A Surround Display Warp-Mesh Utility to Enhance Player Engagement

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Abstract. Surround displays are used in simulation, training, and other applications based on virtual worlds. A wide-view display engages the viewer's peripheral vision, providing a more accurate view of the virtual world and therefore a heightened sense of immersion. However, most commercially available surround displays are expensive and complex. We developed a low-cost alternative, which uses a standard digital projector, a hemispherical mirror, and any roughly spherical or cylindrical screen. The software can handle irregular surfaces and will be open-sourced in the next release of the CaveUT/VRGL freeware. We also conducted a pilot study comparing game play in our prototype and game play with a standard desktop monitor. Players using the surround display reported significantly shorter (P = 0.0051) perceived duration of time during play. Reduced awareness of the passage of time during game play was positively correlated with greater engagement and enjoyment.

Keywords: Virtual Environments, Virtual Reality, Immersion, Spherical Mirror Projection, Dome Projection, CaveUT, VRGL, Surround Gaming, Virtual Reality, Warp-Mesh, Texture-Mesh

1 Introduction

Three-dimensional virtual environments for educational and entertainment purposes are most commonly viewed via a small, flat display. Yet a traditional flat display cannot express the dimensions of a virtual scene relative to the user. Most importantly, it cannot offer the spatial cues provided by engaging a user's peripheral vision and head movement. Engaging peripheral vision is a significant component of participating in a virtual world, as is experiencing the environment in its correct scale [1]. Allowing a user to interact in the same space as a virtual object is a powerful method of providing immersion, or the sense of 'being there' [2].

Believable virtual spaces provide new forms of collaboration and expression. A viewer can become mentally absorbed in an artificial environment by cues such as peripheral engagement, binocular disparity, convergence (the degree to which the eyes rotate toward the centre of interest), perspective projection [1], and the act of controlling the animation presented in the material.

Fully featured virtual reality systems, such as the CAVE [1], provide nearly all of these cues, while others provide only some. For example, in 'Fish Tank VR' a single computer monitor produces a stereographic image while a head-tracking system adjusts the perspective effects based on user motion. Other systems achieve a degree of sensory immersion by simply filling most or all of the user's view with a "window" to the virtual environment. We call these "surround displays," with the new all-digital planetarium displays being the best example.

Figure 1: Drawing of our prototype surround display, 110^{o} horizontal FOV

We[1] constructed our own low-cost surround display (Figure 1) and used it to study the effect of visual immersion on user engagement. In this paper we describe how the user-defined warp-mesh utility works and how to use it. We present this design as a low-cost alternative to more expensive immersive displays.

Research Problem

Both CAVEs and Head Mounted Displays (HMDs) are typically expensive and fragile and present difficulties for application designers, which reduces their widespread use. That is why three-dimensional virtual environments for educational and entertainment purposes are most commonly viewed via a small, flat display even though a traditional flat display cannot express the dimensions of a virtual scene relative to the user.

Although recent research suggests that large high-resolution displays improve the user experience [3] and ongoing research is testing planetaria with game-based content [4][5], projection via virtual objects [6], and automatic projector calibration [7], we know of no research into user-modified warping mesh for home entertainment. Warping calibration typically involves an expert who sets up and calibrates an application for a specific environment. For home entertainment, on the other hand, software needs to be flexible, easy to use, affordable, and free of any requirement for programming knowledge.

Modifying an existing game eliminates the need for specialized software to create a multiple-projector virtual reality system [8]. Even so, the overhead of acquiring and positioning a minimum of two digital video projectors and dedicated client computers constrains the average classroom or gamer from utilizing such a system. The shortcomings of both head-mounted displays and CAVEs indicate the need for an inexpensive surround-projection method. Recent developments in projection methods specific to planetarium installations may provide a way to bring the advantages of a surround display [9] to a wider audience. In our surround display, the virtual environment is projected onto a spherical mirror to create a much larger projection than previously possible, and source image correction is provided to deal with distortions created by the mirror and projection surface.

However, there is still a limiting factor to bringing immersive projected displays to a wider audience: the projection surface. As a low-cost alternative, we use a single projector and spherical mirror along with correctional software to project on all manner of surfaces, from professional domes to temporary cylindrical or polyhedral spaces and even the corner of an ordinary room.

