

Low cost projection environment for immersive gaming

Paul Bourke

WASP, University of Western Australia

35 Stirling Hwy, Crawley

Perth, WA 6009, Australia

Phone: 61 8 6488 8097

Email: paul.bourke@uwa.edu.au

Abstract: As computer performance and graphics hardware continue to improve, the gamer is increasingly being presented with richer and more realistic visual environments. Viewing these virtual environments is generally still based upon display technology that does not exploit two very important characteristics of our visual system, namely stereoscopic vision that is responsible for the enhanced depth perception we see in the real world and a wide field of view that allows us to sense activity in our far peripheral vision. In what follows it will be argued that for immersive gaming a wide field of view is both functionally more useful and places less stress on the visual system than stereoscopic viewing. In order to support gaming with a wide vertical and horizontal field of view a low cost projection system will be introduced and the implications for game developers discussed.

Index terms: gaming, immersive environments, image warping, peripheral vision, stereoscopy, virtual reality

I. INTRODUCTION

There are two components of the human visual system that contribute significantly to our visual experience but are generally not catered for when game playing within a 3D virtual world. We have two eyes that are horizontally offset from each other and therefore two slightly different views are presented to the visual cortex. These two views are responsible for giving the strong sense of depth experienced in the real world compared to the lack of the same sense of depth when looking at a virtual 3D environment on a standard 2D display. Additionally, our eyes have a much wider field of view than the 20 or 30 degrees presented to our visual system when looking at a standard computer display. Since these two characteristics of our visual system play such a significant role in the way we experience the real world then they would also be expected to enhance the experience within a virtual environment. In conjunction with increased realism, if the stimuli makes the maximum use of the visual sense then there is more chance of a sense of immersion and generally a richer experience when within the virtual 3D world.

A. Stereoscopic displays

Stereoscopic displays are based upon a number of technologies, the most common are: frame sequential or quad buffer stereo, HMD (head mounted displays) passive stereoscopic projection using polaroid glasses or Infitec filters, and more recently autostereoscopic displays that don't require the user to wear any eyewear. Frame sequential stereo require high refresh rate CRT monitors and shutter glasses. The combination of ghosting levels and flicker (even at 120Hz) generally leads to eye strain [1] over what most gamers would consider a short period of an hour. Passive stereo is usually based upon polaroid glasses and matching filters in front of two digital data projectors and a special non-depolarising screen surface. While there is no noticeable flicker with digital projectors, the ghosting level resulting from physical limitations in linear or circular polaroid is the main source of eye strain. The newer Infitec technology employs special optical filters and is remarkable in that it has essentially zero ghosting but has the disadvantage of much higher cost and a very sensitive hardware configuration. HMDs [2] while increasingly affordable are lower resolution and require the user to focus at infinity, not a natural viewing situation. The autostereoscopic displays, while an exciting technology and are being promoted for gaming but are still very low resolution and usually place unnatural limitations on head position and movement.

There are certainly a number of games currently available that support stereoscopic 3D viewing and there are additionally some driver based solutions that provide stereoscopic viewing to games that don't have explicit support. In general one needs to be very careful when presenting stereoscopic imagery so as to give correct depth cues and to minimise the degree of eye strain. Additionally, the eye strain resulting from ghosting (leakage of a little of the image intended for one eye reaching the other eye) requires high quality hardware not found in commodity products. There are very few, if any, stereoscopic viewing systems that can be used for prolonged periods without placing a significant strain on the visual system, usually resulting in headaches. Even in an ideal stereoscopic 3D system there are causes of eye

strain [3], in particular, there is an inherent accommodation and convergence conflict. For these and other reasons very few gamers choose to play games in stereoscopic mode after the initial novelty has worn off.

It will be suggested that enhanced depth perception does not necessarily give the player in stereoscopic mode any advantage over other players with standard 2D displays. In general it should be noted that the depth perception in stereoscopic enabled games is almost never configured to give a correct sense of scaled depth. Even if a system was correctly configured, the depth relationships in a game are most often fairly obvious from occlusion, lighting, shadow, and motion cues. For example there is no significant advantage in being able to accurately judge whether a projectile is 10m or 15m away, the only meaningful information is the existence of the projectile so evasive action can be taken. On the other hand in 3D action games a significant advantage can be obtained by having graphical information in the periphery of our visual system. Indeed, it is likely that this wide horizontal field of view gave our ancestors on the African savannah a similar advantage by allowing them to sense a predator (stalking lion) as early as possible.

