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Development of an Inexpensive Augmented Reality (AR) Headset

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Abstract

We outline our work in developing an Augmented Reality (AR) headset with low purchase and maintenance costs. Similar to Google Cardboard, the headset uses a smartphone to provide the compute power, connectivity and display. Unlike Google Cardboard, our headset does not block the user's view of the world and is therefore suitable for AR applications. The headset uses the Pepper's Ghost illusion to display images from the phone's screen via a transparent sheet located in front of the user's eyes. During a pilot study, we confirmed that the headset is effective in settings with low to medium levels of ambient illumination: in these conditions we demonstrated the effectiveness of using a mobile phone's standard screen brightness settings to present a range of photos, 3D images, short texts and shapes.

Author Keywords

Augmented Reality; Headset; Wearable; Mobile; Smartphone.

ACM Classification Keywords

H.5.1 Multimedia Information Systems: Artificial, augmented, and virtual realities.

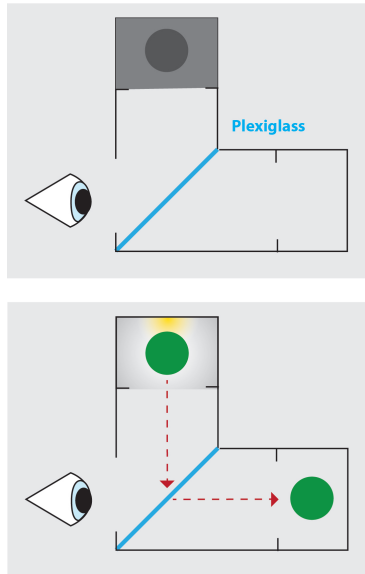## General Terms

Design, Human Factors.

Figure 1: How the Pepper's Ghost illusion works with our headset: the lighter area is in front of the user's eyes, while the top of the headset is dark. A sheet of plexiglass is located inside the headset at an angle of 45 degrees between the smartphone screen and the user's view. When the phone's display becomes brighter, the object appears projected in the user's view via the plexiglass.

Introduction

In recent years, Augmented Reality (AR) has received much attention in both the academic and commercial worlds, mainly for its capability of providing additional content and enhancing people's experience of real objects [2,3]. In particular, the use of AR with mobile devices can be successful in supporting users' everyday interactions and their navigation in real space [8,9]. Mobile devices are personal and portable, so they can physically move with people, keep track of their context [7], and provide users with information regarding their surroundings [1]. However, mobile devices typically need to be held when using them to support AR, which can be tiring and limits the possibilities for hands-free use to enable other activities. Wearable devices such as headsets can mitigate this problem. In the related domain of Virtual Reality (VR), headsets have been around for many years and have improved substantially in recent years by utilizing technology developed for mobile phones to provide relatively lightweight hands-free devices with considerable compute power and quite high-resolution displays; see e.g. Oculus Rift.

More recently, headsets such as Google Glass and Epson Moverio have increasingly been researched and developed. However, such solutions are usually expensive to buy and to maintain. Other innovations such as Google Cardboard have suggested a practical, inexpensive and accessible solution to this problem with respect to VR headsets: users can put their own smartphone into a cardboard frame and experience a virtual world on the mobile screen. However, VR replaces the real world around the user with a virtual world, while AR simultaneously presents both the surrounding real world and "augmenting" virtual experiences [3]. An AR application using a device such as Google Cardboard could be developed by using the phone's camera to capture the environment and rendering the resulting images in real time on the phone's display with whatever augmentations are desired. However, seeing only this rendering of the real world could reduce the quality of the experience, and virtual environments are known to cause issues with spatial orientation and perception [2,6]. As an alternative or complementary approach we have been developing an inexpensive AR headset that utilizes the user's own mobile phone in a similar way to Google Cardboard but which provides an AR experience by overlaying images from the phone's screen on the user's direct view of her surroundings.