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[1] Charles Henden did most of the work, producing the warp-mesh code and conducting the user engagement study as his Master’s Thesis work, supervised by Erik Champion and Ralf Muhlberger. Jeffrey Jacobson’s VRGL and CaveUT software provided the software platform.

Bourke's Spherical Projection

Recently, all-digital projection systems have become popular for planetaria and similar venues which feature a visually-immersive dome-shaped projection screen. Many of them use a single projector with a fisheye lens to spread the image across the entire screen, often providing a view as wide as 180°. Unfortunately, these lenses are very expensive. As a low-cost alternative, Bourke [5][10][11][12][13] found a way to use a convex mirror as a low-cost substitute for the fisheye lens to distribute the image.

In that system, source material must be pre-distorted or modified according to an analytical mapping which represents the dome and mirror. One example projection method is to produce a pre-distorted image which is the inverse of the distortions the mirror and the screen would introduce. The end result is an image which looks correct on the dome. Traditionally, all corrective image manipulation has occurred prior to the projection of the source material. However, interactive environments require that all changes to the rendering output occur in real time.

For either case, static or dynamic, Bourke describes two basic methods to specify the transformations needed. People have been interested in using curved mirrors for projection for thousands of years [14], so our understanding of the required image transformations rests on a considerable body of knowledge.

The first step is to build a mathematical model of the projection environment by (theoretically) tracing a single ray for each pixel from the projector lens to the spherical mirror and then onto the projection dome. Software can use the general formula for calculating each ray to project faithfully on the dome. This is important for software which produces images in real-time, such as a game engine. Simulating the geometry of a new projection surface is the most precise way of correcting for projection distortions. However, the overhead and expertise required for each projection surface is considerable, and the need to keep the surface as a simple shape (a partial sphere or cylinder, usually) is acute.

Bourke suggests an alternative, which is to allow the user to interactively specify the needed transformations. This splits the task of creating an immersive virtual environment through interactive mesh creation into two separate components. The first is to create the "best-fit" corrective mesh via a standalone application, referred to here as the Warp-Mesh. The second part is to modify the rendering output of a pre-existing virtual environment application according to the warping mesh created by the warp-mesh utility.

This approach can handle many irregular projection surfaces and is the most flexible way of dealing with ad-hoc projection environments. We have adopted this approach for our prototype display. For us, the final image produced was of somewhat lesser quality than with an analytic model, but further research and development may correct that disadvantage. In any case, it is a flexible and low-cost method which can bring surround displays to a wider audience of users and developers.

CaveUT and VRGL

CaveUT is an open-source freeware project that uses the game Unreal Tournament 2004 to produce immersive projection-based virtual reality. This software operates using the specification of a regular CAVE, allowing each projector to recreate part of a contiguous view of the environment [11][15]. Virtual Reality Graphics Library (VRGL) is a companion project to facilitate off-axis projection in any application. It utilizes the OpenGL® rendering library by re-interpreting the commands created by an application to render a virtual scene. VRGL can reproduce the resulting image as a part of a multi-screen immersive display.

VRGL also supports features useful in the setup of immersive displays: spherical distortion correction, edge blending and color correction. To implement our prototype display, we added to VRGL the capability of loading warp-mesh format files, generated by our interactive modeler. Due to the integration between Unreal Tournament and the CaveUT system, VRGL had been used extensively in conjunction with Unreal Tournament to produce a variety of immersive displays. For this reason, it was chosen for this pilot study.

3 Design

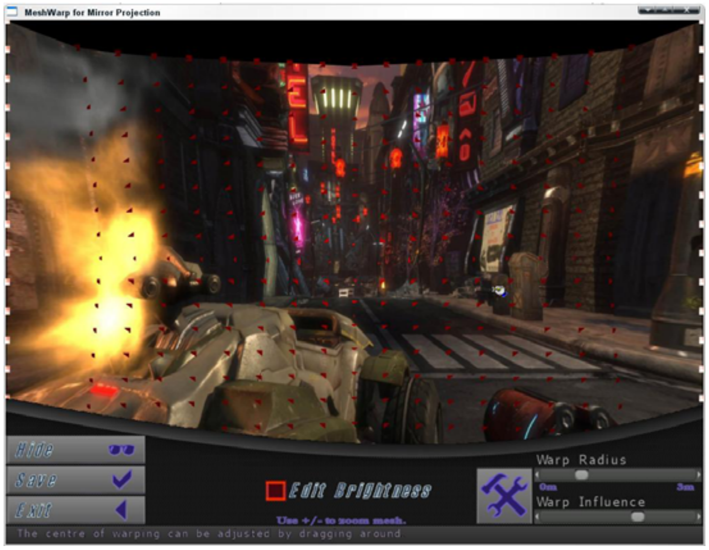
We developed an application to generate and edit a best-fit model for any projection environment suggested by Bourke. To evaluate this approach, we built a low-cost prototype display, which included a projection screen, a projector, a hemispherical mirror, and software. The software was an extension to Jacobson’s VRGL graphics library as used in the CaveUT project [16] to support spherical mirror projection.