B. Engaging peripheral vision

There are a number of display technologies one could propose that would deliver seamless graphics to our peripheral vision. Many have been built for virtual reality and high budget simulators. Head mounted displays don't generally provide peripheral vision but some higher end models [4] do so by aligning multiple small displays and associated optical elements in a 2D matrix. Some, like the CAVE [5] combine both stereoscopic and peripheral vision together. In general they require both multiple projectors and multiple computers [6], finely tuned calibration and/or edge blending, and often need special projection surface geometries. While these environments are certainly capable of delivering an immersive experience, because of their cost they largely remain in the domain of research institutions, used by the military for training, or employed in other specific commercial endeavours.

Gaming with a wide horizontal field of view is traditionally approached by adding separate displays either with multiple graphics cards within a single computer or with external video splitter such as the Matrox TripleHead2Go [7] or external cards by DigitalTigers [8]. The outer two displays are often angled so as to partially surround the viewer. This is not entirely satisfactory, not only is there a border or gap between each display but the field of view is rarely more than 90 degrees. Our actual horizontal field of view is closer to 200 degrees and even our more limited vertical field of view is certainly much greater than that offered by horizontally arranged LCD panels.

If we can seamlessly engage our peripheral vision then not only do we get a greater sense of "being there", referred in some circles as immersion or "presence", but for more reaction based games there is significant benefit from being able to sense movement on the edge of our vision. The discussion here does not suggest that the

gamer moves his/her head around to see objects on the sides of the display as is often the case in driving or flight simulators employing multiple monitors. Rather the gamer looks straight ahead and senses the peripheral imagery in the same way they would in real life. The player then becomes hermetically sealed within the virtual environment, the boundary of the display and the real world are not visible. Importantly, unlike current stereoscopic displays which inherently result in eye strain, peripheral vision is a totally stress free way to view a virtual 3D environment and as such can be used indefinitely.

II. WIDE FIELD OF VIEW PROJECTION

A. Spherical mirror

An essential characteristic of any system that creates a wide field of view is how to scatter the light from a projector(s) onto the display surface. If low cost and maintenance are important then a single projector approach is considered necessary. The traditional way to do this is with a fisheye lens [9], but a fisheye lens fitted to a projector is technically challenging which is reflected in the price that puts them outside the budget of the most gamers.

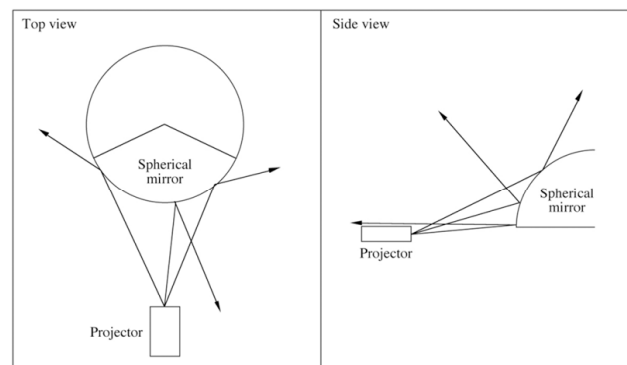


Figure 1. Representative rays from a single projector reflected from a spherical mirror.

Here I propose an alternative single projector based projection system for immersive gaming and other virtual reality applications. It solves the optical problem by using a spherical mirror to scatter light across a wide field of view [10], see fig. 1 for representative rays reflected from a spherical mirror from a single projector. The distortion that would normally result when reflecting a computer generated image off a spherical mirror is corrected for in software with minimal processing overhead thanks to the power of today's graphics hardware. While there are some advantages projecting onto smoothly changing surfaces such as cylinders and hemispheres [11], the approach can also be used to project onto almost any (concave) surface including existing rectangular rooms. It should be pointed out that the idea of using a curved surface is not new in the immersive virtual reality community and robotics [12] but it has so far been limited to image capture. That is, using a spherical or

conical mirror to capture a wide field of view with a single camera.

