The Iterative Design Process of a Location-aware Device for Group Use

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Abstract. We present our approach to the design of two generations of outdoors device that enable visitors to view 3D historical reconstructions when exploring present day sites. Reacting to problems revealed through public trials with our first prototype, we describe how we followed a 'physical form inwards' approach for the design of our second prototype – Augurscope II. We began by refining the physical form of the interface through a series of push tests with low-tech wooden prototypes and subsequently added sensors and finally refined the software. Our experience with the Augurscope II highlights the importance of prototyping, early involvement of users within the intended setting and the subtleties involved in matching physical form, sensors and software in the development of ubicomp devices.

1 Introduction

The development of devices that display context sensitive information is a major topic of research for ubiquitous computing. The leisure and tourism industry has been a popular application domain, with context aware devices being used to enhance visitors' experiences. These include tourist guides [6], devices to augment museum visits [4, 19], campus guides [5] and outdoor devices for sites of historical interest [14, 3]. In this paper, we reflect on the process of designing a location-based device for use outdoors at a historical attraction. Our device allows groups of visitors to collaboratively view a 3D model, in this case a historical reconstruction, as they explore a physical site. At each moment, it shows them a view of the 3D model as it would appear from their current physical vantage point, answering the question "what might you have seen if you had been standing on this spot in the past?"

Designing such a device is challenging, as it has to be mobile and suitable for use by small groups of the general public in an outdoors environment. These requirements push the boundaries of current technologies in areas such as lightweight and sharable 3D displays and the integration of sensor technologies. They also require designers to

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achieve an appropriate balance between physical form factor, sensing technologies and software design, which can be a difficult task as we shall see below.

In this paper we present our approach to the design of two generations of device to provide a solution to this problem and the lessons we learned from this process. Both devices were stand-mounted displays that can be shared by groups of visitors and wheeled around to different locations in a relatively flat physical environment. Our first device – the Augurscope I – emerged from a design process that might be characterised as '***software outwards***'. Taking our existing software, which ran on a conventional computer as a starting point, we added sensor technology and finally wrapped this in a physical structure.

Our current device is the product of a redesign that sought to remedy the issues that arose from public trials of the Augurscope I. In contrast to our initial approach for our second prototype – the Augurscope II – we adopted a design approach that can be characterised as ***"physical form inwards"***. We began with the physical form factor, carefully considering the ways in which the interface could and should be moved and then integrated sensors and software later on. In turn, this led us to reflect more generally on the issues involved in prototyping ubiquitous computing devices and matching physical form to both sensing technologies and application requirements.

2 The Missing Castle: Design Requirements

The context for the development of our outdoor device focused on visualising a medieval castle as it used to appear in relation to its current, quite different site. Nottingham castle is now a public museum and has provided the backdrop for nearly one thousand years of history. However, although in its heyday it consisted of many buildings and was associated with imposing defences, little of this medieval structure remains at the site today as a result of the civil war of the 17th century. Visitors expect to see a fine example of a medieval castle, but are presented with a 17th 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 relationship between past and present: a physical model, a slideshow, guides, brochures and textbooks are available. In addition, the locations of some of the original walls are marked out on the ground of the current site. 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 such as the 'Great Hall' that are entirely missing, having been replaced by areas of open grass.

Our goal then was to design an interface to enable groups of visitors to explore the structure of the medieval Nottingham castle from the site of its modern counterpart and to enjoy this as shared social experience. Our design had to respond to a number of high level requirements.

- **Mobility –** the device should be mobile, enabling visitors to relocate it to various positions around the castle site and from these, to obtain different viewing angles and panoramic views.

- **Outdoors use –** the device must be designed for outdoors use, allowing visitors to explore the castle site. Previous experience with outdoors systems [2] have encountered 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 [18].
- **Small group use** – the device should be sharable among small groups of visitors such as families, responding to the growing recognition that people often visit museums with companions and their museums experience is shaped through interaction with others [10, 19].

3 "Software Outwards": The First Augurscope

In the development of the first Augurscope our broad strategy was to rapidly construct a prototype and then evaluate it through public tests at the castle. We considered several general designs that might meet the above requirements including wearable and head-mounted augmented displays [13] or free moving, wireless and tracked handheld displays [6]. However, we eventually opted for a design more closely related to boom-mounted displays [8] and those that are used for public indoor VR experiences (e.g. [7]). Our design is based on a tripod-mounted display that can be wheeled to any accessible outdoors location and then rotated and tilted in order to view a virtual environment, as it would appear from that particular vantage point (figure 1).

