

Dynamic versus Static Peephole Navigation of VR Panoramas on Handheld Devices

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ABSTRACT

Virtual reality panoramic images are becoming increasingly popular on handheld devices, but navigating them remains a challenge due to small screen sizes. In this paper, we present a formal evaluation and usability studies comparing two interaction concepts. In the first one, the device is seen as a static peephole and the data is moved behind it via touch screen-based scrolling. In the second one, a mobile phone's sensors are used to create a dynamic peephole that can be moved over static content. In the results of our formal analysis sensor-based dynamic peephole navigation performed twice as good in an orientation task, 75% better in an object size discrimination task, and was preferred by 80% of the users. Despite these advantages, additional usability studies indicate that if they are sitting, a majority of users resort to touch screen-based static peephole navigation when interacting. Our results therefore demonstrate benefits of dynamic peephole navigation for virtual reality panoramas but also illustrate its limitations depending on the current context of the user.

Categories and Subject Descriptors

I.3.6 [Computer Graphics]: Methodology and Techniques – interaction techniques.

General Terms

Design, Experimentation, Human Factors.

Keywords

VR panoramas, dynamic peephole navigation, mobile interaction.

1. INTRODUCTION

Modern handheld devices such as smart phones can display rich multimedia contents including video and 3D graphics. However, in order to keep devices mobile, screen sizes have to remain relatively small, thus creating extra challenges when navigating such data. As a result, interaction via touch screen has replaced button-based input on most major smart phones. In addition, there

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MUM '10, December 1-3, 2010, Limassol, Cyprus

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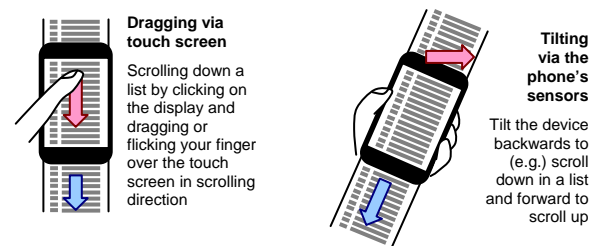


Figure 1. Scrolling one-dimensional data (e.g. lists) via touch screen input (left) or tilting (right).

is a common trend towards utilization of sensors such as accelerometer and compass for interaction purposes. For example, navigation in one-dimensional data (e.g. lists; cf. Fig. 1, left) is commonly done via dragging or flicking your finger over a touch screen forcing the one-dimensional content to scroll in the same direction. Alternatively, researchers experimented with the utilization of tilting sensors [1, 3, 6, 9], for example to scroll lists depending on the tilt level of the device (cf. Fig. 1, right). For two-dimensional content, such as large images and maps, Mehra *et al.* [8] describe scrolling in 2D as navigating spatial layouts by moving the layout behind a **static peephole** (similarly to scrolling in 2D on a desktop by dragging or using scrollbars; cf. Fig. 2, left). In addition, they introduce the concept of a **dynamic peephole**, where sensors are used to create a peephole that can be moved over a static layout (cf. Fig. 2, right). For three-dimensional data, aside from touch screen based interaction, tilting has become a common way to navigate virtual 3D environments, for example, in mobile gaming [5] (cf. Fig. 3).

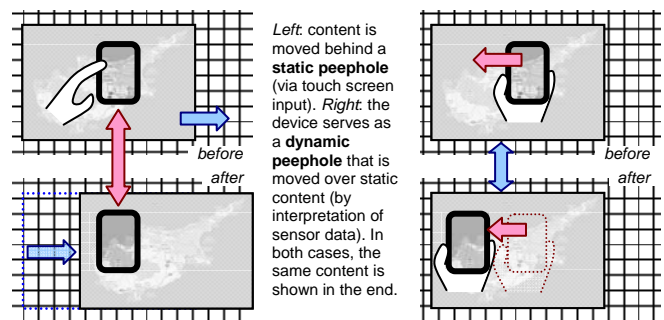


Figure 2. Scrolling two-dimensional data (e.g. maps) via static (left) or dynamic peephole navigation (right).

