Panoramic Mosaics of Slit Images with Depth*

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Abstract

In this paper, we present a new image based rendering technology called panoramic mosaics of slit images with depth. By limit camera motion only in a horizontal plane, a slit image with united depth value is used as the element of rendering. Compared with panorama, this method can support the movement of virtual camera. Multiple panoramic mosaics of slit images with depth can be joined up to provide a wider range movement of virtual camera. The panoramic mosaics of slit images with depth are easy to capture, and the data size is as small as panorama. We present here the capturing, construction as well as rending process of panoramic slit images mosaic with depth. In addition, we present the join up process of multiple panoramic slit images mosaic with depth.

Keywords: Image based rendering (IBR)   Panorama Slit images

1. INTRODCTION

Traditional computer graphics try to generate realistic scene view from a geometric model. Computer vision extract geometric model by analyzing images from real scene. Combine them together we got the idea of Image-based rendering (IBR), which generate realistic scene view from some analyzed real images (photographs) alone the motion of a virtual camera. The modeling of scenes photorealistically is then easier, and the rendering speed is faster.

Panorama [1] is one of the first Image-based rendering (IBR) technologies used and is still using widely. Using this technology, a set of photographs was taken in a viewpoint. The photographs was then registered [9][3] and stitched together to construct a panorama. The advantage of panorama is easy to capture and small in data size. Its disadvantage is the viewpoint is fixed and only the viewing directions and camera zoom can be altered.

This paper presents panoramic mosaics of slit images with a united depth. It supports the movement of virtual camera. In addition, several mosaics generated by this technology may join-up to provide wider range virtual camera motion.

Slit images are kind of 1-D images with width only 1 pixel. We can treat them as a column of a normal image. The concept of slit image comes from computer vision [5][10], and it is used in several image-based rendering systems. In *Multiple-Center-of-Projection (MCOP) images* [6], a set of slit images instead of normal images is taken to achieve uniform sample. MCOP images is a kind of range image, that is, every pixel in image has its depth value sampled by special equipment (e.g., range finder).

Another image-based rendering technology using silt image is the *concentric mosaics* [7]. In concentric mosaics, cameras move alone planar concentric circles, and create concentric mosaics using a manifold mosaic for each circle (i.e., composing slit images taken at different locations). Concentric mosaics index all input image rays naturally in 3 parameters: radius, rotation angle and vertical elevation. Novel views are rendered by combining the appropriate captured rays in an efficient manner at rendering time.

The paper is organized as follows. We introduce the research works we have done on depth recovery from slit images and present the concept of slit images with depth in Section 2. In Section 3 we present the sampling and constructing process of panoramic mosaics of slit images with depth as well as the rendering of novel view using this mosaics. In Section 4 we present an experiment system to verify our idea. We summarize our work with some conclusion in Section 5.

2. THEORY AND CONCEPT

2.1 Slit Images with depth

As recent research show, geometric information can help to reduce the photos needed in new scene view synthesizing. [2] In other words, with same number of photos, more geometric information, more view can be synthesized. If we know nothing about the scene geometry, a panorama is only the panorama itself: no new view available if we leave the original viewpoint. However, if we know some depth information, we can deduce the corresponding points in the new view of pixels in original photos. Assume the surface is Lambertian, We can synthesize the novel view from the original photos by interpolation [2] or morphing [8]. However, it is hard to get the depth value of every pixel in a real scene.

Most computer graphics technology is used to simulate human motion and observing. The character of human motion is, motion usually only in 2-D: left and right, or forward and backward. In such condition, pixel change in horizontal direction is much faster than that in vertical direction. If the motion of virtual camera is limited only in a horizontal plane, we can make a helpful simplification: combine vertical pixel together, use the combination i.e., slit images to be the element in image warping. A *united depth value* is used for the whole slit image.

