

# Cylindrical and Conical Mirror Anamorphosis for Image Display

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## **Abstract**

*Anamorphosis is a deformed image that appears in its true shape only from a certain point of view, out of which it is seen distorted and the illusionary effect is lost. In this paper, we describe a simple method for achieving anamorphosis by utilizing image coordinate transformation. The novelty of this work is the creation of the framework for the implementation of cylindrical and conical mirror anamorphosis, resulting in a tool for artists and designers. A qualitative evaluation approach is proposed to carry on comparative study with other methods. Experimental results demonstrate that using the proposed method one may get a good undistorted image in a mirror with much less user-interaction compared to other approaches. In addition to implementing the illusionary effect, some applications of the anamorphosis are also presented.*

**Keywords:** *anamorphosis, cylindrical mirror, conical mirror, applications*

## **1. Introduction**

“Anamorphosis” is a painting technique of drawing distorted images. The viewers are required to use special devices or to take a specific perspective to recognize the undistorted image. The term “Anamorphosis” can be defined as a distorted or monstrous projection or representation of an image on a plane or curved surface, which when view from a certain point, or as reflected from a curved mirror, appears regular and in proportion. Specifically, the anamorphoses that use a cylindrical mirror are called cylindrical anamorphoses. Similarly, the anamorphoses that use a conical mirror are called conical anamorphoses.

Given the importance of anamorphosis, many studies on anamorphosis have been conducted. For example, Suga *et. al.*, [1] presented an interactive system which takes the technique of Anamorphosis, with a 2D display and a cylinder mirror. In this system, a distorted image is shown on a flat panel display, and the original image will appear on the cylindrical mirror when a user puts it on the display. Kent [2] developed an executive software call “Anamorph Me” to allow users to carry out the anamorphic transformations. Ravnik *et. al.*, [3] proposed a dynamic anamorphosis which adapts itself to the changing position of the observer so that wherever the observer moves, he sees the same undeformed image. Hansford *et. al.*, [4] presented a method for achieving anamorphosis of 3D objects by utilizing a variation of a projective map that is well-known in the computer graphics literature. The novelty of this work is the creation of anamorphic 3D digital models. However, the specific implementation steps of cylindrical mirror anamorphosis or conical mirror anamorphosis are not the focus of these references.

In this paper, we show how to produce cylindrical and conical anamorphoses, which results a good tool for artists and designers to create more maps rendering works. Some applications of the anamorphoses are also discussed. The organizations of this paper are

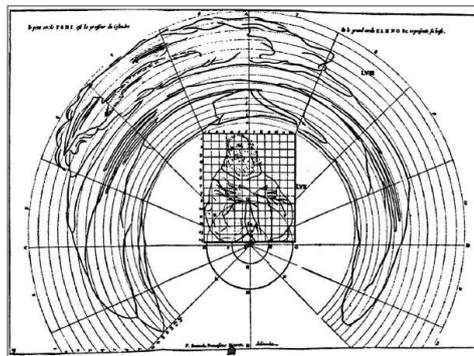
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as follows: we first discuss the classic principle and philosophy of anamorphosis in Section 2. Next, in Section 3 we describe the implementation steps of the cylindrical and conical mirror anamorphosis. The experimental results for the anamorphosis are given in Section 4. In Section 5, we discuss the possible applications of the anamorphosis. Conclusions are provided in Section 6.

## 2. Anamorphosis

Traditionally, anamorphosis has been created using grid templates [5, 6]. One starts by marking the anamorphic transformation of an empty square grid, according to certain choice about the position of the viewpoint, the size and angles of the mirrors, etc. Then, the square grid is put on top of the original picture, and the contents of each small grid element are copied across to the corresponding element of the distorted grid. Once this is done, the grid must be removed to leave the anamorphosis. Figure 1 shows a set of grids prepared by Jean-Francois Niceron to make a cylindrical mirror anamorphosis.



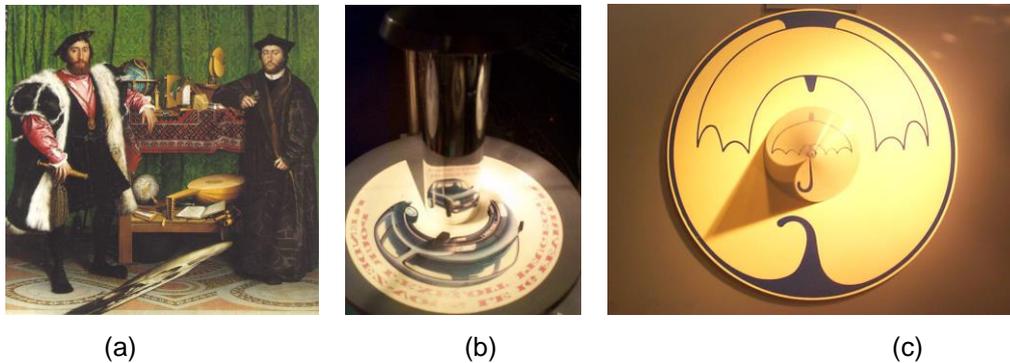
**Figure 1. Making a Cylindrical Mirror Analysis**

Needless to say, using grids is a time-consuming business, and requires a fair amount of artistic skill. With computers, anamorphosis is much easier to make because the algorithms for anamorphic distortions can be written as computer programs, which can then be directly applied to many thousands of individual pixels of a digital image. Therefore, in this paper, we mainly present the generation algorithms of cylindrical and conical anamorphoses.

