ON THE CREATION OF PANORAMIC IMAGES FROM IMAGE SEQUENCES

Petteri PÖNTINEN
Helsinki University of Technology,
Institute of Photogrammetry and Remote Sensing, Finland
petteri.pontinen@hut.fi

KEY WORDS: Cocentricity, Panorama, Projective, Transformation, Least Squares.

ABSTRACT

This paper considers the creations of panoramic images from image sequences. The main guideline is to create physically correct panoramic images, where the focusing surface is a cylinder and all the light rays from the object to the focusing surface are straight and cross on the axis of this cylinder. This requires that the images of the sequence have a common projection center. Also the camera parameters and the relative orientations of the images of the sequence need to be known. If these conditions are fulfilled, the resulting panoramic images will be consistent.

1 INTRODUCTION

Panoramic images have a history of more than 150 years. One of the pioneers of panoramic imaging, Joseph Puchberger from Austria, patented his swing lens panoramic camera already in 1843 (IAPP, 1999). Many other inventors in different countries all over the world were also working with panoramic imaging around that time. Because most of them worked independently their devices were also quite different. However, the basic solutions were similar: either a very wide angle optics, a swinging lens or a rotating camera. The first devices were hand-driven and the first panoramic images were exposed on curved glass plates.

The application areas of panoramic images vary from art to aerial surveillance. Artists and photographers are probably the biggest user groups of panoramic images. Also people who work with virtual environments utilize panoramic imaging. There have also been some studies on the use of panoramic images in photogrammetry (Antipov and Kivaev, 1984, Hartley, 1993), but the topic hasn't been very popular among photogrammetrists in general.

The old panoramic techniques are still in use, but modern technology presents also other possibilities. One alternative is to create panoramic views from digital image sequences, which is considered in this paper. The main guideline is to create physically correct panoramic images, where the focusing surface is cylinder and all the light rays from the object are straight and cross on the axis of this cylinder. It's not enough to just stitch the adjacent images together so that the result looks nice.

The panoramic camera model is introduced briefly in section 2. Some general demands for the image sequence are also considered. The procedures for combining the images are presented in section 3. Two alternative ways are considered. The first one is based on the rotations between the images and the second one on the two-dimensional projective transformations between the images. Section 4 presents one example and section 5 contains the conclusions.

2 PANORAMIC IMAGE

2.1 Panoramic camera model

The main feature of a panoramic camera is the wide field of view, usually more than 90 degrees. In spite of the different constructions of different panoramic cameras, they can all be modelled as a camera with a cylindrical focal surface (Hartley, 1993) and a projection center that lies on the axis of the cylinder. Figure 1 illustrates the major difference between a standard camera and a panoramic camera. It is clear that the field of view of a standard camera never exceeds 180 degrees and is usually much less. This means that with panoramic techniques the object can be photographed from a shorter distance.

Figure 1: Two projections. On the left the focusing surface is a plane and on the right a cylinder.

2.2 Demands for a correct panoramic image

If the panoramic image is constructed from an image sequence by combining adjacent images, some conditions must be fulfilled. One of the conditions is that the sequence must be cocentric, which means that the camera must be rotated around its projection center. If this condition is not fulfilled (i.e. if the projection center moves during the camera rotation) the following problem occurs: the adjacent images have been taken from different viewpoints, which means that different things are visible on their overlapping areas. This makes the combining of the images in principle impossible.

The first thing to do is to mount the camera on a tripod so that it rotates around its projection center. For that purpose there are for sale so called pano-heads for certain camera and lens combinations. The same thing can be done, for example, with the help of a theodolite and a special rotation tool that allows the camera to be moved freely in two dimensions on a tripod (see Figure 2). The rotation axis of the tool and the vertical axis of the theodolite should be joined when they are mounted on the tripod. The procedure is as follows:

1. Using the theodolite and four poles, construct two lines that intersect on the vertical axis of the theodolite (see Figure 3).
2. Replace the theodolite with the camera mounted on the rotation tool. Now the two lines intersect on the rotation axis of the rotation tool.
3. Move the camera on the rotation tool so that the poles seem to be in line (see Figure 4). This moves the projection center to the rotation axis.