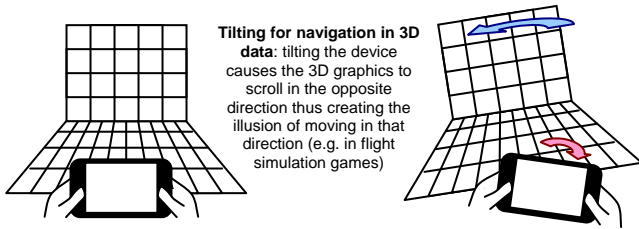


Figure 3. Navigation in three-dimensional data (e.g. 3D graphics in mobile gaming) via tilting of the device.

In this paper, we are focusing on virtual panorama image data (**VR panoramas**) where 360 degree images (both photos and rendered 3D graphics) are represented in a perspective way creating the illusion of being “inside” of a scene or some sort of “pictured-based” virtual environment (cf. Fig. 4). Such images are popular on the web, for example for advertising purposes, and on mobile devices, mostly due to the Google Street View application that is part of Google maps (both mobile and on desktop PCs). We introduce different interface implementations for this kind of data that are based on the concepts illustrated in Figure 1-3. In particular, we compare touch-based static peephole approaches with sensor-based dynamic peephole techniques. After discussing related work in the next section, we present a formal experiment in Section 3 where participants have to perform two tasks using both dynamic and static peephole navigation. Based on these results, we discuss several informal user studies in Section 4 with tasks aimed to investigate applicability of the findings to actual user interfaces. Section 5 concludes the paper and provides an outlook on future research.

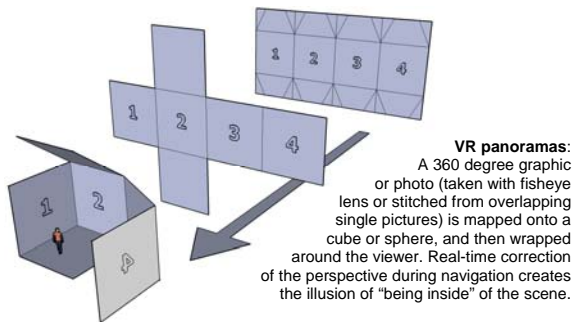


Figure 4. Illustration of VR panoramas.

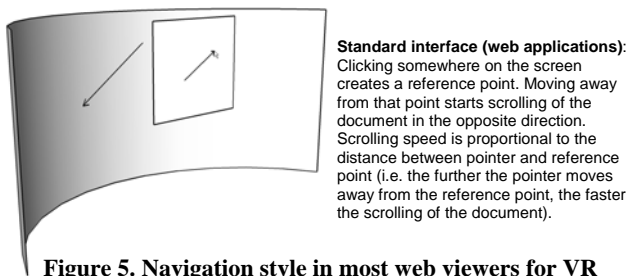


Figure 5. Navigation style in most web viewers for VR panoramas.

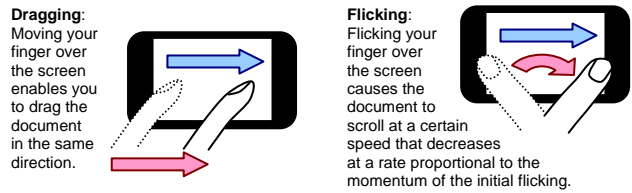


Figure 6. Navigation of VR panoramas on a mobile via dragging (left) and flicking (right).

Compass mode: Moving the device around enables a user to explore the VR panorama. Sensor information (compass and accelerometer) is used to change the visual feedback on the device as if it would be a “window” into the virtual world.

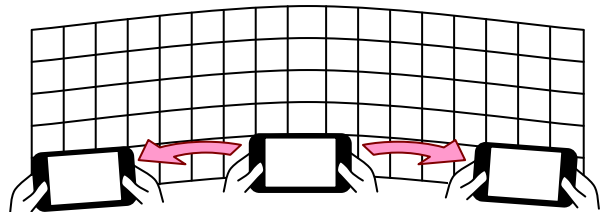


Figure 7. Navigation of VR panoramas on a mobile by moving it around in compass mode.

