Insights from Deploying See-Through Augmented Reality Signage in the Wild

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ABSTRACT
Typically the key challenges with interactive digital signage are (1) interaction times are short (usually in the order of seconds), (2) interaction needs to be very easy to understand, and (3) interaction needs to provide a benefit that justifies the effort to engage. To tackle these challenges, we propose a see-through augmented reality application for digital signage that enables passersby to observe the area behind the display, augmented with useful data. We report on the development and deployment of our application in two public settings: a public library and a supermarket. Based on observations of 261 (library) and 661 (supermarket) passersby and 14 interviews, we provide early insights and implications for application designers. Our results show a significant increase in attention: the see-through signage was noticed by 46% of the people, compared to 14% with the non-see through version. Furthermore, findings indicate that to best benefit the passersby, the AR displays should clearly communicate their purpose.

Author Keywords
AR; public displays; digital signage; interaction; attention

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation: User Interfaces—*Input devices and strategies*

INTRODUCTION
Digital signage has become omnipresent in our daily life – and while commercial systems use sensors mainly for audience measurement (e.g., Microsoft Kinect), researchers exploit such capabilities when building interactive applications with the aim of creating engaging user experiences. At the same time, such installations are often not as well received as expected, hence resulting in rather low user numbers. Reasons for this are manifold and range from displays installed

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Figure 1. Example of an AR digital signage application for a public library: a life video feed from the area behind the display is augmented with information on where to find the different sections of the library.

in a way that makes them difficult to be perceived (e.g., installation orthogonal to the trajectory of passersby) via deployments in locations where passersby cannot easily stop without followers bumping into them, to applications that include complex content and interaction techniques [3, 17]. Prior work has shown that providing a tangible benefit for users is crucial for user engagement [2, 22] and interaction techniques need to be very easy to understand [15]. If displays fail to address these challenges, users tend to walk away, simply because the barrier to participate (e.g., learning how to gesture-interact or installing a mobile application to control the display) is too high compared to the expected gain.

In this work we argue that interaction with digital signage needs to blend with both users' expectations and behavior. Displays need to immediately communicate their benefit and interaction should be subtle, instantly possible with no need for learning, and eventually be implicit so that users do not even need to be aware of interacting. As a solution we suggest the use of see-through augmented reality for digital signage applications. In this way, valuable information about the space behind the display is immediately available – for example information on where to find special offers in a supermarket, where particular exhibits are to be found in a museum, which shops in a pedestrian area are sill open late at night, or where to find the different areas of a library (see Figure 1). At the same time, interaction is based on user position, which makes it not only subtle but users can simply interact (implicitly) without using their hands.

In this paper we present an augmented reality see-through application for public displays that augments the environment behind the display with information. We are particularly interested in the ability of this approach to attract the attention of passersby, which is the first step towards user engagement [20]. We compare a static video see-through visualization and a Fish tank AR visualization. By Fish tank AR we mean that the visualization changes based on the position of the user, hence allowing the space behind the display to be explored by moving in front of the display. Presenting the content in a static manner is used as a baseline. Our results show that both AR modes lead to significantly more attention, compared to static content. In addition, we report on audience behavior based on observations and interviews.

CONTRIBUTION STATEMENT

The contribution of our work is twofold. First, we present the implementation of a see-through augmented reality digital signage application. Second, we report on observations from the first real-world deployments of such a system. Insights gathered during a study in a public library and in a supermarket yield implications for the design of future applications utilizing see-through signage.

RELATED WORK

Prior research related to our work falls into three main areas: firstly those related to public displays; secondly those focusing on Augmented Reality, in particular, see-through displays; thirdly, studies conducted in shopping mall settings and public libraries.

Attention of Passers-by towards Public Displays

Much of the related work in the area of public displays focuses on interactive public displays. In particular the phase where passers-by initially take notice of the display is important to our work, and thus relevant to introduce here.