Fig. 1. Augurscope I at the castle green

In contrast to wearables or PDAs, a small group can easily share a stand-mounted display, with several users being able to see the screen at once and reach out to point at it or to alter its position. Additionally, users can engage and disengage simply by stepping up to and away from the display. We also felt that a tripod mounting would allow the device to be held in a fixed position for several minutes at a time while visitors discussed the content, and might also support more fine-grained, accurate and stable positioning than a handheld solution. However, there was also a more pragmatic motivation for our choice; we were concerned that a suitably large 3D display combined with the location and movement-sensing technologies would be too heavy and bulky for sustained use.

In order to rapidly construct our first prototype, we used off the shelf technologies. The overall design process can be characterised as augmenting a conventional laptop computer, which ran our existing software to display a 3D model of the medieval castle, and provided the interactive core of the device. We augmented this device by:

- Interfacing a series of movement sensors (a GPS receiver to measure global position and orientation and an accelerometer to measure vertical tilt).
- Mounting the augmented laptop on an existing camera tripod and adding a further sensor (a rotary encoder) to measure the horizontal rotation of the display relative to the tripod.
- Adding wheels to the tripod and a wooden casing around the display to shield it from bright sunlight.

We publicly tested our prototype at the Castle. A detailed account of the design and evaluation of the Augurscope is given in [16]. To summarise, positive findings were that visitors appeared to comprehend the purpose of the interface and responded with enthusiasm. Most could operate it with little training, and rotation and tilting were used frequently. However, several problems also became apparent.

- **Limited mobility** – visitors generally appeared reluctant to move the device because of its weight, physical bulk and the roughness of the grassy surface. When moving the device, one of the tripod legs had to be lifted off the ground making it quite unstable. Consequently visitors seemed to prefer viewing the virtual world from a single location, and movement of the device was limited to short distances.
- **Segmentation of the experience –** the three legs of the tripod appeared to constrain rotation of the display, effectively cutting the space to be explored into three 120˚ segments. Users, whether individually, or in small or large groups, appeared to treat the legs as cut-off points for standing.
- **Accessibility** – there were also some problems with differences in height, especially for family groups where we saw instances of parents having to lift children to give them a better view. Even when lowered all the way the device was still too high for some visitors.
- **Sunlight readability –** finally, 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 of interest here is that many of the root causes of these issues lay not with the interactive software and sensors that provided the core of our initial prototype but rather the eventual physical form that emerged from our approach of augmenting an existing laptop. This form had emerged from a design process that might be characterised as '***software outwards'***, meaning that we began with our existing software, which ran on a conventional computer. We then added sensor technology and finally wrapped this in a physical structure. In other words, to generalise somewhat, the order in which we tackled key design issues was: software then hardware/sensors and finally physical form-factor. While this may have been a sensible approach to developing a first prototype, we decided to adopt a different approach to designing the second version of the device and in doing so address the problems noted above – improve the mobility, deal with the barrier introduced by the wide-base tripod legs, provide height adjustability and cope better with bright sunlight.

4 "Physical form inwards": The Augurscope II

In response to these issues we decided to concentrate on the physical form of our device, effectively reversing the design process compared to the first Augurscope. Therefore we would begin with the physical design before integrating bespoke rather than off the shelf electronics and then refining the software. The strategy was to drive the design from a consideration of the physical form and to involve users more directly in the prototyping of the physical form. The strategy can be considered in terms of four closely related stages.

- **Phase 1:** The initial physical design proposal that emerged from a series of reflections on the lessons of the initial device and the physical constraints of technology and anticipated use.
- **Phase 2:** Physical prototyping sessions with users through a series of trials of exploring the interactive affordances of the physical form.
- **Phase 3:** Development of the final deployable prototype and the refinement of the interactive software to exploit the new physical affordances.
- **Phase 4:** A series of in-situ evaluations with users to further assess and refine the deployed prototype.

