

FULL-VIEW PANORAMIC NAVIGATION USING ORTHOGONAL CROSS CYLINDER

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ABSTRACT

Orthogonal Cross Cylinder (OCC) is an object created by intersecting the cylinder of Y-axis and the cylinder of the Z-axis. OCC mapping is a new method for effectively mapping the environment. This method eliminates the singularity effect caused in the environment maps and shows an almost even amount of area for the environment occupied by a single texel. The surrounding environment can also be stored more effectively through more accurate sampling. Improvement is also achieved in the rendering time of the OCC mapping method and octahedral mapping method based on OCC mapping. Therefore, the OCC mapping method is suitable to be applied on environment navigation systems due to its effective storage of the environment and faster sampling time.

Keywords: Sampling, Environment Mapping, Image Based Rendering.



Figure 1: Orthogonal Cross Cylinder

1. INTRODUCTION

The implementation of a virtual environment system where the user can actually explore the real world through navigation has become possible with the improvement of computer graphics technology. Information on its environment is required for the navigation of the interior and outer space. Traditional model based computer graphics implements diverse rendering methods to simulate natural phenomenon through collecting its environment information and constructing 3D

models. Image based rendering techniques that use pictures of the actual environment for expression are the main focus today instead of the traditional 3D model construction and rendering techniques. View interpolation, plenoptic modeling, lightfield rendering, lumigraph and view morphing are some of the methods used to express the surrounding environment using real images[Bregl00]. The method using environment mapping is the general method used to navigate the surrounding environment from a fixed point of view[Chen95, McMil95]. A sphere, cube or cylinder is used for the

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environment mapping but these methods may cause sampling problems in the process of the projecting 3D space to 2D space.

The Orthogonal Cross Cylinder (OCC) map which would eliminate such sampling problem and store the environment information more effectively is suggested in this study. An OCC map can eliminate such singularity effect caused in an environment map and effectively store the surrounding environment (Fig. 1). OCC mapping has the two following characteristics. The area subtended by a texel of the environment map is almost even in the OCC map. It also eliminates the singularity problem caused at the pole. It also stores the surrounding environment more effectively and can also be used to obtain a high-resolution image using cheaper tools than other methods.

This paper is composed of the following parts. The environment mapping method, used to express the surrounding environment, and a method for creating a panoramic image, that forms the environment map, are examined as well as the advantages and disadvantages of using such method. The method for constructing an OCC map from a synthetic scene and a real scene is and the properties of OCC mapping are explained in the following chapter. The method for storing the OCC map more effectively, rendering method used for expressing the OCC, and an example of an OCC mapping implementation are presented before presenting the final conclusion.

2. RELATED WORK

2.1 Environment Mapping

Environment mapping is a method of adding realism to a scene by using special texture indexing methods. This method refers to the process of reflecting a surrounding environment in a shiny object and environment mapping was originally introduced as a cheap alternative to ray tracing. In image-based rendering, the virtual viewer replaces the shiny object and that part of the map intercepted by viewer's field of vision is presented to him as a two-dimensional projection. Environment mapping is essentially the process of pre-computing a texture map and then sampling texels from this texture during the rendering of a model. The texture map is a projection of 3D space to 2D space. The ways to project a 3D surface to a 2D surface are sphere mapping, latitude mapping, cube mapping, cylindrical mapping and paraboloid mapping [Mizut00, Zimmo00, Blyth99].

Blinn/Newell Latitude Mapping used a latitude-longitude map indexed by the reflected ray[Blinn76].

The texture map's U coordinate represents longitude (from 0 to 360 degrees) and V coordinate represents latitude (from -90 to 90 degrees). Latitude-longitude map's distortion will become apparent if the environment map is applied to planar objects with consistent neighborhood relationships such as a mirror. An object with curved surfaces will alleviate the distortion inherent in the environment map image. Furthermore, there is a singularity in the mapping at the pole.

Sphere mapping is a type of environment mapping in which the irradiance image is equivalent to that which would be seen in a perfectly reflective hemisphere when viewed using an orthographic projection. Sphere mapping use a single texture image. This means that look-ups are fast and the environment is represented compactly. But, there is a singularity in the mapping at the outer edge and it does not use all the texture in the texture map. There is a waste of texture memory.

