Applying Embodied Interaction and Usability Engineering to Visualization on Large Displays

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Large displays have repeatedly been shown to help the field of visualization with better performance time, better accuracy, and additional insight. Large displays allow people to use more of their embodied resources to better perform their tasks. However, a large display can only be used as well as it can be interacted with. We present a number of interaction techniques and devices including pointing, touch screens, 3D mice, head and hand tracking, and control panel interaction and evaluate each. We also include the summary of one experiment and refer to others on how large displays with embodied interaction can dramatically help people perform tasks.

resolution, large displays, interaction, visualization.

1. INTRODUCTION

Large displays have been shown to increase performance and accuracy with visualization tasks (e.g. [17]). They allow people to use a greater amount of their field of vision to perceive a greater amount of data. This increased field of view allows a greater amount of perception which allows greater insight into one's data [13]. They allow people to gain insight into data that in ways that are impossible with small displays.

However, large displays are inherently different from small displays [18]. They require different interactive techniques and paradigms. Techniques that work well on a single monitor may not work at all with a large display. Also, issues such as mouse rowing, losing one's cursor, and trying to click on a widget five feet away are all issues that either do not exist or are minimized on a single monitor.

In this paper we briefly explain five of the leading interactive paradigms with large displays (point, touch, mouse, head tracking, and control panel) and explain our experiences with each. We then evaluate each of the paradigms. When appropriate we show experiences applying usability engineering principles to improve the interaction. We also explain that in order for an interactive technique to be used effectively it should have the following characteristics:

- Embodied interaction (natural usage)
- Easy to learn
- Easy to use

1.1 Embodied Interaction

Paul Dourish explains that embodied interaction is "interaction with computer systems that occupy our world, a world of physical and social reality, and that exploit this fact in how they interact with us [7]." In other words, an interactive device or technique that takes advantage of embodied interaction principles take advantage of how people actually interact with their real-world surroundings. These devices or techniques should be an extension of one's body in as much a natural way as possible.

The human mind is not a disembodied computing device with visual input devices and discreet output devices, but the body works as a single integrated whole. Motor memory, proprioception, spatial memory, etc. are all resources of people that allow them to take advantage of large displays and help them more quickly create mental models of data that are more accurate than when relying more on virtual navigation.

For example, a hammer becomes a natural extension of one's body when one wants to pound something. A device or interactive technique might be easy to use, but at the same time not be natural. For example, a mouse is intuitive but not natural. One can easily grasp the mental model that moving the mouse on the table moves the cursor on the display in a similar way. However, the mouse is not natural because one must indirectly move the cursor. One must move the mouse on the horizontal plane (table) to have it move on the vertical plane (display).

Examples of natural devices might include touch screens or pointing devices. If one wants to "click", or push, a widget, possibly one of the most natural ways to do so it to push it with one's finder on a touch screen. Likewise, if one wants to point to something on a display then why not just point to it with one's finger or a laser pointer? The more natural a device is, the easier it will be for people to learn how to use it and the easier it will be for people to actually use it. In addition, natural devices and interactive techniques allow for a larger population to understand and use them.

1.2 Easy to Learn

Don Norman explains that in order for a device to be *easy* to learn, people must be able to easily create an appropriate mental mapping of the device [11]. In other words, people must be able to understand how the device works in some abstract way for them to use it. Any device or technique that does not seem intuitive or that require large manuals to use are less likely to catch on. If one cannot learn it, one cannot use it.

1.3 Easy to Use

For any interactive device or technique to last the tests of time it must be easy to use. A device or technique that requires large amounts of mental or physical effort will not easily catch on or be used long term. Usability engineering principles of keeping things easy to use are usually lacking from most devices that people use [Norman]. It has been said that it is easy to create something complex; it takes genius to create something simple that is usable.

2. RELATED WORK

Czerwinski et al. [6] explain the current state of performance measurements and explain that their own study showed conclusively that participants using a multi-monitor configuration affording increased resolution (3 monitors wide) performed better than on a single monitor. Tan, et al. [19] also show how retention can be increased by using extra screen space to display different images in the user's periphery to help recall more from a particular task session using their prototype called Infocockpit. Shupp, et. al [17] explored how performance of large displays varies with display size and display curvature.

A few longitudinal studies have been performed on multiple monitors. Bishop and Welch [5] created a "desktop" environment that used projections on the wall to alleviate bezel and ergonomic issues. They report improvement in everyday work and an increase in physical interaction. Ball and North [1] performed a similar study but with multiple LCD monitors for a six month period of time with multiple users. They report a number of benefits in perceived increase in productivity and problems with bezels, adaptation to the display, and interaction problems.

