Evaluation of Viewport Size and Curvature of Large, High-Resolution Displays

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Abstract

Tiling multiple monitors to increase the amount of screen space has become an area of great interest to researchers. While previous research has shown user performance benefits when using two monitors next to each other, little research has analyzed whether very large high-resolution displays result in better user performance. We compared user performance time, accuracy, and mental workload on geospatial search, route tracing, and comparison tasks across one, twelve (4×3), and twenty-four (8×3) tiled monitor configurations. Additionally, we included display configurations that involved uniformly curving the twelve and twenty-four monitor displays. Generally, the larger the viewport size the faster users perform. We show that user frustration is significantly less in the twenty-four monitor condition than the one monitor condition. We also show that curving displays increases user performance.

Key words: High-resolution, large tiled display, reconfigurable display, viewport size, curvature, geospatial

1 Introduction

Tiling multiple monitors to increase the amount of screen space has become an area of great interest to researchers. Previous research shows that user performance benefits when using two monitors next to each other. Yet there is great potential for using larger high-resolution displays as power desktops for scaling up visualizations in single-user environments (as opposed to collaborative powerwalls). Furthermore, there is a need for design guidance for display size and form of such displays.

In this paper, we explain an experiment using a large, high-resolution (96 DPI), high-pixel-count (approximately 32 million pixel) display. The experiment used a range of geospatial tasks that may be used in aerial imagery comparison and analysis. Geospatial data is ideal because it is naturally a high-resolution, multi-scale, and dense data set. This type of data is also useful to various people, including those in the intelligence community.

Our motivation behind the experiment in this paper is twofold:

- Quantify the user performance benefits of increasingly larger displays (viewport sizes) for geospatial tasks.
- Determine if and how the curvature of a large display affects performance for geospatial tasks.

The first part of the experiment, which we refer to as the *viewport size* (portal size) comparison, was designed to understand how user performance and accuracy change as the size of the display increases (greater pixel-count). To test the viewport size variable we had participants perform a range of geospatial tasks on one, twelve, and twenty-four monitor displays. This part of the experiment involved all flat displays. The second part of the experiment, which we refer to as the *curvature* comparison, was designed to explore the benefits of having a curved display.

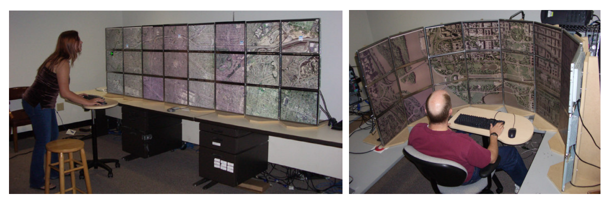

Figure 1: Twenty-four monitor configurations

Furthermore, we wanted to know how people's physical behavior changed as the viewport size increased.

2 Motivation

We hypothesized that user performance would improve with greater viewport sizes because users would have more data available at once. Furthermore, we believed that curving the display would decrease the amount of physical navigation required to approach far away pixels. Our main motivation for curving the displays was not to find an optimal curvature but to see if there exist any benefits of curving such a display compared to keeping it flat. Therefore, we chose the same curve for all curved conditions (Figure 7). The following is an analysis of the interaction between visual acuity and display curvature.

We used Dell 1740FPV Color Monitors that each have a maximum resolution of 1280×1024 and dot pitch of

0.264mm×0.264mm. The dot pitch is the size of an individual pixel. "A standard definition of normal visual acuity is the ability to resolve a spatial pattern separated by a visual angle of one minute of arc" [18]. Therefore, we can use the dot pitch of 0.264mm x 0.264mm and the normal visual acuity of one minute of arc (Figure 2) to calculate the maximum distance for which we can resolve a pixel on the display.

Figure 2: Normal (20/20) Visual Acuity For Resolving Two Points is 1/60th degree (1 minute of arc)

We do this by considering half of the pixel so that we can form a right triangle (Figure 3).

