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The Augurscope: Refining its Design

Abstract

In this paper we explore the iterative design of the Augurscope, a mobile mixed reality device for open-air museum experiences. It allows a 3D virtual environment to be viewed as if overlaid on an outdoor physical environment. While exploring a heritage site, groups of visitors can experience simulated scenes from the past from a dynamic user-controlled viewpoint by moving, rotating, and tilting the device. The development focused on creating an interface to a visualization of a medieval castle as it used to appear in relation to its current, quite different site. We describe the development and application of the Augurscope through two iterative design stages. We discuss the issues revealed through public trials with the first prototype and how they informed the design of the Augurscope 2. The deployment of this second prototype then enables us to offer insights into what makes such a novel presentation device successful in an outdoor museum environment.

1 Introduction

Making the invisible visible is a challenge faced by exhibition curators at many historical sites. Archaeological excavations bring up a wealth of information but making this material accessible to non-experts in a non-destructive way is non-trivial (Refsland, Ojika, & Addison, 2000). In this paper we explore the design of the Augurscope, a mobile mixed reality device for open-air museum experiences. The Augurscope allows a 3D virtual environment (i.e., reconstruction of an archaeological site) to be viewed as if overlaid on an outdoor physical environ ment. Using this device, groups of visitors can experience virtual scenes from the past from a dynamic user-controlled viewpoint, while exploring a physical heritage site.

There are a number of research areas relevant to the development of the Augurscope. The rapid spread of wireless communications, mobile computing devices, novel display technologies, and positioning systems has stimulated a growing interest in mixed reality applications for museums where the visitors' experience is enhanced with digital information. This represents a fruitful development area as museums have often been keen to adopt new interface technologies to enhance the presentation of and interaction with artifacts and sites. More specifically, there has been a growing interest in the use of

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technology to enhance visitors' experiences of historically relevant sites and their buildings. This spans from presenting interactive multimedia content to onsite augmented reality presentations (Addison, 2000).

In this paper we describe the development of our device and its application through two iterative design stages, Augurscope 1 and 2. We discuss the issues that have emerged during the process of developing and deploying Augurscope 1 and how this information informed the design of the second prototype. The deployment of Augurscope 2 based on the same application, the virtual recreation of a medieval castle, then enables us to offer insight into what makes such a novel presentation device successful in a museum environment. We begin by providing a brief overview of studies of visitors behavior in museum settings and related novel presentation technologies for museums, which help us to formulate our design requirements.

2 Understanding the Museum Environment

There is a growing body of work within the area of museum studies that is concerned with explicating the behavior and learning of visitors to museums and galleries. One enduring message from this research is that interaction with exhibits is critical to the learning experience in such settings (e.g., Falk & Dierking, 2000). Further studies (Walter, 1996; Heath, Luff, von Lehn, Hindmarsh, & Cleverly, 2002) suggest that in many cases although technology can serve to enhance an individual's experience of an exhibit, it can often impoverish interactions between people. The problem with many interactive exhibits is that while museum visitors can witness the conduct of someone operating the technology, they cannot see the details of what the person is responding to.

This is problematic as in recent years it has been recognized that people often visit museums and galleries with companions and they also share these public environments with others. The museum experience is shaped through interaction and discussion with others within a group (McManus, 1998; Diamond, 1986). For example, discussions among family members enhance memories of the visit, including information about exhibits and how family members feel and think about them (Stevenson, 1991; Leichter, Hensel, & Larsen, 1989). Furthermore users frequently learn by watching others interact with exhibits, a practice that extends beyond the bounds of the local group to encompass more peripheral observers (vom Lehn, Heath, & Hinduarsh, 2001).

Responding to these studies there has been a growing interest in creating dissemination technologies that facilitate interaction, communication, and collaboration between museum visitors. There has been a proliferation in museum environments of interactive displays based on technologies such as touch screens. These displays are often used to present additional material about exhibits or to enable visitors to complete tasks helping them to improve their knowledge, or refine their feelings and opinions. Interactive displays have mostly been used indoors but there are examples of outdoor use such as the Ename 974 project, where visitors to an archaeological site are presented with a virtual recreation of some of the buildings that have been excavated (Pletinckx, Callebaut, Killebrew, & Silberman, 2000). There has also been a drive towards the use of larger screen projections and non-screen media for the creation of spatial, immersive experiences suitable for small groups of participants. For example, in The Legible City, visitors are able to ride a stationary bicycle through a simulated representation of a city (Shaw, 1989).

The use of portable electronic devices to provide visitors with additional information about exhibits and sites of interest is also becoming commonplace. Often these are audio guides but personal digital devices are also increasingly deployed. The London Canal Museum is exploring the use of mobile phones to provide visitors with information during a canal towpath walk (Mobile Internet, 2003). The use of electronic guidebooks (based on a visual interface running on a PDA) for obtaining information about objects in a historic house has been studied (Woodruff, Aoki, Hurst, & Szymanski, 2001) and wireless handheld tablets have been used to

