

# The Augurscope: A Mixed Reality Interface for Outdoors

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## ABSTRACT

The augurscope is a portable mixed reality interface for outdoors. A tripod-mounted display is wheeled to different locations and rotated and tilted to view a virtual environment that is aligned with the physical background. Video from an onboard camera is embedded into this virtual environment. Our design encompasses physical form, interaction and the combination of a GPS receiver, electronic compass, accelerometer and rotary encoder for tracking. An initial application involves the public exploring a medieval castle from the site of its modern replacement. Analysis of use reveals problems with lighting, movement and relating virtual and physical viewpoints, and shows how environmental factors and physical form affect interaction. We suggest that problems might be accommodated by carefully constructing virtual and physical content.

## Keywords

Mixed reality, augmented reality, virtual reality, mobile and wireless applications, outdoors applications.

## INTRODUCTION

The rapid spread of wireless communications, mobile computing devices and global tracking systems such as GPS has stimulated a growing interest in outdoors augmented reality in which the physical world is overlaid or enhanced with digital information [1,2]. Wireless handheld tablets have been used to aid navigation or to deliver location-based information to tourists in a city [4]. Wireless wearable computers, complete with see-through head-mounted displays have enabled digital information to be overlaid on and registered with an outdoors environment [7]. These early examples hint at the potential to move beyond today's uses of mobile phones and PDAs to a new generation of more interactive and media rich mobile applications, providing that key challenges can be met concerning lighting, weather, power and tracking [2].

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At the same time, recent advances in video processing and display technologies raise the possibility of new augmented virtuality experiences in which hitherto preprogrammed 3D virtual worlds can be enhanced with live information from the physical world or can even be constructed on the fly [6]. These include advances in building 3D models from video, extracting the movements of people and objects, and displaying multiple video textures in a virtual world [11].

Considered together, augmented reality and augmented virtuality represent two forms of mixed reality, a continuum of experiences in which virtual and physical are merged in different ways, stretching from the purely physical to the purely virtual [10].

This paper explores the design of a mixed reality device for use outdoors. This device, called the augurscope, supports both augmented reality and augmented virtuality. For augmented reality it allows a virtual environment to be viewed as if overlaid on an outdoors physical environment. For augmented virtuality it captures real-time video from this physical environment that can then be embedded into the virtual environment.

Two potential applications of the augurscope are in cultural heritage and environmental planning. In the former, visitors to historical buildings and sites of special interest can experience scenes from the past as they explore an outdoors site. In the latter, they can explore scenes from the future as part of consultation over designs for new buildings, transport systems and other public facilities. Our paper describes a first public application of the augurscope belonging to the former category, an open-air museum experience, and presents initial reflections arising from field observations.

## DESIGN REQUIREMENTS

Our design for an outdoors mixed reality device has been driven by the following requirements.

**Use by public groups** – our intended applications involve directly engaging the public. Our device should be open and inviting to the public. It should be immediately usable by non-expert first-time users with only minimal training. Deployment in public settings also requires consideration of aesthetic quality as well as robustness and maintainability. Our device should also be sharable by groups of users, a requirement that has emerged from previous studies of

interactive museum exhibits [12] and art installations [3] that have shown how displays are frequently shared by small groups of family or friends. In such situations, several users will often view a display at once, even if only one is able to interact. Furthermore, users frequently learn by watching others, a practice that extends beyond the bounds of the local group to encompass more peripheral observers [12]. Our device might also be used by domain-experts such as tour guides and town planners to present to a small group.

**Relocatable** – users will need to move our device to different viewing positions within an extended physical setting such as a town square, a building site or around the perimeter of a large building. Beyond this, it should be only a few minutes work to set-up and configure the device to work in an entirely new setting. Typical operation might be for a tour guide or town planner to arrive at a location, set-up the device and then move between a number of different viewpoints.

**Networkable** – there are several reasons why our device should be able to communicate with other devices. First, we are interested in its use with live (i.e., dynamically updated) virtual environments. We are especially interested in the device itself providing the live input to such environments, by capturing and transmitting information from its surrounding physical environment. Second, we are interested in our device as a potential communication tool between users out ‘in the field’ and those ‘back at base’, for example as part of remote guided tours and meetings. Third, we require the device to be able to link to and control other secondary displays such as projected interfaces in order to address more users and to support remote management.