4.1. Phase 1: Developing the Design Proposal

At the outset, we decided to try and reduce the overall weight of the device, but perhaps more importantly, to lower its centre of gravity in order to make it more stable. At the same time, we aimed to improve the wheelbase by using larger bicycle-style wheels in the hope that this would also increase mobility. To improve access to all areas of the experience without segmentation we aimed to reduce the size of the base without affecting its stability or the seemingly comfortable viewing distance (given by the relationship between handle and screen) afforded by the original Augurscope. Finally, we decided to remove the wooden shielding at the top as this added weight and bulk and yet was not very effective at dealing with bright sunlight.

At this point we produced our first general design concept, shown in figure 2. In contrast to the first Augurscope, this had a base unit on two large wheels that housed the main computer that would render the 3D virtual environment. A separate top unit consisted of a sunlight-readable display and tilt and rotation sensors which was to be mounted on a rotating handle, balanced by a counterweight. The entire device would be levelled by rotating its two wheels until horizontal and then using the hinge provided above the base. One of the main features of this proposal was the lightweight top unit that would communicate wirelessly with the computer in the base unit. As well as lowering the centre of gravity of the whole device, this also opened up the possibility that the top unit might be temporarily removed from the stand and used in handheld mode, providing additional flexibility for how the Augurscope II might be deployed.

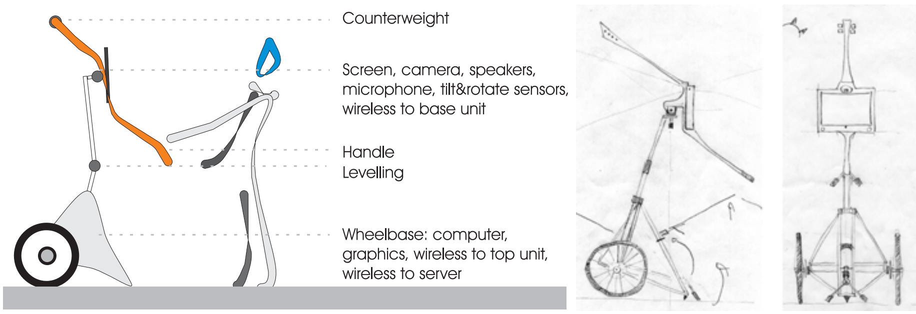

Fig. 2. Design proposal: Version 1 & 2

4.2 Phase 2: From Design Proposal to Physical Prototype

Given this general proposal for the overall form of the device, our next priority was to consider the key issue of how it would be moved. We began by considering two versions as shown in figure 2. To move version 1, shown on the left, the device would have to be tilted forward so the back foot lifts off the ground. Users would walk beside it, balancing the device and would not be able to see the screen while moving. The pencil sketches on the right, drawn at a later stage, show version 2 that included a foldable push handle attached to the base unit. To move it, the handle would need to be picked up and extended to a position that allows walking behind it without treading on the back foot. This would support viewing of the screen during movement, a positive behaviour as we had learned from trials with the first Augurscope.

Comparing these two versions led us to realise that we desired both immediate movement (without having to mess around with extendable handles) as well as the ability to view the screen while moving. It also led us to realise that we needed to base our design on more practical experiences of how people might actually push and move such a device. We therefore embarked on a process of more detailed refinement of our physical design through a series of 'push and rotate' tests with basic wooden structures, initially containing no electronics, but loaded with appropriate weights that matched our estimated targets for the top and base units. From our description of the physical prototyping work below, it will become clear how our approach has led us to implement important changes to our original proposal relatively quickly and at an early stage in the design.

Test 1 – Base unit. The aim of our first test was to establish the basic movement of the platform. We constructed the prototype shown in figure 3 from soft timbers that were easy to cut and shape and whose joints were held together by clamps, so facilitating adjustment during testing. The wheels were two small bicycle wheels. In order to support immediate movement and viewing of the screen during that movement, we changed the original design by moving the foot from the back to the front and by adding a fixed push handle (golf-trolley rather than wheelbarrow style interaction). Simple tests involved colleagues pushing and pulling it around our laboratory. Frequent changes to the clamped joints gave us a better idea of the ideal handle and screen positions. We concluded that the overall design was promising, while the base unit appeared to be too wide.