2. RELATED WORK

Various options exist to navigate and explore VR panoramas. For example, for the standard interaction mode in many web browser plug-ins, users create a reference point by clicking somewhere on the screen. Automatic scrolling is initiated by moving the mouse pointer away from this reference point. Scrolling direction is reverse to dragging direction. Scrolling speed increases with the distance between current pointer position and reference point (cf. Fig. 5). In Google Street View however, a similar interaction results in dragging and moving of the actual content (cf. Fig. 6, left). Its mobile implementation on Android devices and the iPhone extends this dragging-style navigation with two-dimensional flicking (cf. Fig. 6, right). In addition, it features a so called compass mode, where the panoramic data is static and explored by moving the device around (cf. Fig. 7).

According to the notion introduced by Mehra *et al.* [8] (cf. Fig. 2), the first three options implement static peephole navigation, where the device is held in a static position but the content is moved behind it. The latter one realizes a dynamic peephole, where the content is static and the device is moved across it. Such dynamic peepholes are a special case of spatially aware displays. Fitzmaurice *et al.* [4] were the first to apply this concept to handheld screens using a Wizard-of-Oz realization. Yee [12] presented an implementation on a PDA and evaluated its combination with pen-based input. In order to compare static and dynamic peephole navigation, Mehra *et al.* [8] performed experiments with a line length discrimination task. Their evaluation shows that dynamic peephole navigation is perceived as more natural because it allows users to rely on their spatial memory. As a result, dynamic peephole techniques were found to be more effective than other methods for navigating information on the screen. Their experiments were done with a 2D layout by

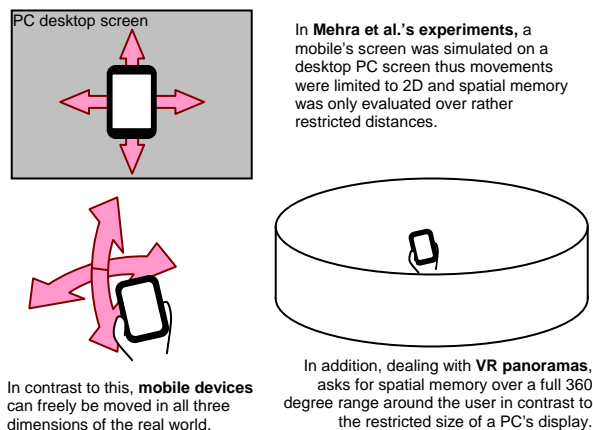


Figure 8. Major differences between our work and Mehra *et al.* [6].

simulating a small screen device on a flat, two-dimensional desktop display. In their study, the position on the screen determined what part of the layout was visualized. Since it was the dynamic peephole that was moving while the information did not change its location, users could rely on their spatial memory during navigation. However, movements were restricted to the size of the desktop screen. In contrast to this, VR panoramas cover the whole 360 degree view of an observer (cf. Fig. 8, bottom right). Newer work explores this kind of interaction in an unlimited two-dimensional space. For example, Rohs and Essl [10] and Rohs *et al.* [11] present various dynamic peephole implementations on mobile devices and evaluate them with respect to certain parameters and applications. However, they target tasks such as map navigation, i.e. interaction with data that is naturally flat and not spherically aligned around the user. Hence, the related interactions are usually done in a plane and resemble more the movements over flat computer screens that have been evaluated by Mehra *et al.* [8]. In contrast to this, we can expect users to move the phone freely around in all three dimensions of the real world when exploring VR panoramas (cf. Fig. 8, bottom left).

The major goal of the research presented in this paper is therefore to evaluate if device-orientation-based dynamic peephole navigation of panoramic virtual environments presents benefits over static peephole navigation techniques in a real world setting using state of the art mobile smart phones. To the best of our knowledge, this is the first detailed analysis of device-orientation-based dynamic vs. static peephole navigation with this kind of 3D data. Hürst and Wittmer [7] also investigated different interaction modes for virtual reality panoramas. However, their work relies on pen-based input on rather small screens with a lower resolution, and it only looks at variations of static peephole navigation, not taking into account sensor information about the device's orientation.

