Mosaicing of Paintings on Curved Surfaces

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Abstract

This paper presents a new approach for reconstructing images painted on curved surfaces. A set of monocular images is taken from different viewpoints in order to mosaic and represent the entire scene. By using a priori knowledge about the support surface of the picture, we derive the surface localization in the camera coordinate system. An automatic mosaicing method is applied on the flattened images in order to obtain the complete scene. The mosaiced scene is visualized on a new synthetic surface by a mapping procedure.

1 Introduction

When taking a picture of a painting on a curved surface the projected image is distorted due to the surface geometry and the perspective projection. In this study, we consider various images taken from different viewpoints as shown in Figure 1, using monocular vision, in order to obtain a complete scene and a better resolution.

In [11] a genetic based flattening method is proposed for curved surface visualization. In our approach in order to backproject an image to a curved surface we need to find the localization parameters. In Section 2, we describe the localization of the curved surface [9, 10].

Based on the localization parameters, in Section 3 we describe how to flatten the respective painting from the surface. These two parts are done separately for each image and the result is an image containing the painting without geometrical distortions caused by the perspective view of the curved surface. In Section 5 we propose an automatic procedure for mosaicing a large painting based on matching each two individual regions from two given images of the same painting taken from different viewpoints. This approach is similar to the block matching algorithm [6] used for motion detection. Finally, we show how to map the painting on a new curved surface.

The most appropriate area of application for this work is in painting representation and restoration [3]. The proposed algorithm is applied for reconstructing the paintings from curved surfaces. We mosaic the flattened representations after finding the localization parameters. Then, we visualize the whole scene as taken from a virtual viewpoint when it is mapped on a new surface as a cylindrical one.

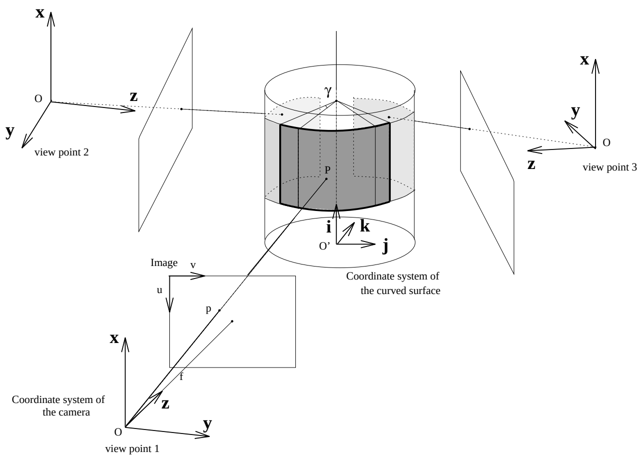


Figure 1: Images taken from different viewpoints around a curved surface.

2 Localization from a single perspective view

The localization is done separately for each view. By using symmetric axes, it is possible to represent the geometry of curved surfaces [4, 7]. This Section deals with finding the projection of two axes representing the geometry of the surface in the image. We use a priori knowledge in order to find these axes. In the image we detect two curves that are perspective projections of parallel curves of the surface, as shown in Figure 2, [9].

Figure 2: View of a church arch with two parallel curves.

Based on the equation of these two axes we obtain the three rotation angles θ_x, θ_y and θ_z between the coordinate system of the camera $(O, \vec{x}, \vec{y}, \vec{z})$ and that of the object $(O', \vec{i}, \vec{j}, \vec{k})$, where O is the viewpoint, as can be seen in Figure 1.

In our approach, we identify the common normal between the projections of two parallels in the image of size $2u_0 \times 2v_0$ defined in the image coordinate system (u, v). We use an iterative method based on successive derivations of normals to the curves, stopping when two successive found points from the same curve are very close to each other [8]. We obtain then an axis passing through the two poins P_1 and P_2 as shown in the Figure 3. In the image coordinate system, the equation of this axis is :

$$v = A_1.u + B_1, \tag{1}$$

where A_1 and B_1 are the coefficients of the straight line determining this axis.