**Use outdoors** – as noted earlier, previous experiences with augmented reality have encountered a number of difficulties [2]. Flat-screen displays can be difficult to read in bright sunlight. Protection is required against adverse weather conditions. Outdoors positioning systems such as GPS can suffer from variable accuracy and reliability and don’t work at all well under some conditions. Devices have to be self-powered, a particular problem where 3D graphics hardware is used as this is relatively power hungry and has only recently become available in laptop computers.

### THE DESIGN OF THE AUGURSCOPE

We considered several general designs that might meet this combination of requirements, 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 1). This display can be moved to any accessible outdoors 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. At the

same time, it captures and transmits a video view of the physical environment from this location.

We named our device an ‘augurscope’ because it augments both reality and virtuality and also because one of its potential uses is to peer into the future (‘auguring’).

Of course, boom or stand mounted 3D displays are already familiar from virtual reality, where devices such as the Fakespace Boom [8] are commercial products. 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 [13].

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.
- The required combination of a laptop computer and various tracking, video and audio peripherals is both bulky and weighty (especially as current laptops with 3D graphics hardware are relatively heavy). Early tests showed that users would quickly tire of carrying them, ruling out a handheld solution.
- 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.
- We were able to enclose the display in an outer casing, improving both its overall aesthetic and ruggedness and also making it more tamper-proof.

Our design process involved two major iterations of construction and testing. The first focused on general physical form factor and produced a standalone device. The second refined this initial design, extending it with video capture and networking. The remainder of this section describes the final design of the augurscope.

### Physical form

The augurscope (figures 1 and 2) is built around a laptop computer (a Dell Inspiron 8000 with a 15 inch display and NVIDIA Geforce2 Go 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 that features:

- two handles for easy manipulation
- a counterweight for a well balanced and smooth rotating and tilting action so as not to tire users and to maximize accuracy of use.

- a button that when pressed zooms in the virtual viewpoint by a factor of six times and that when released returns to the normal setting.
- a removable cover that bears simple instructions and also conceals the keyboard from users but that can easily be removed if it is needed for administration or maintenance.
- surrounding wooden panels that provide 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. On-board shielding might also be supplemented with external shielding such as parasols.

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 on-board technology. As a result, we then built a second set of more outdoor wheels with inflatable tyres that were more suited to grass and rougher surfaces.

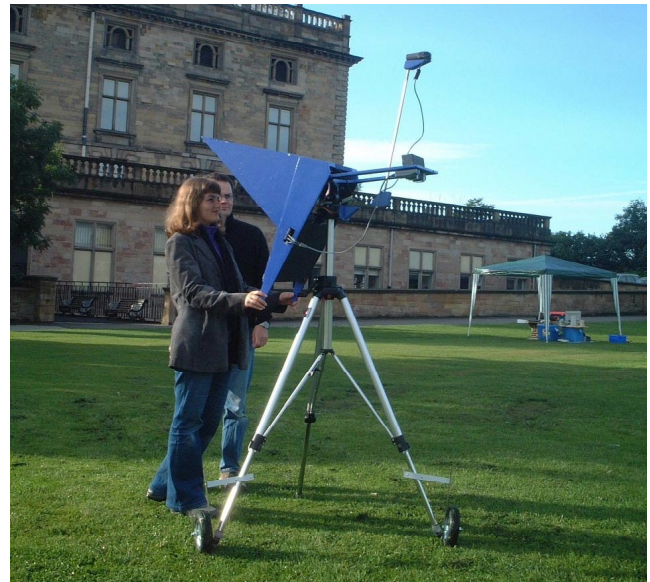
**Position and movement tracking**

The most basic interaction with the augurscope is carry 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.