B. Perspective projections

The first consideration for developers planning to support any wide field of view projection is that a single perspective projection is no longer adequate. Unfortunately orthographic and perspective projections are usually the only camera projection models supported by games because they are based upon what is supported by graphics accelerated APIs such as OpenGL. A perspective field of view of more than about 100 degrees becomes increasingly distorted and the pixel efficiency drops in the most important region, the central part of the image. See fig. 2 for examples of a 100 degree horizontal field of view and a 140 degree field of view (both perspective). The distortion is quite evident at 140 degrees but that is not nearly as wide as our visual system can absorb. It is clearly not possible to create a 180 degree perspective horizontal field of view by using a single perspective projection let alone larger angles.



Figure 2. 100 degree (top) and 140 degree (lower) horizontal field of view using a perspective projection.

C. Cubic maps

For immersive environments a more useful image format are cubic maps, that is, the six 90 degree perspective projections from the current camera position to each face of a unit cube centered on the camera. This is not a new idea for games or virtual reality applications which have long employed cubic maps to create high quality backgrounds or environmental lighting [13]. If all six cubic maps are available then the entire visual field is defined and therefore any projection geometry can potentially be created, it is simply a image transformation exercise. For most immersive displays not all six cubic faces are required, for example in fig. 3 it can be seen that only four are required to create the fisheye that would fill a hemispherical dome surface. If the fisheye image in fig. 3 were projected through a fisheye lens located near the center of a hemispherical dome then the result on the

dome surface would look undistorted to a viewer also located near the center of the dome.

The software model for capturing the cubic faces is often referred to as the multipass texture capture. The virtual camera of the game is modified such that it has a 90 degree vertical and horizontal field of view. The scene is rendered up to six times, each render has the camera pointing in a different direction, namely towards the center of each face of the unit cube. On each render instead of displaying the image to the user on the graphics display, the image is copied to a texture for later use. At the end of these passes all the textures are applied to a mesh which is then rendered and displayed, typically using an orthogonal camera model.

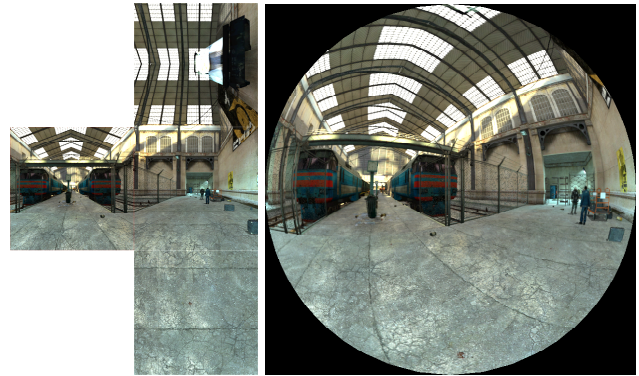


Figure 3. Four cubic maps (left) is the smallest number required to reconstruct a fisheye (right) for a hemispherical display.



Figure 4. Example of a warped image for projection onto a hemispherical dome after reflection from a spherical mirror.

D. Image warping

Consider positioning the image from a data projector on a portion of a spherical mirror. The light will be scattered across a wide angle, the exact coverage depends on the area of the mirror used, the curvature of the mirror, and the relative position of the projector. It is relatively straightforward to achieve 180 degrees horizontally and 140 degrees vertically, see fig. 1. An image reflected in this way and falling onto a surface such as a hemispherical dome would appear quite distorted. It is possible to predistort the image (from now on referred to as warping) so that the result looks correct on the display surface. Such a warped image for a particular

mirror/projector/dome arrangement is shown in fig. 4. The problem then is how to determine the image such that when it is reflected from the spherical mirror and lands onto the final display surface, appears correct.

The warping can be most easily derived by simulating the projection environment and effectively casting rays from a virtual projector through points in the image plane. Calculating where these rays strike the spherical mirror and then where that reflected ray hits the final display surface allows one to calculate the warping required. The result is a knowledge of both where any point in the projected image plane appears on the display surface as well as where any position on the display surface appears in the image plane. In the same way that a fisheye image inscribed within the 4:3 aspect ratio of most data projectors means that parts of the image plane are not used, there may be parts of warped image plane that are not used. For a spherical mirror these may correspond to parts of the image plane that don't strike the mirror or parts of the image where the corresponding rays would miss the intended display surface area.