Brignull and Rogers [6] discuss peripheral and focal awareness of public displays, reporting that the initial impression and one of the factors driving passers-by to become focally aware of a display is based on the attractiveness its content at a distance. Additionally, the placement of displays in positions where there is a natural traffic flow of passers-by is proposed as a method to foster engagement with the display. The term 'display blindness' has been used to describe the case when people's expectations that the display content will be uninteresting for example, advertisements, causes them to ignore the display [22]. The authors propose using more informative content as a potential approach to reduce this phenomenon. Kukka et al. [15] report that, of the variants tested, colored static text was the best performing method of attracting passers-by to displays deployed in a university campus. Müller et al. [21] concluded that passersby are more attracted by a mirror image, or silhouette of themselves than graphical and textual indications.

While we obey these findings (for example, display placement, content design), our work is novel in that it is first to suggest augmented reality employed for different visualization modes to attract attention. In our design of see-through signage, we sought to take into account the positive findings reported in prior art. Hence our solution includes both textual elements [15] and images of people (resembling silhouettes [21]).

See Through Displays and AR

The perception of being able to see through a transparent display can be created either optically (*optical see-through*) or using video processing technologies (*video see-through*) [9, 14]. In addition, mobile projection can be used to create an illusion of see-through physical objects, such as walls [7]. The technical approaches to create AR experiences have been summarized by Azuma et al. [4], of particular interest being those related to see through displays.

An interesting evaluation of differences between optical and video see through has been presented by Rolland et al. [25]. Considering Virtual Reality (VR), Ware et al. [27] introduce the concept of *Fish tank VR*, where tracking the position of the viewer's head, and adjusting a perspective projection of a 3D scene accordingly provides the illusion of depth. While this approach has been widely studied in the context of VR [19], we look at an AR application, where, to the best of our knowledge, it has been little considered, for example, the work of Hill et al. [11] being a rare example. Whereas they focus largely on technical aspects and usage in a lab environment, we are first to take our research to an in-the-wild context.

Various application areas for see-through displays have been proposed, ranging from their use in stores[1] to their use as heads-up displays in cars [26] and as home windows [**?**]. These projects focus on augmentation in the form of textual annotation or GUI overlay, rather than the more demanding 3D blending of real and virtual scenes utilized in other AR application areas.

Display Research on Shopping and Library Contexts

Prior research considered public libraries and shopping contexts as promising environment to adopt ubiquitous screen technologies. Researchers looked into how the shopping environment could be enhanced using displays, e.g., screens attached to a trolley for navigation in a supermarket [12]. In [13], the user is provided information on how far a product travelled and whether a maximum temperature was exceeded by means of different color LEDs and emoticons. Gehring et al. [10] developed a shop counter equipped with a gesture UI and a display, showing the items pointed at. User perceptions on mobile augmented reality (MAR) applications for shopping centers have been investigated in [23]. In the library context, related work has largely focused on augmenting bookshelves, for instance projecting covers on the bookshelf to help in searching books [16]. Alt et al. deployed a digital bulletin board in a library [1].

[1] Intel digital signage concept: `http://youtu.be/ZOaeSnK01_0`

Summary

We present the first systematic research, including a user study, of the use of public see-through AR displays in the wild and the first attempt to use Fish tank AR in a live deployed system. Here, we highlight findings by Dünser et al. [8], who report that only 10% of AR papers between 1992 and 2007 included even an informal user evaluation. We extend the current body of research by aiming to understand the influence of this novel approach on user attention in a real-world setting.

PROTOTYPE

Our prototype AR display was based on a large 47" flat screen TV as the display element (see Figures 2 and 5). We added a web camera (Logitec C270 720p, 30fps) and a Microsoft Kinect. The software application that provided the AR images ran on a laptop PC. The Microsoft Kinect was used to log the head positions of people identified as being in its range for use in later analysis, and as an input to the Fish tank AR mode (described later). Three-dimensional position coordinates were recorded when a new person was identified by the Kinect, and the movements of each person, up to a simultaneous maximum of 6, were logged until they left the range of the sensor.

Content Modes

The prototype supported three content modes, which we were able to switch using a Bluetooth keyboard connected to the laptop PC. In each mode the content was identical.