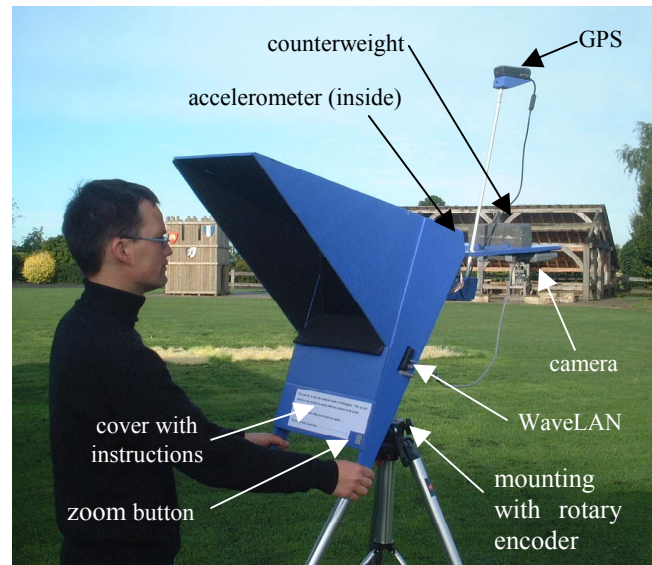
An etrex GPS receiver with electronic compass attached to the display mount on the tripod gives the position and orientation of the augurscope relative to the surrounding environment. Position data has a typical accuracy of between two and four meters, although this varies according to weather and proximity 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.

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. This consists of a cannibalized mechanical mouse, where the wheel that normally detects vertical mouse movement is fixed so that it presses against the tripod. The display can therefore be rotated indefinitely.



**Figure 1: The Augurscope and secondary display in the background.**



**Figure 2: The Augurscope close up.**

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. The following table summarises the roles and characteristics of these three tracking technologies.

Technology	Purpose	Characteristics
etrex GPS compass	Global position of display mount Global orientation of display mount	Two second delay, fluctuates by 2 meters Two second delay, fluctuates by 1°
Rotary encoder	Rotation of display relative to tripod	Negligible delay and fluctuation
Accelerometer	Tilt of display relative to gravity	Negligible delay and fluctuation

The fluctuation and delay in the GPS data causes problems. Applying each update directly causes the virtual viewpoint to continually jump around. We therefore only apply position updates when they show a significant movement (sufficient to clearly indicate that the augurscope has been moved). A threshold of two meters seems to give a satisfactory balance between stability and responsiveness. In a similar way, the electronic compass reading cannot be used directly while the display is being rotated because of the considerable latency. The absolute orientation of the device is therefore only updated from the electronic compass when it is stationary, in our case after five stable readings have been obtained.

**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.

Our current prototype uses the MASSIVE-3 collaborative virtual environment software for the virtual environment. This supports multi-user/device access to a shared virtual world. An additional software platform called Equip supports the integration of the tracking system with standard MASSIVE-3 interface components.

**Video capture**

In order to support augmented virtuality applications, video capture is enabled through an onboard camera. This is positioned to look out from the augurscope so as to capture the physical scene at which it is pointing. However, it could also be turned round to face the user to support conferencing applications.

**Networking**

Networking with other devices is supported through a WaveLAN card on the laptop. This enables the augurscope to receive live updates from remote virtual world servers and to transmit position and orientation data as well as live video back to these servers. The augurscope can therefore synchronise with other devices by publishing its position and orientation data via the shared virtual world. These other devices can then subscribe to this data in order to follow its viewpoint as it moves.

Given that WaveLAN is a local area technology and may not always be available, the augurscope can also be configured to work in a stand alone mode in which the 3D environment is stored locally and there is no need to access a remote world server.

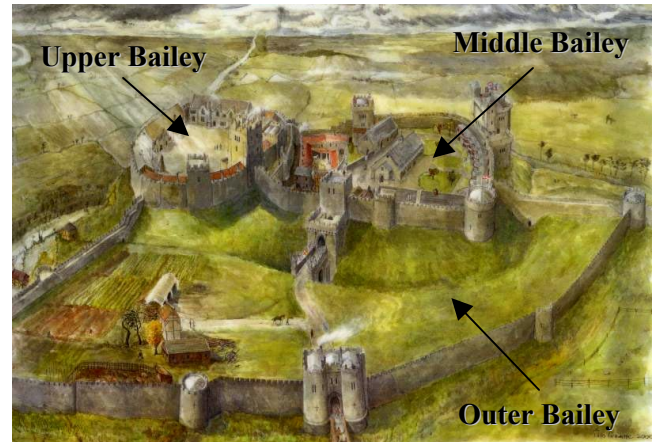
**RECREATING NOTTINGHAM’S MEDIEVAL CASTLE AS A PUBLIC DEMONSTRATION**

For our first public trial of the augurscope we chose a historical application: recreating Nottingham’s medieval castle on the site of its modern castle.

