ELLIPTIC-CYLINDRICAL PANORAMA

Yo-Rong Chang (張祐榕), Chiou-Shunn Fuh (傅楸善)

Dept. of Computer Science and Information Engineering,
National Taiwan University, Taiwan
E-mail: b99902015@ntu.edu.tw

ABSTRACT

This paper presents a novel panorama stitching system of photos taken by a fixed rotating camera with a different projection coordinate. Instead of following the conventional preprocessing step to warp the photos into plane or cylindrical coordinate, we project the photos into an elliptic-cylindrical coordinate. We show that such elliptic-cylindrical projection is a compromise of planar and cylindrical projections, which does not lead to serious scale distortion and curving. Furthermore, to deal with the panorama with wide angle of view (more than 180°), we propose the method of changing the center of view to get more compelling results.

Keywords *Panorama; Elliptic-Cylindrical; Projection;*

1. INTRODUCTION

The conventional preprocessing step of panorama creation with fixed camera center is warping the photos into plane or cylindrical coordinate. But plane projection causes serious scale distortion (Figure 1(a)) and cylindrical projection causes nonlinear distortion which results in curved straight lines (Figure 1(b)).

(a)

(b)

Figure 1. Conventional preprocessing step of panorama creation [1]: (a) projection into plane, and (b) projection into cylindrical coordinate.

In this paper we construct a compromise system by warping the photos into elliptic-cylindrical coordinate, which is more pleasant to eye without serious scale distortion and curving effects. We discuss on the steps of projecting images into elliptic-cylindrical coordinate in section 2, and compare different projections in section 3. In section 4 we will deal with the problem of panor-ama with wide angle of view by changing the center of view.

2. ELLIPTIC-CYLINDRICAL PROJECTION

Figure 2 shows the relation between projections of plane, cylindrical, and elliptic-cylindrical coordinates. We can see that elliptic-cylindrical projection is an intermediate between cylindrical and planar projections. Therefore, the projection of elliptic-cylindrical coordinate can balance the effects of scale distortion and curving, which are cause by planar and cylindrical projection respectively.

We decompose the elliptic-cylindrical projection into five steps: motion matching, angle calculation, arc length calculation, alignment and blending.

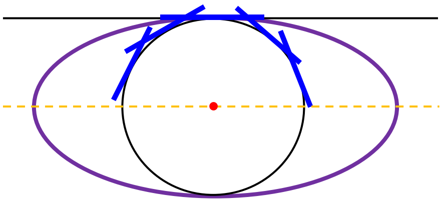
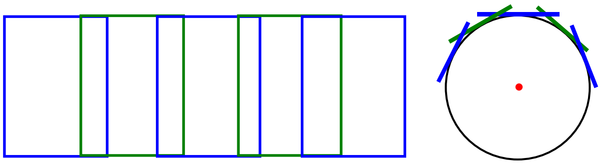


Figure 2. Relation between different projection coordinates. The red point is camera center; blue line segments are images.



(a) (b)

Figure 3. The arrangement of image positions. (a) In image coordinate. (b) In camera coordinate. The colors are meaningless, which are just for identification.

2.1. Motion Matching

We first detect and match the feature points, and then calculate the motion between nearby images. Now we only care about the horizontal motion $move_h$ in order to get the relatively horizontal positions, the vertical motion is ignored. The result looks like Figure 3.

2.2. Angle Calculation

After arranging horizontal positions of the images, we could calculate the angles in camera coordinate.

First we set $\theta_0 = 0$ and calculate θ_1 to θ_{N+1}, where N is the number of images; θ_i for $i \in [1, N]$ are angles of middle of images; θ_0 and θ_{N+1} are angles of left end and right end.

$$\theta_1 = \tan^{-1}(\frac{W/2}{f}),$$

$$\theta_i = \theta_{i-1} + \tan^{-1}\left(\frac{W/2}{f}\right) + \tan^{-1}\left(\frac{move_h^{i-1} - W/2}{f}\right), \qquad i \in [2, N]$$

$$\theta_{N+1} = \theta_N + \tan^{-1}(\frac{W/2}{f}),$$

where f is the focal length, and W is the image width. And then in order to adjust the angle = 0 into center, let $\theta_i = \theta_i - \theta_{N+1}/2$. Finally, we can calculate the remaining angle in image by $\theta = \theta_i + \tan^{-1}(x/f)$ with image according to θ_i ; x is the horizontal image coordinate with origin in image center.