Static Content Mode

As a baseline we used a static mode, where the sign displayed non-transparent poster type content.

Live Video Based AR Mode

To create the illusion of seeing through the display, we used a video feed from a web camera mounted on the back of the display and overlaid text-based information labels.

Fish Tank AR Mode

The Fish tank AR mode utilized a static image of the view from the back of the display that we took previously, when there were no people present. We then overlaid text-based information labels to the image. When displayed on the screen, the image was scaled such that only approximately 20% of it was visible. The horizontal and vertical position of the image was then moved based on the viewer's head position, obtained from the Microsoft Kinect sensor. Hence, we were able to create the perception of view changes similar to moving in front of a small window. We fine-tuned the exact movement parameters, i.e. how much the image moves for a certain head movement, to provide what we considered to be the most natural result. If multiple people were detected only the position information from the first person detected was used.

STUDY I: ATTENTION

The first driving question behind our research is, how the attention of passersby towards a public display (and ultimately their perception of the content) could be raised in situations where exposure is sought to be minimal. These obviously contradicting goals have engaged researchers and practitioners for decades, since people often cannot stop in front of a display, for example, as they are walking past it in a crowd of people. Digital displays offer novel opportunities to tackle this challenge and we believe our idea of a public see-through AR display to be a promising first step into that direction.

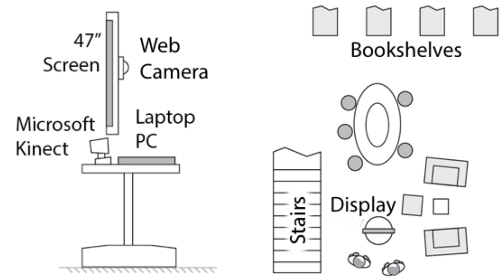

Figure 2. Deployment of our AR prototype – Display setup (left) and floor layout of the library where the display was deployed (right).

As a consequence, we investigate the *influence of the video see-through visualization on attention*. As mentioned before, we compare video AR where content is embedded into a live video of the area behind the display against a fish tank AR visualization, where the perspective on the space behind the display changes based on the user position. We hypothesize, that the latter visualization attracts more attention, since it provides a higher level of responsiveness.

For evaluation, the system was deployed in a public library. Figure 2–right depicts the floor layout. Just inside the entrance to the library a non-digital sign showed the location of different sections of the library and the location of the information desk. For the duration of our study, we removed the existing sign and replaced it with our AR display, placed on a 1.2 m high table (Figure 2–left). We setup the display in the same location and used the same orientation.

Setting

We adapted the content of the non-digital sign for the static content mode. In the two AR modes we showed arrows labeled with the different sections of the library as well as the sign of the information desk. The arrows pointed into the respective direction (Figure 1). The live video based AR mode used a live video feed; the Fish Tank AR mode was built on top of static images from the location. The setting was maintained for the entire duration of the evaluation. Our study ran during a week-day and the display mode was switched hourly.

Data Collection

In addition to the data logged by the Kinect, a researcher observed people's behavior near the display. The researcher was sitting on a bench among other clients in the library to blend into the environment and draw as little attention as possible. Following the audience funnel model [20], the observer recorded the number of people passing the sign and the number that paid attention to the sign during 30 minutes in each mode. By noticing the display we mean turning their head towards the display. Every action from a short glimpse at the display to pausing and looking at it for a longer time was counted. Also the number of users approaching the content, returning to the display after first passing by and trying to interact with the displays was counted.

	Static	AR Video	AR Fish tank
Library: Kinect Data			
Active time (min)	60	73	70
People tracked	182	208	251
People per Minute	3.0	2.8	3.6
Library: 30 minute observation			
Passersby	77	74	110
People noticing display	11	34	29
People noticing display (%)	14%	46%	26%

Table 1. Log data – the results show that both AR modes led to a significant increase of attention towards the display. Furthermore, during the AR video mode significantly more people looked at the display compared to the AR Fish tank mode.

