–68, 2015.

[7] S. Feiner, B. MacIntyre, M. Haupt, and E. Solomon. Windows on the world: 2d windows for 3d augmented reality. In *Proceedings of the 6th annual ACM symposium on User interface software and technology*, pages 145–155, 1993.

[8] S. K. Feiner. Augmented reality: A new way of seeing. *Scientific American*, 286(4):48–55, 2002.

[9] R. Grasset, T. Langlotz, D. Kalkofen, M. Tatzgern, and D. Schmalstieg. Image-driven view management for augmented reality browsers. In *2012 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, pages 177–186. IEEE, 2012.

[10] W. Lages and D. Bowman. Adjustable adaptation for spatial augmented reality workspaces. In *Symposium on Spatial User Interaction*, page 20. ACM, 2019.

[11] W. S. Lages and D. A. Bowman. Walking with adaptive augmented reality workspaces: design and usage patterns. In *Proceedings of the 24th International Conference on Intelligent User Interfaces*, pages 356–366, 2019.

[12] V. Lepetit and M.-O. Berger. A semi-automatic method for resolving occlusion in augmented reality. In *Proceedings IEEE Conference on Computer Vision and Pattern Recognition. CVPR 2000 (Cat. No. PR00662)*, volume 2, pages 225–230. IEEE, 2000.

[13] K. Makita, M. Kanbara, and N. Yokoya. View management of annotations for wearable augmented reality. In *2009 IEEE International Conference on Multimedia and Expo*, pages 982–985. IEEE, 2009.

[14] M. M. Shah, H. Arshad, and R. Sulaiman. Occlusion in augmented reality. In *2012 8th International Conference on Information Science and Digital Content Technology (ICIDT2012)*, volume 2, pages 372–378. IEEE, 2012.

[15] M. M. Wloka and B. G. Anderson. Resolving occlusion in augmented reality. In *Proceedings of the 1995 symposium on Interactive 3D graphics*, I3D '95, pages 5–12, New York, NY, USA, 1995. Association for Computing Machinery.