This paper presents our initial work on the development of a unique wearable Augmented Reality (AR) headset that will allow the use of the personal smartphone to augment a real space. The headset holds the smartphone above the user's eyeline to allow an unimpeded view of the environment, while images from the mobile screen are projected via a transparent surface in front of the user's eyes. Since users use their own mobile phones to provide the compute power, connectivity, display etc, the purchase and maintenance costs of the AR headset are modest. Given these low costs, the headset can be treated as effectively disposable and has multiple potential applications. We are investigating it in particular for use in museums where it can be handed out much as electronic mobile audio guides currently are but at much lower cost and with less need for intervention and control by museum staff. We are collaborating with the UK's National Trust to investigate the use of the headset to enhance the experience of visitors to the Trust's many historical sites.
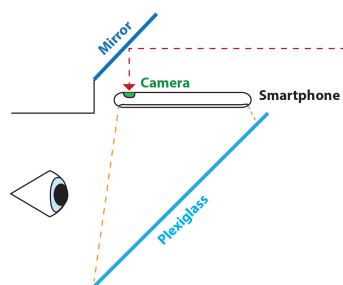
Figure 2: The periscope system: a mirror installed on the top of the headset reflects the view of the room into the phone's camera.

AR Headset

The headset consists of a lightweight frame that holds a smartphone above, rather than in front of, the user's eyeline. Users simply need to install a mobile application and put their phone in the headset frame. We developed a prototype application using Unity 3D and the Vuforia SDK. We fixed the orientation as landscape. The Unity scene includes the AR camera and a plane with black texture attached as a child. Since the background is set as a child of the AR camera, it follows the movements of the mobile phone's camera. We added an image target and a set of virtual elements as children of the image target. When the real-world object is tracked, those virtual items appear on the phone's screen against the black background. The content from the phone's screen is then projected in front of the user's eyes by means of the Pepper's Ghost illusion, overlaying their view of the real world with the virtual items but without the black background which is not projected by the headset.

Pepper's Ghost
The Pepper's Ghost illusion is a technique sometimes used by magicians that allows objects to appear and disappear inside a room: there are actually 2 rooms, one lighter main room and one hidden darker room (see Figure 1). A sheet of glass, plexiglass or similar transparent, semi-reflective film is placed between the 2 rooms, usually at a 45-degree angle, so that it can reflect the view of the darker room into the lighter room. When the lighting level in the darker room is increased, objects from the hidden room can be seen to appear in the main room.

In our case, the main room is the space right in front of the user's eyes, while the hidden room is the phone's

screen located at the top of the headset. A sheet of plexiglass is inside the headset at an angle of 45 degrees between the smartphone screen and the user's view. When the application running on the smartphone displays an object on the phone's screen, the phone's screen becomes brighter and so the object appears projected in the user's view via the plexiglass.

User View Tracking System
Since the phone is placed on the top of the headset with the screen facing down, the phone's camera is facing the ceiling and cannot track the view in front of the user's eyes. In order to solve this problem, we installed a small mirror on the top of the headset, rotated 45 degrees over the mobile camera (see Figure 2). The mirror reflects the view of the room into the camera, however, the image viewed by the camera is reversed so we had to flip the image tracker as well, and reimport it into Unity. Finally, we mirrored the location of all the items to be projected accordingly to the new image target.

As the user walks around, the mirror reflects the view of the surroundings on to the phone's camera. In this way the application is able to track the environment in front of the user and display objects and text in the appropriate place and orientation in the user's view.

Pilot Study

We have run a pilot study in order to test the capacity of the Pepper's Ghost illusion to produce a sufficiently clear visual display of a range of textual and graphical images using a prototype of our headset with a common mobile phone using its standard screen brightness settings under a range of indoor lighting conditions.
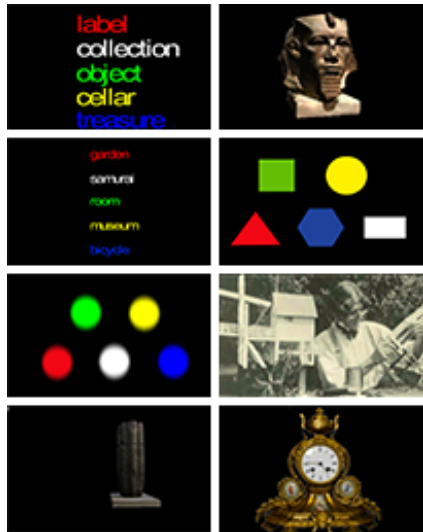
Figure 3: Screenshots of the mobile application. Left column, starting from the top: Words Arial 50 and 25, circular blurs, the 3D column. Right column from the top: 3D pharaoh's head, set of shapes, black and white photo and colour photo.