As more studies show the usefulness of large displays, different interactive techniques have followed. A number of different types of techniques, from using less traditional input techniques to different ways of interacting with the mouse have been developed. Large displays and multiple monitor displays are inherently different from smaller displays and logically should be interacted differently [18].

A large amount of research has been done on pen-based interaction. For example, Tivoli [8], and Fluid Interaction [9] are all well-known examples. These techniques have historically been used for white-board type interactions.

Mouse-based interactions have also been developed. Of particular note is the high-density cursor by Baudisch, et al. that focus on a greater visibility of the mouse cursor [4].

Touch screens and camera-based touch gestures have also been implemented with large displays (e.g. Ringel, et al. [14]). Other well-known interaction techniques also exist, such as laser pointers (e.g. [12]), head-tracking (e.g. [1]), and hand gesture tracking (e.g. [20]).

Khan, et al. [10] created an interface for physically larger displays that allows a user to see through a "telescope," similar to a porthole, to another part of the display. The user then can manipulate the other part of the display through the telescope similar to remote computing. In addition, Microsoft Research has been active in the area of interaction for large displays. Their work can be summarized in [15].

3. EXPERIENCES

We have experimented with a range of interaction devices and techniques. We will briefly discuss our experiences and the pros and cons of each. They include:

- Pointing interaction
- Touch screens
- Wireless 3D gyro mouse
- Head tracking interaction
- Wired mouse
- User interfaces and notification systems
- Control panel interaction

3.1 Pointing Interaction

We constructed an interactive pointer with our large display by tracking where the pointer is and where the display is. By taking the direction of the vector of the pointing device and intersecting that with the display plane we are able to accurately point to any location on our large display.

Specifically, we used a VICON system (a near-infrared tracking system that tracks reflective beads) to track where the wand is in 3-dimension space. In addition, we used the VICON system to track the position of the display. Briefly, the VICON system takes the positions of all known objects every 1/60th of a second. We took the output of the VICON system and mapped the directional vector of the wand to the display. By using the VICON system we were also able to track the positions of the bezels and adjust accordingly. (Other pointing techniques, such as using laser pointers are described in [12].)

In order to test the utility of the interactive pointer as a formative study we invited a kindergarten class to try the technique. To make the experience interesting for the children we created a simple OpenGL program that allows one to draw wherever one is pointing. The children were given no instructions other than to draw pretty shapes and have fun. Figure 1 shows a child painting on the large display.

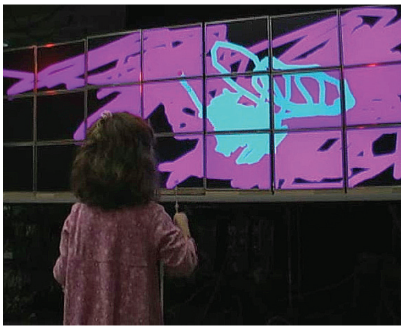

FIGURE 1: A child using a pointer to draw on a large display.

The children using the wand were able to accurately point to the display by receiving instant feedback of the position of the directional vector of the wand by seeing where they were pointing. The further back from the display the less accurate the exact position of the directional vector. As we knew the distance of the wand from the display using the VICON system, we adjusted accordingly by having a larger drawing cursor. The closer the wand was to the display the more accurate the drawing and the smaller drawing cursor.

From our experience we found that the children were able to quickly learn how to use the display. In addition, the pointer seemed very natural to the children; where one points is where one draws. With instant feedback, any inaccuracies can quickly be correctly by simply moving one's hand accordingly.

In addition, the pointer was easier to use than expected. Figure 1 shows a child using the pointer with her elbow bent and using mostly her wrist. By using a more relaxed arm movement the children did not fatigue as quickly as expected.

However, there are two main problems with the pointing method that we used. First, although the cursor is positioned wherever one points, the cursor is only as steady as one's hand. Second, in order to stop drawing or to change the color in our application one needs to have an additional device in the other hand. This problem is overcome using pointers that have buttons on them or possibly using speech or other similar techniques. However, these techniques introduce problems of their own. For example, pushing a button on the pointer usually moves the pointer however slightly and consequently moves the cursor as well.