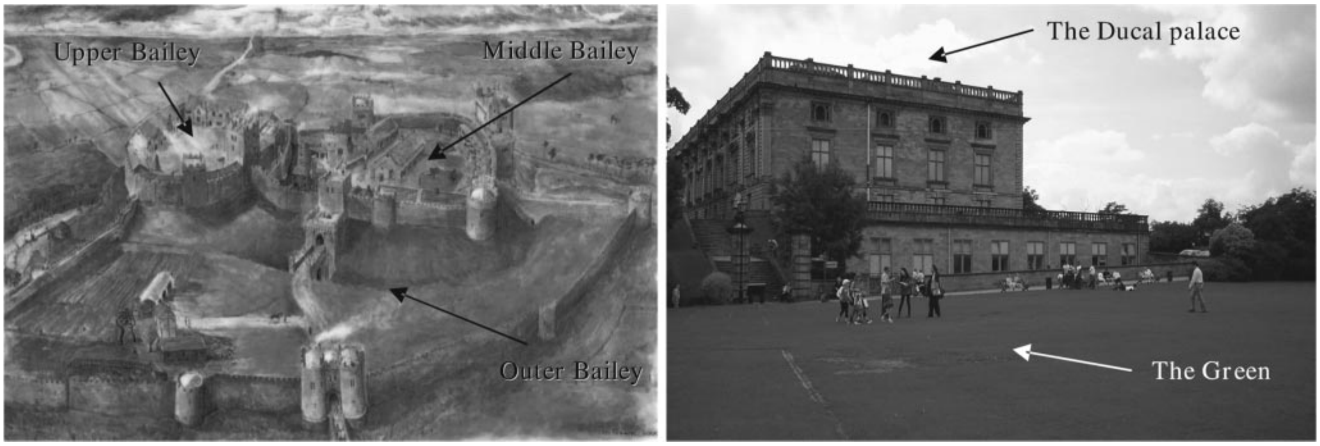

Figure 1. *Artist's impression of the medieval castle and Ducal Palace today as seen from the Green.*

aid navigation and deliver location-based information to tourists in a city (Cheverst, Davies, Mitchell, Friday, & Efstratiou, 2000). Similarly, Benford et al. have created a museum experience where participants use wireless laptops and PDAs to explore an outdoor location, hunting for buried virtual artifacts that they then bring back to a museum for more detailed study (Benford et al., 2001).

Aiming to give visitors a more immersive experience, the use of wearable computers and head-mounted displays is also explored within museums. Examples include a campus tour augmented with labels and virtual representations of buildings (Höllerer, Feiner, Terauchi, Rashid, & Hallaway, 1999) and the wearable system developed by the Archeoguide project that provides visitors to historic sites in Olympia, Greece with reconstructions of artifacts found on site (Gleue & Dähne, 2001). An important aspect of the above examples is that they are typically designed for individual use and so they cater less well for groups of visitors that are so common in museum environments.

3 The Missing Medieval Castle

As a test bed for the Augurscope, the grounds of our local museum and art gallery, situated on the historically very relevant site of Nottingham's medieval castle, seemed ideal. The museum has numerous functions spanning from exhibiting local heritage to showcasing historical and contemporary visual arts. In addition to this museum staff also attempt to explain the topographical relationship between the present site with only very few medieval structures remaining and the imposing defenses once associated with Nottingham. The first fortified castle was built there in 1067. Over the next six hundred years it was extended by a succession of kings to become one of the most important and impressive medieval castles in England. Figure 1 (left) shows an artist's impression of the castle as it was in the late fifteenth century. However, in 1651 the castle was destroyed and the ruins subsequently cleared so that the modern Ducal Palace could be constructed that occupies the site to this day as a museum (see the right picture in Figure 1). Herein lays a major problem. Tourists expect to see a fine example of a medieval castle, but instead are presented with the seventeenth century Palace in its place. Not only is this disappointing, but it is also difficult to understand how the more complex medieval castle was structured, where its parts would have been in relation to the current site, and how they would have appeared.

The museum already employs various mechanisms to give visitors some sense of the medieval castle: a physical model is on display inside the museum; a slideshow, guides, and brochures are available. In addition, the locations of some of the original walls are marked out on the ground of the current site, and public displays explaining the site's topography have been placed at key viewpoints. However, according to the museum management, not enough is currently being done to explain the history of this site effectively, especially as there are remaining medieval structures that visitors cannot identify without some help.

4 Design Requirements

Based on the issues raised by previous work in museums and the specific requirements of the test application in the grounds of Nottingham Castle, the design of our mixed reality device has been driven by the following high level requirements.

Mobility. The device should be mobile, enabling visitors to relocate it to various positions within an extended physical setting (the castle site in this case) and from these, to obtain different viewing angles and panoramic views.

Outdoor Use. The device must be designed for outdoor use, allowing visitors to explore the castle site. Previous experience with outdoor systems (Azuma, 1999) has pointed out a number of difficulties that the design needs to address, such as the need for battery power, shielding against adverse weather conditions, poor screen readability in bright sunlight, and variable positioning accuracy.

Public Use. As our intended application involves directly engaging the public, the device should be usable without significant training or effort. It should be easy to engage with and disengage from without having to strap on significant amounts of equipment (an important issue when there is a regular turnover of visitors, each with a potentially short dwell time). It should also enable new visitors to easily learn how to use it by watching current ones.

Small Group Use. The device should be shareable among small groups of visitors such as families, responding to the growing recognition that people often visit museums with companions and their museum experience is shaped through interaction with others.