3. EVALUATION OF DYNAMIC VERSUS STATIC PEEPHOLE NAVIGATION

Being able to orient oneself in an environment, both virtual and real, implies the ability to judge the angular distance between any two points (cf. Fig. 9), which is important for two reasons. Firstly,



Figure 9. Angular distance between two points.
In the experiments, users had to estimate the angular distance between two points that have been placed on the horizon of the panoramic image (green and red dots). The photo covered a full 360 degree. Yellow notes have been added here for illustration but did not appear in the image during the test. In the evaluation, a different image depicting the Grand Canyon was used that is not illustrated here for copyright reasons.

angular distances determine our perception of relative position of objects in the environment. Secondly, angular distances between the edges of an object let us estimate its dimensions. Often auxiliary clues, such as perpendicular intersections of straight roads or presence of objects of known sizes can aid in perceiving relative positions of other objects or their dimensions. But in cases when such clues are not available, our perception heavily relies on the ability to estimate angular distances. In order to evaluate orientation and angular distance perception in VR panoramas for dynamic versus static peephole concepts, we implemented four different interaction modes related to the ones illustrated in Figure 5-7. For the experiments, we used an Android 1.5 based HTC Hero smart-phone. It is equipped with an accelerometer and compass, and features a 3.2 inch TFT LCD touch screen with resolution of 320x480.

3.1 Implementation and Setup

Our viewer for full cubic panoramic images uses code from the open source PTViewerME [2] to read panoramic images in QuickTime VR format and extract six images that constitute the panorama (cf. Fig. 4). These are drawn as textures on a box around the camera (i.e. the viewer's position) using OpenGL ES. Our viewer features four different navigation modes:

1. *Device-orientation-based panning*: Orientation of the device determines the viewing orientation in the virtual environment (comparable to the compass mode in mobile Google Street View; cf. Fig. 7).
2. *Drag-based panning*: Dragging the image with a finger results in panning of the panorama. This mode also includes flicking, where flicking motion results in a damped rotation of the panorama in that direction (comparable to the default mode of mobile Google Street View, cf. Fig. 6).
3. *Touch-controlled rotation*: Dragging the finger on the screen results in rotation of the panorama in the opposite direction. The further the drag is, the faster the rotation (comparable to default navigation mode of virtual panoramas on the web, cf. Fig. 5)
4. *Device-tilt-based rotation*: Tilting the device away from some neutral orientation causes the panorama to rotate in the opposite direction. The more the tilt angle, the faster it rotates (comparable to navigation in 3D graphics in mobile gaming, cf. Fig. 3).

It should be noted that the readings of accelerometer and especially compass are noisy. This can potentially undermine the usability of sensor-based interfaces. In order to smoothen the panning based on sensor readings we therefore implemented a filter that uses weighted average values of several last readings. This reduces jitter but on the other hand introduces a small but noticeable lag.

3.2 Methodology and Experiment Design

As described in the previous section, we implemented four panorama navigation modes. One of those, the orientation-based panning, is a dynamic peephole navigation mode. The other three are static peephole modes. To focus on comparing static and dynamic peephole navigation techniques we set up an informal pre-study in order to identify the most promising of the static peephole approaches. Based on our initial observation, the device-tilt-based rotation mode was rather inconvenient and far inferior to the other two modes. When comparing between drag-based panning and touch-controlled rotation both the accuracy of the responses and overall feedback were in favor of the drag-based panning in a trial experiment with a sample of four subjects that did not participate in the actual experiments later. Hence, we limited the evaluation to compare device-orientation-based with drag-based panning.

3.2.1 Basic conditions and setting

There were no special requirements for the setting of the experiment, except for one – participants needed to be able to stand up and freely rotate around with the device in order to be able to explore the full possibilities of orientation-based panning. Consequently, the experiments were conducted at various environments, indoors and outdoors. During the experiments it was ensured that the participants were comfortable conducting them, were not under time or social pressure, and potential distractions were kept to a minimum.

3.2.2 Subjects

A total of 24 people (13 male, 11 female) participated in the experiment. About half were young professionals whose age was between 24 and 32 years old. A third of the participants were students of Utrecht University. The remaining ones were taken from the general public and had varying levels of formal education and industry experience. Subjects were not compensated for participation, but expressed interest or curiosity about the new technology and willingly completed the tasks.

3.2.3 Data acquisition

Paper forms were used to collect participant responses. In addition, subjective feedback was collected via interviews after the subjects performed the experiments and a neutral observer made notes of interesting observations during the evaluation.