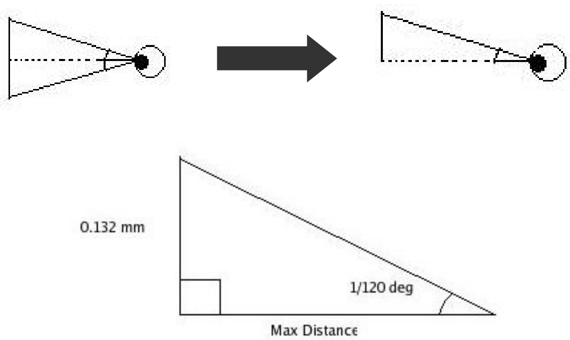

Figure 3: Right Triangle for Calculating the Maximum Resolvable Distance from a Pixel

Now to calculate the maximum distance (d_{max}) in Figure 3 we can use the formula:

$$\tan(angle) = \frac{opposite}{adjacent}.$$

We get

$$\tan\left(\frac{1}{120}^{0}\right) = \frac{.132_{mm}}{d_{\max}} ,$$

Which simplifies to:

$$d_{\max} = \frac{.132_{mm}}{\tan\left(\frac{1}{120}^{0}\right)} = 907.565_{mm}.$$

Using these calculations, we now know that with the given pixel size on the Dell Monitors that were used, the maximum distance at which a pixel can be resolved from an adjacent pixel is 907.565mm (90.7cm or 35.7inches).

Now consider what happens for flat vs. curved displays. The maximum number of pixels wide that can be resolved for a flat display occurs if the user is standing in the middle of the display and close to it (setting aside the problem of the viewing angle for simplicity). That means that the maximum distance from the middle of the display to each side equals the maximum distance between the user's eye and a pixel. This means the maximum display size is 907.565mm×2 = 1815.13mm. This translates to 1815.13mm/0.264mm = 6875.49 pixels wide.

Now suppose we curve the display. The maximum distance from a pixel remains the same. But now, the maximum number of pixels wide that can be resolved for a curved display occurs if the radius of the circle is the maximum distance from a pixel. Using the fact that Circumference = π×Diameter we can now calculate the maximum curved display width to resolve all pixels. Circumference = π×1815.13mm = 5702.4mm. Half of that is 2851.2mm of display if curved, which is 2851.2mm/0.264mm = 10,800 pixels wide.

Considering the calculations above, if we know the maximum distance between a user a pixel, then:

$$flat\_width_{\max} = 2d_{\max}$$

and

$$curved\_width_{\max} = \frac{\Pi(2d_{\max})}{2}.$$

It is easy to see from these formulas that

$$curved\_width_{\max} = \frac{\Pi}{2}\cdot\left(flat\_width_{\max}\right).$$

Therefore, the maximum display width for which a person can visually resolve all pixels with only head and eye movement is 6875.49 pixels for a flat display and (π/2)×6875.49 pixels wide = 10,800 pixels for a curved display. This is a π/2 increase in the maximum display width.

3 Related Work

The majority of research related to large high-resolution displays has been about the physical construction of the display [8],[13],[19],[22],[23], or the software and algorithms available for distributing the graphics [15],[25]. Less research has been done on the usefulness and usability of these displays.

Additionally, most research has been done on using these displays for collaboration [10],[17],[27] rather than for single-user applications. Our focus is on quantifying the user performance benefits of a larger higher-resolution display for a single user.

3.1 Single-user Benefits on Large High-Resolution Displays

One common single-user scenario is using multiple monitors to expand the desktop. There are two paradigms for multiple monitor users, either the idea of partitioned spaces used as different rooms, or used as one large space [11]. People tend to use monitors to the left or right as separate rooms and monitors that are tiled vertically as single spaces [2]. There are many open issues with interaction [1],[12], notification [16], and window management [15] across multiple monitor desktops.

Because our application is for geospatial analysis, we are more interested in the *one large space* paradigm. Research in this area has shown that large high resolution displays can result in better performance than panning and zooming on smaller displays [3], that larger displays improve performance even when the visual angle is maintained [28], and that using larger displays narrows the gender gap on spatial performance [7]. However, the highest total pixel-count display used in these experiments was a 3×3 tiled monitor display with 3840×3072 total pixels. With this experiment, we go beyond those totals to much larger displays.

A concern when using a tiled display is the impact of the bezels. Mackinlay and Heer [21] suggested techniques of working around these issues. Other research suggests that discontinuities are only a problem when combined with an offset in depth [29]. However, in this work we do not address this particular issue, so no information is hidden behind the bezels.