Of course, especially in forward and backward motion, depth variance alone slit images also cause pixel change in slit images. If we want this simplification approaches the truth, another assumption is needed: for most pixels in a slit image, the depth variance should be small. In some type of scene, this assumption

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is true. when most objects in a scene are very far away from the viewpoint, this assumption could think to be true.

We call a slit image with a united depth value "slit image with depth", and will use a panoramic mosaics of slit image with depth for our rending.

2.2 Analogical Slit images

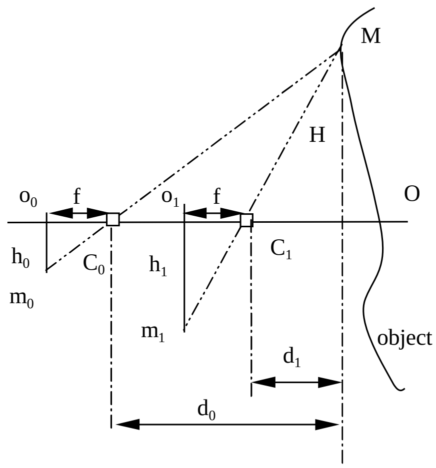


Figure 1: Analogical slit images

As shown in figure 1, two slit images that are captured by the same camera, from a same direction but at two different positions is called the *analogical slit images*. [4] Because they contain the projections of almost the same scene objects, especially when the camera positions of two slit images is near. Now consider a point *M* in scene, its projection in two analogical slit images is m_1 and m_2 respectively. m_1 and m_2 are called corresponding points in the term of computer vision.

Denote the optical center of the two cameras is C_1 and C_2 respectively. Using pinhole model of camera, we can deduce the following (When H is not equal to zero):

$$\begin{cases} \dfrac{f}{d_1} = \dfrac{h_1}{H} \\ \dfrac{f}{d_2} = \dfrac{h_2}{H} \end{cases} \qquad (1)$$

Where f is the focus length of cameras in pinhole model, H is the distance from M to the optical axis of camera. d_1 and d_2 are length of projection in the optical center of MC_1 and MC_2, h_1 and h_2 are distance from the optical center to m_1 and m_2, respectively.

Obviously, when H is not equal to zero, neither h_1 nor h_2 will equal to zero. From equation 1 we will get:

$$\frac{h_2}{h_1} = \frac{d_1}{d_2} \qquad (2)$$

or

$$\frac{h_1 - h_2}{h_2} = \frac{d_2 - d_1}{d_1} \qquad (3)$$

These equations can be used to recover depth from looming parallax. If we knew the corresponding point of the two slit image, we can deduce the d value from the above equations. Another usage of the equation is that after we assumed the slit image has a united depth value, a scale up and down process will be applied to the slit image to simulate the looming parallax while viewpoint moves:

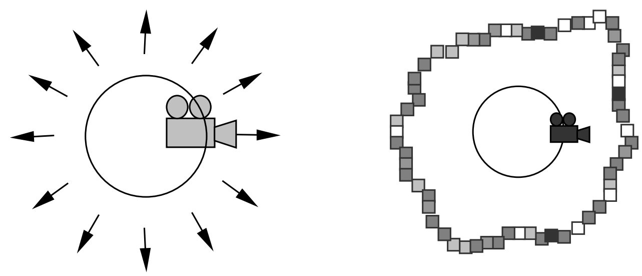
$$\frac{l_O}{l_V} = \frac{d_V}{d_O} \qquad (4)$$

Where d_O is a initial depth value of a slit image, l_O is a initial length of a slit image. d_V is depth value from a given virtual camera, and d_V is the new length of the slit image at that viewpoint. The slit image is scaled up/down for the simulation.