The prototype headset was made of cardboard and contained a 15x15 cm sheet of plexiglass inclined at an angle of 45 degrees. We placed an LG Nexus 4 mobile phone in the top of the headset. The bottom of the headset was open to allow the projection of images from the phone's screen on to the plexiglass.

For this study we developed a mobile application using Unity 3D and installed it on the phone. The Unity scene included a black skybox, a directional light, and a set of elements to be displayed. In each trial in our study, the items appeared sequentially for 20 seconds each, one after another against the black background. They were displayed as "slides" in the following order:

- Five words written in Arial 50: object, treasure, label, collection, cellar;
- Five words written in Arial 25: samurai, museum, bicycle, garden, room;
- Five circular blurs, each of a different colour: blue, red, green, yellow and white;
- A 3D column with a dark texture;
- A 3D pharaoh's head with a lighter texture;
- A set of coloured shapes: a green square, a yellow circle, a red triangle, a blue hexagon and a white rectangle;
- A black and white photo of Charles Wade (collector and late owner of the National Trust's Snowshill Manor; see below);
- A colour photo of a clock (see Figure 3).

When our development of the headset has moved beyond a work in progress to a sufficiently robust and reliable deployable device, we will investigate its use by visitors to National Trust properties. The Trust's Snowshill Manor is a useful test site as it combines dimly lit interiors with a large and eclectic collection displayed throughout its rooms. Hence, the words on the first 2 slides were selected from the content of the Snowshill Manor website. The text remained the same but changed colour for each trial. We could not test every possible colour but each text, shape and blur had a different hue: we used the four fundamental hues (blue, red, green and yellow) and pure white. For each colour we used the maximum brightness value in the RGB scale to maximise the effectiveness of the Pepper's Ghost illusion: 255-0-0 for red, 0-255-0 green, 0-0-255 blue, 255-255-0 yellow, and 255-255-255 white.

After each trial, the application paused for 40 seconds while the researcher changed the ambient lighting level in the room before restarting from the beginning of the next trial, i.e. from the five words written in the larger font size.

Procedure
There were 12 participants, 10 males and 2 females, aged between 18 and 45 years old. Each participant sat at a table, in front of a white wall. The participant placed the headset in front of his face and looked through the plexiglass towards the white wall in front of him (see Figure 4). As the trials proceeded, the participant was asked to tell the researcher if he saw anything appearing in front of him. If so, he was asked to describe what he saw and if he saw it clearly or poorly. Each session was audio recorded and the researcher also took notes.

For each slide the researcher recorded on a form if the participant saw nothing (0), poorly (1) or well (2). If the participant saw just a faint unrecognisable image, then the researcher recorded 0.5. If the image was
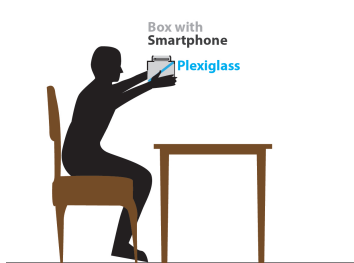
Figure 4: Pilot study setting with table and prototype headset held by the participant.

almost clear, missing some details, then the researcher recorded 1.5. At the end of each trial of 8 slides, the observer changed the ambient illumination of the room using a digital light meter. Then the participant ran the next trial of 8 slides. Each participant ran a total of 6 trials: four with a different room illumination and twice with different phone screen brightness settings. Each trial lasted about 3 minutes. Each evaluation lasted about 20 minutes.

Light Settings
We considered 2 factors: the brightness of the phone's screen (195 at medium screen brightness and 355 lux at maximum), and the intensity of the environmental illumination (measured right in front of the headset). The following four ambient illumination levels, based on the Illuminating Engineering Society guidelines [10], were tested with the phone's default medium screen brightness setting:

- From 50 to 80 lux: interiors rarely used for visual tasks such as night-time sidewalk, parking lots;
- 100-160 lux: interiors with minimal demand for visual acuity such as corridors and changing rooms;
- 200-300 lux: interiors with low/some demand for visual acuity such as foyers and entrances, dining rooms, libraries and teaching spaces;
- 400-500 lux: interiors with moderate demand for visual acuity such as general offices, retail shops and kitchens.