3.2 Touch Screens

Similar to pointing devices, touch screens are natural devices that are both easy to learn and easy to use. In addition, unlike a mouse, a touch screen provides multiple points of access instead of a single point. However, unlike a pointer, one must physically move to the desired point on the large display in order for the cursor to be there. In addition, widgets on the display need to be larger than normal to compensate for finger widths.

Touch screens can easily solve the problem of finding one's cursor on a large display. Generally speaking, users do not inherently care where their cursor is; they simply wish to perform a task. Regardless of where the cursor might be, a user could use a touch screen in conjunction with a mouse to simply position the cursor wherever they desire by touching the screen, then using the mouse as usual; there is not need to know where the cursor was, only to position the cursor where one wants it.

Touch screens have recently gained in popularity for short term repetitive tasks. They are often found in restaurants and grocery stores where the server or cashier can quickly go through a sequence of button menus to make a food order or check out a customer. Using the concept of spatial memory they can streamline the process of ordering food or checking out.

In addition, touch screens in conjunction with pointing devices have great potential as their strengths and weaknesses balance each other out. Also, large curved desktop displays, such as seen in Figure 2, can take advantage of the proximity of the monitors to the user. In other words, as people are in the center of a circle they can reach out to touch any part of the display with the same effort without the need to walk to distant parts of display. For more information on large, curved displays see [17].

FIGURE 2: A user in the middle of a curved desktop display. If the monitors used are touch screens then the user can use less effort to touch any screen than if the display were flat.

Our experience with touch screens shows that without adjusting widget sizes for finger width, precision with normal sized desktop icons can be problematic. This has especially been an issue with the start menu where a large number of links are available and precision is important to start the application that a person is interested in.

By adjusting the widget size one has the increased problem of being able to use less of one's display space although this is less of an issue with large displays. Another software problem that can occur is that if one succeeds in increasing the size of all of one's widgets, one does not necessarily want the size of text to increase as well.

Finally, possibly one of the largest drawbacks to using touch screens is fatigue. Touch screens used in restaurants and grocery stores are often used for short tasks that take less than a few minutes to complete. However, if one completely replaced one's mouse with a touch screen in a desktop situation, then arm fatigue would not be a trivial issue.

3.3 Wireless 3D Gyro Mouse

A gyro mouse is a wireless mouse that one can use without the need for a table; one can walk around a room while still using the device. The gyro mouse is able to sense up and down movement as well as side to side movement while ignoring forward and backward movement. A picture of a gyro mouse can be seen in the red square in Figure 3.a. In contrast, Figure 3.b shows a user with a traditional mouse on a mobile table.

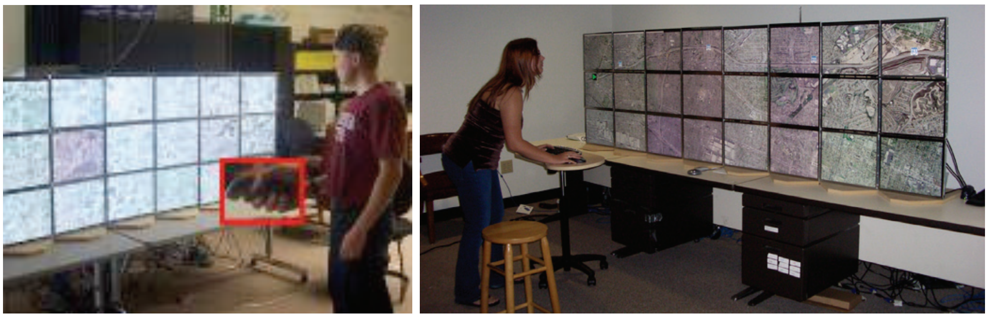

FIGURE 3: a) A participant using the gyro mouse with the display. The gyro mouse is enlarged in the red square. b) A participant using a traditional mouse on a table.

This device allows for a more natural interaction over standard mice. Instead of having to mentally map a horizontal plane to a vertical plane one need not have as complex a mental mapping as the cursor mimics physical movement. However, the gyro mouse is not as natural as a pointer in that it is still a mouse in that all movement is relative to the position of the cursor, not to where one is pointing. Also, other disadvantages that the gyro mouse has are similar to pointing devices: First, a device that one must hold requires more effort than a device stationed on a table and, second, the device is only as steady as one's hand.

In an experiment we ran 32 participants (10 female, 22 male) from the local area on a large display (see Figure 3) with ages that ranged from 24 to 39 through a series of geospatial visualization tasks: navigate to a target, find a target, find a specific pattern, and find as many patterns as possible. The experiment was a with-in subject experiment in that all participants performed all tasks. Using a VICON system we tracked participants' physical navigation (their physical movement related to the task).