3.2 Reconfigurable Displays

One question that arises is if there is a point of diminishing returns. For example, is there a point where a wider field of view no longer increases user performance? Additionally, at what point are there so many pixels in a large high resolution display that performance no longer increases? One method of decreasing the access cost is to curve the display so when a user turns their head the display is still at an equal distance from them.

Curving displays can be challenging, after all you can't currently bend a monitor. Dsharp is a display that uses multiple projectors in creating a curved display by carefully aligning the images [6][26]. NASA's hyperwall allows monitors in a 7×7 tiled array to be tilted and rotated [23]. Also available are rear-projected blocks that can be stacked [24]. However, to the authors' knowledge, there is no empirical comparison of user performance between flat and curved displays.

In summary, this experiment builds on and extends previous research by considering single user performance on geospatial tasks using a larger higher-resolution display than used in other experiments. It also considers the user performance benefits of reconfiguring the display by uniformly curving it when other research considered only a curved display or only flat displays. Without demonstrated user performance benefits the cost of single user large-high resolution display would be hard to justify.

4 Method

4.1 Hardware and Software Used

The display was made up of twenty-four seventeen inch LCD monitors and twelve GNU/Linux computers. Each monitor was set to the highest resolution of 1280×1024. Each computer powered two monitors. We removed the plastic casing around each monitor to reduce the bezel size (gap) between monitors. We then mounted three monitors vertically on each reconfigurable wooden stand. Since users may experience slight neck strain when looking up for long periods of time, we designed our power desktop to have no more than three monitors high [2]. Therefore, the majority of the monitors were added to the width of the display, making it wider than it is tall. This configuration produced an 8×3 matrix.

We networked the twelve GNU/Linux computers together in a private network using a gigabit switch. We then installed DMX (Distributed Multihead X) to create a unified display [9]. DMX is a proxy X server that provides multi-head support for multiple displays attached to different machines. For all appearances to the user, when running DMX the display appears to be one single GNU/Linux desktop that runs a standard windows manager(e.g. KDE, GNOME, Fluxbox, etc.).

For the curvature variable, we curved the display on the horizontal plane such that the monitors would uniformly face the user. To do this the columns were faced inward such that the angle between each column was the same. Thus, the display was part of a circle with a radius equal to 2.5 feet.

All users were given a standard keyboard and mouse. Users could navigate using the keyboard. The keyboard stand had wheels for easy mobility and was used across all conditions. Users were familiar with this navigation by the end of the tutorial. The mouse was used for marking checks on the view, which is explained below.

For the experiment we used a modified version of the NCSA TerraServer Blaster, an open-source application that Paul Rajlich from NCSA (National Center for Supercomputing Applications) wrote for visualizing imagery from the national TerraServer database using Chromium [5]. Chromium is an open-source application that uses real-time parallel rendering of openGL.

4.2 Tasks

For the experiment we chose three different task types: search, route tracing, and image comparison. We chose search and route tracing tasks based on previous research in geospatial data on larger displays [4]. We chose an image comparison task based on expert geographers and cartographers. Participants performed two of each task type (an easy and a hard task) for a total of six tasks. All tasks involved navigating extremely large aerial images at different scales.

Search tasks involved locating a specific unaltered object in the aerial view. The hard search task involved searching all of Chicago for a real bull's eye on the roof of a building (Figure 4). Participants were told to physically point to the located object when they found it so that the proctor could visually verify the answer (dependant variables are time and accuracy).

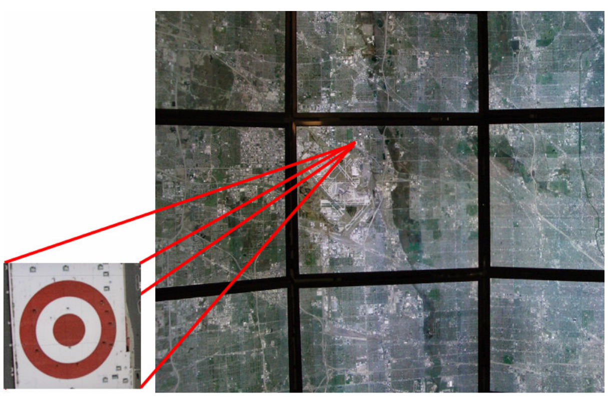

Figure 4: Search task for a bull's eye on the curved twenty-four monitor condition

For the route tracing tasks, users followed a given route, marking either overpasses or underpasses along the route. A green arrow and red octagon icon indicated the start and stop points on the route (Figure 5). Users could mark the imagery with checks with the mouse each underpass/overpass using the mouse. Users were instructed to tell the proctor when they had completed the task (dependant variables are time and accuracy).