Cube mapping was invented by Ned Greene in 1986[Green86]. The cube map stores the environment as six textures. Each texture represents the view out of one face of the cube as seen from the center of the cube. Cube map is easier to generate than a sphere map and less distortion those other mappings. But, Cube mapping requires indexing through several textures to compose the final image. Also, the discontinuity is introduced by the edges of the map and result in seams along the object

For cylindrical mapping, a cylinder can be easily unrolled into a simple planar map. The surface is without boundaries in the azimuth direction. One shortcoming of a projection on a finite cylindrical surface is the boundary conditions introduced at the top and bottom[McMil95].

Dual paraboloid environment mapping was invented in 1998 by Wolfgang Heidrich and Hans-Peter Seidel[Heidr98]. The dual-paraboloid mapping requires two textures to store the environment, one texture for the front environment and another texture for the back environment. The underlying geometry of the mapping is based on a parabola which has the desirable property of containing a single point of focus for incoming rays. Dual-paraboloid map compared to the sphere map approach are better sampling of the texture environment, the elimination of sphere mapping's sparkle artifacts. But, constructing the dual-paraboloid map requires warping two textures instead of just one and it requires two rendering passes or the use of multi-texturing. Also, almost 25% the pixels are not used and edge pixels between maps need to perform special blending in order to reduce artifacts from using two maps.

OCC mapping is a new type of mapping that would eliminate the singularity problem occurring at the pole of the environment map and the problem of the size of the area (solid angle) subtended by a texel of environment map being various. The properties of OCC mapping is presented in chapter 4.

2.2 Wide Angle Image

Panorama is an unbroken view of a surrounding area. Namely, panorama is an unusually wide picture that shows at least as much width-ways as the eye is capable of seeing. Many different methods have been developed for creating panoramic images. One of the methods is to stitch together the images obtained by rotating a camera from a single point of view [Szelei97, Telle98]. Another is to capture the image a single line at a time using a panoramic camera and then align them [Hartl94]. Panoramic images of high resolution can be obtained at a reasonably cheap price using these methods but cannot obtain a full panoramic image containing its entire surrounding environment. In other words, although it is possible to obtain the whole area for the horizontal field of view, the vertical wider field of view cannot be obtained through this method. The camera should be pitched up and down from a fixed point of view to acquire the cylindrical panoramic images, which will be stitched together to obtain the wider field of view. This restricts the use of rotating systems to static scenes and non real-time application.

Another way is to use a lens with a wide range of view such as a fish eye lens [Xiong97]. A panoramic image can be obtained using fewer images than the above-mentioned method with this method but the process for calculating the deformation on the image becomes complicated and there is an extra cost for the wide-angle lens. The biggest problem with this method is that the resolution decreases as the field of view increases through the use of the wide-angle lens.

Another method is to directly acquire the image reflected on a single camera looking off a single non-planar mirror to acquire a wider field of view [Nayar97]. All the images of the surrounding environment can be obtained quickly using this method. However, it is difficult to acquire an image with high-resolution, and the scene must also be very brightly illuminated.

In this paper, a wide-angle lens has been attached to the camera for acquiring an image that rotates around 360 degrees to obtain an image of the whole environment at a reasonably cheaper cost. The acquired image is reproduced as a panoramic image through a panorama tool [Dersch01] developed by Helmut Dersch and an image editor.

3. ORTHOGONAL CROSS CYLINDER

The Orthogonal cross cylinder has been developed for evenly sampling the environment map by the pixels on the screen and its effective storage while maintaining the characters of the cylindrical map. It is an object created by intersecting the XZ cylinder of Y-axis and the XY cylinder of the Z-axis (Fig. 1). The process of expressing the surrounding environment using an OCC mapping consists of creating a XZ & XY cylindrical map, reproducing the OCC map through eliminating redundancy, and rendering through OCC map sampling (Fig. 2).