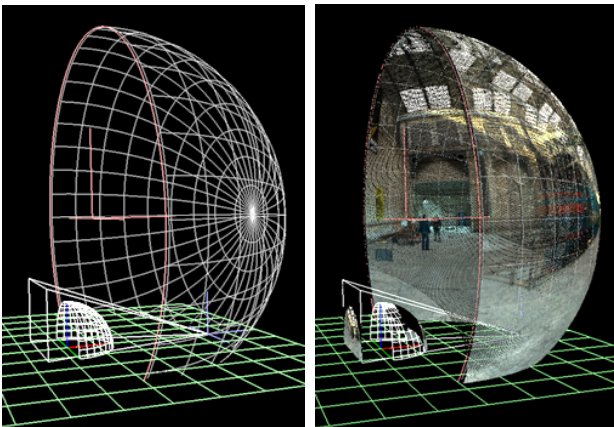


Figure 5. Example of ray casting simulation, model of physical geometry and projector specifications (left) and verification of simulated projection test (right).

See fig. 5 for an example of the projection geometry for an upright dome and a simulated verification of the resulting warped image on the dome surface. Fig. 6 shows the warped image itself and the result on the upright dome surface.

The warping can be implemented in OpenGL by applying the cubic maps as textures on a suitably constructed mesh. This mesh is made up of nodes and texture coordinates derived from the simulation such that when the cubic maps are applied as textures and the result viewed with an orthographic camera, the result is the desired warped image. Equally one could first create a fisheye image and then apply that to a different mesh, but one that creates the same visual effect, namely an undistorted view on the display surface. Fig. 7 shows the triangular mesh onto which four cubic maps are applied in order to create a fisheye image as well as the triangular mesh that achieves a warped result for projection using a spherical mirror into the same upright hemispherical dome surface. The texture coordinates at each node are obviously important but can't be readily illustrated in fig.

7 except by their effect on the fisheye image texture. In reality a much higher resolution mesh would be used than is shown in fig. 7, a coarse mesh is illustrated there simply for clarity.

It should also be noted that it may be necessary to perform brightness corrections, this is equally straightforward using a textured mesh in OpenGL without any additional performance penalty. This intensity correction can be required to compensate for different path lengths of the light or to reduce the effects of diffuse reflection on different parts of the display surface. A further extension is to perform a colour correction to compensate for projection surface colour and/or colourisation introduced by various mirror coatings. These effects can be derived from the simulation of the physical environment. In practice they are usually unnecessary and are outside the scope of this discussion except to point out they are not trivial, for example, they need to take account of the gamma of the projection system and are thus dependent on the attributes of the data projector.

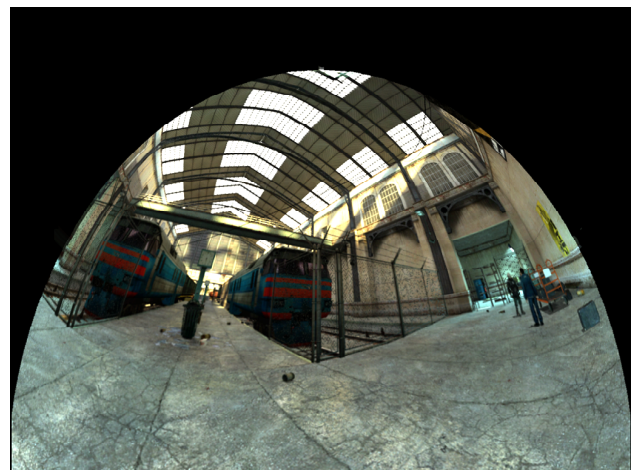
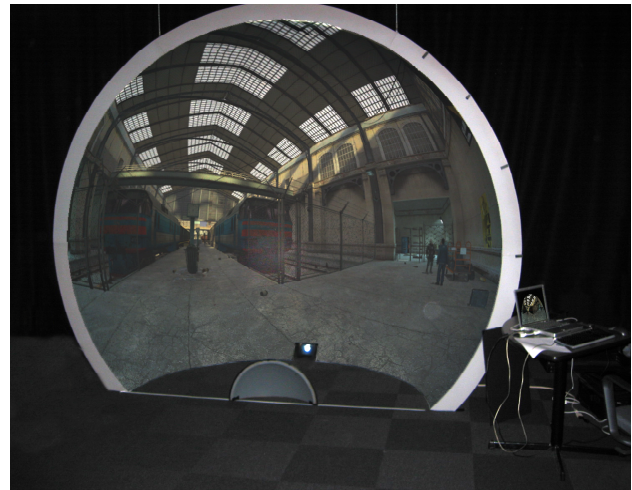


Figure 6. Photograph showing an upright [5] dome (top) and a matching warped image (bottom).