3. PANORAMIC MOSAICS OF SLIT IMAGES WITH DEPTH

3.1 Sampling and construction

The Panoramic Mosaics of Slit Images with Depth is sampled as figure 2(a) shows. We use a single off-centered camera that rotates along a circle(called the *sampling circle*) to sampling the scene, and the direction of camera is always alone the normal direction of the circle. At each rotation angle, a slit image is captured. (An alternative solution is to capture a normal image, and pick out the middle column of the image.) We call these captured slit images as sampled slit image. All sampled slit images are stitched together to construct a panoramic mosaics.



(a) sampling method (b)sampled slit image

Figure 2: the sampling of Panoramic Mosaics of Slit Images with Depth

The next problem is how to get the united depth of the sampled slit images. If we sample another panoramic mosaic of slit images in a concentric circle but with different radius, the depth of every slit image in the mosaic can be recovered using the analogical slit image method introduced in section 2.2. Every slit image can find its analogical slit image in the second mosaic easily. We have developed an algorithm that can automatically find out the corresponding point between analogical slit images [4]. The corresponding relations can also be interactively specified. The depth of pixels can be derived from equation 2. Then a small depth value range, which can best approaches the depth distributing of the slit image, is selected to be the united depth of the sampled slit image. If the scene geometry is simple, the depth can even be specified directly from a predefined map.

Note for a sampled slit image, the united depth of is not assigned by a single value, but a small range. Also should note although the sampled slit images are only one pixel wide, they still have a small horizontal field of view (FOV). These make those sampled slit images with depth look like some colored "fine pillars" with volume rather than some one-dimension lines, as shown in figure 2(b). Sampled slit images can be treat as a set of ideal slit images with same pixel values. In the following, the term "slit image" is used to denote ideal slit images, that is, 1-D slit image.

3.2 Rending using Single Panoramic Mosaic of slit images with depth

3.2.1 Mapping slit images

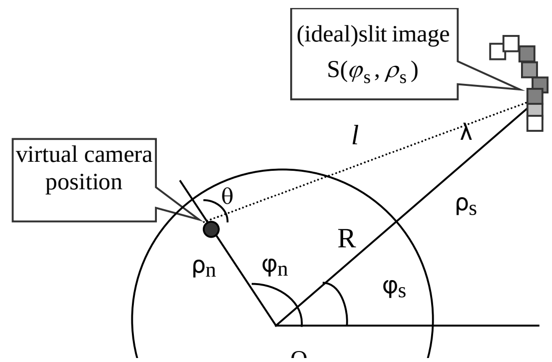


Figure 3: Mapping from slit images in the panoramic mosaic to the virtual camera

In a single panoramic mosaic of slit images with depth, every (ideal) slit image is identified by polar coordinate, written as S(ϕ, ρ). The origin point of the polar coordinates O is located at the center of sampling circle. where $\rho$is the “distance” from slit image to the origin point O, equal to the united depth value of slit image plus the radius of sampling circle R.

Now if the virtual camera located at position (ϕ_n, ρ_n), the relations between the virtual camera and the slit images are:

$$\begin{cases} \dfrac{\rho_s}{\sin(\pi+\theta)} = \dfrac{d_n}{\sin(\phi_n - \phi_s)} = \dfrac{\rho_n}{\sin\lambda} \\ \pi + \theta + \phi_n - \phi_s + \lambda = \pi \end{cases} \quad (5)$$

Whereθ is the viewing angle there the slit image S(ϕ_s, ρ_s) will appear in the novel view, d_n is depth value of a slit image in the virtual camera, and λ is the angle of incidence to the slit image. Using equation 5, we can define a forward mapping from slit images in the panoramic mosaic to the virtual camera, and construct the novel view.

3.2.2 Synthesizing images

Normally, the novel view is not a panoramic one, it is specified by a horizontal field of view (FOV) ω and the virtual camera direction θ_n. That is, after the mapping, only slit images map to the region $\theta_n - \pi/2 \le \theta \le \theta_n + \pi/2$ is needed. The mapped slit images are then scaled up/down to simulate the looming parallax as introduced in Section 2.1.