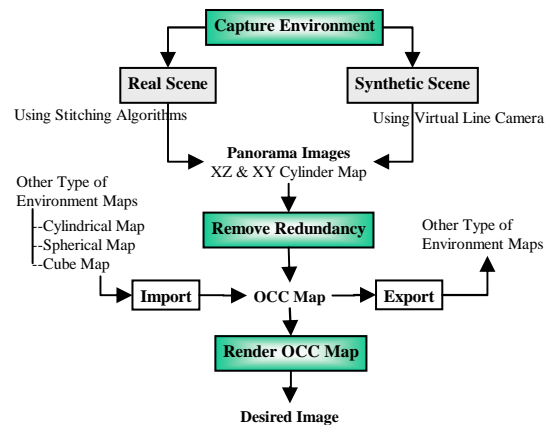


Figure 2: The step of OCC mapping

The environment map is created using a virtual line camera in the environment made up three dimensionally when created off computer generated images and using the stitching algorithm when created off real-world images. The XZ & XY cylindrical maps created through these methods would contain ineffective samples that overlap. Therefore, a step for eliminating such redundant samples is required in the process for constructing a more effective OCC map. The OCC map is composed in a way to be compatible with other environment maps. An image can be created in any direction through rendering based on texture mapping and ray casting using the OCC map created,

3.1 Creation of OCC Map

3.1.1 Synthetic Scene



Figure 3: The setting up of virtual camera and XZ & XY cylindrical map

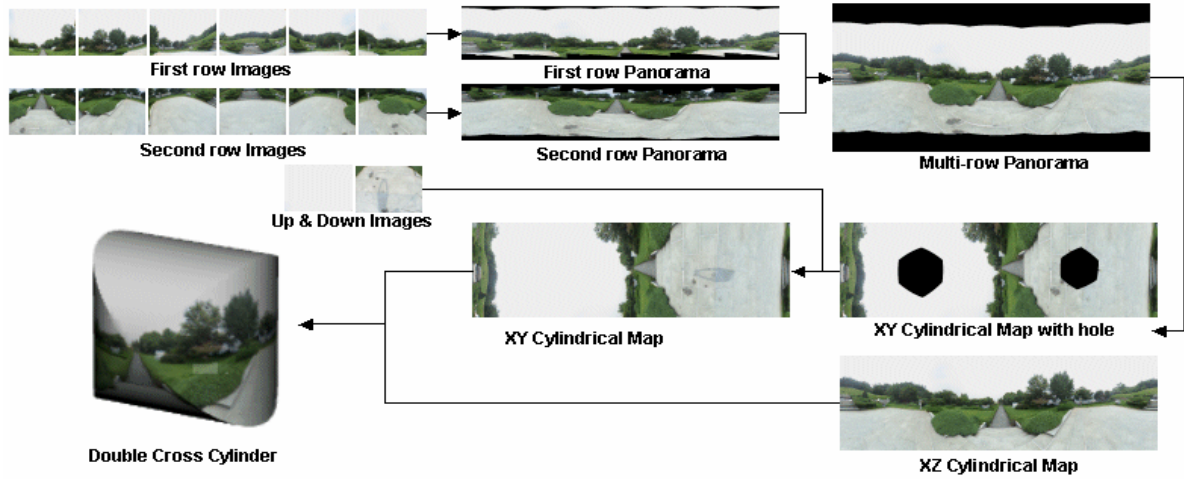


Figure 4: Creation of OCC map from real scene

A three dimensional geometry model for the surrounding environment, rendering system and a virtual-line camera are required to create an OCC map from a virtual space. An OCC map consists of a XZ cylindrical map and a XY cylindrical map. The XZ cylindrical map rotates the virtual camera 360 degrees against the Y-axis from a single fixed point of view and the XY cylindrical map rotates it 360 degrees against the Z-axis from the same point of view (Fig. 3). The degree and speed of movement is maintained when rotating the virtual camera to create the image and a center strip is abstracted from the obtained image-buffer. The strips that have been obtained through this method are aligned to form a cylindrical map. The vertical and horizontal FOV of the camera must be maintained at 90 degrees because the size and range of the object within the scene is altered by the camera's FOV and the whole surrounding environment can be obtained only when the FOV of the cylindrical map is larger than 90 degrees, just as in constructing a cube map.

The following relations should be considered upon storage of the XZ and the XY cylindrical map. First of all, the relationship between the radius (r) and the height (h) of the cylinder should be as followed [Ryoo01].

$$h = 2r \tan \frac{FOV}{2} \quad (1)$$

The relationship between the width (w), height (h) and the radius (r) of the cylinder when the FOV is set to 90 degrees, defined by Eq. 1, of the cylinder is as followed.

$$w = \pi h \quad \because w = 2\pi r, h = 2r \quad (2)$$

Therefore, the cylindrical map should always be stored in a way that the relationship between width and height of XZ & XY cylindrical maps be $w = \pi h$.