As far as we know, there are some explanations behind the physical phenomenon. Our mind is constantly interpreting and giving structure to the raw visual input from our eyes. We prefer an ordered world, familiar shapes and regular patterns. One of such features of human perception is that our brain tends to order visual features in a regular, orderly, symmetric and simple manner, as formulated by the Gestalt school in psychology [7]. Therefore where possible, we see stable rectangular forms although these forms appear most of the time distorted due to perspective projection. This principle is called shape constancy [8]. Perspectival anamorphosis or anamorphic projection was discovered in art in the late fifteenth century both as a challenge and as a confirmation of the rules of linear perspective which were discovered at the same time [9]. Classical linear perspective is based upon the Euclidean paradigm that light travels in straight lines and when light reflected from an object intersects a planar surface an accurate representation of the original object is reflected on that surface. While we normally look at images frontally from a limited range of viewing angles, the viewer of an anamorphic image must usually be at a radically oblique angle to the picture plane to see the anamorphic image undistorted. The anamorphic image looked at up front is in such cases usually so distorted as to be unrecognizable.

Probably the most famous example of anamorphosis in art history is the painting “The Ambassadors”, by Hans Holbein [see Figure 2(a)]. On the bottom of this painting appears

a diagonal blur which appears as a human skull when viewed from the upper right [10]. Nowadays, the cylindrical mirror anamorphosis and conical mirror anamorphosis have attracted more attentions due to their strong vision impact. Figure 2(b) and Figure 2(c) show some examples of the two kinds of mirror anamorphosis. As can be seen in the figure, we can see an undeformed car or an umbrella with the help of cylindrical mirror or conical mirror.



**Figure 2. Anamorphosis examples. (a) The Ambassadors by Hans Holbein. (b) Cylindrical mirror anamorphosis. (c) Conical mirror anamorphosis.**

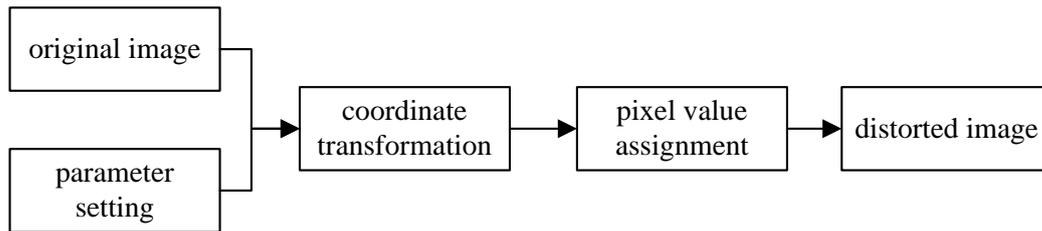
Besides, since the appreciation of anamorphic images requires an eccentric viewing point as opposed to a normal or orthogonal viewing point, anamorphosis becomes a term popular with many postmodern theorists used mainly as a metaphor for the relativity of vision or the subjectivity of human experience [10]. Anamorphosis serves as a model for the concept of the gaze, which suggests that visual appreciation rather than passive looking requires active observing [11, 12]. To appreciate an anamorphic image requires indeed from the observer that he positions himself precisely in the right spot and directs his gaze in the right direction as opposed from the normal or centric vision [13] where the viewer sees himself at the center of the world. Further philosophical considerations of anamorphosis are nicely summed up by Massey [14]. The exact mechanism that supports correct space perception from deformed retinal images is still disputed in the human perception research community. Cutting [15], for example, explains that the visual system corrects the distortions based on the assumption that objects are rigid. Sedgwick [16] gives a theoretical analysis based on the concept of available visual information. More recent research in human perception has shown that the adjustment to oblique viewing is achieved before the contents of the image are interpreted [17]. As an unconventional way of seeing, anamorphosis opens a door to artistic creation. Here we describe a simple method for achieving anamorphosis of original input image by utilizing a simple image coordinate transformation. The novelty of this work is the creation of a framework for cylindrical mirror anamorphosis and conical mirror anamorphosis, resulting in a tool for artists and designers.

### 3. Implementation

#### 3.1. Algorithm Procedure

Specifically, the proposed algorithms have two steps to produce cylindrical mirror anamorphosis or conical mirror anamorphosis: the first one is to determine the size of distorted image according to the mirror radius and angular size. The second step is to find out the corresponding relations between the original input image and the final distorted image by using coordinate transformation, and then assign pixel value for the distorted results. The goal of our algorithms is to let the distorted image appear normal when

viewed with or reflected from a cylindrical or a conical mirror. The flowchart of our method is depicted in Figure 3.



**Figure 3. Flowchart of the Proposed Algorithm**

### 3.2. Cylindrical Mirror Anamorphosis

The coordinate transformation for cylindrical mirror anamorphosis is illustrated in Figure 4. The origin of projection is at the center of the cylinder. The angle  $\theta$  is called the angular size of the anamorphosis. The radius of the cylinder is  $R$ , and the size of the original input image is  $M \times N$ . Thus, the size of the final distorted result is  $2(R+M) \times 2(R+M)$ .

Specifically, the arc-length  $l$  corresponding to the central angle  $\theta$  is first calculated. Then, we compute the value of  $\alpha$  ( $\alpha = l/N$ ) to determine whether to supplement missing pixels ( $\alpha > 1$ ) for the distorted image or not ( $\alpha \leq 1$ ).

For  $k = [\alpha j - \alpha/2, \alpha j + \alpha/2]$  and  $j$  from 1 to  $N$ , the angle  $\gamma$  can be calculated as:

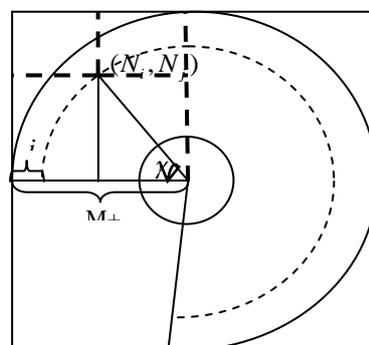
$$\gamma = (k-1) \frac{\theta}{N \times \alpha} \times \frac{\pi}{180} \quad (1)$$

As illustrated in Figure 4, the pixel coordinate  $(N_i, N_j)$  of distorted image can be expressed as:

$$N_i = R + M - (R + (M - i)) \times \sin(\gamma) \quad (2)$$

$$N_j = R + M - (R + (M - i)) \times \cos(\gamma) \quad (3)$$

In Eqs. (2) and (3),  $i = 1:M$ ,  $1 \leq N_i \leq 2 \times (R + M)$ ,  $1 \leq N_j \leq 2 \times (R + M)$ . Once we have the pixel coordinate of distorted image, its pixel value and the related neighbor pixel (missing pixel) values can be assigned according to the corresponding pixels in the original input image. Note that in the anamorphosis result, right and left seems reversed. We thus subtract the image width coordinate from the image width  $N$  to make the illusion formed by the distorted result look more comfortable. The same operation is also performed for the conical mirror anamorphosis.