5 Augurscope 1

5.1 Description of the Device

We considered several general designs that might meet the combination of requirements outlined in the previous section, including those based on head-mounted, wearable, and handheld displays. We eventually opted for a design based on a tripod-mounted display that can be assembled in different outdoor locations and then carried or wheeled around the physical environment (see Figure 2). This display can be moved to any accessible outdoor location and then rotated and tilted on its tripod in order to view a virtual environment, as it would appear from that particular vantage point. The device was named an Augurscope because it augments reality and also because one of its potential uses is to peer into the future (auguring), for example when using it for environmental planning applications. Full details of the original Augurscope can be found in Schnädelbach, Koleva, Flintham, Fraser, Chandler, Foster, Benford, Greenhalgh, Izadi, & Rodden (2002).

Of course, tracked displays are already familiar whether they are handheld (Fitzmaurice, 1993) or boom or stand mounted for virtual reality applications (Fakespace Boom, 2001). Stand-mounted rotating displays have also been used in augmented reality, for example the Panoramic Navigator overlaid text and graphics on a video see-through view captured from an onboard camera, and also included hyperlinks that could be selected via a touch screen (Cook, Pettifer, & Crabtree, 2000). We based our design around a portable stand-mounted display due to the core issue of physical scale. In contrast to wearables or PDAs, a stand-mounted display can be shared by a small group. Users can engage and disengage by stepping up to and away from the display, an important issue when there is a regular turnover of users such as in a museum. Furthermore, the required combination of a laptop computer

Figure 2. *Augurscope 1: overview and detail of top unit.*

and various tracking, video, and audio peripherals is both bulky and weighty. Early tests showed that users would quickly tire of carrying them, ruling out a handheld solution. A portable stand allows users to rest the device in a stable position without much effort and affords more fine-grained interaction. Finally, the tripod provides a platform for mounting a variety of other devices such as GPS, cameras, speakers, and other accessories as we shall see below.

5.1.1 Physical Form. Augurscope 1 is built around a laptop computer (a Dell Inspiron 8000 with a 15 inch display and NVIDIA Geforce2Go 3D graphics). This is mounted on a rugged tripod using a camera mounting that allows indefinite horizontal rotation and vertical tilting between 25° degrees upwards and 90° downwards (when the display becomes completely horizontal and can potentially be used as an interactive table). The laptop and its mounting are boxed in a wooden casing with the following features. It has two handles for easy manipulation, a counterweight for a well balanced and smooth rotating and tilting action and a zoom button (×6). In addition a removable cover bearing simple instructions conceals the keyboard and surrounding wooden panels add shielding from bright light. In designing the shielding we were aware of a tradeoff between shielding from sunlight and restricting peripheral viewing and hence inhibiting group use. Indeed, at one point we had considered incorporating a waterproof fabric hood (similar to that used with old fashioned cameras) but decided that this would compromise the open and inviting nature of the device and use by groups. Bearing in mind that current laptop screens offer a relatively narrow viewing angle, a sensible compromise is to allow shielding to restrict the viewing angle up to but no further than the viewing angle afforded by the laptop screen.

Wheels were added to the base of the tripod to facilitate movement to new locations. During the course of development we experimented with two sets of wheels. The first was an off-the-shelf accessory wheel-base supplied by the manufacturers of the tripod (Manfrotto). These featured three small rotating wheels on a rugged base with a foot-pedal operated brake. These proved suitable for smooth surfaces, but generally unsuitable for rough surfaces and grass where they were difficult to move and resulted in a very rough ride for the onboard technology. As a result, we then built a second set of more outdoor wheels with inflatable tires that were more suited to grass and rougher surfaces.

5.1.2 Movement Tracking. The most basic interaction with Augurscope 1 is to move it to a new location, set it down, and then rotate and tilt it in order to look around. This is made possible through a combination of three onboard tracking technologies.

An Etrex GPS receiver with electronic compass attached to the display mount on the tripod gives the position and orientation of the Augurscope 1 relative to the surrounding environment. Position data has a typical accuracy of between two and four meters, although this varies according to weather and proximity to buildings. The compass provides rotational data with a typical accuracy of 1°. However, there is a delay between moving the device and receiving an update of more than a second. Furthermore, position and orientation readings fluctuate by approximately two meters and one degree respectively, even when the device is held stationary. In addition to the compass, a rotary encoder is attached to the tripod mounting in order to provide rapid and accurate measurement of the rotation of the display relative to the tripod. The display can be rotated indefinitely. A solid-state accelerometer mounted on the wooden frame measures the tilt of the display relative to the tripod. The delay and fluctuation associated with this and the rotary encoder are negligible compared to the GPS receiver and compass.

5.1.3 Virtual World Display and Interaction. The Augurscope's display presents the user with a viewpoint into a 3D virtual world. This provides a first person perspective from the point of view of the device itself so that the virtual world appears to be overlaid on the physical world. Sound is played out through a pair of small battery powered speakers hidden inside the frame. Augurscope 1 uses the MASSIVE-3 collaborative virtual environment software to create the castle visualization (Greenhalgh, Purbrick, & Snowdon, 2000). This supports multi-user/device access to a shared virtual world. An additional software platform called Equip (Greenhalgh, 2002) supports the integration of the tracking system with standard MASSIVE-3 interface components. We were fortunate enough to obtain an existing 3D model of the medieval castle that could be readily adapted and imported into MASSIVE-3, calibrated with GPS readings from the current site, and then run on Augurscope 1.

5.2 Public Trials and Issues Found

The development of Augurscope 1 and the castle application involved a sequence of site visits and public tests. Several visits to the castle were made to select key sites for deployment, to obtain reference GPS coordinates, to clarify the relationship between the medieval castle model and the physical site, to measure WaveLAN signal strength at different locations, and to calibrate and test the Augurscope 1.