The specification for the mesh-warping file is very similar to the original format specified by Bourke [10]. The warping is performed in the x, y, z coordinates, in the u, v coordinates, or both. The spatial coordinates of x, y and z allow correction to be made for the surface on which the virtual environment will be projected. The texture coordinates of u and v define the warping for the convex mirror that is to be utilized. The file format specifies a number of parameters:

- The first line contains the mesh type of 1 for polar and 2 for rectangular as described in Bourke’s research.
- The second line contains the mesh dimensions, which usually correspond to a multiple of the aspect ratio of the source material.
- Subsequent lines define the nodes of the mesh, containing the following 8 values, each expressed as a floating point number delimited with a space character:
- Spatial coordinates for x, y and z in normalized OpenGL space. Upon mesh generation, all z values will be identical.

- Texture coordinates u and v, ranging from +/-1.0f.
- A value for r, g and b color value to be applied to the mesh. These values are used as a multiplicative intensity for per-color, gamma-corrected edge blending. An additional use for these values is correction for brightness and material differences in compound projection surfaces. Values outside the 0.0f to 1.0f range will be clamped to their minimum or maximum.

A utility to create these warping meshes must be easy to use and must incorporate the majority of common functions required for a variety of projection surfaces. For example, to facilitate projection into the corner of a room, the mesh must be able to be deformed about the centre, stretching the scene locally to avoid information loss at the crease of the wedge. The size, shape and scale of the mesh must be completely editable in order to provide the flexibility to adapt to any projection surface.



Use +/- to zoom mesh.

The centre of warping can be adjusted by dragging around

Figure 2: The GUI allows any user to change the warping mesh graphically.

We built a modification to VRGL to allow warping, and a GUI (Figure 2) to allow a typical user to change the nodes of the warping mesh by eye. The software tool to read, write, and generate warp-mesh files was written in C++ and uses the OpenGL graphics library to display the mesh while editing and to preview the results of the completed warping. The user (editor) does not need to be a programmer or be highly computer-literate in order to use the software. We then created a curved surface on which to project (Figure 3).

The experiment was conducted using a typical low-end gaming PC with a GeForce^{TM} 6200 video card used for rendering the virtual environment via OpenGL

1.5. The computer was connected simultaneously to a projector for the surround display and to a traditional computer monitor. The traditional display consisted of a 17-inch LCD monitor with a resolution of 1024 x 768 pixels. The projector was a LCD model commonly used for data display, matching the resolution of the LCD monitor.

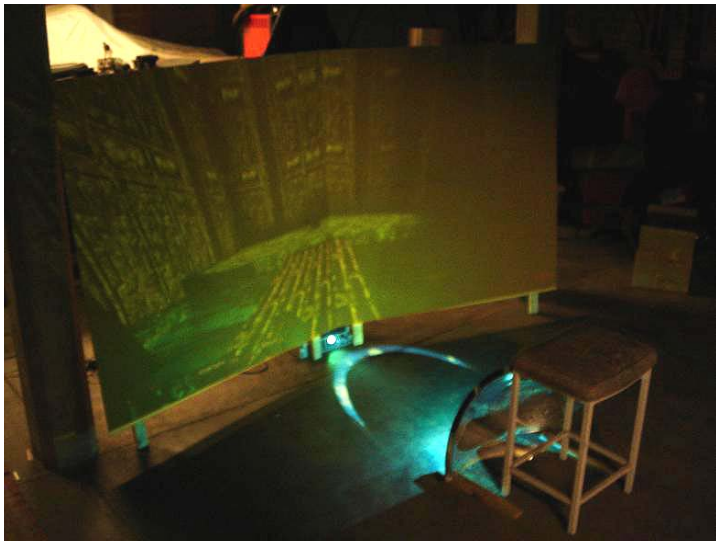


Figure 3: Experimental display system with curved mirror

The surround display's projection surface consisted of a set of two curved display stands covered in white blackout cloth. The surface was 2.4 meters wide, situated 1.2 meters from the participant, yielding an effective field of view of 110 degrees (Figure 3). The curved display stands were constructed especially for the study from low-cost, readily available medium-density fiberboard and tubular steel framing. The surround screen and LCD monitor were located next to each other to facilitate a quick change between the two displays.