It can perhaps now be appreciated that the warping can be calculated irrespective of the geometry of the final display surface, the only difference is the exact warping mesh to which the cubic map textures are applied. This

warping mesh can additionally be computed for any mirror shape but there is the advantage of simplicity and availability of spherically shaped mirrors. Indeed, once software has been written to support one sort of warping then it can be used in any projection geometry, the only difference is the description of the warping required. This description can be stored in a data file that is unique to each installation.

E. Performance

There is clearly a performance penalty in rendering the scene a number of times and then performing the final textured mesh render. The multipass rendering performance is proportional to the scene complexity but there are often implementation efficiencies that mean the performance factor is less than the number of rendered views. For the environments discussed here only four cubic maps are required for sufficient display coverage, testing indicated a typical frame rate penalty factor of 2.5 compared to a single perspective view. It should be noted that this does depend on characteristics of the scene, for example the amount of geometry that is placed within display lists in OpenGL.

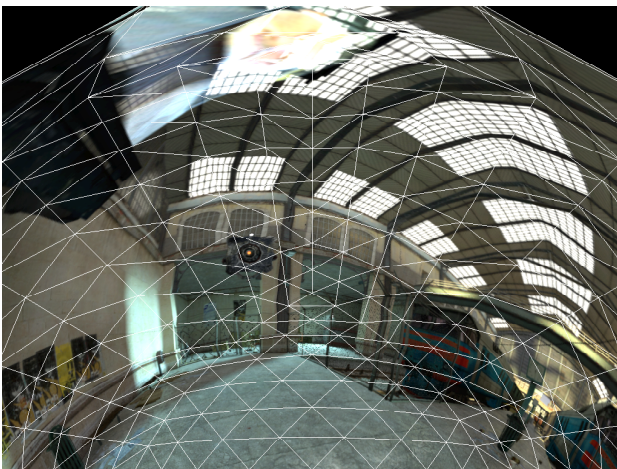
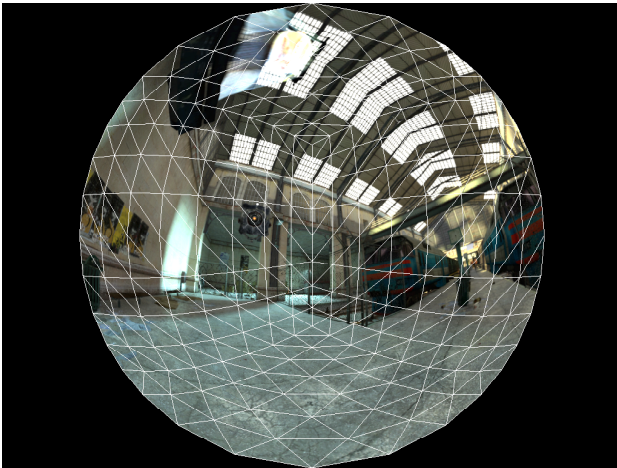


Figure 7. Textured mesh that warps cubic maps to a fisheye image (top) and the corresponding mesh to achieve the warping when projecting onto a dome using a spherical mirror (bottom).

The final rendering phase only involves applying a single image (fisheye) onto a 2D mesh and thus has very

little performance penalty using today's graphical hardware. This final rendering phase is weakly dependent on the display resolution and it is independent of the scene complexity. As an example, for an SXGA+ projection system (1400x1050 pixels), an appropriate fisheye resolution is 1536x1536 pixels. In this case the final texture mapping onto an 80x60 resolution warping mesh had less than 2% impact on the overall frame rate.

F. Fisheye vertex shader

For completeness, there is an alternative to the cubic map approach described above. This involves a vertex shader [14] that transforms each vertex such that when the result is viewed with an orthographic camera it appears as a fisheye projection. The resulting fisheye image is warped by applying it to the same mesh as discussed above. This is potentially very fast both because it is a single pass algorithm and because the vertex shader is implemented on the graphics card.