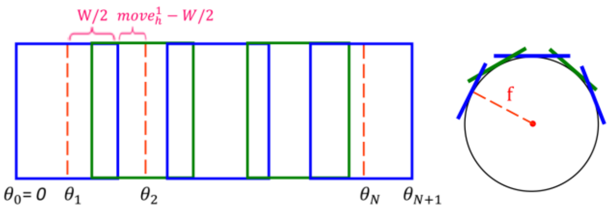


Figure 4. Angle calculation. The red dashed lines show the median of the images.

2.3. Arc Length Calculation

After getting the angles, we can approximate the arc lengths by integration, and get the polar coordinate with the origin at the center of the ellipse, (θ, r) with the clockwise angular coordinate θ measured from the semi-minor axis.

$$r(\theta) = \frac{ab}{\sqrt{(b\,sin\,\theta)^2 + (a\,cos\theta\,)^2}} \,,$$

where a and b are the semi-major and semi-minor axes (1/2 of the ellipse's major and minor axes), respectively.

Then we can project the images into elliptic-cylindrical coordinate by

$$x' = arc(\theta)$$

$$y' = y\,\frac{r(\theta)}{\sqrt{x^2+f^2}}.$$

Note that (x, y) and (x', y') are in different coordinates. Figure 5 illustrate the elliptic-cylindrical coordinate projection.

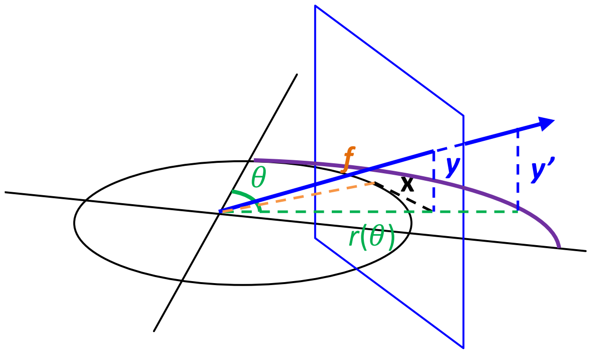


Figure 5. Project the images into elliptic-cylindrical coordinate (the purple curve).

2.4. Alignment and Blending

After projecting the images into elliptic-cylindrical coordinate, we already have approximately correct new x coordinate. Now we can re-compute the motion to get new y coordinate and more accurate new x coordinate. Moreover, we could fix up the end-to-end alignment at the same time.

Then we can get the panorama result by blending the overlap regions.

2.5. Implementation Details

For the detection and matching of the feature points, we use SIFT implemented by VLFeat [2] and use RANSAC to exclude the outliers from fitting model of motion matching.

For the focal length of images, we use the estimation result of Matthew Brown's AutoStitch software [3].

To approximate the arc lengths by integration, we divide the whole ellipse into *Nseg* pieces. We use 10,000 as *Nseg* in our implementation. Then we consider the small arcs as straight segments, and accumulate their lengths as the whole arc length. The segments end point coordinates are calculate by

