# TubeMap: A Projection for Omnidirectional View Interpolation

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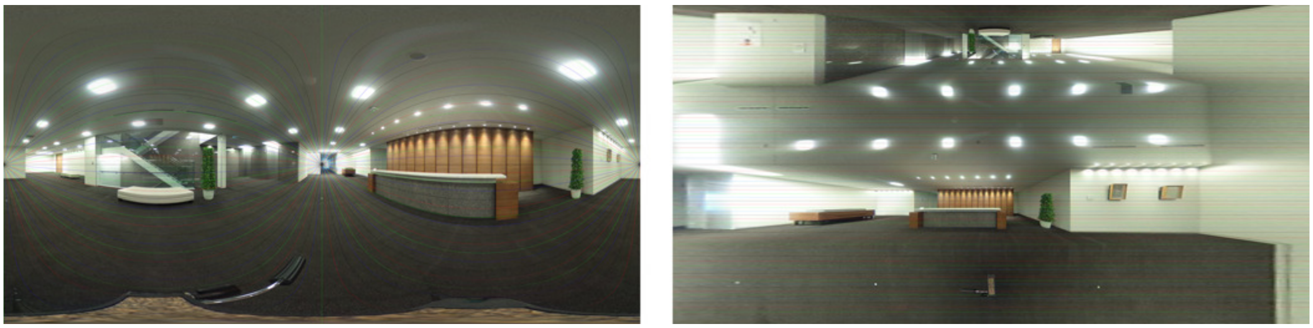

**Figure 1: Conversion of an omnidirectional image: from a) equirectangular projection, to b) TubeMap with epipolar lines.**

## ABSTRACT

We propose a projection for omnidirectional images called TubeMap which is efficient for omnidirectional view interpolation. This new projection keeps linearity on the captured scenes and covers almost every direction in a single region with no discontinuities by extending the projection planes of a cube map along the direction from one camera towards another. TubeMap makes it easy to construct correspondence between two omnidirectional images while eliminating distortion on interpolated views.

## CCS CONCEPTS

• **Computing methodologies → Image-based rendering**; *Texturing*; *Virtual reality*.

## KEYWORDS

omnidirectional image, map projection, walk-through

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## 1 INTRODUCTION

Image based rendering with omnidirectional images was first proposed by [Chen 1995]. Applications based on this idea such as city navigation [Anguelov et al. 2010] can be seen on a daily basis. Currently, most of the applications using multiple omnidirectional images update the virtual viewpoint with a pseudo transition using the so-called cross and fade technique which decreases a sense of reality in continuous locomotion. [McMillan and Bishop 1995] proposed a method for generating intermediate views from two omnidirectional images captured at adjacent locations. However, new views include measurable distortion coming from the original images projected on warped cylindrical planes, especially in applications implemented with texture mapping which projects textures linearly. Equirectangular projection, one of the recent standard projections, has the same type of distortion as the cylindrical projection. Some successor methods such as [Fiala 2005] have introduced a cube map to keep linearity in scenes. But the cube map divides the overall scene into six planes, and we need to find a line that corresponds to each border in one image from another. This association is very difficult when the image has been divided at a region with no obvious features. The HEALPix, a projection which also keeps linearity, has the same boundary problem as the cube map. We propose a projection for omnidirectional images called TubeMap which achieves both linearity and spacial unification.


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## 2 THE TUBEMAP

### 2.1 Conversion into TubeMap

Figure 2 illustrates the arrangement of four projection planes for composing a TubeMap. The green circle indicates an omnidirectional image captured in advance, and the square tube drawn with cyan lines explains the arrangement of four side faces of the TubeMap. We introduce a right-handed coordinate system as the world coordinate system. The $Z_W$ axis directs to a coaxis of two omnidirectional images; a line connecting the locations of the cameras where the two images ware captured. The tube is placed parallel to the $Z_W$ axis with an arbitrary length. The cross section is defined as a unit square, and each side face parallels the $X_W Z_W$ plane or the $Y_W Z_W$ plane. Since it is defined as a hollow tube, TubeMap has no faces for projecting the exact $\pm Z_W$ directions.