3.1.2 Real Scene

In this study, the Sony DCR-TRV20 digital camcorder, a tripod and a semi fish-eye lens have been used to obtain an image of the surrounding environment from a real scene. The process of creating an OCC consists of acquiring the image of the surrounding environment, stitching of the acquired image, transforming the XZ and XY cylindrical map and the removing the hole in the transformed cylindrical map.

Fig. 4 is a flow diagram of the process to construct an OCC from a real scene. An image is acquired by pitching up the camera, with a semi fisheye lens attached to it using tripod, by 30 degrees from the horizontal plane and taking the six images by rotating anti-clockwise around the Y-axis in 30 degrees interval. The camera is then pitched down by 30 degrees from horizontal plane and rotated around the Y-axis to acquire the six images in 30-degree interval. Finally, the bottom and the top of the scene after the tripod has been removed are captured as an image.

The images acquired from the first rotation are stitched together as a cylindrical map using the panorama tool. The images acquired from the next rotation are put together to form the second cylindrical map. A panoramic image with a wide angle can be obtained by stitching two different cylindrical maps together in the same way. However, the panoramic image obtained through this method cannot include its entire surrounding environment due to the lack of information on its surrounding environment around each pole. The panoramic images are transformed into a XZ and a XY cylindrical map to resolve this problem. The transformed XZ cylindrical map produces a perfect solution by acquiring all the necessary information on its surrounding environment whereas the solution from the XY cylindrical map would have holes due to

the lack of information on the top and bottom of the image. These holes can be filled by using the image of the top and bottom acquired in the first step of the process and an image-editing program. The environment map has been edited using a layer-based photo-shop program.

OCC can be constructed using the XZ & XY cylindrical maps created through this process. However, the XZ and XY cylindrical maps used to create the OCC are not suitable to be used as OCC maps because they contain redundant environment data. This problem is discussed in the following chapter.

3.2 The Shape of OCC Map

The XZ and XY cylindrical maps used to create the OCC have a problem of containing redundant data on the environment. The Intersected area of the XZ and the XY cylindrical map has to be obtained and only the area actually used for the OCC mapping should be stored to avoid such redundancy. The various types of map used for constructing the OCC map effectively are explained below.

3.2.1 Intersection between XZ and XY Cylinder

An equation for the determining the intersection between the XZ cylinder and the XY cylinder is required for each cylinder. The equation is as followed.

$$\begin{aligned} \text{XZ Cylinder: } & X^2 + Z^2 - 1 = 0 \\ \text{XY Cylinder: } & X^2 + Y^2 - 1 = 0 \end{aligned} \quad (3)$$

The relationship will be defined as follows by inserting the intersection point between the two functions, (a, b, c), into Eq. 3.

$$b^2 = c^2 \Rightarrow \pm b = \pm c \quad (4)$$

An arbitrarily chosen coordinate of P(X, Y, Z) will be mapped onto coordinate (θ, ν) through the following relationship.

$$\begin{aligned} \theta &= \tan^{-1} \frac{Z}{X} = \cos^{-1} \frac{X}{\sqrt{X^2 + Z^2}} \quad 0 \leq \theta < 2\pi \\ \nu &= \frac{Y}{\sqrt{X^2 + Z^2}} \quad -1 < \nu < 1 \end{aligned} \quad (5)$$

The intersection point can be expressed as $(\pm\sqrt{1-\xi^2}, \pm\xi, \pm\xi)$ by substituting b and c with ξ in Eq. 4. The intersection area can be expressed with following equation by applying the intersection points on Eq. 5.

$$\theta = \cos^{-1} \sqrt{1-\xi^2} \quad \nu = \xi \quad (6)$$

The intersection area of the XZ & XY cylinder can be defined as following function through substituting ξ with ν from Eq. 6.

$$\nu = \pm \sin \theta \quad (7)$$

The following relationship can be obtained by normalizing Eq. 7 while taking the radius of the cylinder into account.

$$\begin{aligned} \theta &= r \cos^{-1} \sqrt{\frac{r^2 - \xi^2}{r}} \quad \nu = \xi + r \\ \nu &= r \pm r \sin \frac{\theta}{r} \end{aligned} \quad (8)$$