A gyro mouse was given for the first three tasks specifically so that participants did not feel tethered to any particular location. However, for the last task participants were given a mobile lecture stand to write the patterns that they perceived from the visualization on the display on paper. The experiment compared varying degrees of display size from approximately one monitor to twenty-four monitors.

We found for the first task (navigating to a point) that the physical range of movement was statistically significant with an average of 371% increase in range of movement from the one monitor to the twenty-four monitors ($F(1,508)=123.28$, $p <0.01$). The second task (finding a target) found similar results of an average of 304% increase in range of movement from one monitor to twenty-four monitors ($F(1,762) =82.3$, $p<0.01$). The third task (finding a particular pattern) also found similar results of an average of 466% increase in range of movement from one monitor to the twenty-four monitors ($F(1,84)=39.4$, $p<0.01$). However, for the last task, the task with a mobile stand, statistical analysis of the physical range of movement resulted in non-significance.

Performance times were seen to improve for each task with larger display sizes except for the last task. Specifically, the first task (navigating to a point) improved 247% in performance time ($F(1,508)=118.9$, $p<0.01$); the second task (finding a target) improved 205% in performance time ($F(1,762)=38.18$, $p<0.01$); the third task (finding a particular pattern) improved 150% in performance time ($F(1,90)=3.53$, $p=0.06$).

However, statistical analysis of performance for the last task (non-directed pattern finding) resulted in non-significance with performance time.

As a post-hoc analysis, we found a linear regression of physical navigation to performance time with an R^2 of 0.858. This shows that the performance of the tasks was highly correlated to the physical navigation exhibited by the participants.

In fact, we found that people felt “tethered” to the mobile table even though it had wheels. Peoples’ performance time for the tasks was consequently affected. In summary, the larger the display and the more people could freely move around, the better people’s performance time. On the other hand, the larger display did not help performance time when people were “tethered” to the mobile table thus showing the important of interaction devices with large displays.

In addition, we found that participants always chose to physically navigate before exploring virtual navigation (navigating with the mouse) possibilities. For example, for the first task there was an option of physically navigating to a target versus virtually navigating to a target. 100% of the participants (32 out of 32) chose to physically walk to the target instead of virtually panning the target in front of them. Such preference was also seen in all other tasks in that participants would exhaust their physical navigation options before resorting to virtual navigation.

3.4 Head Tracking Interaction

Another natural approach to interaction is head tracking. Head position and orientation can be used to simplify interaction with a large display. For example, in [1], head orientation was used to control which screen the mouse cursor occupied in a multi-monitor environment. Other device mappings are conceivable.

Using a simple 3-DOF head-orientation tracker, we modified a geospatial visualization program to respond to head rotation as input. By looking left one may pan the map to the right and vice versa. Similarly, by looking down one may pan the map up and vice versa. The program also accepted two different forms of mouse input. The first type of mouse input is the traditional click-and-drag panning in which one clicks on the map and drags it in the opposite direction of the desired panning direction. The second type of mouse input is a click-and-drag continuous panning technique in which one clicks on the map and drags the mouse in the direction of the desired panning direction. Panning will continue in a given direction until the mouse is released and will be faster the further one drags.

We ran a formative evaluation comparing head tilt tracking (see Figure 4.a), hand tilt tracking (see Figure 4.b), and the two different mouse interaction techniques. The data used were maps of Washington D.C. and downtown Chicago. The tasks consisted of finding and comparing different objects in the map.

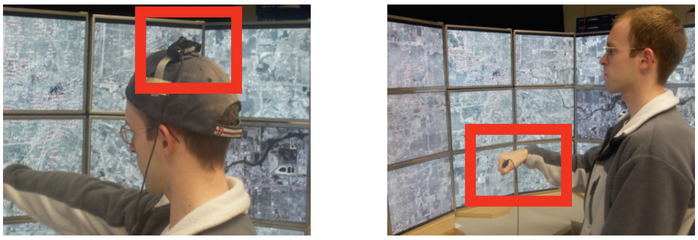

FIGURE 4: a) A participant using a head tilt tracker, highlighted by the red rectangle. b) A participant using a hand-head tilt tracker, highlighted by the red rectangle.

We found that the hand tilt tracker was the most efficient in terms of both user preference and performance time. Participants were able to naturally look at any part of the display they desired and then pan the map according to which direction they moved their hand. The mouse techniques were ranked a close second and third in terms of user preference and performance time.