Holes and overlaps are key problems with forward mapping. Hole here means on one viewing angle θ in the novel view, no slit image is mapped to. Overlap here means more than one slit image is mapped to one viewing angle θ in the novel view. To solve the overlap problem, note d_n in equation 5 is depth value of a slit image in the virtual camera, we can pick the slit image with the minimum d_n for this viewing angle. For the hole problem, we can use the way similar to [2], fill the hole by interpolating nearby slit images.

Holes are caused by insufficient sampling. The interpolation is just an inaccurate method. To solve this problem, we need more scene information.

Although there is no explicit limit for the motion of virtual camera in the 2-D plane, A single panoramic mosaic of slit images can just offer a finite sample of scene. The far the virtual camera leaves the center of sampling circle, the less slit images can be used for novel view. This will cause the degradation of image quality and potentially limit the motion range of virtual camera.

3.3 Rending using Multiple Panoramic Mosaics of slit images with depth

Multiple panoramic mosaic of slit images with depth can be joined up (figure 4). Holes may be filled by new information, slit images from different mosaics can prevent the degradation of image quality and expend the potential motion range of virtual camera.

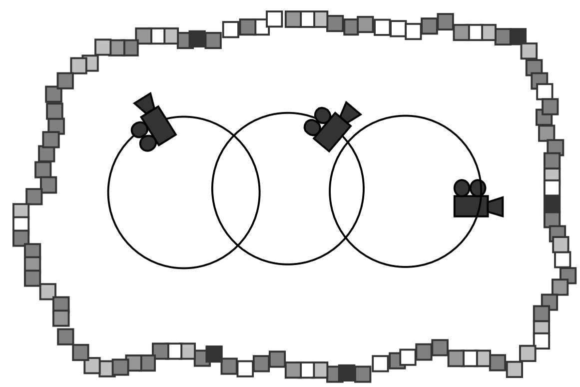


Figure 4: Multiple panoramic mosaic of slit images with depth

However, the forward mapping will consume more time as the number of slit images increase. This will slow down the rendering process. To solve this problem, we define a three-step method for the mapping.

3.3.1 A three step mapping

As shown in figure 5(a), we first define some *reference circles* in the scene. The virtual camera motion will be limited inside those circles. Uniformly pick out some points alone every circle to be the *reference points*. For clarity, only a few reference points are drawn in figure 5 (a), but in practice a large number of reference points in each reference circle will be needed.

At each reference point, record all slit images that can be seen “outward” the circle. (figure 5b) The process could also be thought as put a virtual camera on the reference point, the virtual camera direction is alone the normal direction of reference circle and horizontal FOV is π, then find slit images for the novel scene just like in Section 3.2. Instead of generate a novel image, slit images are recorded as well as their distance (i.e., d_n in equation 5).

Define an index to record the slit images. For every reference point on each reference circle, every viewing angle (note viewing angle is also discrete) define a structure:

IDX(reference_circle, reference_point, viewing_angle)

{

slit_image_ID;

distance;

incidence_ angle;

}

Its content is a global ID of a slit image, the distance from slit image with depth to the reference point, and the angle of incidence (λ in equation 5). The angle of incidence is actually the difference between the direction from which the slit image is captured and the direction from which is looked in the novel scene. The larger the difference is, the more error will appear. We must consider this in the context of rending using multiple panorama mosaics and pick out the slit image that has the smallest angle of incidence to constitute the novel scene. Now if a slit image whose global ID is *s_ID*, the viewing angle relative to a reference point *r_point* is *v_angle*, the distance form the slit image to the slit image is *dis*, and the angle of incidence is *i_angle*, record them as following:

$$IDX\,(r\_circle, r\_point, v\_angle) : (s\_ID; dis; i\_angle)$$

r_circle is the reference circle which *r_point* belongs to. The viewing angle is defined as the angle between the normal direction of reference circle at the reference point and the line from reference point to the slit image. Use counter-clockwise direction as the positive direction. So that a valid("outward") viewing angle should between –π/2 andπ/2.