3.2.2 Storage of OCC Map

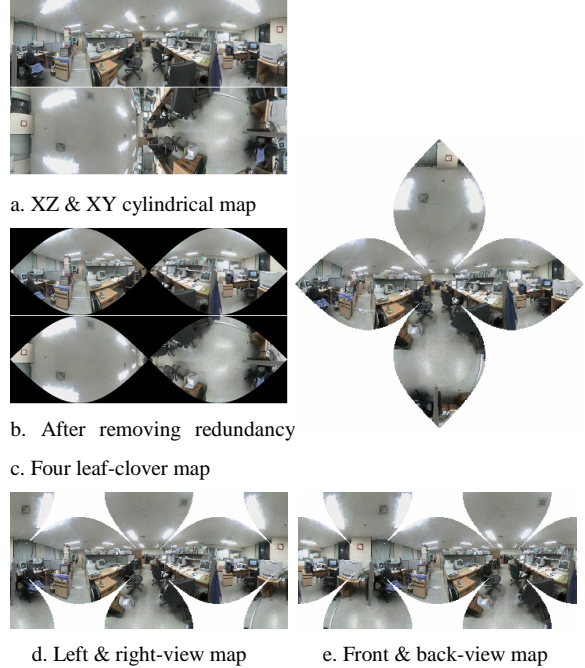


Figure 5: Various environment map using OCC

The easiest way of mapping the OCC onto a 2D screen coordinate is to use the XZ & XY cylindrical map. However, since the two cylindrical maps contain redundant environment data, it is necessary to discard such redundancy beforehand (Fig. 5-b). This cylindrical map has an ineffectiveness of having 35% of its storage space left as an empty space. The XZ & XY cylindrical map is similar in its shape to a clover with four leaves (Fig. 5-c). Each end of the leaf of the clover meets at a single point. A map that maps the right side and the left side of the OCC (Fig. 5-d) and a map that maps the front and the back side of the

OCC (Fig. 5-e) can be constructed through this character of the OCC map. The space for storing the samples needed to construct an OCC can be reduced by 25% and the waste of space can be reduced by 19% through this method.

The front and the back side of the map can be used through warping for even more effective use of space (Fig. 6). The octahedral map is formed through warping the pixels towards the straight line to fill the space left empty in the front and the back-view map.

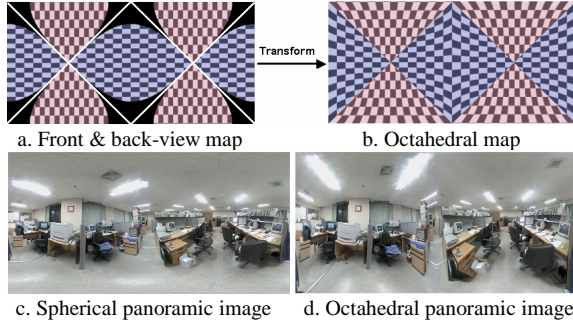


Figure 6: Creation of Octahedral Map

3.3 Rendering of OCC Map

A method of mapping the texture onto an actual 3D model and a ray casting method of sampling the texel onto the corresponding screen pixel of the OCC map has been used for rendering the image using the OCC map.

3.3.1 Texture Mapping (Model Transformation)

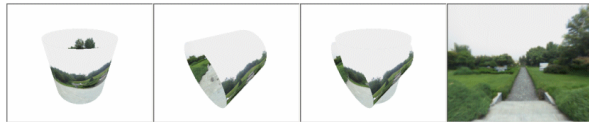


Figure 7: OCC rendering using texture mapping

Texture mapping is a method of mapping the necessary texture from the OCC map by modelling the OCC three dimensionally using the XZ cylinder and the XY cylinder (Fig. 7). The OpenGL has been used for 3D modelling and texture mapping to implement the algorithm. A model transformation method of rotating the actual model to acquire the required image from the point of view has been used in this method. Model transformation has an advantage of being able to observe the object freely, regardless of the up vector.

3.3.2 Ray Casting (Viewing Transformation)

Ray casting is a method of sampling the texel onto the screen coordinate using the OCC and the intersection of the ray. This method consists of ray creation,

intersection of the ray and the object, and the texel sampling for the intersection. The ray is obtained through the viewing coordinate and the view plane. The intersection of the ray and the OCC consists of the intersection of the ray and the XZ cylinder and the intersection of the ray and the XY cylinder.

Fig. 8 shows the process of testing the intersection between the XZ cylinder and the ray.