In addition, we tested the 2 extreme levels of environmental illumination (50-80 and 400-500 lux) with the phone's screen set to maximum brightness.

Findings
The study showed that the blurred circles and shapes were more visible than any other content, both at medium and maximum screen brightness. At medium brightness they were clear up to 200-300 lux while at maximum brightness they were fully visible in both the tested ambient illumination conditions, i.e. 450 and 50 lux. The black and white photo was harder to see than the colour photo and its details were recognisable only at maximum screen brightness and 50 lux illumination.

The 3D column was fully visible only at 50 lux and maximum screen brightness, in which conditions participants were able to describe details of the column. At both 450 lux with maximum screen brightness and 50 lux with medium screen brightness, participants were able to see only the base of the column, which was lighter than the rest of the 3D model, and the general shape of the column. The pharaoh's head, which had a lighter texture, was more visible than the column: users were able to see the head with more ambient illumination and less screen brightness while the column was almost invisible in any ambient light over 50 lux with medium screen brightness.

With all forms of content (i.e. text, shapes, blurs, photos and 3D models), blue and red were the colours that were hardest to see. The blue and red text was invisible to most participants when the environmental illumination was above 50 lux with medium screen brightness, while they were completely visible at both 50 and 450 lux with maximum screen brightness. The bigger text was usually clearer than the smaller text, but the bigger and smaller text were equally visible – because both were perfectly clear – at 50 lux with maximum screen brightness.
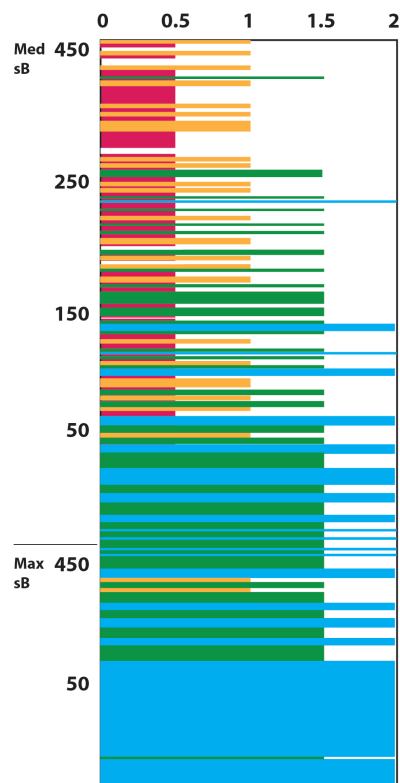
Figure 5: AR content visibility scores according to levels of ambient illumination (450, 250, 150, 50 lux) at medium (Med sB) and maximum (Max sB) screen brightness settings. Scores colour code: 0.5 objects almost invisible (red); 1 poorly visible (yellow); 1.5 good visibility (green); 2 perfect visibility (blue).

Even with the brightest ambient illumination of 450 lux, maximum screen brightness gave good results, with similar visibility scores to those for medium screen brightness and 50 lux ambient illumination. In both those conditions (i.e. 450 lux with maximum screen brightness and 50 lux with medium screen brightness), only the small text, the 3D models and the black and white photo were poorly visible. Unsurprisingly, maximum screen brightness with 50 lux ambient illumination gave the best results, with maximum visibility of almost every displayed object, except the column and the black and white photo which were scored 1.5 by 2 participants because they were still not completely clear to them (see Figure 5).

Conclusion

Our findings so far demonstrate that our prototype AR headset is able to project virtual content right in front of the user's eyes, overlaid directly on his view of the real world. Our pilot study has shown that a range of virtual content in different colours is very visible using the headset in conditions similar to many historical properties, such as those of the National Trust, which maintain quite dimly lit interiors in order to help preserve the heritage artefacts within them. Crucially, we have demonstrated the effectiveness of the headset using just a standard mobile phone and its default screen brightness settings. In our ongoing work we will develop a more robust, wearable headset and test it in the field at Snowshill Manor in summer 2015.

Acknowledgements

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