**The problem – Nottingham’s missing medieval castle**

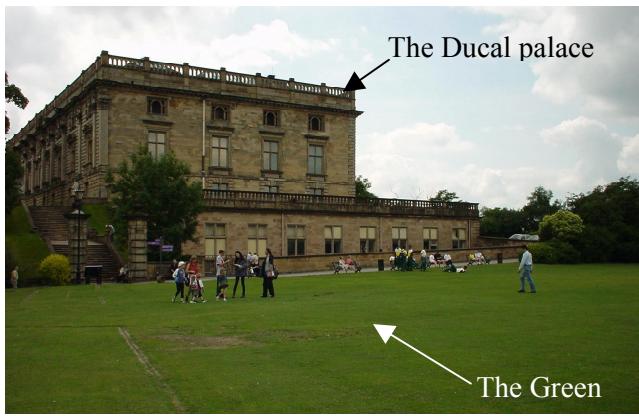
A fortified castle was first built at Nottingham on a large outcrop of sandstone in 1067. Over the next six hundred years the castle was extended by a succession of kings to become one of the most important and impressive medieval castles in England as well as the backdrop to the adventures of the mythical character Robin Hood.

Figure 3 is an artist’s impression of the medieval castle as it was in the late 14<sup>th</sup> century. It shows how it was divided into three main areas: the Upper Bailey, the smallest, highest and most protected; the larger Middle Bailey containing many buildings including the Great Hall; and the Outer Bailey, a large open space with no buildings.



**Figure 3: Artist’s impression of the medieval castle.**

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 figure 4). Herein lies a major problem. Tourists expect to see a fine example of a medieval castle, but instead are presented with the 17<sup>th</sup> 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 problem of recreating the missing castle on the current site seemed to us to provide an ideal test application for the augurscope.



**Figure 4: The Ducal Palace today seen from the Green.**

The castle 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, brochures and text books 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 have been placed at key viewpoints. Finally, costumed actors occasionally play medieval characters roaming the site (Figure 5).



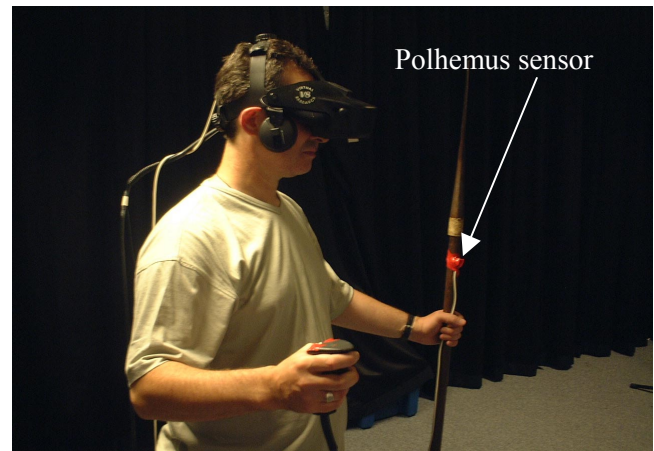
**Figure 5: Actors in role at the castle.**

**Deploying the augurscope at Nottingham Castle**

We were fortunate 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 the augurscope.

We also hired one of the castle’s actors to come to our laboratory and pre-record several 3D scenes involving a guard avatar moving through the 3D model and talking as they went. This made use of MASSIVE-3’s record and replay mechanism to capture all of this avatar’s movements and speech in the virtual world so that this could be replayed live later [5]. In a day-long session we recorded five separate scenes at different locations in the virtual model in which our guard described various features of the castle and medieval life in general. Figure 6 shows our actor making the recording. As an aside, note that we

attached a polhemus sensor to his spear so that he could use it to gesture during the recordings. In this way we avoided infeasible movements of the virtual spear – such as passing it through his own body – that occurred at first when he was empty handed. Figure 7 shows the avatar in the model.