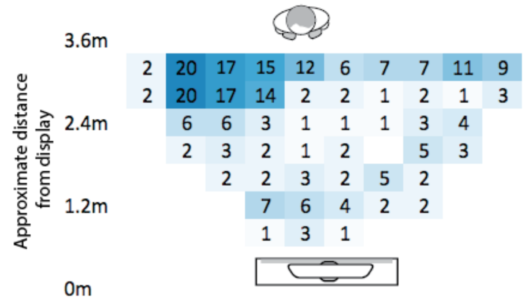

Figure 3. Heatmap of positions where users first stopped for AR Fish tank mode in the library context. Data from other modes was similar.

Figure 4. Supermarket Deployment – In the static mode (left) we showed ads for products in the display vicinity. In the Fish tank AR mode (right), we showed the particular location and price of these products.

Results

The Kinect sensor identified a total of 641 people (Table 1). The application logged each 'skeleton' the Kinect identified separately. If individuals passed by the display on more than one occasion they would be counted each time they passed.

In the *static content mode*, 14% of people passing near the display (11/77) noticed the installation while others did not pay any attention to the signage. Those who noticed the display seemed to be mostly interested in the physical installation itself. In the *Live Video AR Mode*, 46% of the passersby glanced at the display (+32%). At the same time, none approached the display or tried to interact. Also in the *Fish tank AR Mode* (26% attention, +12% compared to static mode), although the display content was moving based on the people passing by, this movement did not appear to entice any users towards the display. This is also backed by the fact that the majority of people who stopped did so at a distance of more than 2.4 m (see heat map depicted in Figure 3).

Chi-squared tests show that the differences between the static and AR video, and the static and fish tank AR were statistically significant (χ^2=18.1, p<0.001 and χ^2=3.9, p=0.047, respectively). Additionally the difference between the two AR modes was found to be significant (χ^2=7.5, p=0.006).

Though we found a significant increase of both AR modes in general, it is interesting that the live video AR mode led to more attention than the Fish tank AR mode. A reason may be that due to the rather short glimpses and the lack of any explicit interaction, no engaging and immersive experience was created. We believe this worthwhile to be further explored, for example by deploying an application that aims at supporting a long-time engagement of the user, such as a game.

STUDY II: AUDIENCE BEHAVIOR & EXPECTATIONS

In a second study, we focused on understanding how the audience behaves in front of a see-through AR display and what their expectations towards such a display are. We deliberately decided to run the second study in a fundamentally different setting, that is a supermarket, to obtain additional insights.

Setting

The store where we conducted our study in followed a typical large supermarket layout with different signs present in-store. In addition to large amounts of paper-based signage, there were 10 digital signage displays (similar to Figure 4).

Typically, the existing digital signage displays were located at end-of-aisle locations, in parallel with the aisle, and in some cases back-to-back (see Figure 5). The original content shown on the screens was a slide show of static advertising content. Together with the store management we reviewed possible locations for our prototype AR display, eventually deciding on a location in the fruit and vegetables section. This location was selected because the floor layout was more open compared other sections and it allowed the display to be placed perpendicular to the isle, such that the products would be visible through it (Figure 5, position D).

The content shown on our prototype display consisted of pictures of fruit and vegetables, and their prices. Products were selected based on their near location and visibility from the display. The products were also in sales campaigns at the time of the experiment. The content was created based on information provided by the store and followed the corporate layout. We ran our study sessions between 11 am and 3 pm on three consecutive weekdays (Tuesday – Thursday). Each test mode was active for approximately three hours.

Data Collection

Similar to the library context, we logged interaction with the Kinect. We also observed passersby and people interacting from an inconspicuous position. In addition to the first study, the front of the display was video-recorded with a hidden camera. Observations lasted for 60 minutes per condition. In addition, 14 people who interacted with the display or seemed to notice the display but decided not to explore it more closely were interviewed.