If more than one slit image at the same view angle relative to a reference point, only the slit image with the minimum distance is recorded.

An algorithm for this step is presented as following, using a C-like style:

init all IDX, set distance to be ***maximum distance value****, set slit_image_ID to be* ***null****;*

for every slit image s_image in scene

{

for every reference point r_point in every reference circle r_circle

{

calculate the viewing angle v_angle from s_image to r_point;

if v_angle ∈ (-π/2, -π/2)

{

calculate the distance current dis from s_image to r_point, and the angle of incidence i_angle.

if

current_dis is less than the distance value in current IDX(r_circle, r_point, v_angle)

or

the difference between current_dis and distance is small and i_angle is smaller than the incidence_ angle in current IDX(r_circle, r_point, v_angle)

{

record s_image to IDX(r_circle, r_point, v_angle), update dis. i_angle:

IDX(r_circle,r_point,v_angle):(s_image ;current_dis; i_angle);

}

}

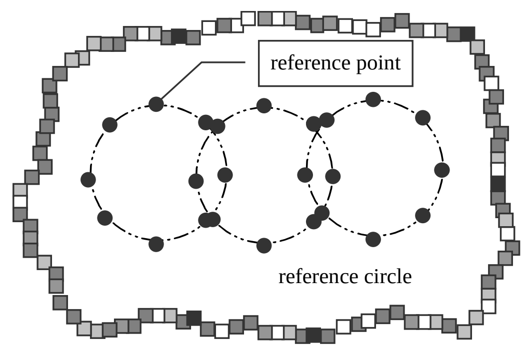
}

}

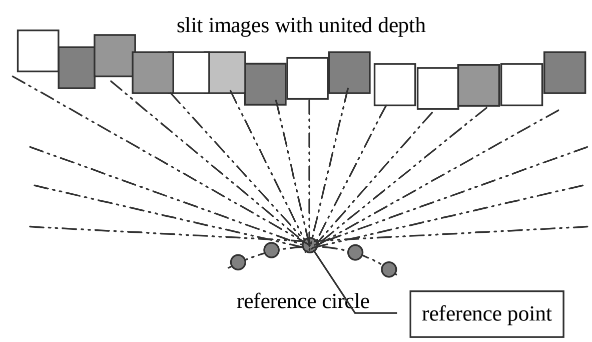
3.3.2 Synthesizing images

While virtual camera moving, for every viewing angle in the field of view, find the nearest reference point (figure 5c) and calculate the angle of incidence to that point. From the point and the angle, corresponding IDX can be found alone with the slit image ID and *dis*. The distance between current virtual camera and the slit image is equal to the distance from virtual camera to reference plus *dis*.

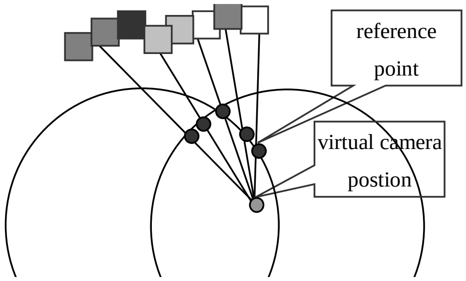
The novel view is synthesized using almost the same method like in Section 3.2.2. Slit images are found out and scaled up/down according to the distance. Because the use of IDX simplified the mapping of slit image, the rendering speed can be in real time.