Fig. 3. Test 1 and 2

Test 2 – Base unit and cantilevered arm. For our second test we added a top unit that could be tilted (but not yet rotated) using a cantilevered arm to achieve an appropriate balance. We also narrowed the base unit and added approximate weights to the structure to represent the electronics that would eventually be integrated. We carried out a series of mobility tests, again with colleagues, but this time on a rough grassy surface. Our aim was to assess general mobility, the tilting action, heights of handles and screen and the distribution of weight. Our tests showed this structure to be fairly mobile and ergonomically more appropriate.

Users could comfortably grasp both handles and tip the prototype onto its two wheels and then move and rotate the whole unit. Critically, the push handle did not hinder interaction with the top unit when the device was stationary. However, the cantilevered arm was heavy and unwieldy and we were also concerned that its protrusion at the back of the device might collide with bystanders when rotated. In addition, with only two wheels, the structure did have to be tipped in order to be moved and in combination with its top-heaviness this made it feel unstable.

Test 3 – Base unit and gimbal. For the third test, a front wheel was added to the base unit. We also replaced the cantilever with a gimbal mechanism, complete with two handles to support both left and right handed users. This also included two fasteners to allow the display (still a wooden frame holding a book) to be removed from and replaced back into the structure. In consultation with local ergonomics experts, a height adjustable central column (with levelling mechanism) and base unit handle were added that would allow use of the device by an adult through to a typical 10 year old child. Our tests suggested that the gimbal was a great improvement and that the additional wheel improved stability and manoeuvrability. Indeed, we were pleasantly surprised so see examples of two handed interaction, where users would be able to grasp the two handles and then move and rotate the whole structure while also rotating the top and occasionally tilting the structure on to its two wheels. The height adjustable joints performed well, however the gimbal and levelling mechanism were far from robust enough and in fact disintegrated completely during testing.

Fig. 4. Test 3 and 4

Test 4 – Covered based unit and final top unit. For test 4 we covered the base unit to make it resistant against adverse weather and added the electronics. A removable tray was attached at the bottom that would hold the main lead acid batteries. The top unit that had been developed and tested in parallel around the electronics hardware (mainly a sunlight readable Corona TFT display and sensors) was added into a new sturdier gimbal. Tests at that point confirmed that the overall design was successful as the device was still very mobile and interaction around the base unit seemed unrestricted. We also consulted with safety experts who suggested further modifications in terms of removing sharp edges, creating a less 'spiky' push handle and adding some safety stops to the base unit to prevent it from falling backwards.

4.3 Phase 3: Realising the Final Deployable Prototype

Our final prototype, shown in figure 5, included two further modifications to the design of the handles. We had experimented with different central handle (tilt and turn) designs. The result shown here provides good access to both left- and right-handed people (slightly favouring the latter) without physically restricting the range of tilt. The push handle was also re-shaped to prevent possible injuries and to allow a good grip from different positions. Finally, the prototype was finished with a coat of paint and a period of technical testing followed, the description of which would go beyond the scope of this paper.

Fig. 5. Final Prototype

4.3.1 Movement Tracking

The sensing technologies for the Augurscope II were chosen to accommodate the new physical form and its interactional affordances. As the top unit is detachable, rotation tracking needs to be independent of tracking the movement of a physical joint. As a result we chose to use a single Honeywell HMR3000 digital compass to measure both global rotation and tilt in place of the accelerometer and rotary encoder from the original Augurscope, enabling the top to be used independently from the base. Similarly a Trimble GPS receiver was used to provide global position as it is lighter and requires less power than the unit used with Augurscope I. In order to take advantage of the increased mobility of the Augurscope II, we used a CSI RTCM receiver for differential GPS corrections, giving us a theoretical accuracy of 1-2 meters for the global position of the device within its environment. Consequently as the device is wheeled around the updates to the virtual environment are more fine grained.

4.3.2 Revisiting the Interactive Software

Once we had integrated the sensing technologies and other electronics (displays, computer, batteries and communications) into our physical design we then revisited the software. We found that we needed to adapt the software to deal with consequences of our design. One obvious alteration was that new software had to be written to communicate the GPS and compass data wirelessly from the top to the base using 802.11b.