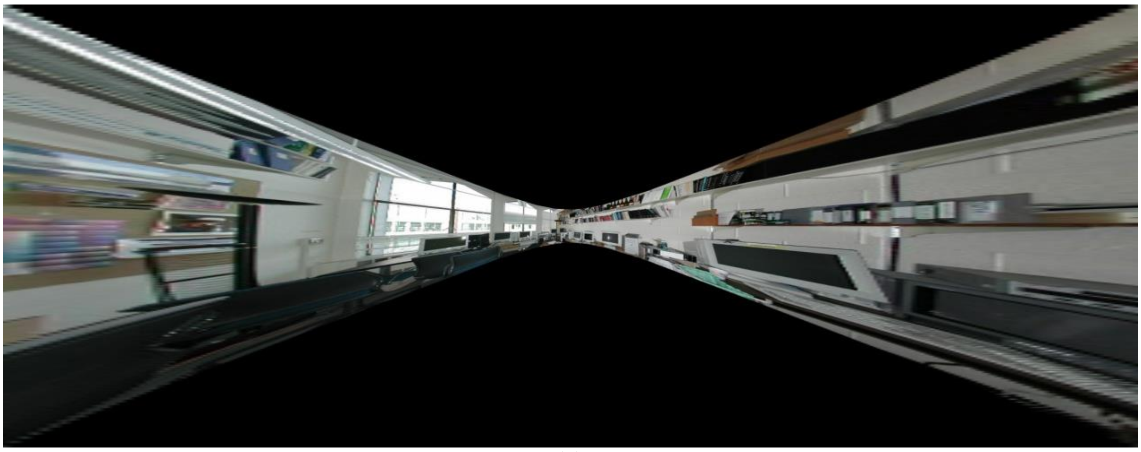
$$x = sin(\theta)\,r(\theta)$$

$$y = cos(\theta)\,r(\theta).$$

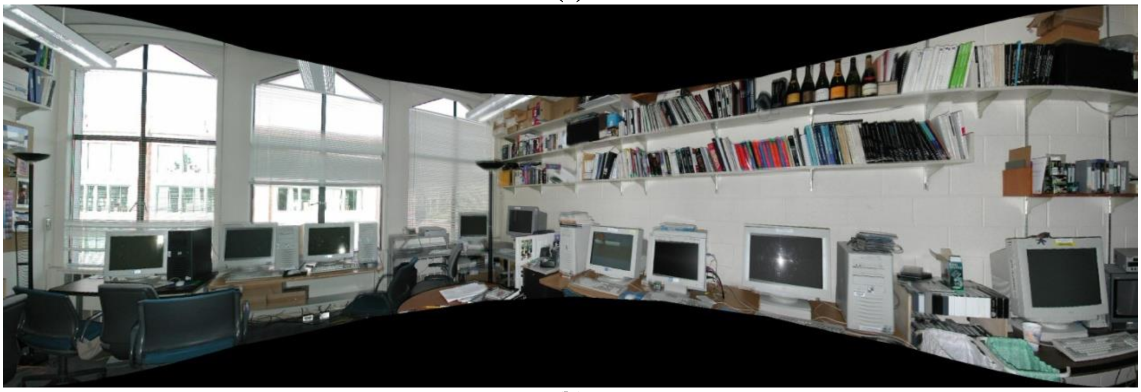
Since we cannot get the angle by the given arc length, it is really hard to do elliptic-cylindrical projection from backward warping. Thus we do the projection forward, and then fill the holes by bilinear interpolation.

3. COMPARISON AND LIMITATION

In Figure 6 we compare the different projection coordinates. We can see that elliptic-cylindrical projection is more pleasant to eye without serious scale distortion and curving effects.



(a)



(b)

(c)

Figure 6. Projection into (a) plane, (b) elliptic-cylindrical coordinate with $a = 2f$, $b = f$ and (c) cylindrical coordinate.

And we compare the elliptic-cylindrical projection with different coefficients in Figure 8. The larger the ratio of major and minor axes is, the less curving but more scale distortion the result panorama has.

However elliptic-cylindrical projection is suitable for panorama with angle of view smaller than 180°, because it would cause serious curving when projecting to the end of major axes of ellipse as shown in Figure 9.

4. PROJECTION WITH NEW CENTER VIEW

Our solution to the problem about wide angle panorama draws inspiration from human behavior. Since the angle of visual field in human is fixed, we usually would step back when we want to get a wider field of view. To overcome the limitation of angle of view (AOV), we change the center of view as Figure 7. In panorama with AOV larger than 180°, we use the midpoint of endpoints of the panorama images as the new center.