To assign the color onto pixels on the TubeMap, we first calculate the location of the pixel $P_T$ in the world coordinate system. We next obtain the direction of $P_T$ viewed from the origin $O$ by converting the location $P_T$ into the spherical coordinate system of which the zenith directs to the $Y_W$ axis using equation(1). Finally the color of the pixel $P_E$, the pixel in the obtained direction on the original omnidirectional image, is copied onto the pixel $P_T$.

$$
\begin{cases}
r = \sqrt{X_W^2 + Y_W^2 + Z_W^2} \\
\theta = \cos^{-1}\left(\frac{Y_W}{\sqrt{X_W^2+Y_W^2+Z_W^2}}\right) \\
\phi = \tan^{-1}\left(\frac{X_W}{Z_W}\right)
\end{cases}
\tag{1}
$$

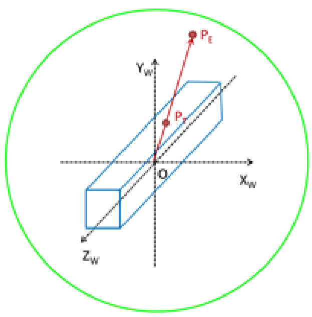


**Figure 2: Projection planes for TubeMap.**

## 2.2 Observation on TubeMap

Figure 1 shows an example of a) an original equirectangular image and b) a converted TubeMap. The TubeMap consists of four horizontal belts. Each belt represents left, top, right and down side of the scene from the top to the bottom of the image.

The straight lines in the scene, such as edges of walls and edges of fixtures, keep their straightness in the TubeMap while they appear as curves in the equirectangular image. This linearity can be expected to eliminate distortion in interpolated views generated by texture mapping. In addition, epipolar lines appear as parallel lines in the TubeMap while they appear as radial curves in the equirectangular image, as drawn in both images at intervals of 5 degrees around the coaxis. TubeMap has an advantage over a cube map in that it covers almost the entire direction within a single rectangle region just as well as a cylindrical projection.

On the other hand, some regions around the $Z_W$ axis are missed in TubeMap because the length of the tube is finite. Overcoming this drawback needs further consideration. It can be assumed that the disparity among objects appearing in the missed areas is considerably small if the length of the tube is long enough, and it is expected to look natural by filling the two holes using billboarding in the final step of rendering.

## 3 RESULT AND CONCLUSIONS

Figure 3 shows an example TubeMap we used for view interpolation. In this case, the tube is seven times as long as its section, and two regions which compensate for missed regions are added to the left side of a pure TubeMap. Each of two regions is clipped in 90 degrees of the field of view as a standard cube map would be, and it is used for capping the aperture of a TubeMap. We next associate feature points appearing in a pair of TubeMaps. Because straight lines keep their straightness in TubeMaps, the couples can be specified line by line. In addition, the TubeMap has enough of the region duplicated in both the tube and the caps to makes it possible to associate features over the entire direction at visually obvious lines in the same part of the capped TubeMap.

Figure 4 shows the transition of the generated views rendered with two adjacent virtual viewpoints. The view transition looks natural including the capped regions which fill holes by billboarding. Figure 5 shows a comparison on interpolated views between two projections. The result a) by equirectangular projection shows a certain distortion on borders of the fixture, while the result b) by TubeMap contains no remarkable distortion.

**Figure 3: A capped TubeMap.**

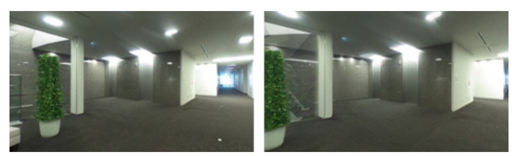

**Figure 4: View transition.**

**Figure 5: Interpolated view from a) equirectangular projecttion and b) TubeMap.**

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