Among all the parallels on the surface only one is projected on the image as a straight line. This straight line, defined as the second axis, belongs to the plane passing through the respective parallel and through the view point. In [10] we explain how to find the second axis which is orthogonal to the axis defined by (1). In the Figure 3 the equation of the second axis is :

$$v = -1/A_1.u + (v_0 + u_0/A_1), \tag{2}$$

where (u_0, v_0) are the coordinates of the image center. We denote by (Δ_u, Δ_v) the vector distance between (u_0, v_0) and the intersection of the two axes P_0.

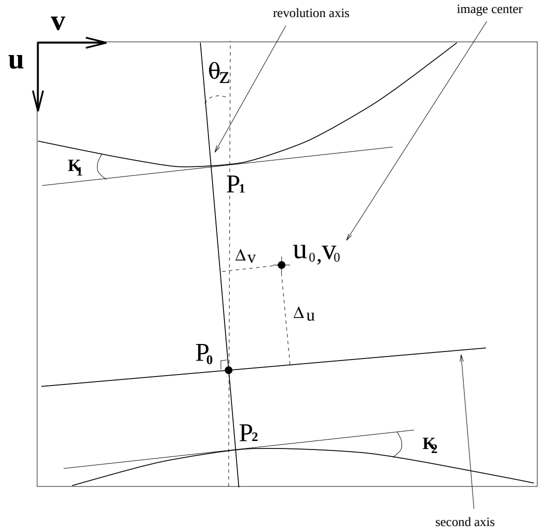


Figure 3: The revolution and the second axes detected from two curves.

From the equations (1) and (2), we obtain the three rotation angles :

$$\left\{ \begin{array}{lcl} \theta_x & = & \arctan(\frac{\Delta_v}{f.k}) \\ \theta_y & = & \arctan(\frac{\Delta_u}{f.k}) \\ \theta_z & = & \arctan(A_1) \end{array} \right. \tag{3}$$

where f is the focal distance and k is the resolution factor. The rotation angle θ_z corresponds to the angle between u and the revolution axis.

From these results we are able to localize the curved surface in the coordinate system of the camera [10]. Based on these three rotations of the camera described by (3), we can backproject the image on the curved surface. In the case of a cylinder, the analysis of the perspective projection distorsions is provided in [2].

3 Flattening the curved surfaces

By straigthening the projection of the parallels we derive a view of the curved surface where all the curves have their curvatures equal to zero. Let us consider a surface having the curvature different than zero in only one direction $z = f(y)$, $\forall x$. We take a cross-section x of the curved surface, containing $2m$ points as shown in the Figure 4.

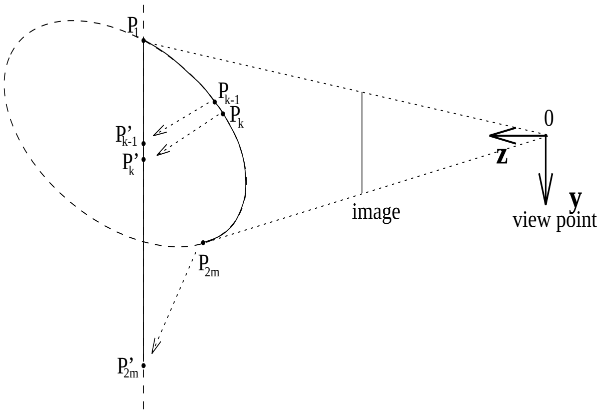


Figure 4: Flattening the curved surface.

Let us denote the points of this cross-section by P_k having coordinates $(y_k,\, z_k)$, with $z_k = f(y_k)$, $k \in \{1, \ldots, 2m\}$, and by $|\widehat{P_k P_{k-1}}|$ the arc length between P_k and P_{k-1}.