3.2.4 Task 1: Estimating Angular Distances

The first task was to determine the angular distance between two points in a virtual environment created with a cubic panoramic image. Each participant was presented with a full 360-degree panorama of the Grand Canyon. It was chosen so that it did not contain humans, roads, buildings, or other objects that may serve as clues for relative orientation or dimension estimation. In the panorama, we marked two spots on the line of horizon (cf. Fig. 9).

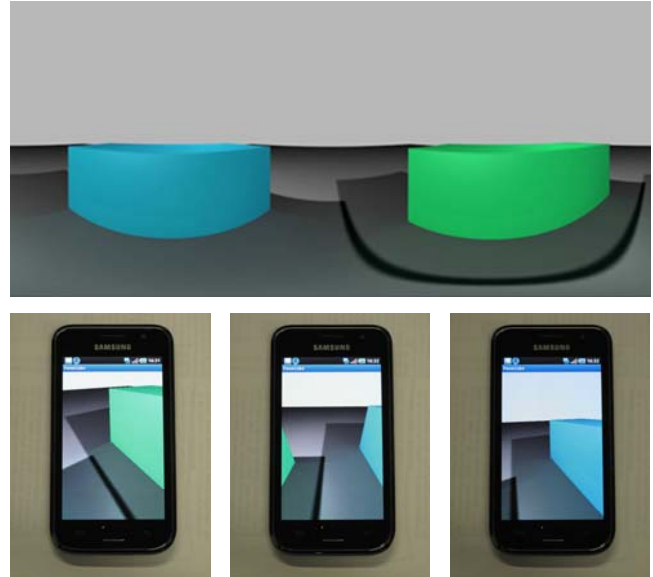


Figure 10. One of the images used in the box size discrimination task (top) and its appearance on the mobile phone during the tests (bottom).

They were located so far from each other as to not be both visible on the screen at the same time. The device was used in portrait mode. The participants' task was to locate both spots, and mark their perceived position on a circle on the paper form. We used a within-subjects and repeated measures design, i.e. each user had to do the task twice – once for each navigation mode. In both navigation modes the panoramas were identical, but the positions of the color spots were different. After performing the task in both modes, the participants were asked which navigation mode is better suited for accurately estimating relative positions of the spots. For the orientation-based panning mode, the angular distance from red spot to green was -140 degrees. For the dragging-based panning mode, the angular distance was 160 degrees. The order was counter-balanced, i.e. half of the participants started in orientation-based panning mode and then did drag-based panning mode. The other half did them in the reversed order.

3.2.5 Task 2: Size Discrimination Task

The second task was box size discrimination in a virtual environment created by 3D graphics. This can be seen as a three-dimensional generalization of the task of 2D line length discrimination used by Mehra *et al.* [8]. The participants were presented with a panorama of a fully augmented 3D scene that contained two box-shaped objects (cf. Fig. 10). Both objects were that long that neither would fit entirely on the screen at once. The objects had equal height and depth but their length differed by 13%. We found 13% to be the optimal value via a set of trial experiments with four subjects that were not involved in the actual study. For 15% or larger the difference in length became very apparent and if the value was 11% or smaller it became nearly impossible to discriminate between the lengths. To choose a way to distinguish between the objects we used different colors. To minimize optical effects of different colors of the objects,

colors had the same brightness and saturation and only slightly differed in hue. The participants' task was to determine which object was larger. Like in the first task, we used a within-subject and repeated measures design, i.e. each participant evaluated each navigation mode. Afterwards they had to indicate which mode was preferable for the task. For different modes, the objects slightly differed and were also positioned differently. Again, the order of modes was counter-balanced and devices were held in portrait mode (cf. photos in Fig. 10).

3.3 Results and Observations

For the first task in drag-based panning mode the correct angular distance between two spots was 160 degrees. The participants' responses lied mostly in the wrong semi-circle from the correct position. Average response was -176.1 degrees, which is 23.9 degrees away from the correct position. Standard deviation of the responses was 45.0. Average of absolute values of error was 40.3 degrees with a standard deviation of 30.6. The range in which the responses fell was 157 degrees. For the same task in orientation-based panning mode the correct angular distance was -140 degrees. This time the responses were more accurate. The range of responses was 77 degrees and the average response was -137.5 degrees with a standard deviation of 21.2. Average of absolute values of error was 15.6 degree and the standard deviation -11.9 degrees. A t-test verified the significance of this observation ($t(46) = 3.67, p < 0.05$). Hence, in orientation-based panning mode significantly more people determined the angular distance more correctly than in drag-based panning mode. In addition, all except for two participants found orientation-based panning mode more accurate for finding angular distances between two points.