**Figure 4. Coordinate Transformation for Generating Cylindrical Mirror Anamorphosis**

In our algorithm, there are two inputs: the mirror radius  $R$  and the angular size of the anamorphosis  $\theta$ . The operation is performed on three color channels independently. The pseudocode of the cylindrical mirror anamorphosis generation is presented in Figure 5.

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Algorithm 1 : Cylindrical mirror anamorphosis generation
Input: Original input image  $I$ , Mirror radius  $R$ , Angle size  $\theta$ 
Output: Distorted image  $I_{new}$ 

Step 1 // Initialize the distorted image
1.1 mrows =  $2 \times (R+M)$ ; ncols =  $2 \times (R+M)$ ;
1.2 Set the size of the three color channel in the distorted image to be mrows×ncols, respectively.

Step 2 // Coordinate transformation and pixel value assignment
2.1 Determine whether the missing pixel exists.
 $\alpha = \theta \times \pi \times (R+M-i) / (180 \times N)$ ;  $i \in [1, M]$ ;
if  $\alpha < 1$ 
 $\alpha = 1$ ;
end
2.2 // Coordinate transformation
For  $i \in [1, M], j \in [1, N], k \in [\alpha \times j - \alpha/2, \alpha \times j + \alpha/2]$ , we have
 $\gamma = (k-1) \times (\theta / (N \times \alpha)) \times (\pi / 180)$ ;
 $N'_i = R+M - (R+(M-i)) \times \sin(\gamma)$ ;
 $N'_j = R+M - (R+(M-i)) \times \cos(\gamma)$ ;
2.3 // Pixel value assignment
For  $i \in [1, M], j \in [1, N], c \in \{R, G, B\}$ , we have
 $I_{new}^c(N'_i, N'_j) = I^c(i, N-j+1)$ ;  $N'_i \in [1, mrows], N'_j \in [1, ncols]$ ;
 $I_{new}^c(N'_i+1, N'_j+1) = I^c(i, N-j+1)$ ;  $N'_i+1 \in [1, mrows], N'_j+1 \in [1, ncols]$ ;
 $I_{new}^c(N'_i-1, N'_j+1) = I^c(i, N-j+1)$ ;  $N'_i-1 \in [1, mrows], N'_j+1 \in [1, ncols]$ ;
 $I_{new}^c(N'_i, N'_j+1) = I^c(i, N-j+1)$ ;  $N'_i \in [1, mrows], N'_j+1 \in [1, ncols]$ .

Step 3 // Result display
3.1 Combine the three color channel of the distorted image;
3.2 Display the cylindrical mirror anamorphosis result  $I_{new}$ .
    
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**Figure 5. The Pseudo-Code of the Cylindrical Mirror Anamorphosis Generation**

### 3.3. Conical Mirror Anamorphosis

For conical mirror anamorphosis, there are two situations: 1) use all of the original input image; 2) clip the original image (use just a central circular portion of it), as shown in Figure 6. Here, an algorithm is proposed to produce the two kinds of conical mirror anamorphosis.



**Figure 6. Conical Anamorphoses. (a) Using all of the Original image. (b) using the Clipped Image**

As can be seen in Figure 6, the transformation procedures anamorphosis which look especially distorted, because the conical mirror has the effect of “inverting” the image: the center of the original becomes the outside of the anamorphosis, and vice versa. The coordinate transformation for conical mirror anamorphosis, illustrated in Figure 7, is used for both of the above situations.

Specifically, for the first situation, there are two input parameters for the transformation: cone radius  $R$  and cone angle  $\theta$ . Thus, the size of the final distorted image is  $2r \times 2r$ , where  $r = R + R/\sin((\theta/2) \times (\pi/180))$ . Suppose the size of input original image is  $M \times N$ , the radius  $L$  of the circumcircle of the final illusion image can thus be written as:

$$L = \frac{\sqrt{M^2 + N^2}}{2} \quad (4)$$

As illustrated in Figure 7, the distance  $R_r$  between the point  $p$  in the final illusion image and the center of the illusion is

$$R_r = \frac{(r-i+1) \times L}{r-R} \quad (5)$$

In (5),  $i \in [R+1, r]$ . Suppose  $\alpha = 2\pi i$ , the angle  $\gamma$  can thus be calculated as:

$$\gamma = \frac{(j-1) \times 2\pi}{\alpha} \quad (6)$$

where  $j \in [1, \alpha]$ , the pixel coordinate  $(N_i, N_j)$  of distorted image is:

$$N_i = r - i \times \sin(\gamma) \quad (7)$$

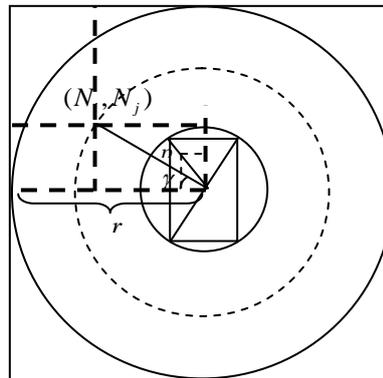
$$N_j = r - i \times \cos(\gamma) \quad (8)$$

The coordinate of the point  $p$  in the final illusion image can thus be expressed as:

$$p_i = \frac{M}{2} - R_r \times \sin(\gamma) \quad (9)$$

$$p_j = \frac{N}{2} - R_r \times \cos(\gamma) \quad (10)$$

Finally, each pixel value of the distorted image and its neighbor pixel values are assigned according to the corresponding pixels in the original input image. Figure 8 shows the pseudocode of the conical mirror anamorphosis generation.