4 Experimental Study and Evaluation

Hypothesis

For this study, we proposed that the immersive effect of the surround display would be greater than that of a flat display because a surround display engages the participant's peripheral vision and covers a much larger field of view than a traditional display. We then hypothesized that the display that produced the largest differential between actual time taken to complete the task and the subject's perception of the time taken would be categorized as producing the most immersion.

Also, and conversely, we hypothesized that the display for which subjects would report more time taken to complete the task (compared to the actual amount of time taken) would indicate boredom and a lack of relaxation.

Of primary interest were the quantitative results pertaining to the amount of time participants spent completing each display in contrast to how long they perceived they spent. For many gamers, losing track of time is a positive experience and is one of the main reasons for playing video games [17]. **Table 1** shows the differential between actual time and perceived time for both the surround and traditional display for each participant. A negative time shows that the time the participant believed was spent completing the task was longer than the time actually spent. Conversely, a positive time indicates the participant losing track of time and spending longer in the virtual environment than he or she believed.

Protocol

We recruited twelve participants from the undergraduate computer science laboratories by offering each one a randomly drawn prize for their participation. We asked them about their familiarity and usage of virtual environments, specifically computer and video games. Of particular importance was the number of hours each subject spent playing 3D games per week and what display the subject usually employed.

We randomly assigned each subject to use either a standard desktop monitor or our prototype surround display. Then we showed the subject how to navigate in a virtual environment using the physical controls, answered any questions, and asked the subject to find twenty-five virtual goal objects. This forced the subject to navigate through a majority of the environment, creating a similar experience for everyone. The experimenter used a stopwatch to record the time taken.

After completing the first task, the subject switched to the other display type and began another hunt for twenty-five goal objects in a different virtual environment. It was important for the second task to begin without a break so that the subject would not forget the impression of switching displays. The experimenter also timed this exploration task. Switching the overhead fluorescent lights off during use of the surround display controlled the amount of light in the room.

The two virtual environments had different maps to eliminate a training effect between one task and the other. Randomly assigning the order in which each test subject completed the tasks eliminated ordering effects. Finally, there was probably little if any training effect in the use of the controls because they were fairly straightforward and familiar to our test population.

After finishing the second task, the subjects completed a questionnaire detailing their experience. Most importantly, the questionnaire asked them how long they thought they spent performing each task. It also asked subjects to record which display made them feel like they were “in the game” along with the strengths and weaknesses of each display.

The study attracted participants with a moderate to high level of experience with computer-generated 3D environment and a high frequency of game playing, due to the description of the study published on notices and the nature of the prize – a video game store gift voucher. Although the participants were not pre-selected, the method of recruitment resulted in an all-male sample group. This was mainly due to gender distribution in the undergraduate computer science courses and, to a lesser extent, to the tendency of males to play video games much more often than females [17]. There were no explicit prerequisites to participation in the study and all participants were advised on the possibility of motion sickness induced by the movement of the virtual environment.

Questionnaire

In order to correct the results from each participant, the pilot study questionnaire was designed in the following format. Names and gender of participants and their answers to the following questions were recorded.

1. On average, how many hours a week would you spend playing computer or video games that involved a three dimensional environment? 1-2, 2-4, 4-8, 8 or more
2. What games are you playing regularly at the moment (please list)?
3. What kind of display do you use when playing games? CRT Monitor, LCD Monitor, Projector, Other (please specify).
4. What is the approximate size of the display you use when playing games? 15" or smaller, 17", 19", 20" and larger?
5. What input devices do you usually use to control computer and video games? Joystick, Game pad, Keyboard Only, Mouse Only, Keyboard and Mouse, Other (please specify).
6. In what posture are you most comfortable playing video games? Standing, Sitting, Lying down, Other (please specify).
7. Which display method did you prefer to view the game with? LCD Display, Surround Display?
8. What were the strengths (if any) of using the LCD display?
9. What were the weaknesses (if any) of using the LCD display?
10. What were the strengths (if any) of the surround display?
11. What were the weaknesses (if any) of using the surround display?
12. Did either display give you the sensation of being immersed inside the game world? LCD Display, Surround Display, Neither?
13. How long did you think you played for (in minutes)?