Another condition that has to be fulfilled is that the camera parameters (camera constant, principal point coordinates and lens distortions) must be known. Otherwise the original shapes of the bundles of image rays are not known and the creation of the correct panoramic image is impossible. The values of the camera parameters can be found by calibration. The principal point coordinates can also be derived directly from the cocentric images (Hartley, 1994).

3 COMBINING OF IMAGES

This section introduces two alternative methods for combining the single images of the sequence. The first method is based on the rotations between the adjacent images and the second one on the two dimensional projective transformations

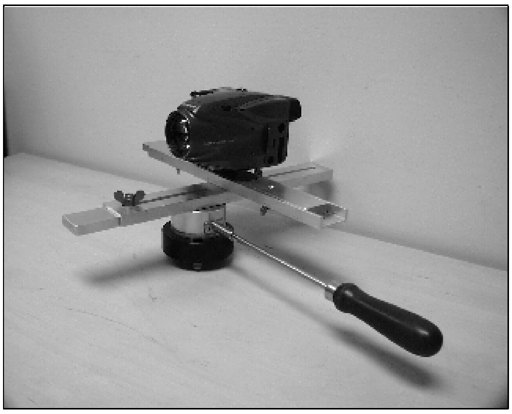

Figure 2: Camera mounted on a special rotation tool.

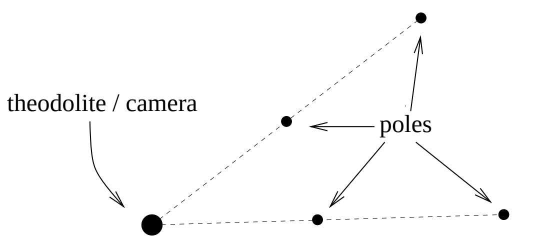

Figure 3: Arrangement for the camera adjustment. The two lines intersect on the vertical axis of the theodolite and also on the rotation axis of the rotation tool.

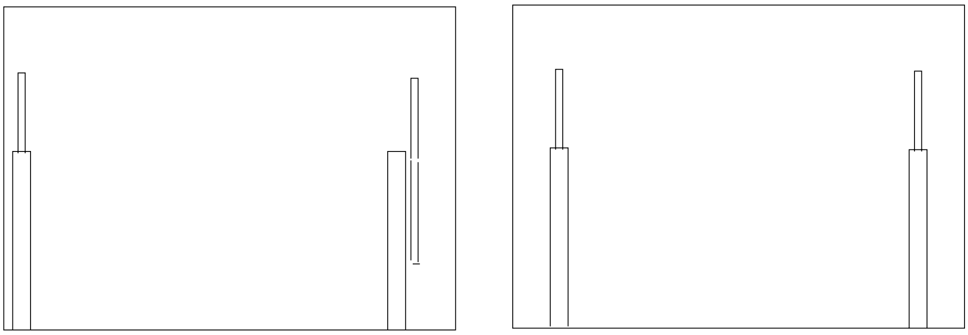

Figure 4: Views through the camera. When the poles are in line (right) the correct position has been found.

between the images.

3.1 Combining based on rotations

Because the image sequence is assumed to be cocentric, only the three rotations between the images need to be solved. Although the projection center is fixed the three rotations allow more or less free trajectories for the images.