There are a couple of reasons why it is not often the best solution. One reason has to do with an assumption made about geometry within a perspective projection that does not hold for the projections discussed here, namely that we can draw a straight line between two points in a perspective projection. In a fisheye and many other projections one cannot draw a "straight" line between the end points of a line segments. The solution is to split a line segment into many smaller sections and draw each one, the more segments the better the approximation to what the true appearance of the line segment should be. This introduces more geometry into the rendering pipeline and while modest for a line segment it is much more significant for planes. A plane needs to be tessellated into many smaller plane segments and due to the two dimensional nature the increase in geometry rises as the product of the number of tessellations along each axis. There are algorithms one can imagine that tessellate only when necessary and to an acceptable degree but these are not trivial and can quickly overwhelm the gains made by this approach over the cubic map algorithm.

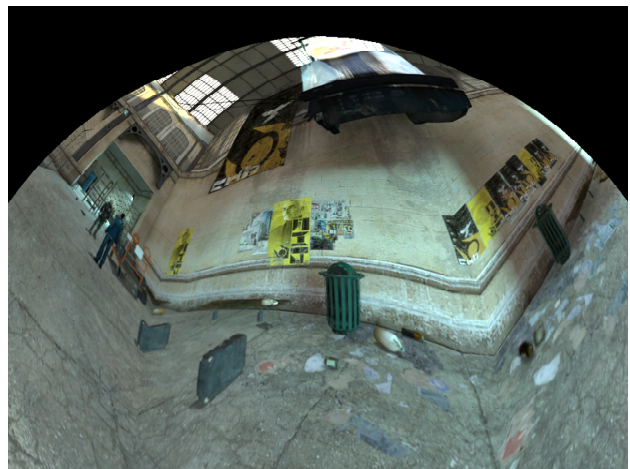


Figure 8. Warping example for projection into a rectangular room using a single projector and spherical mirror.

G. Viewer position

In all these environments the view is only strictly correct for a single position, although it may be constructed for any viewing position. For gradually curved screen surfaces such as domes or cylinders the distortion experienced by viewers at other positions is rarely a problem for a range of modest distances from the position the imagery is created for, this is largely because the distortion changes smoothly across the display surface. However straight lines in the 3D virtual world will still only be perceived as exactly straight when viewed from the correct position. It should be noted that this dependence on viewer position is true for all immersive displays including stereoscopic displays. The only solution is to employ head tracking so that the content changes with viewer position, this by definition means the environment only appears undistorted for a single user.

For projection surfaces with corners it is much more important to be located at the correct position otherwise, for example, objects moving in a straight line that crosses a discontinuity such as a corner will appear to bend for all viewing positions except the one position the warping is computed for. Similarly camera panning will result in very obvious distortions at the corners. Fig. 8 is an example of warping where the virtual environment is projected onto three walls and ceiling in a rectangular room, the game player position is arranged directly above the mirror such that their peripheral vision is filled and they don't experience reflected light off the mirror.

The approach discussed is based upon single projectors for reasons of cost and simplicity, this does however limit the resolution of the projected display. This resolution limit is another feature of the human visual system that is not fully utilized on most projected displays. Fortunately SXGA+ (1400x1050 pixel) resolution is now available at commodity prices, and there are appropriate HD projectors are being released to satisfy the home cinema market.

III. SUMMARY

Presented here is a low cost immersive projection system requiring a single data projector and a low cost spherical mirror. The final projection surface can be any reasonable shape, for example, a partial cylinder enveloping the gamer, a hemispherical dome, or a rectangular room. For this and indeed for any immersive projected environment, game developers need to start thinking beyond single perspective projections. One option discussed here is to implement the cubic map multipass rendering pipeline. Once this is done it is a straightforward mapping of the cubic map images as textures onto a mesh with appropriate texture coordinates

to form a wide range of possible projections. Furthermore, supporting a new projection environment only involves reading a data file containing the new warping mesh, no other aspect of the game needs to change. While stereoscopic projection is more common in games, it is expected that peripheral vision supported by the immersive environments discussed here will give the player a gaming advantage compared to the questionable advantage obtained with stereoscopic displays and without the associated eyestrain.

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