The head tilt tracker was deemed the worst both in user preference and performance time. According to user feedback, the display was too small vertically. Users typically had to tilt their heads far above or below the bounds of the display to achieve a reasonable scrolling speed. Not only did users find this uncomfortable, but it drew their attention away from the display and the task at hand. Another possible explanation for the poor performance of the head tilt tracker is that scrolling and gaze direction were tightly coupled. In other words, it was difficult for a user to scroll the map to the right while also scanning the map to their right. This was not the case with the mouse techniques or the hand tilt tracker.

3.5 Wired Mouse

Although wired mice are not as natural as the gyromouse, not everyone has a gyromouse available to them or not sufficient motivation to move from a stationary location. As a result, in a related paper we showed the scalability of a dynamic size and speed cursor for large, high-resolution displays [3].

We introduced the idea of a dynamic paradigm for wired mice. In our experiment we compared different paradigms of cursor input and speed cursor to cursor warping and standard cursor settings. In the experiment we found gender bias for two different tasks (clicking and simple drag and drop), found that the cursor that was visually larger and had a much higher acceleration rate generally outperformed cursor warping and the standard cursor setting. In summary, we found that if a person has to use a wired mouse and, therefore be tethered to a single location, then it is better to adjust the cursor for size and speed to better fit the additional screen real estate available.

3.6 User Interfaces and Notification Systems

Following the idea of a stationary person, we found that user interfaces and notification systems that are designed for a single monitor are not suitable for a large display. For example, a notification system that shows data and visualizations at the top of a single monitor may be several feet away from the user with a large display. As a result we studied notifications systems and user interfaces for large displays with games [16].

As a possible solution we introduced a number of improvements to the user interface to a popular strategy game. The different types of improvements included bringing the notifications to the user’s cursor when events occurred, on demand by the user, at scheduled intervals, and always shown hovering around the cursor. An experiment testing the different types of notifications varied for different tasks. However, one relevant conclusion is that not changing the interface by keeping the notification systems in the same locations as was designed for a single monitor (i.e. the control part of the experiment) resulted in poorer performance times.

3.7 Control Panel Interaction

In order to gain the maximum number of pixels for large displays one would need to control the displays from an external source. One common way of doing this is using the control panel approach. This approach involves controlling the display from another machine. The main advantage to this is that every pixel on the large display can be used for viewing data without the need to waste space for interaction purposes. Historically this approach is the most used approach.

Unfortunately, when using this approach one usually uses a display that is smaller than the display one is trying to control introducing less than a one-to-one mapping of pixels. This approach suffers from not being natural and not easy to use although it is relatively easy to learn. It is not natural in that one must change the representation of a display on one display in order for it to affect another. Also, it is not easy to use as there is no longer a one-to-one mapping of pixels requiring a greater amount of mental mapping so that clicking widgets or dragging windows can be difficult. However, if one is developing an application for a large display that requires little interaction, this may be a viable approach.

4. CONCLUSION

Large displays have considerable potential in general from multi-tasking performance improvements [2][6], retention improvements [19]. They have also been shown to improve strategies and insights in dynamic geospatial visualization environments [16]. They especially have potential in the field of scientific exploration and knowledge discovery.

However, in order for large displays to be used by the general population they must have interaction devices and techniques that are a natural extension of one’s body, easy to learn, and easy to use. Any device or technique that takes too much effort to learn or use will either not gain acceptance or will be replaced.

In this paper we have shared our experiences of how well different devices and techniques achieve success with interacting with large displays. Specifically, our contributions are:

1. Physical navigation is preferred over virtual navigation.
2. Un-tethered devices, such as wireless gyromice, encourage users to take advantage of the size of larger displays.
3. Pointing devices by themselves are difficult to use as they can only point, but have potential coupled with other interactive methods.
4. Touch screens are a natural method for interaction but can lead to fatigue quickly.
5. Wired mice, if used, should be adjusted to the size of the display.
6. Control panels, while easy to develop, are not suitable for most interactive applications of large displays.

In conclusion, visualization is helped with large displays with performance, accuracy, and additional insight. However, the interactive techniques and devices used help or hurt these advantages. Interactive techniques and devices that do not confine people to one location, that allow people to move naturally and take advantage of their body, not just their mind, allow for people to perform at their fullest capability.

5. FUTURE WORK

1. Compare different techniques and devices to each other and explore multi-modal inputs.
2. Explore how people's behavior might be different when interacting with displays when they are standing/walking versus being stationary.

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