**Figure 7. Coordinate Transformation for Generating Conical Mirror Anamorphosis**

**Algorithm 2: Conical anamorphosis generation using the whole input image**

Input: Original input image  $I$ , Mirror radius  $R$ , Angle size  $\theta$

Output: Distorted image  $I_{new}$

**Step 1** // Initialize the distorted image

- 1.1  $r = R + R / \sin((\theta / 2) \times (\pi / 180))$  ;  
 $mrows = 2r$ ;  $ncols = 2r$ ;  
 $L = (1/2) \times \sqrt{M^2 + N^2}$  ; //  $L$  is the radius of the circumcircle of the final illusion image
- 1.2 Set the size of the three color channel in the distorted image to be  $2r \times 2r$ , respectively.

**Step 2** // Coordinate transformation and pixel value assignment

2.1 Determine the distance between the point  $p$  in the final illusion image and the center of the illusion

$$R_r = (r - i + 1)(r - R) \times L; \quad i \in [R + 1, r]$$

2.2 // Coordinate transformation

For  $i \in [R + 1, r]$ , we have  $\alpha = 2\pi \times i$

For  $j \in [1, \alpha]$ , we have

$$\gamma = (j - 1) \times (2\pi) / \alpha ;$$

$$N_i = r - i \times \sin(\gamma) ; \quad N_j = r - i \times \cos(\gamma) ;$$

$$p_i = M / 2 - R_r \times \sin(\gamma) ; \quad p_j = N / 2 - R_r \times \cos(\gamma) ;$$

2.3 // Pixel value assignment

For  $i \in [R + 1, r]$ ,  $j \in [1, \alpha]$ ,  $c \in \{R, G, B\}$ , we have

$$I_{new}^c(N_i, N_j) = I^c(p_i, N + 1 - p_j); \quad N_i \in [1, mrows], N_j \in [1, ncols], p_i \in [1, M], p_j \in [1, N];$$

$$I_{new}^c(N_i + 1, N_j + 1) = I^c(p_i, N + 1 - p_j); \quad N_i + 1 \in [1, mrows], N_j + 1 \in [1, ncols], p_i \in [1, M], p_j \in [1, N];$$

$$I_{new}^c(N_i - 1, N_j + 1) = I^c(p_i, N + 1 - p_j); \quad N_i - 1 \in [1, mrows], N_j + 1 \in [1, ncols], p_i \in [1, M], p_j \in [1, N];$$

$$I_{new}^c(N_i, N_j + 1) = I^c(p_i, N + 1 - p_j); \quad N_i \in [1, mrows], N_j + 1 \in [1, ncols], p_i \in [1, M], p_j \in [1, N].$$

**Step 3** // Result display

- 3.1 Combine the three color channel of the distorted image;
- 3.2 Display the conical mirror anamorphosis result  $I_{new}$  using the whole input image.

**Figure 8. The Pseudo-code of the Conical Anamorphoses Generated using the Whole Image**

For the second situation, the image used for display is first clipped according to the minimum value of image height  $M$  and image width  $N$ . Suppose the minimum value is  $Len$ ,  $Len = \min(M, N)$ . Thus, the radius of the circumcircle of the final illusion image is  $L = Len/2$ . The maximum value between  $M$  and  $N$  is denoted as  $Len\_max$ , that is  $Len\_max = \max(M, N)$ . Using Eqs. (5) to (10), we can obtain our final distorted result, as shown in Figure 6(b). However, different from the first situation that performs the operations on the whole input image, the value range of the coordinate of a point  $p$  in the final illusion image is assigned according to the clipped image. Therefore, the procedure for assigning pixel values is as follows. Given is an original input image  $I$  with a size of  $M \times N$ , and the output is the distorted image  $I_{new}$ .

(1) If  $M > N$ , we have

$$I_{new}^c(N_i, N_j) = I^c(p_i, N + 1 - p_j);$$

$$N_i \in [1, mrows], N_j \in [1, ncols], p_i \in [(len\_max - len) / 2, (len\_max + len) / 2], p_j \in [1, len];$$

$$I_{new}^c(N_i + 1, N_j + 1) = I^c(p_i, N + 1 - p_j);$$

$$N_i + 1 \in [1, mrows], N_j + 1 \in [1, ncols], p_i \in [(len\_max - len) / 2, (len\_max + len) / 2], p_j \in [1, len];$$

$$I_{new}^c(N_i - 1, N_j + 1) = I^c(p_i, N + 1 - p_j);$$

$$N_i - 1 \in [1, mrows], N_j + 1 \in [1, ncols], p_i \in [(len\_max - len) / 2, (len\_max + len) / 2], p_j \in [1, len];$$

$$I_{new}^c(N_i, N_j + 1) = I^c(p_i, N + 1 - p_j);$$

$$N_i \in [1, \text{mrows}], N_j + 1 \in [1, \text{ncols}], p_i \in [(\text{len\_max} - \text{len}) / 2, (\text{len\_max} + \text{len}) / 2], p_j \in [1, \text{len}].$$

(2) If  $M \leq N$ , we have similar operations, the only difference is that the value range of  $p_i$  now change into  $[1, \text{Len}]$ , and the range of  $p_j$  now change into  $[(\text{Len\_max} - \text{Len}) / 2, (\text{Len\_max} + \text{Len}) / 2]$ .

This procedure ensures the final illusion image within the range of the clipped image.