In the drag-based panning mode, the angle between the red and green spots was 160 degrees clockwise – or to the right – from the red spot. However, the majority of participants began panning in the counter-clockwise way – to the left – and unless they applied extra effort most of them failed to think beyond 180 degrees and responded that the angle was between -140 and -180 degrees, while the correct answer was +160, which is -220 degrees. This indicates the limitations of perception of spatial orientation in a virtual environment in the drag-based panning mode.

In the second task, 40% of participants correctly selected the longer box in the drag-based panning mode, while in the orientation-based panning mode 70% were able to pick the bigger box correctly. 80% of respondents preferred orientation-based panning mode for the task of dimension discrimination. The significantly improved performance in angular distance estimation and object size discrimination in orientation-based panning mode clearly demonstrates the benefits of dynamic peephole navigation technique for size discrimination tasks.

4. APPLICATIONS AND USABILITY STUDIES

Our formal evaluation verified advantages of dynamic peephole navigation for orientation and angular distance perception. To some degree this confirms the positive results that Mehra *et al.* [8] achieved for similar 2D navigation tasks on desktop PCs. However, since we were addressing three-dimensional data (cubic virtual reality images created from panoramic photos and via 3D graphics) and actual hand movements in three dimensions, users needed to be able to fully rotate the device. This is generally only

possible to do comfortably while standing. This requirement largely narrows the range of applications that could employ dynamic peephole navigation techniques in their interfaces. However, in situations when users cannot fully rotate themselves, they often still have at least some degree of freedom in rotating the device. Hence, adding dynamic peephole navigation on top of conventional static navigation techniques and using the combination of the two could offer new ways for interface designs combining the advantages of both approaches. To evaluate such possible applications of dynamic peephole navigation we conducted two informal user studies – one where people could freely rotate, and one in a more restricted setting. The first one compares device-orientation-based and drag-based panning in relation to a concrete application. In the second one, we investigate an implementation that combines both interaction modes in one interface.

4.1.1 First Study: Free Rotation

Our first study focuses on the situation when a user can freely rotate with the device. In addition, we have chosen an application in which there is a clear relation between the content shown on the device and its actual position in the real world. Eight participants, chosen randomly from the street, were offered to look around in one of two panoramas of the city of Utrecht while standing exactly on the spot from which the panoramic photos were taken (cf. Fig. 11 and 12). The first panorama was taken in the city center of Utrecht on top of a bridge over a canal and included a good view of the tower of the local church, which is a well known landmark of the city. The second panorama was taken at the campus of the local university, just outside the university library building, which at that time was still under construction. Figure 12, top, illustrates this difference between the photo (that only shows the construction site) and the real situation (with the finished building as it is in operation today).

Both images were a few years old and thus contained also several minor but still apparent differences, such as newly planted trees, different stores in the city center, etc. The participants were asked to look around using two navigation modes – device orientation-based panning and drag-based panning – and find four differences between the panorama image and the reality – two in each mode. In the device-orientation-based panning mode the orientation of the panorama matched the reality, i.e. when the device was pointed towards, for example, the church tower, the part of the panorama on the screen also included this tower (cf. Fig. 12 which shows the alignment of photo and reality for the university picture). The task of finding differences was not meant to be quantifiable; it was simply a stimulus to make participants focus on the panorama and explore its content using the different interaction styles.

All participants successfully found four differences in both modes. All of them stated that the device-orientation-based panning mode was more convenient for the task, provided for better connection between the panorama and reality, and was also more interesting and exciting. Afterwards they were offered to look around in another panorama that was taken in Las Vegas outside the entrance to casino Paris. All participants chose to do it in the device orientation-based panning mode. They agreed that it required less effort and provided for better immersion in the environment of the panorama. This study conclusively suggests the high usability of dynamic peephole navigation technique for



Figure 11. Panoramic photo of Utrecht (photo taken at the campus of the local university).