Figure 5: Route tracing task on the curved 24 monitor condition

In the image comparison task users could toggle between two aerial views (Figure 6). One view was an older black and white view of the area using DOQ (Digital Orthographic Quads) imagery; the other view was a more recent view in color. The images were captured several years apart. Superimposed on the views was a 30×15 grid. The task was to identify blocks in the grid where there were urban changes. For example, an urban change might be where there are new buildings, destruction of old buildings, new roads, etc. This did not include natural phenomena such as trees, water or other earthworks. Users could click on a block to *check* that there is a change. Users had fives minutes to check as many blocks on the grid that had urban changes (dependant variable is accuracy).

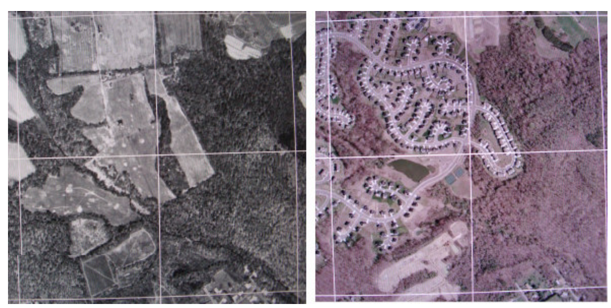

Figure 6: Image comparison task

4.3 Experimental Design

The independent variables were viewport size, curvature, task type, and task difficulty. We chose three viewport sizes: one monitor, twelve monitor, and twenty-four monitor configurations. For the one monitor condition the TerraServer application was simply resized to fit one of the middle monitors. For the twelve monitor condition the application was expanded to half of the display such that it filled a 4×3 matrix of monitors.

For the curvature variable, we chose two curvatures: flat and a curve with radius equal to 2.5 feet (Figure 7).

In general, one can create different curvatures by adjusting the radius.

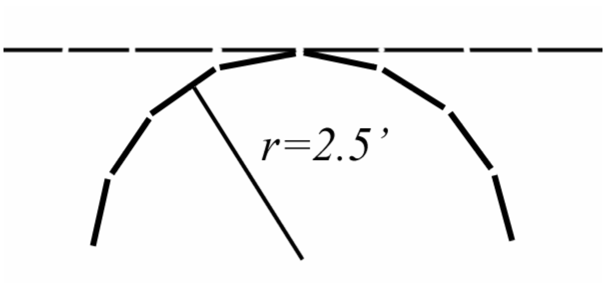

Figure 7: Flat form versus the curved form with a radius of 2.5 feet (76.2 cm)

We chose to test five of the six conditions (Table 1). The one monitor curved condition is not applicable since you can not curve a single monitor.

	Flat	*Curved*
1 monitor	✓	
12 monitors	✓	✓
24 monitors	✓	✓

Table 1: The five conditions tested

Viewport size and curve were between-subject variables because of the time it takes to reconfigure the display.
The order of the task types was counterbalanced using two 4×4 Latin Square designs, where one dimension represented the task type and the other dimension represented four participants. Within each task type (e.g. the two search tasks), half of the participants would get the easy task first and the other half would get the harder task first.

For each condition we used eight participants for a total of 40 participants. All participants were undergraduate or graduate students. The majority of the participants were computer science majors with a few exceptions. The average age of the participants was 25 with a range between 21 and 31 years old. 27 of the participants were male and 13 were female. All had normal to corrected-normal vision. All participants reported as having daily use with computers.

4.4 Procedure

Each user took about one hour to complete the experiment. The tasks took no longer than 5 minutes and there was a timeout of 5 minutes on all tasks.