Another way that the software had to respond to the physical form was with regard to the relationship between the physical structure and the electronics. Specifically, with the new design the top unit can be tilted through a 180° of movement (in both stand mounted and handheld modes), whereas the HMR3000 digital compass can only sense up to 45° of tilt either way from the horizontal. As a result, a user might tilt the display out of sensor range (beyond 45°) at which point their movement would not be tracked and the display would no longer react. Conversely, it would not be possible for the user to adopt certain viewpoints in the virtual model, for example a bird's eye view or looking directly up into the sky. In response, we refined our 3D software, by exaggerating the effects of tilting of the display on the virtual viewpoint. For every sensed degree of physical tilt of the top unit, two degrees of tilt are applied to the virtual viewpoint. Additionally, between 20° to 45° the virtual viewpoint also pulls upwards. At 45°, the virtual camera has tilted to 90° (i.e., is looking straight down) and has risen several tens of meters into the air to give a bird's eye view. The view remains static beyond 45°. The effect of this mechanism is shown below.

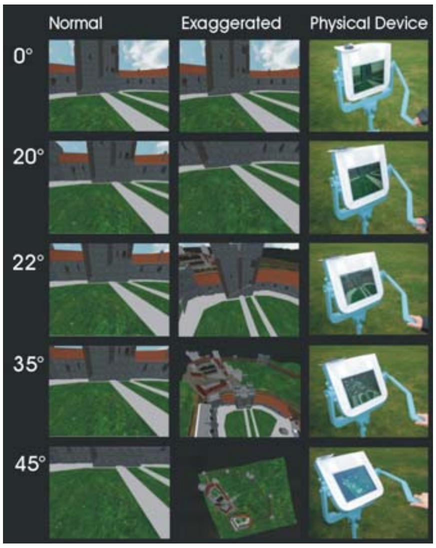

Fig. 6. Normal versus exaggerated tilt

The right hand column of images shows the physical tilt of the top unit. The column on the left shows the virtual viewpoint with no exaggeration applied. The middle column shows the effect of the exaggerated tilting. This mechanism deals with limitations of the chosen sensing hardware, while also enabling users to obtain a useful bird's eye view of the model without having to physically fly up into the air. The completion of the software refinements brought the Augurscope II to a state ready for testing with the public.

4.4 Phase 4: Deployment and Public Testing

Our final stage of the design process was to carry out public testing of our new prototype at the castle. This was conducted over two consecutive summer days. Just over a 100 visitors experienced the prototype (including people that either directly interacted with the device or who were closely involved in the experience and discussions about the experience when watching others). The age of direct users ranged from 10 to 65 while the age of people merely observing ranged from ~3 to75 years. Most interaction on the device was by groups of people rather than individuals. These groups were couples, parents with children, groups of friends and school groups (7-24 members) from a number of different nationalities. The museum management confirmed that our user profile represented well the visitors to the site during the summer holiday period. We collected video and audio data, the latter using a wireless microphone that was attached to the Augurscope II, and also logged GPS data in order to establish a trail of movements.

We regard the evaluation as being part of the ongoing design and development process, rather than as a separate assessment of the effects of that prototyping. We consider the implications of that approach later in the paper. The evaluation process itself was developed, or prototyped, over the two days in the light of what was learned, resulting in three distinct phases. Between those phases small adjustments were made to the device, the experience as a whole and our evaluation method, with the aim of maximizing our understanding of the device in use under different circumstances.

Initial calibration of the device during set-up on day one involved us pushing the Augurscope around the site. This naturally elicited some interest and was in accordance with the overall design objectives of encouraging and modelling use as potential users were able to observe and learn something about use from a distance. Subsequently, when no one was currently engaged with the device, we approached people nearby on the Castle Green, inviting them to try out a device we merely described as developed for a research project, and asking them to tell us if they could work out what it was about. That is, we did not introduce users to the purpose of the device and then set them particular tasks to perform, a common approach in more formal experimental evaluations. Rather we presented the device as a puzzle object in order to gain an impression of the degree to which the device supported exploration. We explained to users how they could tip, turn and push the device and then stood back, but accompanied them in their use. The results were sufficiently promising that we chose to make some minor adjustments for the second phase.

Consequently, for the second part in the morning of day two we added labels to the front of the top unit and the handle of the base unit. The wording for the top was: '(anonymous) Castle in ~1485 / A tour developed by the (anonymous) Lab, University of (anonymous)', 'Turn and tilt to rotate your viewpoint'. The wording for the base was: 'Push me to move your viewpoint'. This was intended to replace our explanation of how to use the device and to see if these small amounts of labelling were sufficient to enable users to guess how to use the device, supplemented possibly by their observation of earlier users.