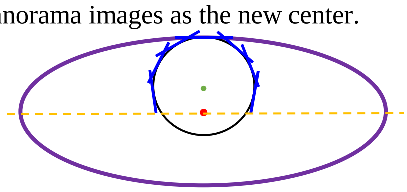
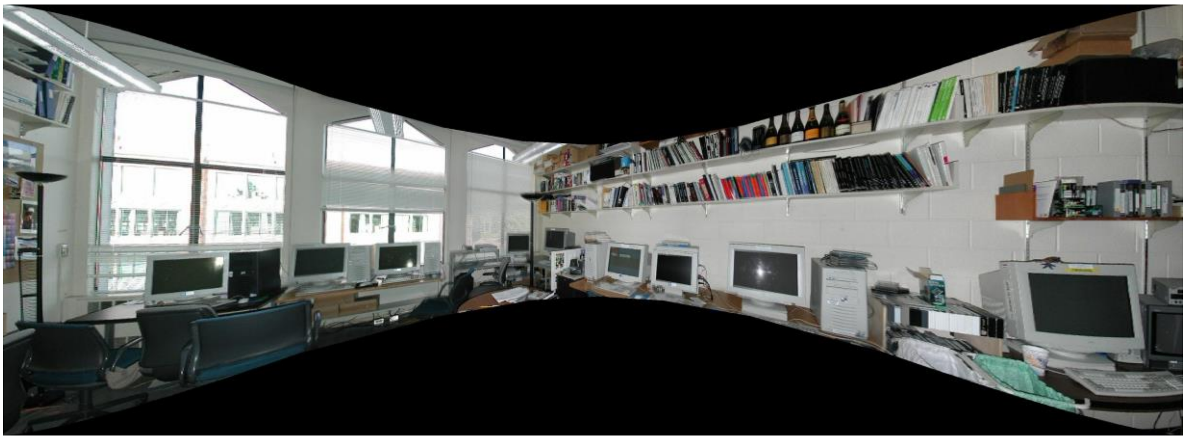


Figure 7. When the angle of view is larger than 180° use the red point as the new center.

As shown in Figure 7, the images would only projected into half of the elliptic-cylinder when the angle of view is larger than 180°.

(a) $a = 1.5f$, $b = f$.

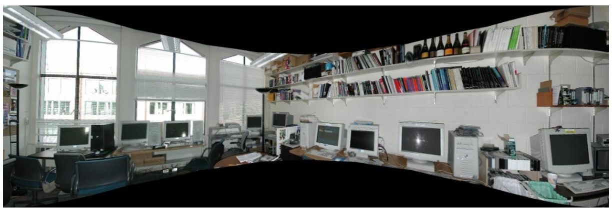


(b) $a = 3f$, $b = f$.

Figure 8. Projection into elliptic-cylindrical coordinate with different coefficients.

(a)

(b)



(c)

(d)

Figure 9. Projection of a 360°room (a) into cylindrical coordinate (b) into elliptic-cylindrical coordinate with $a = 2f$, $b = f$. And projection into elliptic-cylindrical coordinate of room with about 170°view with $a = 2f$, $b = f$, which are the (c) left part and (d) right part of the room.

The procedures of generating panorama with new center of view are approximately same as the previous one, but it needs to use the new angles and project into different coordinates.

4.1. Angle of New Center

After getting the angles in camera coordinate, θ, we can calculate the angles in elliptic coordinate with new center by

$$\theta' = \tan^{-1}\left(\frac{f\, sin\theta}{f\, cos\theta + d}\right)$$

$$d = f\cos(\theta_{N+1}),$$

where d is the distance from the camera center to the new elliptic coordinate center.

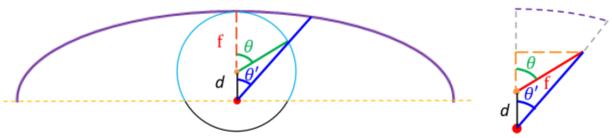


Figure 10. Calculate angles in elliptic coordinate with new center, θ', from θ.