Before beginning the experiment, participants were asked to fill out a demographic questionnaire as well as inform the proctor of any physical conditions such as color-blindness or claustrophobia. Participants had a training session on how to use the program before beginning the experiment in a tutorial. The tutorial covered the buttons used for keyboard navigation. Users were told that they were allowed to physically move with the keyboard stand.

Users were given written instructions for each task on a piece of paper. After answering any clarification questions the user may have had, the area for the task was displayed for the user to begin the task.

After every task type (i.e. after both search tasks), participants were asked to complete the NASA Task Load Index (NASA-TLX) rating both tasks.

5 Results

5.1 Task Completion Times

Task completion time was measured for both the route tracing and search tasks. For the compare tasks participants were always given 5 minutes, therefore completion times for the compare tasks were not analyzed. Additionally, times for participants that timed out after 5 minutes were recorded as 5 minute task completion times. While they may not have completed the tasks, this is the minimum amount of time it would have taken participants to complete the tasks. The one monitor condition had the most times outs. Seven of sixteen users timed out for search tasks, whereas only two or less users timed out in all other display configurations.

Analysis of variance showed a main effect for display configuration, task type, and task difficulty. Search tasks were significantly faster than route tracing tasks and easy tasks were significantly faster than hard tasks. Post-hoc analysis of the display configurations showed a statistically significant difference ($p<.05$) between several of the display configurations.

Figure 8 shows the results of the post-hoc analysis. Overlapping confidence intervals are not statistically significant at the alpha level of 0.05 while non-overlapping are statistically significant. All large display conditions, except for the twelve flat condition, are statistically faster than the one monitor condition. Furthermore, the twenty-four curved condition is faster than the twelve flat condition.

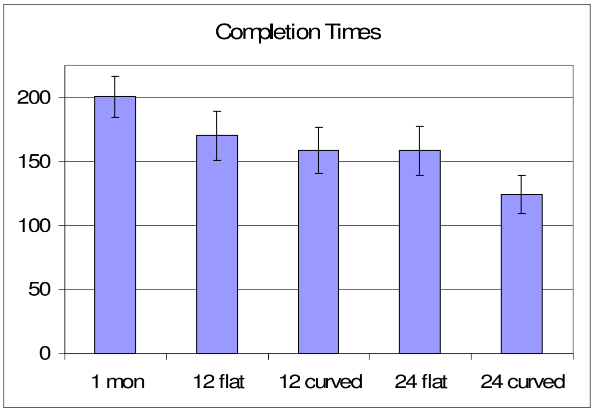

Figure 8: Performance times (s) of all display configurations.

Figure 8 shows the trend that as one curves increasingly larger viewport sizes, one reduces performance time for the same tasks. However, an interesting observation is that by curving the twelve monitor condition (158.5s) the performance times roughly equated that of the twenty-four flat condition (158.3s). However, by curving the twenty-four monitors the performance time again decreased for the twenty-four curved condition (124s).

Analysis of variance showed a trend of flat versus curved conditions with $p = 0.089$. The one monitor condition was not included in the analysis as it did not have a curved counterpart. Figure 9 shows the average time for the flat conditions (157s) and the curved (143s) conditions.

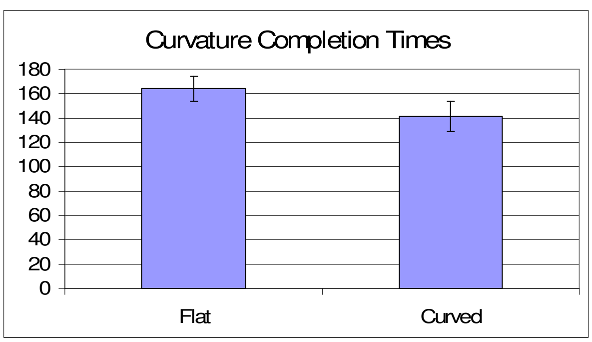

Figure 9: Performance times (s) of aggregated flat versus curved configurations.

5.2 Task Accuracy

Search task accuracy was recorded as either 100% (1.0) or 0% (0.0) since participants either did or did not find the target within 5 minutes. For the route tracing tasks accuracy was recorded as the number of underpasses or overpasses that the participant selected compared to the actual number of under or overpasses. For example, if a person found 14 of 28 underpasses, their accuracy was 0.5 or 50%. Compare tasks were recorded as the total number of differences found by each participant.