Given that initial learning of use seemed very successful, we decided to move to a stronger test of the device in the afternoon. We left the labelled device unattended (although observed from a distance) in a strategic position near the entrance to see whether and how people would interact with it then. This was successful, with Augurscope II attracting a great deal of attention from visitors, walking up and trying it out. There were only relatively short periods during which it was not used. In the following sections we consider how our second generation of the device addressed the general shortcomings of the initial version of the augurscope outlined in section 3.

4.4.1 Mobility

In general, mobility was much improved over Augurscope I. Out of 37 distinct groups of users, 29 groups moved the device, compared to 2 out of 30 for Augurscope I. However, visitors were still somewhat reluctant to push the device at first and often had to be encouraged to do so. Especially during phase 3 of the trials when the device was left alone, the distances travelled went down. It seemed that visitors were unsure whether they had permission to move the device. Visitors are used to interactive static museum displays (albeit usually indoors), but public devices that can be moved around are much rarer.

A further issue was that due to our filtering of GPS updates in our software to remove obvious large sudden jumps in reported position and so prevent a jittery display, the virtual viewpoint did not always update if the device was just moved a little way, which may have discouraged some users from pushing it further. Once moving the Augurscope, their journeys ranged from just a few meters to extensive tours of the Castle Green. Data logs showed that between them, users collectively explored the entire Green and use lasted for up to 10 minutes.

An unexpected observation was that users adhered to virtual (apparent) constraints like 3D representations of walls or paths more than we expected (there is no reason why the device can’t be pushed straight through them). When we suggested that virtual walls could be ‘walked through’ many people seemed surprised. In fact, as well as being an amusing activity, it enables a richer sense of the layout of buildings, and is also the only way to see what a building looks like from the inside (the Great Hall, no longer in existence, contained in its virtual representation furniture and wall hangings appropriate for the period).

4.4.2 Segmentation of the Experience

The rotation of the top unit around its base is now unobstructed resulting in an equal, unsegmented access to the whole 360° virtual panorama from any given physical viewpoint. Along with the other improvements this enabled better access to the physical site and the device itself but also as a result to the virtual model, essential for understanding the relationship between the two.

4.4.3 Accessibility

With the re-design we also improved access to groups of users not catered for well with Augurscope I. This did require the occasional adjustment in height of the central column and the push handle by us and users could not have achieved this easily. However, once adjusted we saw a wide range of people interact with the device with for example groups of children from the age of 10 taking it on extensive tours exploring the views of the Great Hall and the Gate House. We found that even when not adjusted correctly Augurscope II remained useable. Users then simply looked up (sometimes also down) on to the screen though this did result in them being unable to use the overview facility. For that the top unit needed to be tilted down far enough requiring an elevated physical viewing position not achievable by some children, and some were lifted up by their parents for a better view.

The handheld mode of the top unit made it accessible to even more people, as for example when parents demonstrated content to their children (see figure 7). The handheld mode was only tested with two people who themselves suggested that this might be an interesting feature. It is clear that this mode proved to be very useful in certain circumstances but generally it makes it less useable for larger groups of people. One person is in control and also 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. Besides 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.

A further observation was that a large proportion of users interacted with one hand while holding something in the other, for example, ice creams, cameras, or a child. Indeed, one parent pushed the Augurscope II with their body while holding their child. This ‘encumbered’ use made movement more difficult rather than preventing it and yet is to be expected in a public tourist setting. The fact that the Augurscope can be used with one hand was a fortunate effect, but not one that had been planned in its design.

4.4.4 Sunlight Readability

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 also very good (see figure 7 (centre) taken from across the Green). When sunlight hit the screen directly, readability was reduced somewhat but the device still remained useable.