4.2. Projection with New Center View

Since we use a different center of view, we cannot project the images to the coordinate with new center directly. Otherwise, it would project the same object into different position or project different object into the same position, which are shown in Figure 11.

Therefore, we project the images into elliptic-cylindrical coordinate with new center by

$$x' = arc(\theta')$$

$$y' = y\,\frac{f}{\sqrt{x^2+f^2}}\,\frac{r(\theta')}{\sqrt{(f\, sin\theta)^2+(f\, cos\theta+d)^2}},$$

which is actually equivalent to first project into cylindrical coordinate, and then project into elliptic-cylindrical coordinate with new center.

4.3. Scale Adjustment

Since the positions of images around the endpoints of the panorama may be too close to the new center, the scale of their projections would be too large. Especially when constructing a 360° panorama, the distance from the endpoints to the new center is zero, which would lead to infinite projection size. Figure 12 illustrates this scale problem around endpoints.

We adjust the projection scale when absolute angle $|\theta|$ is more than 90° from center. We use the distance from new center to the 90°-point, *Dist*, as base distance, and adjust the ratio of *Dist* to the distance from new center to the image point, $dist(\theta)$.

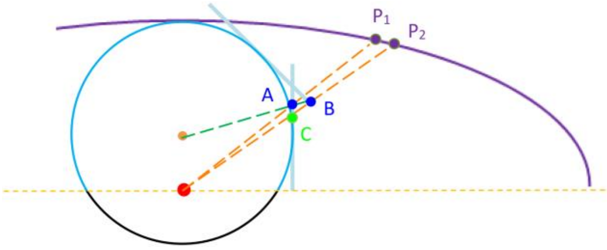


Figure 11. Points A and B are same object on different images, but they are projected into different positions (P_1 and P_2 respectively); points B and C are different objects, but they are projected into the same position P_2.

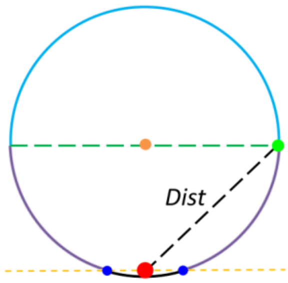


Figure 12. Image points near the endpoints of the panorama (blue points) would be too close to the new center (red point). Green point is the 90°-point. And we would adjust the projection scale of purple area.

We calculate the new projection scale of image points with angle θ more than 90° from center by