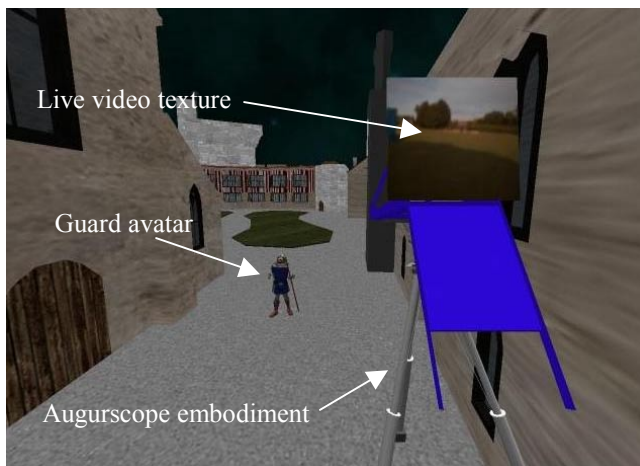


**Figure 6: Recording the medieval guard character.**



**Figure 7: Replaying the character in the castle model.**

Our public deployment at the castle involved two networked displays. First was the augurscope itself. Second was a further public display that was located under a portable gazebo on the castle Green (this can be seen in the background of figure 1). This second display showed a view of the virtual model, with its viewpoint slaved to the augurscope, but offset so that a graphical representation of the augurscope was visible in the foreground. This representation included an embedded live video texture taken from the augurscope’s onboard camera. Figure 8 is a screenshot from this secondary display, showing the graphical embodiment of the augurscope in the foreground. We see that the user is currently looking at the medieval guard avatar. This slaved display demonstrated the logical reverse of the augurscope by showing a view of today’s castle inset into the 3D model of the medieval castle. Our configuration therefore spanned two points on the mixed reality continuum: augmented reality (the augurscope) and augmented virtuality (the slaved display).



**Figure 8: View from the secondary display.**

Finally, a third networked computer in the gazebo provided an interface for manually launching the different 3D recordings from behind the scenes.

### PUBLIC TRIALS AND INITIAL REFLECTIONS

The development of the augurscope and the castle application involved a sequence of site visits and public tests. A first iteration of a stand-alone augurscope was tested in a busy town centre, leading to several refinements including the addition of wheels and the zoom facility. Several visits to the castle were made to select key sites for deployment, obtain reference GPS coordinates, clarify the relationship between the medieval castle model and the physical site, measure WaveLAN signal strength at different locations, and calibrate and test the augurscope.

Eventually, the augurscope was ready for public trials. These were carried out over a day with the set-up described previously. The weather was mostly sunny, but with some overcast periods. A sign was placed near to the Green inviting visiting members of the public to try out the augurscope. Approximately thirty 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 minimise the amount of training and other scaffolding that was given and instead encouraged visitors to use the augurscope as independently as possible. The duration of use varied from approximately a minute up to fifteen minutes. Visitors were also encouraged to view the secondary display, in most cases after they had used the augurscope.

Over the course of the day we collected video of visitors using the augurscope. 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.

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. 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). However, there were some problems with differences in height, especially for family groups where we saw instances of parents having to lift children (this was less of a problem for groups solely composed of children because the display could be raised and lowered via a handle on the tripod).

We therefore feel that the augurscope was broadly successful as an outdoors public mixed reality interface for small groups. That said, the remainder of this paper now focuses on several key issues that were more problematic and that suggest possible directions for the future development of the augurscope and similar devices.

### Shedding light

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. For example, one visitor adamantly maintained that there was nothing at all displayed on the screen, until directed to stand closer in order to block the sunlight with his head. When instructions continued that "you can rotate and tilt the device", his partner advised that his rotation should "probably not [be] towards the sun, [it] might be better coming that way". What is interesting here is not so much the (already reported [2]) observation that bright sunlight is a problem for outdoors displays, but rather the ways in which users react when they are able to freely orientate a display. Turning the augurscope so that the screen faced away from the sun was a common reaction.

There are several potential approaches to coping with bright light. We might change the graphics, perhaps making them bolder and brighter (in fact, we had lightened the textures following initial testing prior to the public trials). At the risk of compromising group use, we might extend the shielding, perhaps with a parasol or in the extreme case a blackout hood. However, the above observation suggests an interesting alternative. We might deliberately encourage users to adopt an orientation that shields the display from the sun. This includes taking advantage of shade at different times of the day. We might do this by marking different vantage points in the physical environment. We might also modify the locations of virtual material. For example, actors

might be advised to position live avatars on the sunside of the augurscope whenever possible.