Public trials were carried out over a day. The weather was mostly sunny, but with some overcast periods. A sign was placed near to the Castle Green inviting visitors to try out Augurscope 1. Approximately 30 members of the public used the device during the day. These ranged from individuals to groups of family and friends. They included tourists (with several overseas groups), local residents, museum designers and staff, the managers of a large public construction project, experts in planning and architecture, other virtual reality and augmented reality researchers, and the media. The pattern of the experience varied between visitors. On the whole, we tried to minimize the amount of training and other scaffolding that was given and instead encouraged visitors to use the device as independently as possible. The duration of use varied from approximately a minute up to 15 minutes.

Over the course of the day we collected video of visitors using our prototype. A camera was placed some distance away, with the zoom facility being used to capture visitors' movements. Audio data was captured via a wireless microphone that was mounted on the Augurscope 1. Subsequent analysis of this data revealed some interesting aspects of visitors' interaction. In general, the public and professionals who tried the Augurscope appeared to comprehend its purpose and responded with enthusiasm. Most could operate the device with little training. Rotation, tilting, and zooming were used frequently and movement of the device did occur, although infrequently as we discuss below. People were able to relate physical and virtual worlds as evident from frequent pointing and referencing of images on screen and the real space around them. We saw examples of groups using the device. Often one person would grasp the two handles to rotate the display while others looked over their shoulder (indeed, we suspect that providing a single central handle might have encouraged more equally shared control). We therefore feel that Augurscope 1 was already broadly successful as an outdoor public mixed reality interface for small groups. However, there were several key issues that were more problematic and drove the development of our second prototype.

5.2.1 Mobility. Visitors generally appeared reluctant to move Augurscope 1, possibly because the combination of the weight of the onboard equipment and frame, the rough grassy surface, and the small wheels caused the device to feel unstable. With two notable exceptions (when the Augurscope was taken on extensive tours of the Green), visitors seemed to prefer viewing the virtual world at a single location, and movement of the device was limited to short distances or to times when the supporting technical team offered help in moving to other viewpoints. One particularly noticeable effect was that visitors tended to engage in detailed discussions of those phenomena that were easily available simply by panning and tilting the device. They also made extensive use of the zoom facility, perhaps as a way of compensating for physical movement.

5.2.2 Accessibility. An interesting feature of the use of a tripod was the way in which the three legs appeared to constrain rotation of the display. The legs of the tripod protrude at enough distance from the central axis to maintain the stability of the device, which also means that they are wider than the handle for rotation reaches out. This seems to have the effect of framing the use of the Augurscope into three 120° segments, each defined by two of the three legs. Users, whether individually or in groups, appeared to treat the legs as cutoff points for standing (we recorded instances of up to twelve people standing within the 120° segment containing the display). A typical pattern of use was to explore a location by thoroughly investigating each segment in turn, before traversing to the next.

There were also some problems with differences in height, especially for family groups where we saw instances of parents having to lift children to allow them a better view. Even when lowered all the way the device was still too high for some people. In addition the weight and bulkiness of the device meant that only adults were ever able to move it.

5.2.3 Sunlight Readability. Despite our attempts to shield the laptop screen, it was noticeable that users sometimes had difficulty seeing the image, even when directly facing it. This became particularly obvious during sunny spells of weather. What is interesting here is not so much the (already reported; Azuma, 1999) observation that bright sunlight is a problem for outdoor displays, but rather the ways in which users react when they are able to freely orient a display. Turning the Augurscope so that the screen faced away from the sun was a common reaction, even though this sometimes meant that objects of potential interest were missed.

6 Augurscope 2

6.1 Description of the Device

Responding to the issues revealed through the public trial of Augurscope 1, the device was redesigned with the aim of making improvements to its mobility, accessibility, and shading from sunlight. In this section we describe the physical form, tracking technology and interaction with Augurscope 2. A full overview of its design process can be found in Schnädelbach, Koleva, Twidale, & Benford (2004).

6.1.1 Physical Form. Our approach to the design of the second prototype was to begin with the physical form factor and then integrate bespoke electronics (rather than a standard laptop) and software. We