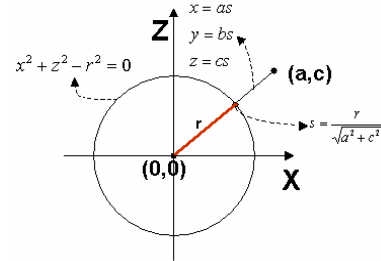


Figure 8: Intersection between the ray and XZ cylinder

The following is the equation used for obtaining the texel (u, v) of the XZ cylinder intersecting with the ray.

$$u = r\theta \quad v = y + r \quad \theta = \cos^{-1} \frac{x}{r} \quad (11)$$

The intersection can be obtained from the XY cylinder using the same kind of the equation. The intersection point with the smaller s value, the point that forms the ray, is sampled onto the actual screen coordinate as the texel. The issue of how to sample the texel is the most important process in ray-casting[Heckb89].

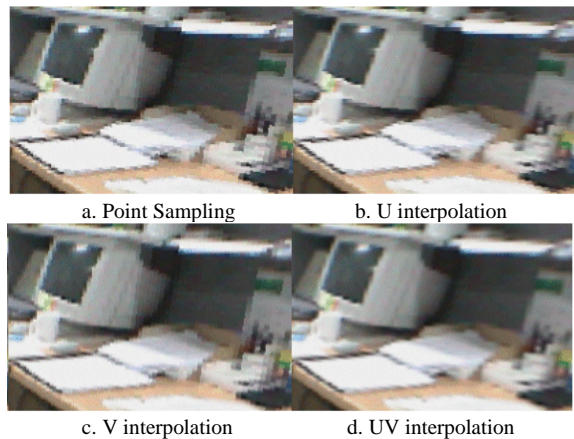


Figure 9: Texel sampling

Point sampling, U interpolation, V interpolation, and the UV interpolation methods have been used to sample the points in this study. Fig. 9 shows the resulting image obtained by implementing each method. The aliasing effect has been removed from the original image by UV interpolation method. A method of transforming the point of view instead of

the object has been used for rendering to rotate and zoom in on the surrounding environment in ray casting. A sudden change in the image may occur in the transformation of the point of view, due to its inability to express the up vector at the pole. To prevent such effect, the range of the pitch has been limited from the pole by considering the fact that actual humans cannot accomplish a complete pitch in looking around his/her surrounding environment.

4. COMPARING OF THE CHARACTERISTICS

4.1 Comparing Sampling Pattern

The accuracy of each map has been evaluated by comparing the texture area corresponding to a certain solid angle and the solid angle corresponding to each texel, in this study.

The size of the area that the screen pixel occupies is more even at the pole and near the equator for the OCC map and the octahedral map than the spherical map, as shown in Fig. 10.

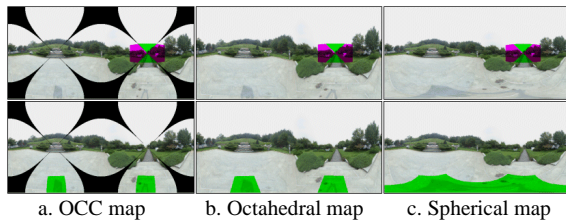


Figure 10: Comparing the area that the screen pixels occupy

Also, the solid angle for each texel has been calculated to measure the effectiveness of the sampling on each map. The solid angle of the texel for the cube map, cylindrical map, spherical map, OCC map and the octahedral map have been each measured in this study. The solid angle is expressed as the area that the ray has been projected onto the sphere for each texel.

Table 1: Comparing solid angle

	Sample #	Solid Angle				Covered Area	
		Total	Min.	Max	Avg.		Dev.
Cube	239756	12.573205	0.000019	0.000100	0.000052	0.000020	100%
Cylinder(90)	125600	8.888219	0.000036	0.000100	0.000071	0.000021	71%
Sphere	197192	12.566737	0.000001	0.000100	0.000064	0.000031	100%
OCC	159764	12.559790	0.000036	0.000100	0.000079	0.000019	100%
Octahedron	197192	12.566234	0.000023	0.000100	0.000064	0.000020	100%