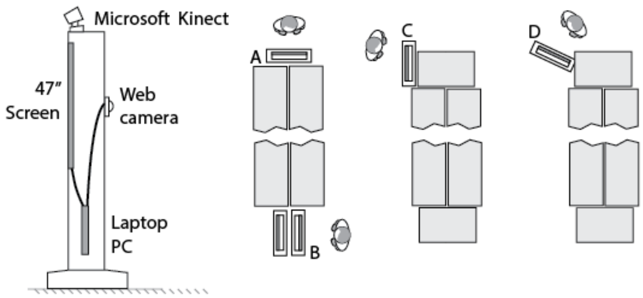

Figure 5. Deployment of our AR prototype – Display setup (left) and layout of the supermarket where the display was deployed at position D (right). A, B and C present typical locations of digital signage in the supermarket.

Results

Behaviour with the Display

The results of the deployment in the supermarket are summarized in Table 2. To ascertain if the differences in the numbers of shoppers noticing the display between the static and AR modes were significant, we performed Chi-squared tests. The result indicates that there was no significant difference (χ^2=3.15, $p <= 0.07$ and χ^2=1.63, p=0.20, for video and Fish tank modes respectively).

Figure 6 shows the times that passersby were in the sensing area of the display, i.e. in front of it, for each of the modes. None of the shoppers tried to interact with the system, for example, by touching the display. Users who came directly from the front or behind usually stayed longer observing the installation. Users who came from the front had time to perceive the moving image in AR cases, which was considered unusual in the context. On the other hand, shoppers who approached the installation from behind paid attention to the unusual setup, the location of the display, and the video camera. If the shopper came from the left, the interaction with the display was shorter. Thus, to maximize attention times the display should be directed to face the direction from which most of the passersby approach. Typically, the shoppers just slowed their walking speed and glimpsed shortly at the screen.

Interviews

In addition to observations and logging, we interviewed 14 shoppers, where 3 saw the display in static mode, 5 in AR video mode and 6 in AR Fish tank mode. Of the interviewees, none of the three with the display in static mode had noticed the display spontaneously or had paid attention to the displays during earlier visits at the supermarket either; and all eleven who saw the display in AR modes had noticed the display. Of the people who saw the display in AR mode (n=11), 4/11 could name at least one product shown on the display. On a 7-point Likert scale (1=not all, 7=very much), people seeing the AR display perceived it Fun (5.4/7), Interesting (4.7/7) and Useful (3.8/7), with n=11.

The interviewees who saw the display in AR mode commented on the display location or, when approaching the display from the behind on the web-camera location: 'This hasn't been here before'. The content items were also commented: 'Is this some recipe?' Many people commented that it was the movement of the image that initially drew their

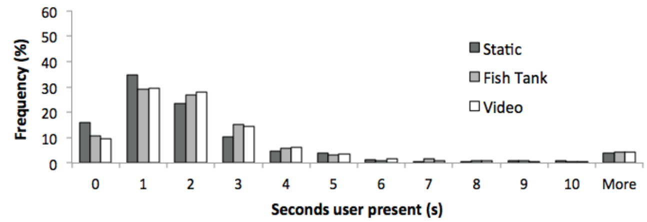

Figure 6. Time spent in front of the display in the supermarket context

	STATIC	AR VIDEO	AR FISH TANK
Supermarket: Kinect Data			
Active time (min)	161	165	215
People tracked	263	565	714
People per Minute	1.6	3.4	3.3
Supermarket: 30 minute observation			
Passersby	159	267	235
People noticing display	4	17	12
People noticing display (%)	3%	6%	5%

Table 2. Log data – Summary of data from the supermarket deployment.

attention, and some people were wondering where the video-camera was placed, when they saw someone moving on the screen. Others commented that it was the unusual content that got their attention.

Three of the six shoppers that interacted intentionally with the Fish tank mode display. One user (#14) stated: 'At first the movement itself drew my attention, but then I noticed how the picture started to follow my movements'. Comprehending the logic of the system was not obvious at first glimpse, so the users had to stay in front of it for a while before realizing it.

The perceived advantages of this kind of public display were to act as a reminder of things to buy and to highlight the products on sale. The interviewees stated that the illusion of see-through and the possibility that it eased locating products were not obvious to them.