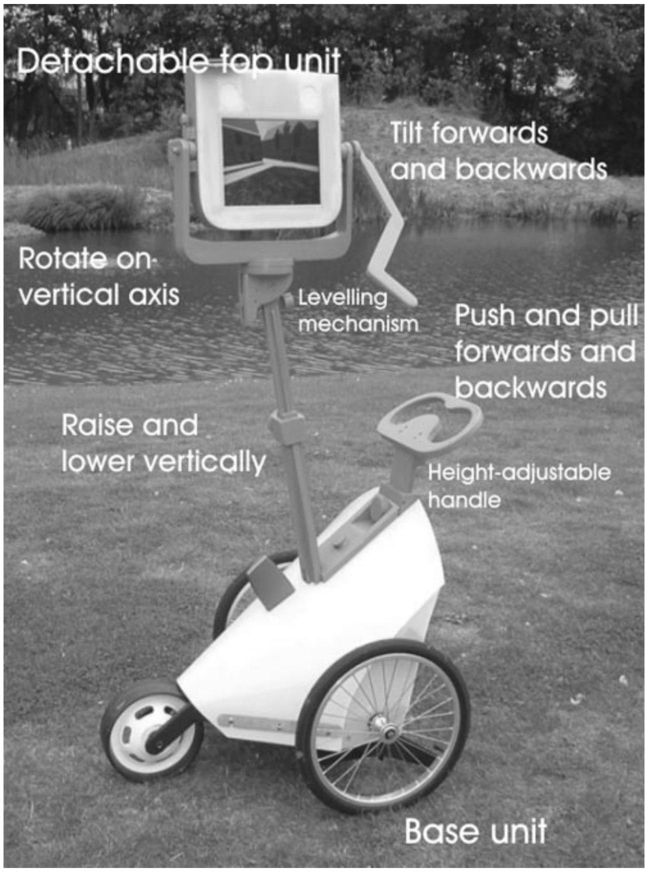

Figure 3. *Overview of Augurscope 2 in stand-mounted mode.*

conducted a series of "push and move" tests with various basic wooden structures (with appropriate weights attached) so as to refine its physical form. The new design comprises two units—a base that houses the main computer (Windows PC with accelerated Nvidia graphics hardware) that renders the 3D virtual environment and a detachable top unit containing the display and sensors. The two are linked wirelessly (Figure 3).

The base unit features three wheels. Two air-filled bicycle wheels at the back add a little suspension and they are big enough to go over small indentations in the ground. The golf cart style wheel in the front is relatively wide allowing users to slide it left and right over the ground when rotating the base. This improves the unit's mobility even on grass and slightly uneven ground. Our new design locates most of the computing, communications, and power supply low to the ground in the base unit. In particular, the base contains the computing power to render 3D graphics that are then communicated wirelessly as composite video to the top unit. The overall weight of the device has also been reduced and leveling has become a lot easier as most of the weight is located below the leveling mechanism. The overall width of the base is much smaller than with Augurscope 1. We have also taken care to make sure that the handle for rotating and tilting the top reaches beyond the base's width. This enables users to freely move around the device. The top unit is mounted in a gimbal on the stand. The gimbal allows indefinite horizontal as well as vertical rotation. By removing two pins, the top can be taken off for handheld use. We made use of a Corona sunlight readable display to cope better with bright conditions. This has made additional physical shading unnecessary. Finally, our design features two handles, one attached to the base and one to the rotating mount for the top. Early push tests suggested that this would give the most stability as users could hold the top steady while pushing the base along. Indeed, with a little practice, quite flexible two-handed use is possible in which pushing can be combined with rotating. The center column and handle are height adjustable. This allows the center of the screen to be adjusted from 122–172 cm in height while the push handle can be adjusted from 75–102 cm in height, which is designed to cater for children of the age of ten to adults of average height.

6.1.2 Movement Tracking. We use two sensing technologies. There is a Trimble GPS receiver to provide global position. It is much lighter and requires less power than the original unit. In combination with this we use a CSI RTCM receiver for differential GPS corrections giving us a theoretical accuracy of 1–2 meters. In place of the accelerometer, rotary encoder, and digital compass in the original Augurscope we now use a single Honeywell HMR3000 digital compass to measure global rotation and tilt. Both GPS and compass are integrated into the top, which communicates their data wirelessly to the base using 802.11b.

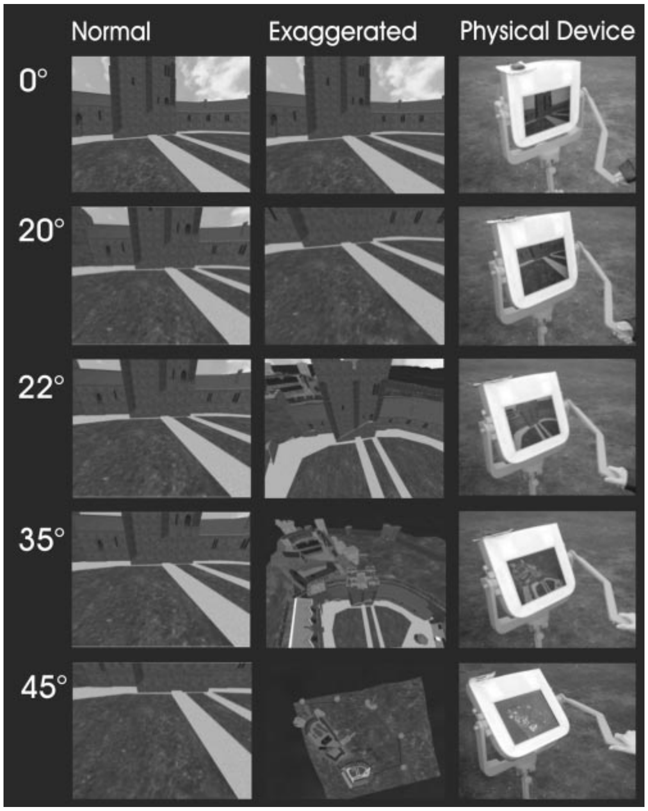

Figure 4. *Comparing normal with exaggerated tilt.*

In contrast to Augurscope 1, the physical tilt of the top unit and the tilt of the camera are not mapped linearly. We have implemented this to enable users to obtain a bird's eye overview of the virtual castle site, both to be able to orient themselves and for the novel perspective that this brings. More specifically, the tilt has been exaggerated so that for every sensed degree of tilt two degrees are rendered. Additionally between 20° to 45° the camera pulls upward. At 45°, the virtual camera has tilted to 90° (i.e., is looking straight down) and it has risen several tens of meters into the air to give a bird's eye view, as shown in Figure 4. The view remains static beyond 45°. This approach deals with limitations of the hardware chosen, as the HMR3000 device can only sense up to 45° of tilt, while at the same time providing a useful view of the virtual environment not available otherwise.