Results

For each subject and for each task, we compared the actual time it took with how long the subject thought it took. If perceived time was less than actual time, we called that a *time loss*, and the opposite a *time gain.* While using the surround display, most participants experienced some degree of time loss. The average subjective time loss was twenty-one seconds, which is eleven percent of the average time taken. In contrast, while using the standard computer monitor, subjects experienced a subjective time gain of one minute and two seconds, which is forty-seven percent of the average time taken.

We did not expect that such a reliable degree of time gain would be recorded for the traditional display. This effect may be due to the familiarity of participants with that display method, with eighty-three percent of participants using a monitor for over two hours per week. Subjects who spent eight or more hours per week playing games which involved a 3D environment recorded the greatest time gain figure for the task using the traditional display. Their time loss for the surround display was not significant.

Table 1. Time loss differential experienced by participants for each display type

Number	LCD (flat monitor) Actual - Subjective Time	Surround Display Actual - Subjective Time
1	-1.46	2.13
2	-0.14	.1
3	0.02	0.17
4	-1.65	-0.47
5	-1.91	-1.47
6	0.35	1.56
7	-1.47	0.03
8	-2.96	0.35
9	-1.84	0.45
10	-0.09	-0.25
11	-0.34	0.24
12	-0.7	-0.29
	Total -12.19	**Total 2.55**
	Average -1.02	**Average 0.21**

A standard **T-Test** on the data shows a highly significant difference between the time loss/gain experienced by the two groups:

P = 0.005

Table 1 shows the subjective time loss/gain for each student while using each display. When we compare the results from the use of each display, a two-tailed uneven-variances **T-Test** shows a high degree of certainty that the subjects are reporting significantly different time differentials for the two displays, with **P = 0.005**, which means there is a 99.5% chance that the observed difference is genuine and not the result of a random variation. The averages and totals show that subjects felt the passage of time was **less** in the surround display. We believe that the less the player feels the passage of time (time loss) the more that player is concentrating on and enjoying the task [8]. From this we conclude that the surround display provided a more engaging experience.

The small and homogeneous sample size used for this experiment does limit the applicability of our result to other populations. The all-male sample also may have skewed the results, because males are more likely to report losing track of time while playing video games than females do [18]. Participants who spent less than two hours per week playing games that involved a 3D environment showed a time loss figure of ten seconds or less, signifying that immersion through 3D games is perhaps a learned ability or appreciation.

Regardless of whether the ability to become immersed in a 3D environment is heightened through repeated regular use, the disparity of times between the traditional and surround display show that there is difference between the displays in the ability for users to lose track of time. While most of the participants recorded that they preferred using the surround display compared to the traditional display, all participants recorded some level of immersion experienced for the surround display.

Of additional value were the qualitative comments relating to the strengths and weaknesses for each display method. The most prevalent comment recorded under the surround display's strengths was that the projected display felt more real. Ninety-one percent of participants recorded an emotive preference for the projected display with sixty-six percent of comments including phrases similar to "feels like you are in the game" or "felt more real" or including the word "immersive". One participant recorded this response: "Much better feel for the game, Better gaming experience. Player feels like they are in the game, more... exciting?"

In comparison, the most common strength recorded for the traditional display was the clarity and brightness of the display, a very noticeable property especially if the projected display was trialed first. In contrast, the most commonly recorded weaknesses for the projected display related to poor brightness, low image quality and blurriness produced by distortions in the projection surface and sub-par lighting conditions.

4 Conclusion and Future Research

Projected surround display via interactive warp-mesh correction is shown to provide a noticeable level of immersion. Therefore, spherical projection is a new, low-cost display option for immersive virtual environments. Given more time, we would have also evaluated the usability of the interface for gamers to configure and adjust the system to suit the often changing conditions of their environment.

Further possibilities for research into alternative surround display systems include the evaluation of head tracking and stereo virtualization tools in conjunction with a projected surround display as proposed in this document. A control method for surround display systems allowing three degrees of freedom would also be of value. There may also exist a commercial opportunity in creating a flexible and inexpensive surround display for the video games and computer entertainment industry, and covering not just OpenGL but also DirectX® games.

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