One way to solve the orientation problem is to force the camera to rotate along a known trajectory with some predefined angles. This often requires extra equipment and work. A more convenient way is to solve the unknown rotations based on the images themselves. This task is not too difficult thanks to the assumed cocentricity. The corresponding image vectors defined by the projection center and the corresponding image points must point to the same direction as shown in Figures 5 and 6. This means that

$$\frac{\mathbf{a}}{|\mathbf{a}|} = \mathbf{R}\frac{\mathbf{b}}{|\mathbf{b}|}, \tag{1}$$

where **a** and **b** are the corresponding image vectors and **R** is the unknown rotation matrix. It is quite obvious that only two corresponding image vectors are needed to fix the three rotations. Also the whole overlapping area can be used to determine the rotation angles ω,φ and κ. The idea is to have

$$g_1(x_1, y_1) = g_2(x_2, y_2) \tag{2}$$

where g_1 and g_2 are the gray values on the different images and x_1,y_1,x_2 and y_2 are the centered image coordinates of the corresponding points. The connection between equations (1) and (2) is

$$\mathbf{a} = \begin{bmatrix} x_1 \\ y_1 \\ c \end{bmatrix} \text{ and } \mathbf{b} = \begin{bmatrix} x_2 \\ y_2 \\ c \end{bmatrix}, \tag{3}$$

where c is the camera constant. Using the least squares principle the optimal rotation matrix, which minimizes the squared sum of gray value differences in corresponding points, can be found.

If the relative rotations of the images of the sequence are known, the creation of a panoramic image is simple. The gray values of the individual images just have to be projected to a chosen cylinder surface along the relatively orientated image rays. The radius of the cylinder can be chosen freely but its axis must go through the projection center.

Lens distortions, non-cocentricity of the sequence, errors in the camera constant and the principal point coordinates, and errors of the orientation parameters cause non-consistency in the resulting image. If the overlapping areas are averaged from the source images, the errors can be seen as a blurring of these areas. Tests with synthetic images show that the consistency was more sensitive to the errors of the orientation parameters than to the errors of the camera parameters. For example in the camera constant the error could be 10% without any clear influence, but already 1% error in the rotations was enough to blur the overlapping area.

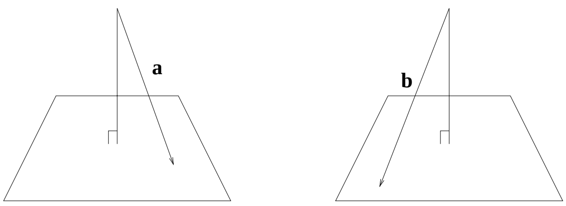

Figure 5: Two corresponding image vectors.

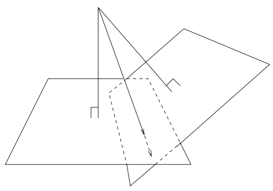

Figure 6: The corresponding image vectors rotated so that they point to the same direction.

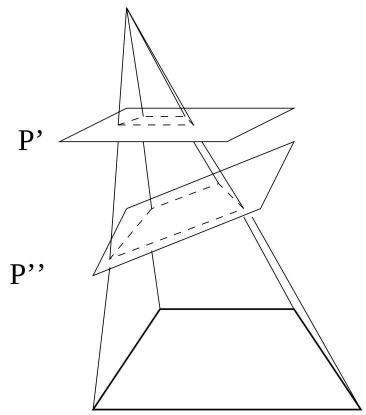

Figure 7: Two image planes intersecting the same image rays.

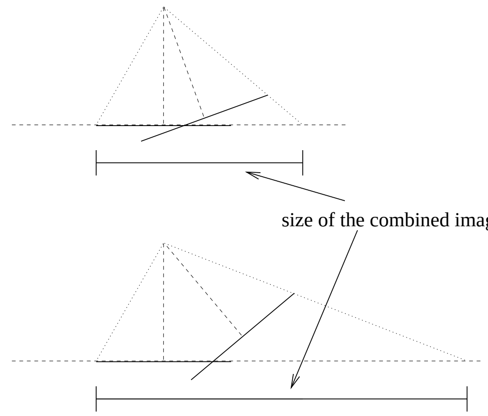

Figure 8: The size of the combined image depends on the rotation between the images.