$$Dist = \sqrt{f^2 + d^2}$$

$$dist(\theta) = \sqrt{(f\, sin\theta)^2 + (f\, cos\theta + d)^2}$$

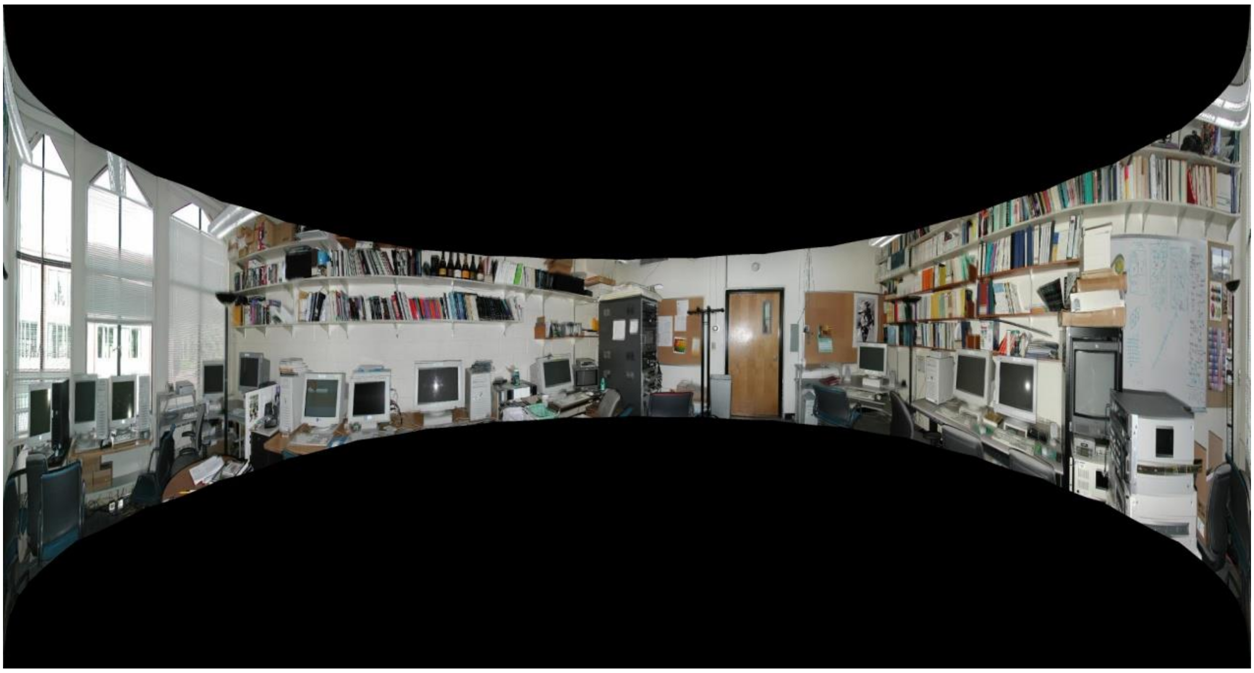
$$mul = \begin{cases} Dist & \text{if } dist(\theta) < 1 \\ \dfrac{Dist}{dist(\theta)} & \text{else} \end{cases}$$

$$y' = y\,\frac{f}{\sqrt{x^2+f^2}}\,\frac{r(\theta')}{\frac{Dist}{\log(\log(mul+1)+1)}}$$