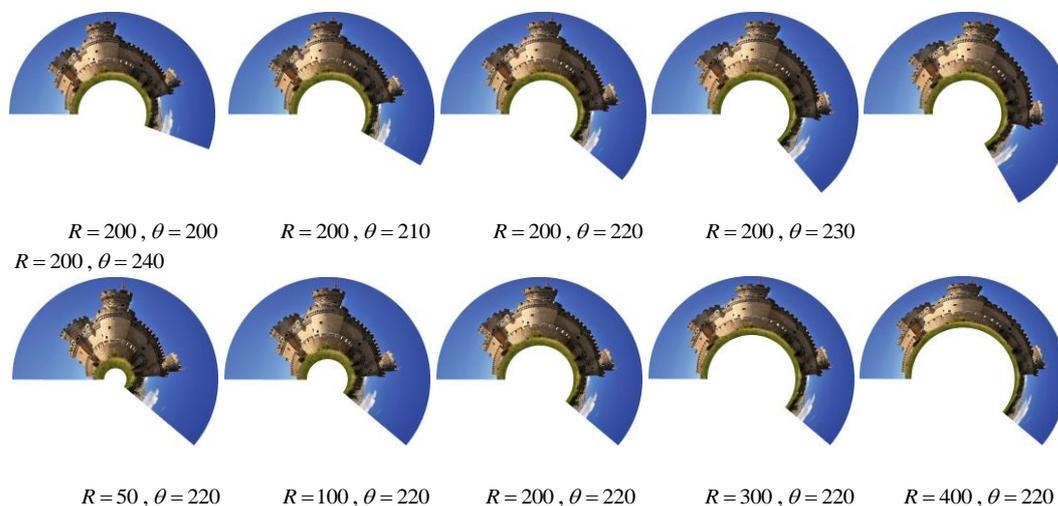
## 4. Experimental Results

In our experiment, we use light reflecting plastic or the stainless steel cylinders which are polished to high reflectiveness as our reflective materials. iPad is also used here for displaying the distorted results and placing the reflective mirrors.

### 4.1. Parameter Setting

Two parameters  $R$  and  $\theta$  are used to control the appearance of the distorted results for both cylindrical and conical mirror anamorphosis. The value of  $R$  control the mirror radius, and the value of  $\theta$  controls the angle of the sector in distorted result.

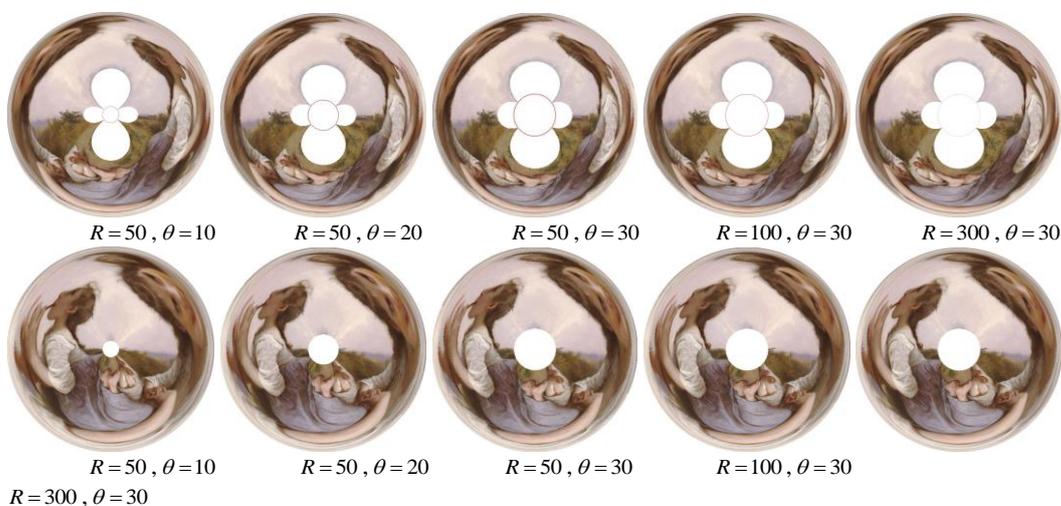
Figure 9 shows different distorted images of cylindrical mirror anamorphosis resulting from the proposed method by adjusting these parameters. In Figure 9, the value of the two parameters are gradually increased, the angle of the sector and mirror radius increases correspondingly. Since the two parameters are very important for the final illusion effects, thus choosing proper parameter values for most input images become the focused issue. In our experiment we find that, although the values of the two parameters are application-based, the proposed method can produce impressive results when we fix the two parameters to  $R = (1/3) \times \max(M, N)$  and  $\theta = 220$  for all the input images with a size of  $M \times N$ . The fixed value of the two parameters may not the best one, but they seem reasonable for each input image and can produce promising undistorted results.



**Figure 9. Different Cylindrical Distorted Results with Different Parameters for a 600\*400 Image**

For conical mirror anamorphosis, there are also two parameters: cone radius  $R$  and cone angle  $\theta$ . The values of the two parameters are selected based on the statistical observations on a large quantity of input images. In our experiments, we find that the visual pleasing results can be obtained for most input images with a size of  $M \times N$  when  $R = (1/2) \times \max(M, N)$  and  $\theta = 30$ . Since it is impossible for us to list all the possible combinations of parameter values, some combinations are chosen to show the obvious

changes in the appearance of distorted images and also to compare with the results obtained by our determined parameter values, as shown in Figure 10. Note that the larger value of R, the larger size of the final distorted images.