3.2 Combining based on two dimensional projective transformation

A picture taken with a traditional camera is in principle a central projection of the target. How the picture looks depends on the location of the image plane relative to the projection center (see Figure 7). If two different planes intersect the same image rays there is a correspondence between the image point coordinates. The correspondence is formulated as (Wang, 1990)

$$x_2 = \frac{a_1x_1 + a_2y_1 + a_3}{a_7x_1 + a_8y_1 + 1}, \tag{4}$$

$$y_2 = \frac{a_4x_1 + a_5y_1 + a_6}{a_7x_1 + a_8y_1 + 1}, \tag{5}$$

where x_1, y_1, x_2 and y_2 are the image coordinates on the different planes and $a_1, a_2, ..., a_8$ are the transformation parameters. These transformation parameters can be solved if the image coordinates of at least four corresponding points are known on both planes and if no three points lie on the same line. After the parameters have been solved, any of the image points can be transformed to the other plane.

Instead of using a set of points, the whole overlapping area can be utilized to determine the transformation parameters, like in the previous subsection. The initial transformation parameters can be solved using four corresponding points' coordinates and then adjusted using the least squares so that the sum of squared gray level differences in corresponding points will be minimized.

If the images are cocentric and have sufficient overlaps, they can be combined into one image using the two-dimensional projective transformation. One of the images can be chosen as a reference image and the other images can be transformed to it. The combined image can then be projected to a chosen cylinder surface. If the camera has been rotated very much (in the extreme case over 360 degrees), all the images can't be transformed to one reference image, because the combined image will grow, in the worst case infinitely (see Figure 8). In that case, the panoramic image must be created in stages. In the first stage, the reference image is chosen and two or three images are transformed to it. After that, the combined image is projected to a cylinder surface. In the next stage, a new reference image is made by projecting part of the cylindrical image back to a plane. After that, the next two or three images are combined to the new reference image and the result is projected to the previously chosen cylinder. If there are more images to be projected, a new reference image is created and the procedure is repeated. This continues until all the images are on the surface of the cylinder. If the created panoramic image covers over 360 degrees, the perimeter of the cylinder (i.e. the distance between the same point on the different ends of the image) should be $2\pi r$, where r is the radius of the chosen cylinder. If the perimeter differs from this, it indicates that the camera constant used has been erroneous (assuming that there are no other errors affecting the image simultaneously).

4 AN EXAMPLE

Figure 9 shows three images of a workshop. They were taken with an Olympus Camedia C-1400 L digital camera. The image size was 1280x1024 pixels. The camera was calibrated using a testfield and the lens distortions were eliminated by resampling the images (see Figure 10). As can be seen, the images overlap by approximately 50%. The corners of the overlap areas of the images were given as source data to a software program which solved the eight transformation

Figure 9: The original three images.

Figure 10: The images after the lens distortion corrections.

Figure 11: The left and right images combined to the middle image.

Figure 12: A zoomed detail of the middle source image.

Figure 13: A zoomed detail of the combined image.