Figure 12. Difference between panoramic photo and reality: in the 4 year old photo the library building is under construction (top) and a tree has been removed (bottom, tree on right side of the photo on the phone).

interfaces in situations when the user can freely rotate around with the device. It also indicates a high usability for applications in which the data on the screen has a relation to the spatial position of the phone. In the first case, this was very obvious because the photo on the phone showed an older image of the corresponding position in the real world. In the second case, there was no direct connection between the content shown on the phone and the real world, but the relative positions of the photo matched the absolute positions of the device in the real world.

4.1.2 Second Study: Combined Interaction Mode

Our formal experiments and the first user study confirmed that dynamic peephole navigation provides certain benefits. However, they can only fully be explored if one can freely move the device around in 3D space. Dragging on the other hand does not require

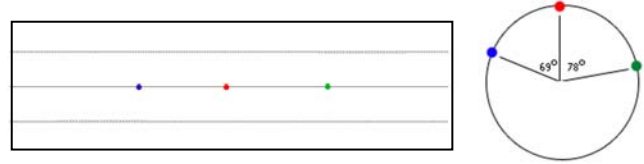


Figure 13. Panorama used for the dot distance discrimination tasks. The circle on the right illustrates how the dots distribute over the full 360 degree view.

the person to move the device in the real world. Hence, it seems promising to combine both interaction modes into one interface in situations where complete freedom of movement can not be assumed. The goal of our second user study was therefore to evaluate such a combined mode, i.e. an interface in which panning can be done in both ways – by dragging and by rotating the device. Twelve students of Utrecht University that have otherwise not been involved in the project and did not participate in the previous experiments were asked to perform a task of discriminating distances between dots on a fully synthetic panorama. The panorama included three dots – green, red and blue (Fig. 13). The red dot was positioned between blue and green and the task was to determine which of the blue and green dots is further away from it. The angular distance between blue and red dots was 69 degrees and between red and green dots 78 degrees. The distances differed by 13% – motivated by the value found during the formal experiment to make the discrimination task challenging but not impossible (cf. the formal experiment discussed in the previous section). The combined angular distance between blue and green dots was 147 degrees, which is smaller than 180 degrees and therefore made it possible to cover the needed range in device orientation-based panning mode without turning the body. Participants were seated on a non-rotating chair for the task, but they were not told that they have to remain seated.

Nine out of twelve participants correctly chose the green dot to be further away from the red dot. Given the previously identified benefits of dynamic peephole navigation combined with the limiting requirement to move around in free space, we would have expected that participants would use drag-based panning to center the panorama on the red dot and then device-orientation-based panning to look at the other dots. However, only two subjects solved the task in this way– one of them gave a correct answer and one an incorrect. All other participants chose to navigate using drag-based panning. Eight of them gave the correct answer. When asked about their choice of panning technique, most participants reported that device-orientation-based panning technique seemed inaccurate, inconvenient and “required some getting used to”.

After completing the first task, participants were asked to look around in the panorama of Las Vegas (cf. previous section) using the combined panning mode. Assuming that the benefits of dynamic peephole navigation technique found in the main experiment held for the combined mode it would be reasonable to expect participants to look around the panorama by moving the device around and using drag-based panning only in order to re-adjust the panorama so that they could see parts that are “behind” them. In practice all participants first tried to look around by moving the device. However, when realizing the ergonomic

limitation of accessing the whole panoramic image while seated, only three participants used drag-based panning to overcome it. Three other participants just switched to drag-based panning altogether abandoning device orientation-based panning. The other six participants stood up and rotated themselves to be able to look “behind”.

Both tasks that were performed to evaluate the combined panning mode showed no advantage of the dynamic peephole navigation technique in situations when users are limited in their ability to rotate freely. Even if the participants only needed to cover a part of the panorama that is so small that it does not require looking “behind” – like it was in the first task – they still found drag-based panning mode to be more convenient and efficient. On the other hand, the second task showed that a majority of users preferred device-orientation-based panning for looking around a virtual environment over drag-based panning if they have the possibility to stand up and rotate freely.