As well as highlighting the ways in which our design responded to the shortcomings of the initial device the trials also revealed how minor differences in the physical affordances of a device can considerably affect the user experience. On day one we noticed that when no-one was touching the handle, the default tilt of the Augurscope screen meant that it was in overview mode. Some users seeing this overview mode and rotating the device with the handle but not tipping, did not themselves discover the ground-based virtual view. Furthermore, physical movements of the device only have a small effect in overview mode, leading one user to note that he could see no point in moving the device, as the virtual viewpoint had not changed. Under these circumstances we encouraged people to tilt the top unit, giving them the viewpoint located on the virtual ground, which is the main point of the Augurscope in allowing a comparison between what can be seen here now and what would have been seen here long ago. This need for intervention revealed a design flaw, but observing the problem led to the creation of a simple fix. For the second day we changed the weighting of the handle to provide the ground-based view as the default. Of course such a solution leaves open the risk of some users now failing to tip down and discover the overview, but this seemed a reasonable trade-off. Subsequent design refinements can be envisaged to introduce users to both modes, ranging from yet more labels to encourage tipping the screen (easy to create but cluttering up the artefact), to use of an animated attractor mode showing the different views possible, by analogy with some arcade games.

Fig. 7. Public Trials

5 Implications for the Design of ubicomp Devices

Through an iterative process of designing, prototyping and testing two generations of the Augurscope, we have managed to create a novel, perhaps even unique, interface in terms of its combination of physical form, sensors and software. We feel that our current prototype demonstrates that this interface has the potential to deliver engaging public experiences that involve exploring an outdoors heritage site. At the same time, we recognise that the current prototype requires considerable further development, especially with regard to weight, bulk, robustness and power, before it can deliver this potential, and that resolving these issues may require us to fabricate an industrial strength prototype.

Beyond the design itself, it is also informative to reflect on the design process, which has drawn upon a number of different design approaches and traditions. Our use of a design proposal as a starting point draws upon techniques common in product design [1]. The involvement of users in the rapid mock up and refinement of the physical form draws upon participative design techniques [9] and our situated formative evaluation [17] of the interactive systems draws upon user centred design [12].

In the following two sections we reflect on the process of prototyping our device. What more general lessons have we learned from our experience and how might these benefit other researchers and designers working on their own quite different novel interfaces?

5. 1 Prototyping of the Physical Form

One important lesson to emerge from this process has been the importance of getting the physical form factor right in detail from an early stage, deciding upon physical size, shape and structure, the movements of key joints and the possibilities for adjustment to suit different users. It was an important step to move from the 'software outwards' process that we followed for the Augurscope I to a 'physical form inwards' process with the Augurscope II. In particular, we feel that iteratively developing a series of low-tech physical prototypes that we then evaluated through 'push and rotate tests' was an essential aspect of evolving the physical design.

When developing ubicomp devices the designer has to consider not just the conventional user experience (just as one would in developing applications for desktop personal computers), but also the constraints of multiple pieces of hardware communicating with each other, and the physical affordances of the artefact as it is used, moved and interacted with in a real setting. With traditional desktop computer applications, this issue of physicality is usually separated off and dealt with by ergonomists who consider seating, screen angle, keyboards etc. The application designer generally can or does ignore the user's body and just deals with the user's mind. Equally ubicomp designers have tended to concentrate on just a subset of these issues, however, we would like to emphasise the importance of considering the ubicomp user experience as a compromise between technological constraints, physical affordances of the artefact and its setting

The issues of physicality do indeed create yet more issues to consider in the design process. However, physicality is not only a problem, it can also be a positive asset. In the case of the Augurscope, the relatively simple and rather large scale body movements and pushing activity that are the means of interacting with the device afford learnability-at-a-distance. Visitors can and did gain a good sense of how to operate the device while observing other users even from 10-30 meters away.

Some issues of stability and failures to fit to human physical constraints can be identified simply by prototyping the physical structure of the device, and the designers trying it themselves or asking colleagues for opinions. This is not to say that authentic user tests are unnecessary, but to note that certain more coarse-grained design problems can be identified quickly, cheaply and easily even in such somewhat unrepresentative contexts. Once these problems have been identified and fixed, it is worthwhile moving to more complex and time consuming evaluations.