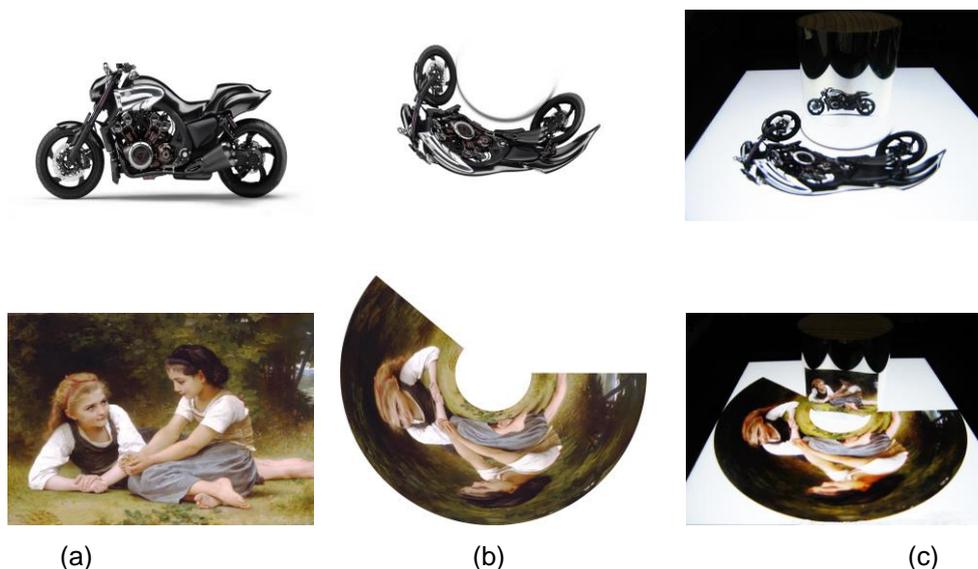


**Figure 10. Different Conical Distorted Results with Different Parameters for a 600\*450 Image**

#### 4.2. Single Image Test

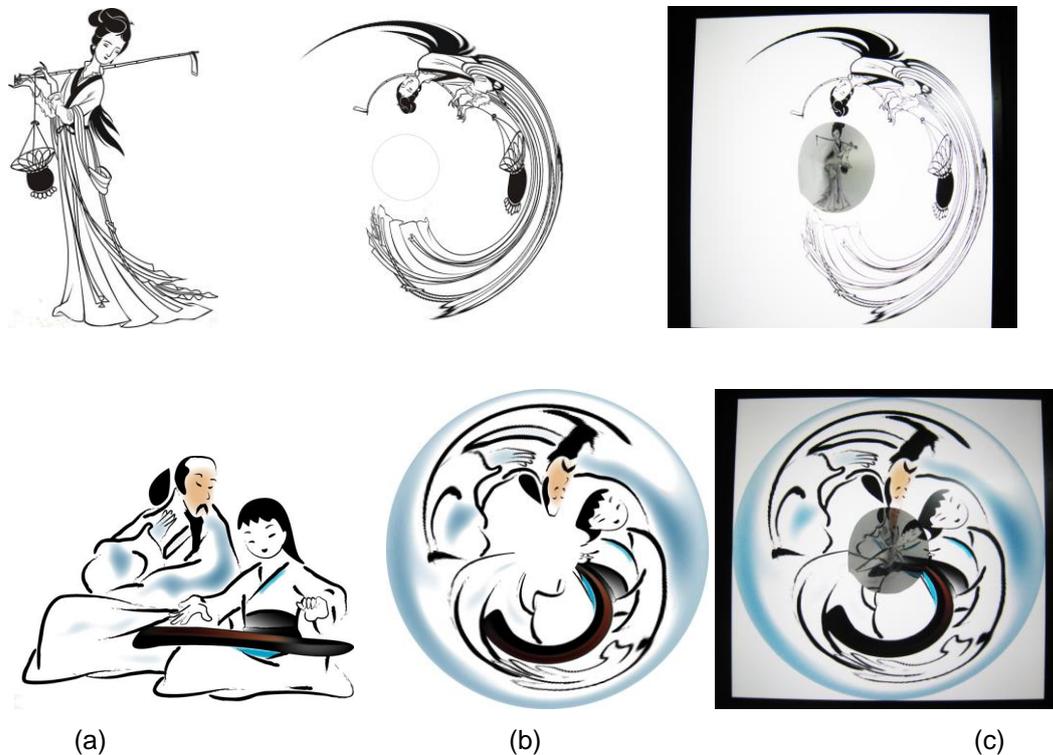
We have done experiments on hundreds of images with various types and scenes. Some results of the proposed algorithms are shown in Figure 11 and 12.

Figure 11 shows some examples of cylindrical mirror anamorphosis results obtained using our method. One can clearly see that promising illusionary effects can be generated with little user interaction. Therefore, even a person with little artistic creation experience can generate an acceptable cylindrical anamorphic result just like artists and designers.



**Figure 11. Some Examples of Cylindrical Mirror Anamorphosis Results. (a) Original Images. (b) Corresponding Cylindrical Distorted Images. (c) Illusionary Effects Generated using a Cylindrical Mirror**

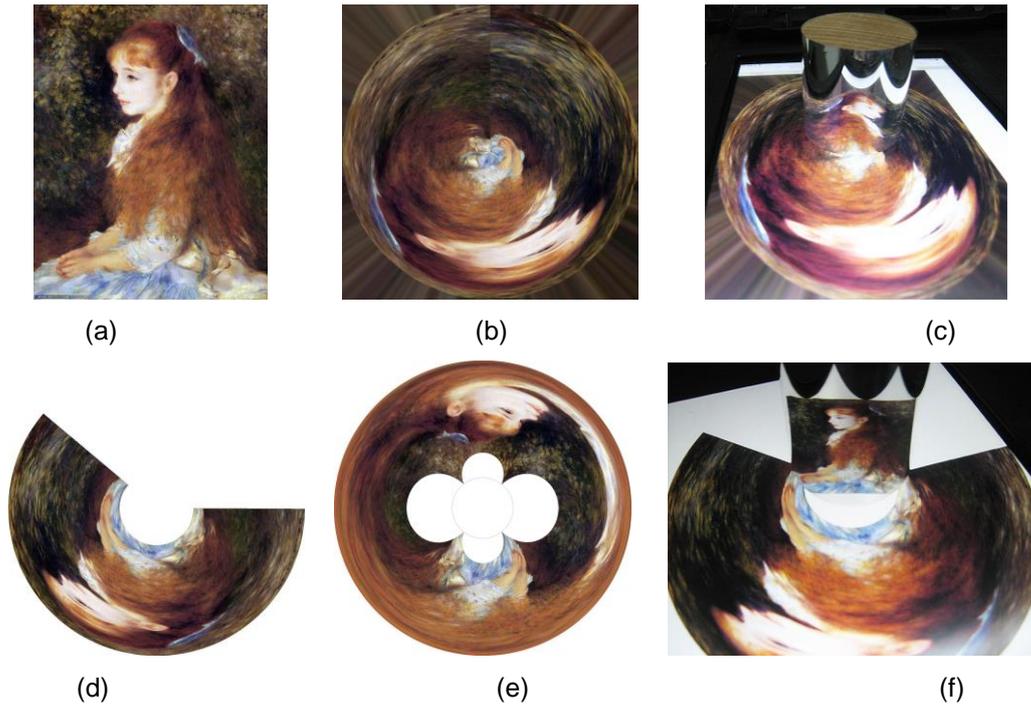
Figure 12 displays some examples of conical anamorphosis results obtained using our algorithms. As shown in Figure 12(b), conical distorted image can be generated using the whole input image or clipped image. From Figure 12(c), we can see that both the two ways can generate visual pleasing illusionary effects with the help of a conical mirror.