The variation of the arc length depends on the perspective from the viewpoint O and the surface geometry. Starting with the point P_1 having the coordinates (y_1, z_1), for each point P_k from a cross-section of the curved surface, we derive a new point P'_k having coordinates (y'_k, z'_k), $k \in \{1, \ldots, 2m\}$ on the plane surface $z = z_1$, for every x and y, with the same arc length : $|\widehat{P_k P_{k-1}}| = |\widehat{P'_k P'}_{k-1}|$.

The curvature does not depend on x and we approximate the arc length between two points P_k and P_{k-1} as equal to the segment length between them. From these considerations and because $z'_k = z_1$, for every k, we obtain :

$$\begin{aligned} |\widehat{P_k P_{k-1}}| &= \sqrt{(y_k - y_{k-1})^2 + (z_k - z_{k-1})^2} = \\ = |\widehat{P'_k P'}_{k-1}| &= |y'_k - y'_{k-1}|, \end{aligned} \tag{4}$$

where $|\cdot|$ is the absolute value. Thus, we derive :

$$y'_k = |\widehat{P_k P_{k-1}}| + y'_{k-1} = y'_1 + \sum_{n=2}^{n=k} |\widehat{P_n P_{n-1}}|, \tag{5}$$

with $k \in \{1, \ldots, 2m\}$. We consider P_1 fixed, $y'_1 = y_1$ and we calculate the coordinates y_k of the other points P'_k as illustrated in Figure 4. Thus, for each point P_k of the curved surface we obtain a new point P'_k belonging to the flattened surface. Eventually we derive an image of the flattened surface, where the curves have been straightened. Figure 5 illustrates the flattening method applied on the Figure 2.

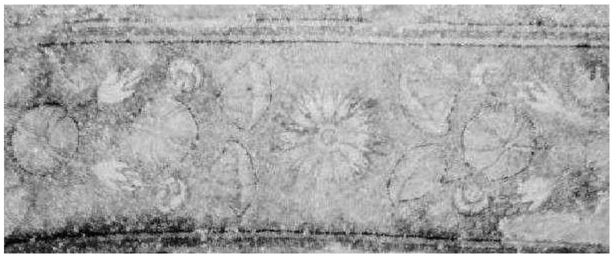


Figure 5: Flattened pictures after localization.

4 Painting reconstruction by mosaicing

Mosaicing is used for assemblying a set of images in order to reconstruct a scene [1]. The classical approach adopted in image mosaicing is based on selecting in a semiautomatic way a set of corresponding points from the overlapping parts of two images [5].

After matching the positions of the selected points in the two images the common part is found. In this study we propose a mosaicing technique for the visualization of the entire scene situated on a curved surface. The images are taken from various viewpoints as shown in the Figure 1. After flattening the curved surfaces as described in Section 3, we find the matching parts of each two neighboring images denoted as p and $p-1$. The matching method is similar to the block matching algorithm used for estimating the motion field [6]. We define a search area in the plane (u, v) which must include the common part of the two images. The region which provides the minimum mean absolute error difference among all the possible given solutions from the search area is chosen as the overlapping part. In Figure 6 (a) is shown the procedure of matching. The matching can be applied either on u or v axes. After the common area of the two images is found we evaluate the displacement of each image with respect to the others.

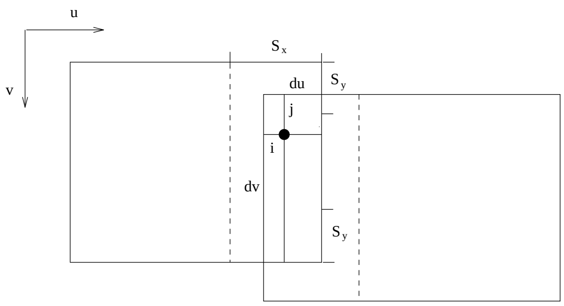
The pixel values from the overlapping parts are calculated based on a weighting function. Firstly, we evaluate the minimum distance from a given pixel site (i, j) to the border of the common part :