(a)



(b)



(c)

Figure 5: A three-step mapping process in multiple panoramic mosaic of slit images with depth

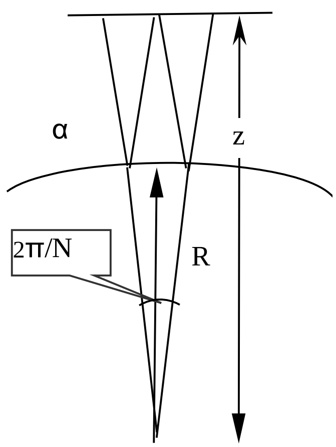


Figure 6: The maximum number of slit images that can be sampled in a circle

4. IMPLEMENTATION

4.1 Sampling

The sampling method has shown in figure 2 (a). The radius of sampling circle will affect the number of slit images that can be sampled. As shown in figure 6, if the maximum number of slit images that can be sampled in a circle is N, there will be the following relation:

$$tg(\pi/N) \approx tg(\alpha/2)(z-R)/z \quad (6)$$

Where R is the radius of sampling circle, z is the distance between scene object and center of sampling circle, and α is the horizontal field of view of a slit image. If the number of slit images in a sampling circle is more than N, the scene view of neighborhood slit images will overlap and no new information can be used.

A bigger radius of sampling circle can gather more information in the horizontal direction – but as shown in Section 2.2, less information in the vertical direction will be gathered. While sampling, this trade off should be considered.

The depth can be deduced from corresponding points between analogical slit images or imported from a predefined scene map. If the latter is used, depths need to be calculated using plane geometry.

4.2 Preprocessing

The preprocessing stage is used when using multiple panoramic mosaics for rendering. The process should:

1. Identify every sampled slit image by a global ID. This ID can be composed of the sampling circle ID and the camera azimuth when the slit image is captured.

2. Position all slit images captured at different sampling circles to one united coordinate.

3. Specify the reference circle and generate the reference point.

4. Using algorithm described in section 3.3.1, generate the IDX structures.

Note while generating IDX structure, some IDX may find no slit image mapped to this reference at this viewing angle(i.e., after execute algorithm in Section 3.3.1, the result *Slit_image_ID* field in a IDX is still *null*), as the “hole” described in Section 3.2.2. If this occurs, the IDX will be tagged as “hole”.

4.3 Interactive rendering

For a single panoramic mosaic, a forward mapping process is executed in the interactive rendering stage. Because the number of slit images is small, forward mapping process will not take much time. The process will be follows:

1. Decide slit images in the novel view using forward mapping. Calculate the slit images’ depth value (distance) relative to the virtual camera. Compare the depth value to solve the overlap problem. Tag holes.

2.Scale slit images up/down according the depth value to simulate the looming parallax. Copy them to the novel image.

3. Fill holes by interpolate the nearby slit images.

In the context of multiple panoramic mosaics, only the first step is different. That is:

1. For every viewing angle of the novel view, find the nearest reference point and calculate the angle of incidence. Find corresponding IDX. From the IDX retrieve the slit image ID. Calculate the depth for every slit image will be used.

2.Scale slit images up/down according the depth value to simulate the looming parallax. Copy them to the novel image.

3. Fill holes by interpolate the nearby slit images.

An example of panoramic mosaics of slit images with depth is shown in figure 7. It is captured from a hall. The novel view alone with virtual camera move is shown in figure 8. We generate the novel views using the algorithm described above with the panoramic mosaics of slit images with depth is shown figure 7.

5. CONCLUSION

The data size verses the virtual camera motion range has long been a trade off for most image-based rendering system. Small data size, like in panorama, means fixed viewpoint. When camera moves, like in Light Field or Lumigraph, many data will be needed.

In this paper, we present a new image based rendering technology called panoramic mosaics of slit images with depth. This method can support the movement of virtual camera, and the data size is as small as panorama. Multiple panoramic mosaics of slit images with depth can be joined up to provide a wider range movement of virtual camera. The panoramic mosaics of slit images with depth are also easy to capture.

By assuming most pixels in slit images have small depth variance, we use a united depth for the slit images. This assumption can not be used in complex scene. That is the limitation of this system. In such condition, an alternative method is to use slit image segments [4] to synthesizing the scene.