### Moving pictures

Visitors generally appeared reluctant to move the augurscope, possibly due to the weight of the onboard equipment and frame combined with the rough grassy surface. 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. Initially, groups and individuals would explore the encountered scene with great deliberation. Only subsequently might movement of the device be attempted. For example, one family explored the Great Hall and its finery by taking it in turns to use the zoom facility to examine all possible content (particularly, the tapestries on the floor and walls), even attempting to zoom through windows. When unable to distract a member of the support team, they continued to view the hall for a short time, and then moved on inside the castle to “go and see the tapestries for real”.

Again, we might deal with this by redesigning the physical device and/or the experience. In the first case, an obvious step would be to reduce the weight of the augurscope, through the use of a different frame made from lighter but similarly sturdy materials, or by using a more lightweight display. We might also change its shape, making the frame smaller (but trading off shielding from sunlight) and providing convenient handles for grasping and lifting. In the second case, the ground surface might be made smoother by the addition of pathways (the augurscope is far more maneuverable on smooth surfaces using the alternative wheelbase – it can even be gently pushed along as it is tilted and panned). More visible physical markers might be used to indicate key viewpoints and these might also be marked on maps and guides. We might also adapt the content of the virtual environment, for example using avatars movements and dialogue to encourage users to move to new locations (it was noticeable that some visitors became quite fixed on the guard avatar, although others tended to focus more on the background model).

### Doing legwork

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. However, this also 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 small or large groups, appeared to treat the legs as cut-off points for standing. We recorded instances of up to twelve people standing within the 120° segment containing the display. Users rarely stood across tripod legs, preferring to move quickly past the legs, before pausing to spend time in the next segment. Where visitors did stand outside this segment in proximity to the device, they often appeared uncomfortable or detached. Such visitors were observed to move to a better viewpoint; to encourage rotation of the device into ‘their’ segment; or even to disengage and try to engage others in related activities, such as side conversations.

A further key aspect of this segmentation, is that the augurscope was often used for long periods of time within one segment. Movement of the display from one segment to another required the effort of traversing a leg, and was far less frequent than movement of the display within a segment. A typical pattern of use was to explore a location by thoroughly investigating each segment in turn, before traversing to the next.

Again, these observations provide interesting cues for designing and managing the overall experience. Dynamic content can be introduced into the current viewing segment if continuity of experience is required or alternatively, can deliberately be placed in one of the other segments in order to encourage the movement of the users and augurscope across a tripod leg into another segment. Actors controlling avatars might choose their direction of approach to the augurscope based on these criteria.

### Relating worlds

Our final issue focuses on resolving relationships between the physical and virtual worlds. This was a particular problem for application developers. Making the 3D recordings raised some tricky issues. The guard avatar needed to be positioned so that he could make reference to key features of the model and also so that viewers could find good vantage points from which they could see him and the features being discussed. Indeed, acting when you don’t know where the audience will be located is itself quite difficult (e.g., you need to avoid some spatial references such as the names ‘left’ and ‘right’). However, this issue was further complicated by the constraints of the physical world: it was also necessary to understand whether there would be an appropriate vantage point on the Green from which to view the action. The most difficult case required the augurscope to be quite precisely positioned on the edge of the Green so that it could see over the edge of a slope to a bridge below (a physical constraint) and yet was on the right side of a virtual wall that ran nearby (a virtual constraint).

Related issues became apparent when deciding when to replay different 3D recordings. A member of the technical team needed to judge when a visitor was in a good position to be able to see a prerecorded avatar. This relied on knowledge of both their physical and virtual location.

Previous studies of mixed reality experiences indoors have shown how performers and crew rely on both physical and virtual monitoring in order to orchestrate an experience from behind the scenes [9]. This becomes more problematic when mobile devices are being used in outdoors locations. The secondary slaved display proved useful here as it showed the augurscope's position and orientation in the virtual world. However, it still proved difficult to resolve the physical and virtual positions (as the two spaces were very different). This suggests the development of secondary displays that show positions overlaid on both the physical and the virtual.