6.1.3 Virtual World Display and Interaction. Interaction is very similar to Augurscope 1. Users control their viewpoint in the virtual environment by moving the physical device. Effectively, we used the same application based on the original 3D model. There were two additions to the software setup of MASSIVE-3 and Equip as used in Augurscope 1: software to deal with the differential GPS corrections and software communicating the tracking data from top unit to base unit.

6.2 Augurscope 2 in Use and Issues Found

Trials with the Augurscope 2 were carried out on two consecutive days in the summer. Conditions were warm and dry with some very bright spells. The good weather attracted a large number of people to the castle in this busy tourist season.

6.2.1 User Profile. The event was not advertised but we had just over 100 participants interacting with the device. People who came to relax in the park, visit the castle museum, play soccer, or simply sunbathe interrupted their activity to engage in a cultural experience for a while before returning to what they were originally doing. We include in the user group people who either interacted with the device directly or who were closely involved in the experience and discussions while watching others. The age range of direct participants spanned from 10 to 65 years while people merely observing ranged from 3 to 75 years. Most of the interaction with the device was by groups rather than individuals. These were couples, parents with their children, groups of friends, and school groups (7–24 members) from different nationalities. The museum management confirmed that the user profile represented well the visitors to the site on a typical summer day.

6.2.2 Management of the Trials. There were three distinct phases to our trials. Between these phases small adjustments were made to the device, the experience as a whole, and our evaluation method with the aim of understanding what would make such a device work under different circumstances.

During the first phase on day one we approached people when no one was currently engaged with the device, asking them to try it and tell us what they thought it was about. An evaluator and technical support were always present at least in the initial stages of the experience. Our presence seemed to reassure and encourage many visitors and allowed us to pose some diagnostic questions or suggest things to try. However, for a few people this was slightly intimidating, putting them under pressure to perform in a kind of test. Thus for the second phase in the morning of day two we added labels to the top unit and the handle of the base unit in an attempt to get users over the initial period of uncertainty with a small amount of additional information. The wording on the top was: "Nottingham Castle in ≈1485 / A tour developed by the Mixed Reality Lab, University of Nottingham," "Turn and tilt to rotate your viewpoint." The wording on the base handle was: "Push me to move your viewpoint." In all other respects the experience was managed in the same way as during the first phase. In the afternoon of the second day, during the third phase, we left the labeled device alone in a strategic position near the entrance to see how people would interact with it then.

It is worth noting that in general Augurscope 2 attracted a great deal of attention from visitors walking up and wanting to try it out. Therefore there were only relatively short periods where it was not used. By providing relatively little explanation on or around the device, we were certainly taking the risk that not every participant would fully understand its content. However, we hoped that by working it out by themselves rather than through explanations, users would gain a better understanding through a more enjoyable process.

We also labeled three key locations on the Castle Green (see Figure 5): the Great Hall (not remaining physically), the Middle Bailey (only recognizable through the topography of the present site) and the location of a good view of the Gate House (physically remaining and the main entrance to the castle grounds of the present day). For day two we moved the markers slightly closer together hoping to entice people to make more use of them.

Figure 5. *Label on Castle Green.*

Another modification was the weighting of the handle. On day one the top unit was leaning forward slightly, which meant that visitors mostly started in overview mode looking down on the virtual castle. On the second day the weighting was changed so that the display was completely upright, giving a starting view that pointed horizontally forward.

6.2.3 Data Capture and Technical Issues. Data capture was similar to the trials with Augurscope 1. From a distance we collected video and audio material for later analysis. GPS data was also logged. Technically there were only a few problems. The battery life determined the length of the sessions (4 sessions between 60–90 minutes). When they did run out a visitor's experience would be interrupted but people were very accepting. In the afternoon of the first day we had problems with overheating of the top unit resulting in inferior image quality. Again, while people noted the fact, they were not deterred from continuing. The range of the video transmission from base to top unit was limited to a few meters when obstructed by people and to slightly more when unobstructed. This was noted by the two users who tried handheld mode. To deal with the problem we kept the distance between the two units as short as possible and attempted to maintain line of sight between them.

Figure 6. *Augurscope 2 in use: handheld mode (left) stand-mounted mode (center and right).*

7 Discussion

7.1 Mobility, Accessibility, and Sunlight Readability

The overall mobility was much improved over Augurscope 1. The GPS logs and the video material show that users collectively explored the entire Castle Green with emphasis on the physically central area coinciding with the virtual Great Hall. In addition, the rotation of the top unit around its base was unobstructed, resulting in an unfragmented access to the whole 360° virtual panorama. Consequently, better access was provided to both the physical site and device, and to the virtual model, helping users to understand the relationship between the two.

The redesign also improved access to groups of users not catered for well with Augurscope 1. The occasional adjustment in height of the central column and the push handle was required and could not have been easily achieved by the users. However, after the redesign we saw a wide range of visitors interact with the device, for example groups of children from the age of 10 taking it on extensive tours to explore the views of the Great Hall and the Gate House. We found that even when not adjusted correctly Augurscope 2 remained useable. Users then simply looked up or down at the screen. Though in the former case they were unable to use the overview facility as the top unit needed to be tilted down and viewed from an elevated physical position (not possible for young children, so some were lifted up by their parents for a better view).