6. REFERENCES

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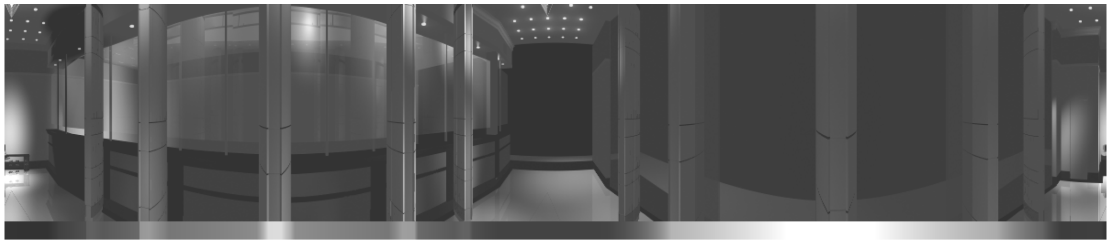
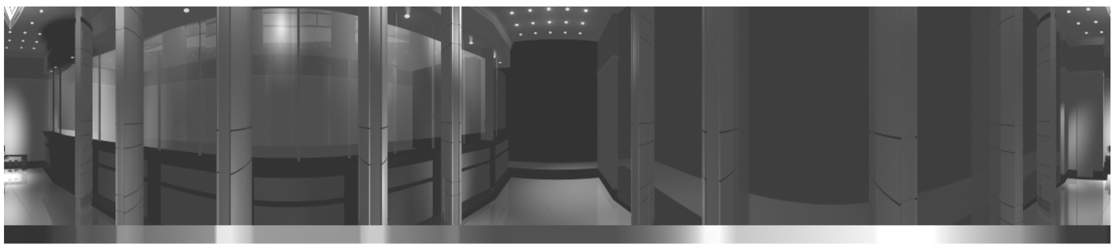
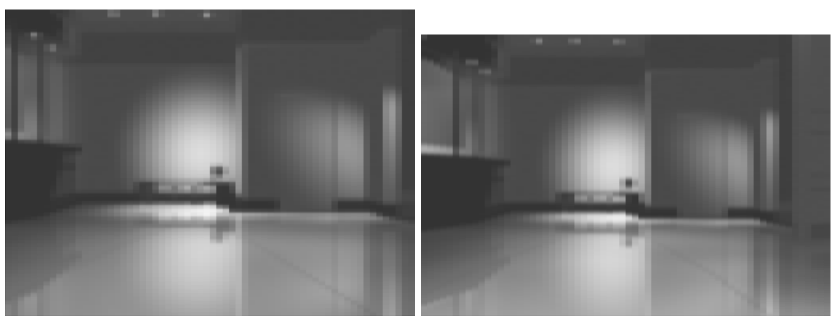


a)

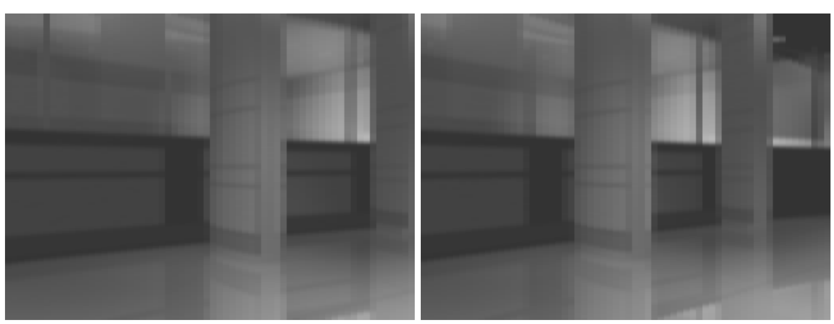


b)

Figure 7: Two Panoramic Mosaics of Slit Images with Depth, the strip below indicates the depth, darker is farther



(a) Moving forward and backward



(b) Moving left and right

Figure 8: Novel view from the Panoramic Mosaics of Slit Images with Depth