**Figure 12. Some Examples of Conical Mirror Anamorphosis Results. (a) Original images. (b) Corresponding Conical Distorted Images. Up: Using the Whole Input Image, Down: using the Clipped Image. (c) Illusionary Effects Generated using a Conical Mirror**

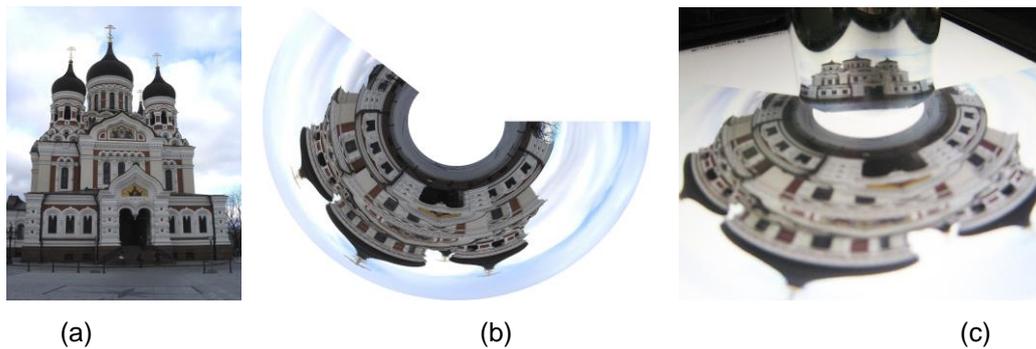
To verify the effectiveness of the proposed algorithms, some anamorphic methods are used here to compare with our algorithm. These existing methods include Suga's method [1] which using Photoshop's polar coordinates filter to obtain the distorted images, and Kent's "Anamorph Me" software [2] to implement the cylindrical and conical mirror anamorphosis.

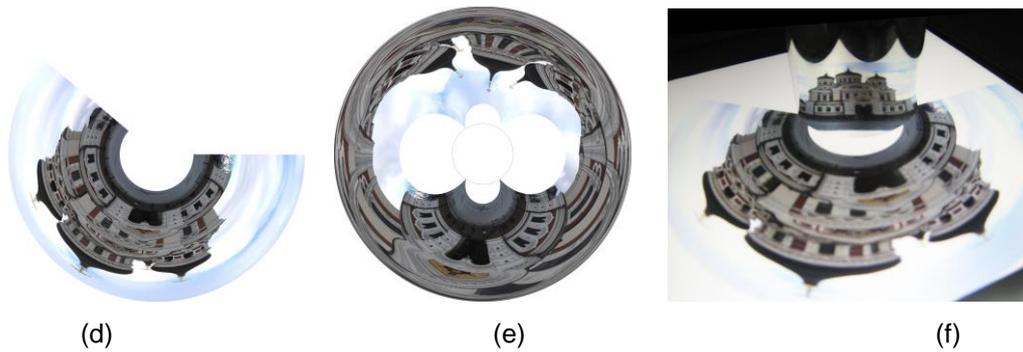
For Suga's method, the whole procedure of using Photoshop's polar coordinates filter has some steps and each step need user involvement. Figure 13 shows the comparison of our result with that obtained using Photoshop. One can clearly see that the illusionary effect produced by the polar coordinates filter is not satisfying owing to the limited information it used for transformation, while our method can produce better illusionary effect with less user-interaction. Besides, the polar coordinates filter can only produce cylindrical anamorphic image, while using the proposed algorithms we can obtain both cylindrical and conical anamorphic results, as shown in Figure 13.



**Figure 13. Comparison Results for an Image of a Girl. (a) Original Image. (b) Cylindrical Anamorphosis Result Obtained using Photoshop. (c) Illusory Effect Obtained by Photoshop. (d) Cylindrical Anamorphosis Result Obtained using the Proposed Algorithm. (e) Conical Anamorphosis Result Obtained using the Proposed Algorithm. (f) Our Illusory Effect**

For Kent’s “Anamorph Me” software, the software provides almost all the traditional anamorphic transformations. However, the specific implementation details of these anamorphic transformations are not known if just using the software. Figure 14 shows the comparisons of our anamorphosis result with the result obtained using Kent’s software. One can clearly see that the proposed method can generate comparable results, as shown in Figure 14(c) and 14(f).



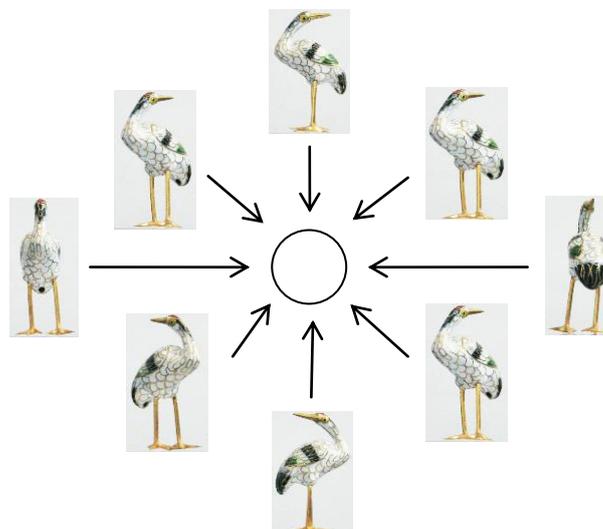


**Figure 14. Comparison Results for an Image of a Castle. (a) Original Image. (b) Cylindrical Anamorphosis Result Obtained using Kent's Software. (c) Illusionary Effect Obtained by Kent's Software. (d) Cylindrical Anamorphosis Result Obtained using the Proposed Algorithm. (e) Conical Anamorphosis Result Obtained using the Proposed Algorithm. (f) Our Illusionary Effect**

### 4.3. Video Sequence Test

Video sequence processing takes into consideration not only the scene object in a single frame but also the appearance change of the scene object due to its different position and rotation.