IMPLICATIONS

Although a few interesting concepts for the utilization of see-through AR have been proposed [24, 26], we believe our experiences on their practical deployment in real world contexts provide novel and useful lessons for following research.

Firstly, our results suggest, that AR can indeed *increase the attention* towards displays. This is in line with findings from Brignull and Rogers [6] who reported attractiveness from a distance to be a key element in gaining focal attention. While this attractiveness of AR seems to increase the attention in general, it is interesting, that the Fish tank AR mode performed significantly worse than the live video in the library – though more movement on the screen occurs in this condition. Though we did not elaborate on it, this finding could be a result of kinesthetic matching [18], i.e. in the live video AR mode users could better relate the movement behind the screen to movements on the screen (for example, other visitors). This is similar to findings from Müller et al. [21] who exploited this fact for conveying interactivity. This implies both an opportunity and a challenge for the designers of AR applications: while video AR could lead to more attention, it must at the same time be assured that enough traffic occurs behind the display. This could be achieved either through orienting the display towards an area that is in general well-frequented (e.g., an aisle) or it must be ensured that people are attracted towards this area (e.g., by placing special offers or, in the case of the library, a table featuring new books).

Secondly, we noted that the *AR mode does not convey interactivity*. No user approached the display to try and interact using mid-air gestures or touch (even though we did not obscure the Kinect, which is an interactivity cue itself). This suggests that AR is well suited to attract attention without conveying interactivity. From this decoupling we learn that on one hand, designers must think about how to convey interactivity through the content shown on the display, if active engagement is desired. On the other hand, this property provides a lot of freedom during application design, since designers could easily apply the concept both to applications that aim at minimizing exposure (e.g., an information display) as well as such seeking to create an immersive, long-term experience, for example, a game – independent of the desired degree of attention.

Thirdly, designers of AR applications on public displays *need to cope with display blindness*. As proposed by Müller et al. [22], this phenomenon occurs when there is the expectation that no interesting content is to be found on the display, i.e., it is advertising in nature. Clearly in the supermarket there was the general expectation that all signage is sales based, whereas in the library we can surmise that expectations are for informative content. Similarly, the dependence of display performance on its location, reported by Behrens et al. [5], was clearly identified between our two situations. Additionally, as our placement contexts were more diverse than those used by Behrens, we can speculate that some of the observed difference was due to context dependent behavior patterns, rather than purely the physical environment.

Our findings also imply that *conveying the purpose* of the display is crucial. We see particular potential in applications that provide a benefit for the passerby. A good example for such an application was suggested by a passerby who thought the products shown on the screen could be part of a recipe. Another application could show customers the items they want to buy in the aisle ahead. This could be realized by transferring the data through a smartphone, which gets the information on required products from a smart fridge in the user's home and then communicates this to the display in the supermarket.

LIMITATIONS

We acknowledge that our study is limited by the tested locations and content. Still we believe that the two fundamentally different situations observed – i.e. a location where people are goal-driven (the supermarket) versus a location where people may be more willing to browse content – allowed us to gather valuable insights. With regard to attention, our findings echo those of [22] where the role of user expectations as to the content shown play a large role in the attention gained by displays in specific contexts. Second, there was an obvious novelty effect which future work should account for.

CONCLUSION

In this paper we investigated the effect of applying see-through AR to digital signage content on user attention. In particular, we compared static content to a live video AR and a Fish tank AR visualization. We found that AR led to a significant increase in attention, as we witnessed an increase from 14% (non-see-through signage) to 46% in live video and to 26% in Fish tank mode. This makes the approach particularly valuable in situations where public display providers seek to attract as many users as possible. At the same time, our findings suggest that see-through AR provides designers with alternatives with regard to interactivity. Our qualitative findings from the deployment in a supermarket suggest that AR application need to clearly communicate their purpose and benefit for passersby.

For future work, we plan to investigate also other types of content and contexts of use. Moreover, we are interested in subsequent steps in the interaction process, i.e., how see-through AR can help to communicate the purpose of the display or to support the motivation of the user to engage into long-term interaction.

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