$$g_{p-1} = \min\{i, j\}\ ,\ g_p = \min\{du - i, dv - j\}, \tag{6}$$

for $du > 0$, $dv > 0$, $i = 1, \ldots, du$ and $j = 1, \ldots, dv$; (du, dv) denotes the displacement between the two images. The pixel value from the common part is given by weighting the pixels from the two overlapping images :

$$pel = \frac{g_{p-1}}{g_p + g_{p-1}}\, pel_{p-1} + \frac{g_p}{g_p + g_{p-1}}\, pel_p, \tag{7}$$

where pel_p and pel_{p-1} denotes two correspondent pixels from the images p and $p-1$, respectively.



(a)

(b)

Figure 6: The matching between two different images which contain a common part. (a) The exemplification of the approach. (b) Painting Mosaicing.

The result of mosaicing two images containing details of a painting is shown in the figure 6 (b). The weighting procedure 7 ensures a smooth luminance transition between each two images after mosaicing. The proposed approach can be used for mosaicing multiple images, overlapping on both u and v axes.

5 Mapping of the reconstructed scene

Considering that we are provided with the description of a certain surface we can map the reconstructed image on it. After mapping the reconstructed scene on the surface we can simulate a camera to obtain various synthetic views. Let us consider a cylindrical surface for mapping the mosaiced image as shown in a cross-section representation in the Figure 7. We consider the horizontal size of the mosaiced image equal to M pixels. Let us denote the points from the cross-section of the mapped picture to the cylinder, by P_k $k \in \{1, \ldots, M\}$.

Let us denote by Δ the distance between two pixels. The goal of the mapping is to maintain the constant distance Δ between pixels. On the cylinder we take the step of the mapping equals to Δ:

$$\Delta = \frac{1}{2\pi R}, \tag{8}$$

with R the given radius of the cylinder.

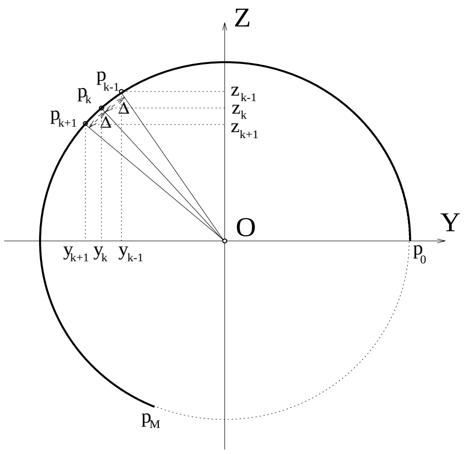


Figure 7: Mapping the image on a cylinder.

We obtain the coordinates y_k and z_k for a point P_k. In parametric coordinates we have the relations :

$$\left\{ \begin{array}{lcl} y_k & = & R\cos(2\pi\Delta k) \\ z_k & = & R\sin(2\pi\Delta k) \end{array} \right. , \tag{9}$$

with Δ, the step defined by (8), and $k \in \{1, \ldots, M\}$. In order to avoid the self-covering of the image extremities when mapped on the cylinder, we impose the condition for R :

$$M < \frac{\pi R}{2}. \tag{10}$$

6 Simulation Results

The proposed flattening and fusion algorithm is applied for reconstructing the scene from the surface of a cup. This scene contains two parallels, the margins of the decorative pattern on the object surface. They are used to infer the localization parameters as described in Section 2.

Three images are taken from different viewpoints in order to obtain a complete scene. Each two successive images contain common areas, as shown in the Figures 8 (a), (b), (c).

Based on the localization parameters, the representations from the three images are flattened as described in Section 3. The three flattened representations are shown in the Figures 8 (d), (e), (f). The result of the mosaicing of the three pictures is provided in the Figure 9. This image consists of the entire representation of the scene depicted on the cup.