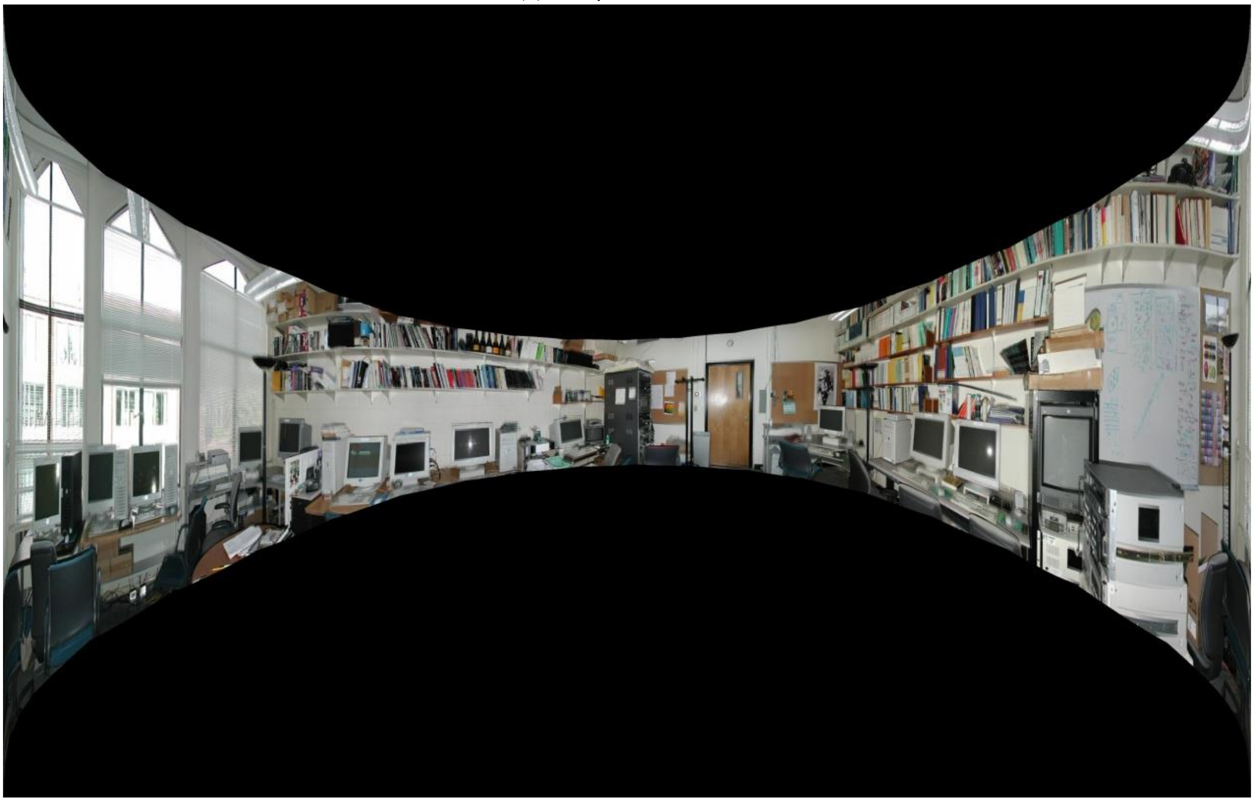
4.4. Result

The results of elliptic-cylindrical projections with new center view are shown in Figure 13, which are obviously more pleasing to the eye and more compelling. But the scale adjustment step causes some notice-able curving in two ends of the panorama results. The better way is to crop parts of the ends if does not want this curving effect.

The appropriate ratio of major and minor axes for elliptic-cylindrical projections with new center view would be smaller than the suitable ratio for original elliptic-cylindrical projection. This is because the minor axis is set as $f+d$ in new center version, and the positions with absolute angle $|\theta|$ more than 90° are quite close to the new center. Therefore, the scale of projection results would be large enough with small ratio for new center projection.



(a) $b = f + d$, $a = b$.



(b) $b = f + d$, $a = 1.5b$.

Figure 13. Projection into elliptic-cylindrical coordinate of a 360° room with new center.

project method \ angle of view		171.8°	367.7°
Plane		17320*6741	-
Cylinder		1904*514	4074*515
Elliptic-cylinder	a/b = 1.5	2379*739	10225*1538
	a/b = 2	2887*972	12446*2049
	a/b = 3	3943*1437	17116*3073
Elliptic-cylinder with new center	a/b = 1	-	3987*2149
	a/b = 1.5	-	5034*3224

Table 1. The result panorama size in pixel (width*height), where the original photo is 34° with 384*512 pixels. The second column is more than 360° because we keep both overlap parts in two ends of panorama. Second column of plane is empty since it cannot construct panorama with AOV more than 180°. First column of new center is empty since we only change the center when AOV is more than 180°.

Table 1 compares the sizes of result panoramas using different projections. Obviously, the scale of elliptic-cylinder projection is far smaller than planar projection. And the larger ratio of major and minor axes we use, the larger the size of result panorama will be. Besides, the new center projection is narrower than the basic elliptic-cylinder one because we only project images into half of the elliptic-cylinder when AOV is larger than 180°; but it is higher because the endpoints is close to the new center leading to large scale projection.

If the user cannot tolerate extreme scale distortion but allows slight curving effects, he/she can choose smaller ratio. Conversely, the user can choose larger ratio if not allows serious curving but some scale distortion. The elliptic-cylindrical projection without changing the center is exactly the conventional cylindrical projection when the ratio is 1. And it is equivalent to conventional planar projection when the ratio approaches infinity. We leave the automating operation of most appropriate ratio selection for the future.

5. CONCLUSION AND FUTURE WORK

Our proposed elliptic-cylindrical projection system is a compromise solution between conventional planar and cylindrical projections, which can avoid extreme scale distortion and extreme straight line curving. When using our system, users can adjust the ratio of major and minor axes by their preference.

REFERENCES

[1] http://www.cambridgeincolour.com/tutorials/image-projections.htm

[2] VLFeat, http://www.vlfeat.org/

[3] AutoStitch, http://www.autostitch.net/