The detachable top unit made the device accessible to even more people; for example parents demonstrated content to their children (see Figure 6 left). Handheld mode was only tested with two people who themselves suggested that it might be an interesting feature. This mode is very useful in certain circumstances but generally it makes the device less useable for larger groups of people. One person is in control and is very close to the display, making it more difficult for others to see what is going on. One user also reported that they considered tilting and turning more difficult compared to when the top is supported by the base. We feel that we could not have expected users to have taken off the top unit on their own initiative and it would certainly have been too heavy for others.

Finally, sunlight readability has improved considerably with the use of the new display. No shading was required even in very bright conditions, while viewing angle and distance were very good (see the center picture of Figure 6 taken from across the green). The improvements in sunlight readability also enhanced access to the virtual content, which often remained difficult to see with Augurscope 1.

By solving the major problems noted during the use of the first prototype we were able to focus the evaluation on the content of the experience rather than the device itself. This will be the subject of the discussion in the following sections.

7.2 Levels of Interaction

Augurscope 2 was clearly visible from across the green and attracted a lot of attention from visitors. Like Augurscope 1 it remained easy to engage with and disengage from with no firm commitment necessary for most of the levels of interaction we identify below. Its movements across the surface and the rotation/tilt of the top unit around the base could be clearly identified from several tens of meters away. Additionally, the presence of an image on the screen while not necessarily its content could also be seen (see the center picture in Figure 6).

Initially, people often watched others interact around Augurscope 2 from a distance. This turned the experience into the subject of discussion among bystanders some distance away as we learned from people walking up to have a look. For example, one woman came up and when asked whether she could guess what the experience was about replied "Sheila has already told me" where Sheila (not her real name) had been a previous user. Often observations and discussions would then continue a little closer by when visitors moved to a distance where the screen was clearly visible. Sometimes visitors would follow movements of the screen affected by others by walking around the base unit before either disengaging again or taking their turn in the experience. In most cases they would then interact with the top for a while. Tilting and turning was used extensively to explore the virtual site from the initial position. Finally, users would start pushing the device, which spanned from very short distances to extensive tours of the Castle Green. We feel that this last step, covering ground on the physical site, was very important and we often encouraged users to "try pushing it" without revealing what effect this would have. As the virtual environment is directly mapped to the physical one, physical travel directly translates into virtual travel allowing users an unmediated access to the dimensions of the original medieval castle.

An interesting observation was that a large proportion of users interacted with one hand while holding something in the other one. These items included ice cream and cameras, for example. One parent pushed the Augurscope 2 with their body while holding their son. This kind of encumbered use is very much to be expected in a public tourist setting and users coped well by adapting their interaction. This made relocations more difficult but did not prevent them; we did note a number of other issues that were sometimes problematic.

When the device was moved only a little, the virtual viewpoint on the screen did not update because GPS data was filtered to prevent jitter. This discouraged some visitors, as they could not see any benefit of moving the device. Also, the process of discovering what this experience was about required some effort. The Castle Green is slightly bumpy and the device itself might have appeared too fragile. In addition, because on day one the default tilt started users in overview mode, changes in the view of the virtual environment due to physical movement were hard to detect. One user argued that he could see no point in moving the device. In these circumstances we encouraged people to tilt the screen back giving them a viewpoint located on the virtual ground and looking forward, making the translation from physical to virtual displacement very clear. This issue was resolved when we changed the weighting of the handle. At the same time we introduced labeling which encouraged visitors especially when the device was left on its own. We recorded a number of instances where users would read out the instructions to each other and then start using the device.

The labels also sometimes overcame another obstacle: the need for permission. Augurscope 2 seemed to be accepted as part of the overall museum exhibition. However, museum exhibits even when they are interactive tend to be fixed in place. Here users had to overcome the threshold of looking for permission either through watching others (they are allowed to move it), our encouragement, or indeed the labels.

Once people did move the Augurscope 2 we found that they adhered to virtual limits like walls or paths as translated to the physical site more than we expected.

When we suggested that virtual walls could be crossed many people were surprised. It seems that users accepted the virtual barriers at least initially as physical constraints, which implies that they translated well the imagery on the screen into spatial information relevant on the physical site. At the same time, crossing virtual walls into a building, for example, often helped users to gain a full understanding of how virtual and physical spaces relate, especially when they took the time to look back to where they had come from (seeing the same wall from the other side).

7.3 Understanding

7.3.1 Stages of Understanding. The mode free, minimalist interface of rotating, tilting, and moving seemed intuitive to most people. The affordances of the two handles seemed to be clear whether this understanding was acquired from previous observations of others or the physical construction of the device. Where any doubts remained, short instructions by us and on the second day the equally brief notes on the labels sufficed to get people going. This stage tended to be followed without much difficulty by the recognition that the physical movement of the device translated to a direct manipulation of the viewpoint in the virtual environment.

People had more problems understanding what the content on the screen represented. This was largely dependent on previous experience, where people with knowledge of CAD or gaming applications immediately recognized the content as a 3D model giving them an advantage. Also, people who already had seen other parts of the Castle Museum transferred the knowledge acquired there, as one man in his 50s explained: "I just looked at the model in there, actually (pointing at the Ducal Palace), yeah, so I remember seeing this actually (pointing at the screen)." He then continued explaining that he had seen some wooden structures in the physical model that he can now identify in our virtual reconstruction. This also indicates that Augurscope 2 was sometimes accepted by visitors as just another tool for understanding the Castle context.