5. 2 Prototyping the Evaluation

The prototyping approach to evaluation illustrated in the previous section has various pros and cons compared to traditional, more formal evaluations such as controlled experiments. Just as prototyping a physical device is about producing a version in a short space of time and thereby making compromises over functionality, robustness, or completeness, we would claim that there is a place for a prototyping approach to evaluation. In brief, it trades breadth at the expense for depth [11]. It allows developers to maximize the information that they can obtain from use testing, assuming that gaining access to end users is somewhat complex and time-consuming, so that they can become a bottleneck in a rapid prototyping cycle. The prototyping approach allows for the opportunistic detection and analysis of unexpected kinds of use in relatively authentic settings. An example from our study is our realization of the impact of encumbered use. Once a problematic issue has been identified to the satisfaction of the developers and they have obtained sufficient use information to inform a redesign, it makes sense to move on to investigate a different aspect of use. This can be by adjusting the task to temporarily bypass the problem and look at something else, or even by incorporating the revised version into the evaluation. Examples from this study include initially explaining to users about how to adjust the device to get the ground view, and changing the weighting to make the ground view the default, respectively.

Prototyping is about making something quickly that is not quite real. The designer can choose what to simplify, to omit or to fake. This allows an approximation of the final product to be created quickly in order to assess and revise it. Similarly, for evaluation, the prototype needs to be 'wrapped' in a supportive infrastructure, as by its nature it is not a standalone device. Our prototype for example required continuous support in terms of its initial set-up, ongoing maintenance (failures of batteries, GPS etc.). The design team were at a discreet distance to deal with any problems but also were available to tailor the experience for example adjusting the height of the handles. Equally, the activities of the evaluator are also a form of wrapping such as any initial instructions or suggested tasks or activities to try. Such wrapping or scaffolding [15] allows for evaluation of parts of the interaction experience, but care must be taken to note where and how the scaffolding occurs so as not to attribute success to the device alone.

Ideally, as the prototyping cycle proceeds, various levels of scaffolding are removed so the device is increasingly tested in more authentic standalone situations. In such informal evaluations, negative evidence should be treated as more reliable than positive evidence. Problems with the device, unless easily attributable to a prototyping decision, are more likely to be genuine and in need of analysis to inform a redesign. Successes have to be considered more circumspectly, as they can be artefacts of the scaffolding process, or lack of systematicity in the nature of the users or the activities they do (although in other ways this is an advantage in gaining insights into the diversity of likely actual use).

6 Conclusions

We have presented the process of designing an interface that enables members of the public to explore 3D historical reconstructions from their present day sites. We have briefly introduced our first prototype, Augurscope I, were we started with existing software, chose the sensors and hardware and designed its physical form to accommodate those. This approach to design can be described as ***'software outwards'***. In response to our experience with this prototype, we effectively reversed our process and adopted a ***'physical form inwards'*** design approach as described above, which focuses on first establishing the physical form of the interface before selecting sensors and hardware and finally refining the application software. As a conclusion we would like to emphasise the importance of prototyping for the development of ubicomp devices in general and in particular would like to point at the following key issues that need to be considered.

The early physical prototyping of ubicomp devices, leaving aside hardware and software integration, can reveal issues with a design that are less apparent on a 'paper' proposal. Those can often be identified merely through the process of building the prototype. During the translation of a design proposal into its physical form, problems with its construction and assembly will be revealed, but in addition a designer will also be able to identify problems with its interaction simply through handling the device her/himself.

As a next step, users can and should be involved as early as possible in the process. In house testing (i.e. with the help of colleagues) often reveals the most pressing problems while later stages can benefit more from outside input when more detailed interactional issues with a device can be explored. While this user involvement will be beneficial for smaller, single-user interfaces, it becomes even more important for larger, shared and situated designs. Importantly, in this case not only the interaction of users with the device but that with others and around the device need to be considered. In the case of the Augurscope II we have benefited considerably from this early involvement of users as described above.

Closely related to this is the benefit of deploying a prototype as early as practically possible in its intended setting to be able to consider the situated nature of an experience. In our case, dealing in practice with the very important and well-reported problem of using a device outdoors [2], but also understanding the physical limitations of the actual site and the user profile allowed us to further refine our prototype.

Finally, as the deployment is not that of a finished product, the evaluation can and should be adapted to the requirements of the setting. Some problems with a prototype will only be apparent when deployed and if they can easily be fixed, designers might be able to use the opportunity to test different versions quickly and easily. Furthermore, when the relative success of a design becomes apparent at a certain stage of the evaluation process, successive levels of scaffolding can be removed to be able to test what types of support or set of instructions a design might need as a final product.

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