### SUMMARY

We have described the design of the augurscope, a portable mixed reality interface for outdoors. We chose a design based on a tripod-mounted display so as to support use by public groups and to provide a stable platform for a 3D display, tracking technologies, a video camera and powered speakers. We explored design tradeoffs spanning physical form, user interaction and the integration of different tracking technologies. For the latter, we used a GPS receiver with electronic compass to locate the device within the surrounding environment and an onboard rotary encoder and accelerometer to support smooth local interaction. Wireless networking allowed communication with remote management tools and slaved displays.

Our first application involved exploring a destroyed medieval castle on the site of its more modern counterpart. User testing raised a number of issues for further exploration. In particular both environmental factors (such as the direction of the sun and the roughness of the ground surface) and physical form factors (weight, wheels and shape) affected interaction. We propose that apparent problems might be addressed by redesigning the device, but might also be dealt with through the careful design and management of both physical and virtual experience. There were also problems with resolving relationships between the physical and the virtual, particularly during application development and orchestration. These might be resolved through the careful design of secondary displays.

To conclude, we believe that the augurscope provides an interesting contrast to other approaches to mixed reality outdoors and that an appropriately refined example might be suited to outdoors applications in public places such as museums. We hope that our experience provides useful insights for the design of other devices.

### ACKNOWLEDGMENTS

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### REFERENCES

1. Azuma, R. T., "A Survey of Augmented Reality", *Presence: Teleoperators and Virtual Environments*, 6(4): 355-385, Aug. 1997.
2. Azuma, R., "The Challenge of Making Augmented Reality Work Outdoors", In *Mixed Reality: Merging Real and Virtual Worlds*, 1999, Springer-Verlag.
3. Buscher, M., O'Brien, J., Rodden, T. and Trevor, J. (2001). "He's Behind You": The experience of presence in shared virtual environments", *Collaborative Virtual Environments: Digital Places and Spaces for Interaction*, 77-98, Springer-Verlag.
4. Cheverst, K., Davies, N., Mitchell, K., Friday, A. and Efstratiou, "Developing a Context-Aware Electronic Tourist Guide: Some Issues and Experiences", *Proc. CHI'2000*, 17-24, The Hague, Netherlands, 2000.
5. Craven, M., Taylor, I., Drozd, A., Purbrick, J., Greenhalgh, C., Benford, S., Fraser, M., Bowers, J., Jää-Aro, K., Lintermann, B., Hoch, M., "Exploiting Interactivity, Influence, Space and Time to Explore Non-linear Drama in Virtual Worlds", *Proc. CHI'2001*, Seattle, US, April 2-6, 2001, ACM Press.
6. Gong, S., McKenna, S., Psarrou, A., Dynamic Vision, Imperial College Press, London, 2000.
7. Höllerer, T., Feiner, S., Terauchi, T., Rashid, G., Hallaway, H., "Exploring MARS: Developing Indoor and Outdoor User Interfaces to a Mobile Augmented Reality System", *Computers and Graphics*, 23(6), Elsevier, Dec. 1999, pp. 779-785
8. <http://www.fakespacelabs.com/products/boom3c.html> (verified 1st September 2001).
9. Koleva, B., Taylor, I., Benford, S., Fraser, M., Greenhalgh, C., Schnädelbach, H., vom Lehn, D., Heath, C., Row-Farr, J., Adams, M., Row-Farr, J., "Orchestrating a Mixed Reality Performance", *Proc. CHI'2001*, Seattle, April 2001.
10. Milgram, P. and Kishino, F., "A Taxonomy of Mixed Reality Visual Displays", *IEICE Transactions on Information Systems*, Vol E77-D (12), Dec. 1994.
11. Reynard, G., Benford, S., and Greenhalgh, C. (1998), "Awareness Driven Video Quality of Service in Collaborative Virtual Environments", *Proc. CHI'98*, 464-471, LA, April 18-23, 1998.
12. vom Lehn, D., Heath, C. and Hindmarsh, J., "Exhibiting Interaction: Conduct and Collaboration in Museums and Galleries", *Symbolic Interaction*, 24 (2), University of California Press
13. Cook J, Pettifer S, Crabtree A., "Developing the PlaceWorld environment" *eSCAPE Deliverable 4.1 The Cityscape Demonstrator* (eds. Mariani & Rodden) Lancaster University, ISBN 1-86220-079, 2000.