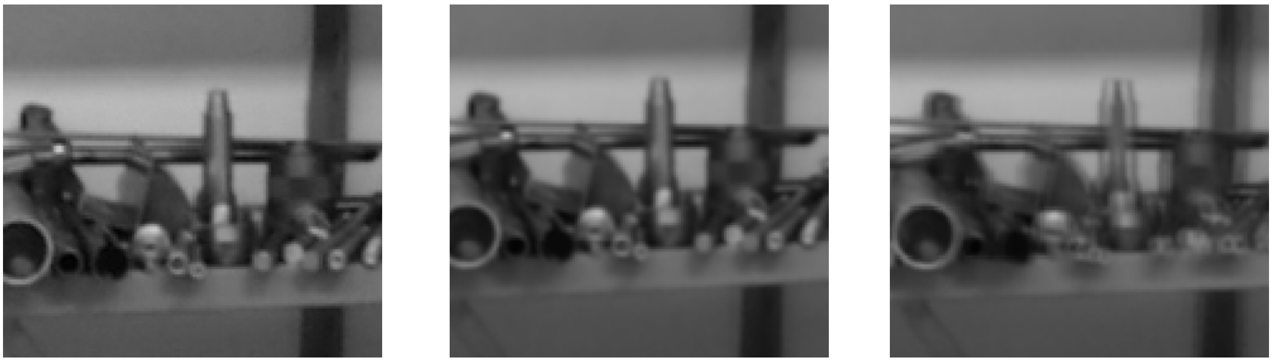

Figure 14: Zoomed details of the original image (on the left), the panoramic image where lens distortions were eliminated (in the middle) and the panoramic image where lens distortions were not eliminated (on the right).

Figure 15: The combined image projected to a cylinder surface.

parameters between the images. The iterative calculation converged nicely and the result of the combination can be seen in Figure 11. The calculations took about 20 minutes with a 200 MHz computer with a 32 MB memory. The calculation time can be reduced easily by using less pixels, for example every second or third pixel, for determining the transformation parameters. The gray values of the overlapping areas were averaged from the two source images.

In Figure 12 is shown one detail from the middle source image. In Figure 13 is the same detail but it is grabbed from the combined image shown in Figure 11. The brightnesses of the original images were different, which is why the image edges are visible in the combined image. Otherwise the result is satisfactory: there are no discontinuities or blurring.

Because in this example the eight parameter projective transformation was used, the camera constant and principal point coordinates were not needed for the combination of the images but for the correct projection to a cylinder surface. This means that errors in the camera constant and principal point coordinates do not cause any blurring. Instead, neglecting the lens distortions cause blurring. In Figure 14 are three zoomed pictures showing roughly the same details. The picture on the left is from one of the original images, the one in the middle is a part of the panoramic image where lens distortions were taken into account, and the one on the right is a part of the image where distortions were neglected. As can be seen, the quality of the last image is clearly worse than that of the other two. The difference between the two first pictures is quite small, although the picture in the middle has gone through three interpolations and one averaging.

The projection to a cylinder surface is shown in Figure 15.

5 CONCLUSIONS

In this paper has been described how to make panoramic images from cocentric image sequences so that the central projections of the original images will be preserved. It has been shown that only the camera parameters and sufficient overlap between the images are needed.

The two combination methods presented here are based on the fact that the image sequence is cocentric. The first method solves the relative rotations of the images and then projects the images to a cylinder surface. The second method doesn't solve the rotations explicitly. Instead, it combines the images using two-dimensional projective transformation before the projection to a cylinder surface. Both the rotations and the two-dimensional transformation parameters can be derived from the overlapping areas of the images. If the used camera parameters were correct the resulting panoramic image was consistent.

The use of the whole overlapping area ties the images strongly together. The bigger is the overlap the better but also the more images are needed for a certain view. One interesting question which will be studied in the near future is if it is possible to solve also all the camera parameters during the panoramic image creation process.

REFERENCES

Hartley, R., 1993. Photogrammteric techniques of panoramic cameras. SPIE Proceedings, Integrating Photogrammetric Techniques with Scene Analysis and Machine Vision, Vol. 1944, Orlando, USA.

Hartley, R., 1994. Self-calibration from multiple views with a rotating camera. In: J.-O. Eklund (ed.), Lecture Notes in Computer Science, Computer Vision - ECCV '94, Vol. 800, Springer-Verlag Berlin Heidelberg.

IAPP, 1999. International Association of Panoramic Photographers, http://www.panphoto.com.

Antipov, I. T., Kivaev A. I., 1984. Panoramic photographs in close range photogrammtery. International Archives of Photogrammtery and Remote Sensing, Vol. XXV, Part A5, Rio de Janeiro, Brazil.

Wang, Z., 1990. Principles of Photogrammetry (with Remote Sensing). Press of Wuhan Technical University of Surveying and Mapping, Publishing House of Surveying and Mapping, Beijing.