With the mosaiced image we can obtain synthetic representations from different viewpoints. Then, after mosaicing the flattened pictures we map the scene on a cylinder as described in Section 5. Finally, we simulate a camera to obtain a new image from a different viewpoint as shown in the Figure 10.

7 Conclusion

In this paper we propose a new approach for mosaicing a scene on a curved surface. For finding the localization of the curved surface we need a certain a priori knowledge. Each projected image taken from a different viewpoint is flattened based on the localization parameters. We estimate the relative positions of the images representing flattened surfaces based on a matching algorithm. This work can be applied for the visualization of paintings. In this case, the scene visualization and restoration performance are increased.

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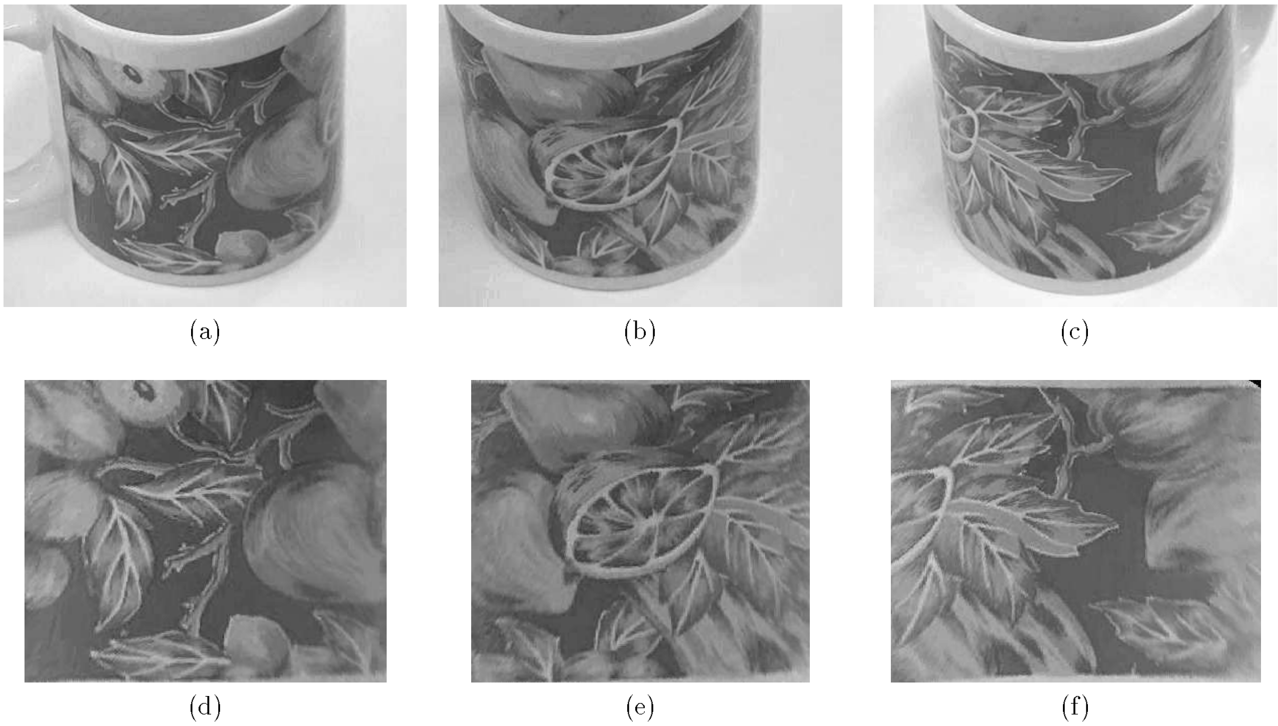

Figure 8: (a), (b), (c) The original images representing the cup surface taken from three different viewpoints ; (d), (e), (f) The representation of the flattened surfaces from the three images

Figure 9: The result of the mosaicing algorithm representing the entire decorative scene depicted on the object.

Figure 10: Synthetic visualization of the scene mapped on a cylinder.