On day one, with no labeling on the device, some users without that experience suggested that there are old buildings but would not connect them with Nottingham Castle. When we introduced the labels this issue was resolved. However, this did not necessarily translate into an understanding that there is a registration between the virtual model and the physical site or that this registration is direct. For example, some visitors suggested that the interior of the virtual Great Hall was what they would see inside the present day Ducal Palace.

As already noted the Nottingham Castle Site offers very few reference points that can be used to map the virtual reconstruction of the medieval castle to the present site. Cer tain events in the experience made this relationship clearer. Passing through walls was particularly effective, especially when they were also marked out on the green (as is the case with the eastern walls of the Middle Bailey). Others found the overview tool more useful and when people had problems understanding the relationship we sometimes used the over view to point out the physical Gate House in the distance and its virtual reconstruction on screen.

The additional reference points we provided on the green (see description above) worked less well than expected. They were frequently used to identify virtual locations once users had arrived at them already. However, they rarely motivated people to move the device from one marker to the next. Although quite large they were difficult to see at a distance at an oblique angle. We placed them closer on day two without too much success. Other measures might make them more useful, for example linking them physically on the green or represent ing them in the virtual environment.

7.3.2 Strategies for Understanding and Collaboration. Users employed a number of different tactics to get an understanding of what the experience was about. Analogies were made with things people knew about already. However, these were often mistaken. For example there were references to surveying in general and geophysics in particular, a technique made popular by a well-known TV archaeology show. A number of people mentioned virtual reality and cameras as reference points. Additionally, the context of the Castle museum was also drawn upon when users referred to their previous experience of the physical model displayed inside and the numerous signs put up in the grounds. We also recorded instances where users took a very systematic approach to finding out how the device worked by proposing hypotheses of what might happen for certain interactions and then testing them out. One man in his thirties with his toddler on the left arm articu lated: "and if I move it along, does the picture change" before pushing the Augurscope 2 forward a little. Later on he suggested before testing the tilt mechanism "like, I guess I am zooming in by doing that, yeah."

As already mentioned, observing others was a strategy frequently employed to get an initial idea of what the experience might be about. Users would watch from a short distance and sometimes discuss the experience with their associates before taking a turn themselves. The physical construction of the device, which afforded large scale movements, supported this approach well as it was possible to understand what someone was doing from a distance.

When closer to the device, people were able to collaborate and explain the device to each other as another strategy providing scaffolding for others to understand the experience. Heath, C., Luff, P., vom Lehn, D., Hindmarsh, J., and Cleverly, J. (2002) argue that a key element in generating interaction and collaboration is the way in which the artifact renders both response and appearance of others visible, both to people they are with and others who happen to be within perceptual range of the event. The ability for people to "animate" exhibits for others through talk and gesture is another critical aspect of interaction in museums and galleries (Heath et al.). As the screen was bright with a wide viewing angle and large enough for a small group of people, it was frequently shared. In addition users also shared the input devices. The wide oval-shaped push handle and the elongated turn/tilt handle for the top provided space for a number of hands to reach the device. We recorded many instances of two or more people pushing the device together while one of them was typically in control of the top unit but we also saw a few examples of people sharing the task of rotating and tilting the top. This allowed visitors to explain the interaction and the content of the experience to others. For example, a man in his thirties and his two daughters of about six and ten years together pushed the device around the Green passing through the Great Hall and toward the viewpoint of the Gate House. After some arguing among the children over who would take control, they stopped in the Great Hall. Pointing at the screen in overview mode the father explained: "We are in that building" (pointing at the Great Hall from above) "that used to be here," before tilting the top unit back and moving the viewpoint inside the Great Hall. They continued with the ten year old pushing and her dad keeping the top unit in view for her. During these interactions pointing and referencing between screen and physical site was also a frequent strategy. This was made easier by the lack of any shading panels on the top unit, which allowed users to glance over and past the screen to compare virtual and physical sites. In a future extension to this work we would consider the use of a video see-through mode to help users register the two environments. This could include a time slider through different models of a heritage site or control allowing users to adjust how much they see of which environment.

8 Conclusions

We have presented an overview of the development of the Augurscope through two iterations. User trials of the first prototype highlighted a number of problems with the device that hindered the understanding of the heritage content of the experience. We redeveloped the original design focusing on providing a better interface to the overlaid virtual and physical sites of the past and present. User trials of Augurscope 2 have shown that it provides a greatly improved access to the experience and that users were able to concentrate on the virtual heritage content. The current Augurscope still fulfils the original design requirements. It is a mo bile mixed reality device that can be used outdoors in a public setting by small groups of users. Our observations also show that interaction around the device and animation of content to others is supported well, which is an important aspect of interactive museums exhibits.

We can see the Augurscope 2 being integrated with little effort as an interactive ex hibit into existing outdoor heritage exhibitions. With a change of the virtual model it can be used as a general-purpose interface to 3D (or 2D) content outdoors. One possible limitation is that the device would need to be accompanied by a member of the staff who would trouble shoot technical problems and provide scaffolding to users where necessary. Nevertheless the approach has the potential to make mixed reality technology available to the general public taking it outside the exclusive domain of experts.

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