In our experiment, we prepared about 56 images of an item taken from various angles. The examples of them are shown in Figure 15. Next, we converted them to anamorphic images using the proposed algorithm. As each anamorphic image of the item shown on the iPad, an image of the item from a certain angle is shown on the surface of the cylinder. Thus, users are able to view the item through 360 degree. An illustrative example is shown in Figure 16, and some snapshots of the illusionary results of a video sequence are given to demonstrate the effectiveness and practicality of the proposed algorithm. In this way, a simple and low-cost method of displaying semi-3D images on a vertical surface over a flat-panel display can be realized. The proposed algorithms can be further applied to develop an interactive system which makes users interact with the image on the cylindrical or conical mirror by detecting the position and rotation of the image, so that users feel as if they can examine the item through 360 degrees by their intuitive direct manipulation.



**Figure 15. The Example Images for 360 Degrees View**



Figure 16. Viewing an Item Through 360 Degree

## 5. Applications

The application examples of anamorphic projection are deformed images or signage which after being projected on slanted surfaces appears undeformed. Here, we mainly discuss how to use the idea of anamorphosis in package design projects.

### 5.1 Package Design

For package design projects, creativity is the first element. Anamorphosis as a way of artistic expression can be used in developing innovative home accessories products to combine the functionality with aesthetics. For example, the anamorphic cup is a product to employ the centuries old visual play of the anamorphic cylinder. The stainless steel cup has a polished mirror finish. The porcelain saucer is printed with distorted images or words. These graphics can only be viewed correctly through the curved, reflective surface of the cup. The image is indecipherable when the cup and saucer are separate, as shown in Figure 17.



Figure 17. Anamorphic Cup Examples

The above application can benefit from the proposed algorithm to easily create more anamorphic works. Figure 18 shows the process of simulating an anamorphic cup. We first transform the normal words we want to express into distorted words using the proposed algorithm. Then, we use an ipad to display the distorted words in order to determine which size and position of these words make them appear most suitable and normal when viewed with or reflected from a cylindrical mirror, as shown in Figure 18(a). Thus, a simulated anamorphic cup can be produced according to these size and position in 3DS Max environment, as shown in Figure 18(b).

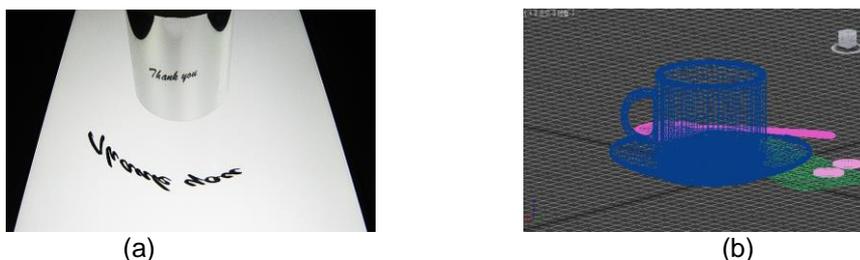


Figure 18. Simulating the Anamorphic Cup Effect using the Proposed Algorithm

## 5.2. Other Applications

Apart from package design, anamorphosis has widely used in many other areas. In our daily life, the most common use of “anamorphic” designs may be the road markings. Traffic markings painted on the road surface are often in reality elongated so that from the perspective of a traffic user approaching the markings they more readily appear in the right proportion. Specifically, the problem is that the markings have to be viewed by road users from an “unconventional” position - at a shallow angle - where the effect of foreshortening (the apparent shrinking of objects as they move further away) is to significantly squash the vertical dimension. Figure 19 shows a typical example. Viewed from a distance, the height of the arrow looks the same as the height of the word CAR below it. Viewed from the side, we can see that the arrow is actually more than twice as high as the word, as shown in Figure 19. Conversely, if the arrow were only the same height as the word then it would appear half as high.



**Figure 19. Anamorphosis Application in Road Marking Shape**

Besides, anamorphic graffiti images are nowadays produced as pavement or sidewalk art, often as part of numerous street painting festivals or advertising and publicity campaigns [18]. Owing to the novelty and interesting of the anamorphic graffiti images, they appear now often in magazines and exhibitions. Figure 20 shows two works designed by Italian graffiti crew Truly Design for the 2013 festival of Architettura in Citta. For these works, an eye and paintbrush can be seen if a spectator stands at a specific angle of the gallery room.



**Figure 20. Anamorphic Graffiti Examples**

## 6. Conclusions

A simple but effective method was proposed to implement cylindrical or conical mirror anamorphosis. What is particularly useful is that the proposed method provides a good tool for artists and designers to produce more creative works, and Maps rendering may be one of its useful uses. In order to obtain the distorted anamorphic image from an input image, we proposed a framework for the implementation of cylindrical and conical mirror anamorphosis. The developed image coordinate transformation plays a critical role in allowing the pixel values of the distorted result to be corresponding to those of the

original input image. Experiment results showed that the proposed method may produce a good undistorted image in a mirror with much less user interaction compared to other approaches. However, the proposed methods also have some limitations. For example, the size of cylinder or conical mirror constrains the variation range of the algorithm parameters. Besides, for the conical anamorphoses, the proposed algorithm may fail for a kind of images with some important parts of the input image near the center. We will try to investigate the anamorphosis techniques that can handle complicated image scenes and extend to more applications (*e.g.*, road marking shape, anamorphic graffiti image, *etc.*) in the future.

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