Table 1 shows the minimum and maximum value, average value and the deviation of the solid angle on each map. The average value expresses the average value of the solid angle that a single texel represents. If the average value is small, the area of the

environment that the texel represents is of a small size and vice versa. The deviation value represents the change in the value of the solid angle. The change in the value of the angle becomes more even as the deviation value becomes smaller. Therefore, an effectively sampled map would have a large average value and a small distribution value. The cube map has the smallest average value of all the maps, but has a small deviation value which causes little change in the value of the solid angle of a texel. The cylindrical map shows a good sampling pattern with a large average value and a small distribution value, but has a problem of not being able to express all the area. The spherical map has a sampling pattern that shows a rapid decrease of the value for the solid angle at the pole and a large different in the value between the minimum and maximum value of the solid angle. The OCC map has the best sampling pattern of them all, with the largest average value and the smallest distribution value.

A spectrum color table has been used to visually express the difference between the solid angle of each texel for the various maps, instead of using the grey shade color table, in Fig. 11-a. Fig. 11 shows that OCC map provides the best sampling pattern which expresses the surrounding environment most effectively.

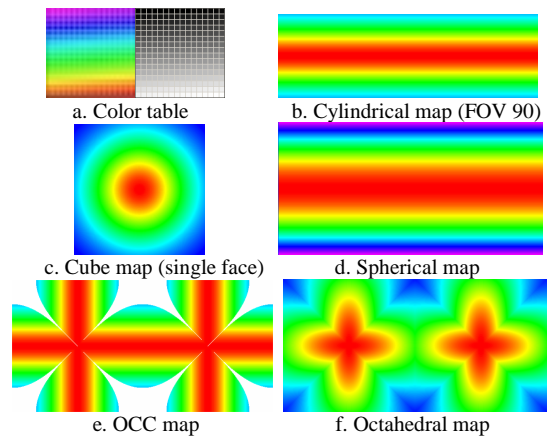


Figure 11: Solid angle per single texel

4.2 Comparing the Rendering time

The OCC map and the octahedral map, explained in the previous chapters, is used to perform a rapid and accurate sampling of the texels through an equation that maps 3D space onto a 2D plane. The rendering time of the spherical mapping, OCC mapping, and octahedral mapping have been compared through the resolution and four types of rendering methods to evaluate the performance of this method. We have implemented texture mapping module in C++ using the ray casting (texel sampling) method mentioned

above. All timing were computed on a Pentium III 750 MHz computer. Pixel duplication is a rendering method of replacing the neighbouring pixels with a key pixel for speed up of the process. In this study, the color of the four pixels has been replaced with the color of the key pixel for rendering. The rendering time of OCC mapping and octahedral mapping is shorter than that of the spherical mapping, as evident in Table 2.

Table 2: Comparing the rendering time

Resolution	Type	OCC Map	Octahedral Map	Spherical Map
1200x800	a	0.281	0.280	0.300
	b	0.381	0.390	0.411
	c	0.902	0.891	0.981
	d	1.292	1.322	1.432
800x600	a	0.140	0.130	0.150
	b	0.180	0.190	0.201
	c	0.451	0.441	0.491
	d	0.641	0.661	0.711
400x200	a	0.020	0.020	0.025
	b	0.030	0.030	0.041
	c	0.070	0.070	0.080
	d	0.100	0.100	0.110

a: Pixel duplication, No interpolation

b: Pixel duplication, Interpolation

c: No pixel duplication, No interpolation

d: No pixel duplication, Interpolation

5. CONCLUSION & FUTURE WORKS

OCC mapping is a new method for effectively mapping the environment. This method eliminates the singularity effect caused in the environment maps and shows an almost even amount of area for the environment occupied by a single texel. The surrounding environment can also be stored more effectively through more accurate sampling. Improvement is also achieved in the rendering time of the OCC mapping method and octahedral mapping method based on OCC mapping. Therefore, the OCC mapping method is suitable to be applied on environment navigation systems due to its effective storage of the environment and faster sampling time.

The size of the area of the environment for the texel is almost even in the OCC mapping method, but not an exactly the same. Research on using other mediums such as a geodesic dome or an object created by intersecting XY, YZ and XZ cylinder is required to make the sampling process even more effective.

Also, the environment mapping method explained in this study only performs its rotation and the zoom-in and zoom-out process of the image from a fixed point of view using a single OCC map. A navigation method using multiple OCC maps is required for navigating through its environment more freely. A new rendering system that extracts more information on the relationship between OCC maps is required for the navigation using multiple OCC maps.

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