When discussing the preference for drag-based panning over device-orientation-based panning in situations with limited ability to rotate, we have to consider different factors. As mentioned before, despite smoothing and non-trivial interpolation of different sensor values, their input can be noisy and lagging. At larger angular distances (over 120 degrees) the ability of users to determine their orientation within the virtual environment using drag-based panning technique diminishes so much that the device-orientation-based panning technique appears to be more convenient, despite the lagging and imprecision introduced by jitter. But at smaller angular distances it becomes much easier to judge orientation in the drag-based panning mode and shortcomings of sensory input quality make the device-orientation-based panning technique inferior.

Another factor against dynamic peephole techniques in situations with limited ability to rotate is the lack of a strong perceptual link between orientation in the virtual environment and physical orientation of the device in reality. This relation existed in the first study (where the content of a photo related to the position in the real world where the device was pointing to), but not in the second one. This suggests that it must be more difficult to establish such link after rotating the device only over a smaller range of angles, rather than over a full 360 degree circle. Furthermore, it is even more difficult to do because of the jitter and lag that, as discussed above, have a more pronounced effect at the smaller range of angles. It was also observed that when using device-orientation-based panning mode while standing up the users rotated together with the device looking at it; so the orientation of the device and the direction of the gaze of the user changed relative to the surrounding environment together. However, while seated, at marginal viewing angles the users tended to rotate the device with their hand to look further “behind”. Therefore, the orientation of the device changed but the direction of the gaze remained the same. This decoupling of device orientation and gaze direction is likely to contribute – at least temporarily – to a weaker perceptual link between orientation in the virtual environment and physical orientation of the device. It is possible that through experience users can learn to account for a device’s independent rotation, but this issue can only be addressed and studied after the problem of lag and jitter is solved.

Overall, our user studies of usability of the dynamic peephole navigation technique suggest that it can be successfully used for applications that are used in situations that allow full freedom of rotation and expect users to pan over a large or full range of viewing angles; for example in applications for virtual tourism. However, due to insufficient quality of sensory input on current mass-market devices, combining dynamic and static peephole navigation techniques for use in situations with restricted ability to rotate does not appear to yield significant usability benefits over static peephole navigation techniques.

5. CONCLUSION

Following the work by Mehra *et al.* [8] that found benefits of dynamic peephole navigation techniques over flat 2D layouts the major goal of the work presented in this paper was to investigate if dynamic peephole techniques offer similar benefits for navigating 3D environments. A dynamic peephole technique was implemented on an orientation-aware mobile device in the form of the orientation-based panning mode for viewing full 360 degree panorama images. The experiment consisted of two tasks – angular distance estimation and object size discrimination. In both tasks, 24 participants showed significantly better performance with the dynamic peephole technique compared to the traditional touch-dragging navigation technique. During the first usability study participants also expressed their preference for dynamic peephole navigation stating it was more convenient, provided for better immersion into the virtual environment as well as being “cooler and exciting”. Both the experiment and our first user study conclusively suggest that dynamic peephole navigation techniques can be beneficially used for navigating 3D virtual environments and viewing surrounding panoramic images on orientation-aware mobile devices.

On the down side, dynamic peephole navigation techniques require the users to rotate, which is not always possible or convenient. Building on the fact that users often still have some degree of freedom in rotating the device it would be reasonable to assume that combining dynamic and static peephole navigation techniques could be advantageous. However, our second usability study showed very little appreciation of a combined mode over traditional drag-based panning by the users. This can be attributed to the lagging and imprecision caused by noisiness of sensory input and a weaker perceptual link between orientation within the virtual environment and physical orientation of the device. While the problem of lack of perceptual connection might be overcome by experience and learning, the shortcomings of quality of sensory input drastically undermine the usability of dynamic peephole navigation in a setting with restricted freedom to rotate. More accurate sensors, such as a gyroscope as recently introduced in the latest iPhone edition, will possibly solve this problem and thus increase the usability and range of possible applications for dynamic peephole navigation even further.

Considering future work, it should be noted that the tasks used for the evaluations in this paper always required panning in the horizontal direction. Taking into account that even when seated users usually have enough degree of freedom to look up and down with the device, further investigations of applications of dynamic peephole navigation techniques for vertical navigation – in combination with conventional drag-based panning – are a promising area to explore.

6. ACKNOWLEDGMENTS

We like to thank CycloMedia Technology B.V. for providing feedback and some of the panoramic images used in our evaluations. In particular, we like to thank Frank Van Den Heuvel and Arjen Swart for their support and valuable comments.

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