Analysis of variance showed main effects for display configuration ($p=0.04$) and task difficulty ($p<.01$). Easy tasks were significantly more accurate than hard tasks. Post-hoc analysis showed statically significant differences ($p<.05$) for display configuration such that overall all the conditions except the twelve monitor flat condition were statistically more accurate than the than the one monitor condition.

5.3 Mental Workload

Mental workload was measured using the NASA Task Load Index. Seven scales (mental demand, frustration, etc.) were each measured on a scale from 0-100 where 100 was good and 0 was a poor rating for that factor.

Using analysis of variance and followed by post-hoc analysis, the only statistically significant difference was on the level of frustration reported by users. Participants using one monitor reported significantly higher frustration levels than participants than on all but the twelve flat condition ($p<.05$).

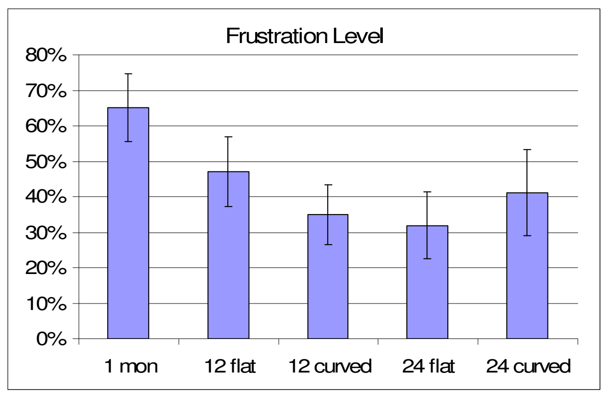

Figure 10: Frustration averages from NASA Task Load Index used.

5.4 Observations

In general, we observed differences in how users interacted in the different viewport conditions. First considering the viewport size, there was a striking difference between one monitor and the twenty-four monitor condition. In the one monitor condition users tended to use more virtual navigation than those in the flat twelve and twenty-four monitor conditions. Specifically, users zoomed in and out significantly more on the one monitor condition to regain their overview of the task area. In the larger viewport sizes users tended to use more physical navigation. This included standing up, walking, leaning towards the sides of the display, and head turning. Often the user's technique for accomplishing the task was the same (e.g. serial searching), but the technique was applied with virtual navigation in the one monitor configuration and with physical navigation in the larger configurations.

In the twelve and twenty-four monitor conditions, many users would adjust their technique for their second task of the same task type. For example, in the first image comparison task users would often search serially, but for the second task they would get an overview of the area looking for obvious changes before zooming in to compare details.

Users interacted physically with the display in different ways on the flat and curved twenty-four monitor conditions. In the flat condition users would either stand or walk; five out of eight users stood up at least once. In the curved condition users would turn their heads or turn their body position. It appeared that there was more physical navigation on the curved condition; however, the physical movements were less strenuous than standing and walking.

Furthermore, users changed their area of focus less frequently on the twenty-four flat configuration than those on the twenty-four curved configuration. Often users on the flat display would focus on nine or twelve monitors at a time. Sometimes their focus area would shift from the left side of the display to the right side of the display over the course of the task. However, most users preferred to sit and use the center of the display as their focus area. On the curved condition users would switch their area of focus more often by a quick turn of the head.

6 Conclusion

In this paper we compare viewport size and curvature of large high-resolution displays for realistic image analysis tasks. Generally, the larger the viewport size the faster users perform. We also show that user frustration is significantly less on the largest display (twenty-four monitors) than the one monitor condition.

We also show that curving displays increases performance. Of all the conditions, user performance was the best on the curved twenty-four condition. It is also important to note that there was no statistical significance between the twelve and twenty-four flat conditions most likely because the users could not utilize the outermost pixels on the twenty-four flat display (as shown in section 2). In the twenty-four flat condition users were at least 4 feet away from the furthest pixels. However, in the twenty-four curved condition the user was never more than 2.5 feet from any given pixel. Therefore, it was not until the twenty-four curved condition that users could perform faster than the twelve monitor flat condition.

Acknowledgements

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