Reconstructing Architectural Environment from a Panoramic Image

Jolanta Dzwierzynska [1],

[1] Department of Architectural Design and Engineering Graphics, Rzeszow University of Technology, Poznanska 2, 35-084 Rzeszow, Poland

E-mail: joladz@prz

Abstract. The use of panoramic images for retrieving information about presented architectural environment is a fast developing field recently. The aim of the herby paper was developing an effective method of reconstruction of the architectural forms from their single panoramic image as well as establishing requirements which panoramic presentation should meet for the restitution purpose. The reconstruction attempt presented in the paper is the conjunction of the descriptive method and computer aid. The starting point in reconstruction process was determination of the base elements of panoramic projection as a horizon line and a base circle, which can be establish in a descriptive way on a flat panorama. Next, the simple formulas were proposed for calculation of 3D coordinates of the characteristic points of the objects given in their 2D unfolded panoramic image. The points established by their spatial coordinates defined lines which in term determined edge models of the presented forms. Presented method of reconstruction seems to be universal and can be useful for restitution of different forms of the panoramic presentation; paintings and photographs. The study shows that reconstructing architectural environment from the single panoramic image mostly depends on the image's content and an initial assumption. It is not always an easy process, however, possible in some cases.

1. Introduction

Generally, panoramic images are the perspective images depicting vide view. The full-view panoramic images that encompass the entire 360-degree surrounding are briefly called panoramas. They differ mainly in terms of geometric surfaces used for the panoramic representation. These surfaces; cylindrical, conical, or spherical define the kind of geometric projection, which is a base of a panoramic mapping. In turn, the panoramic mapping from three dimension to two is defined by projection equations. Therefore, panorama mappings differ from one another both in image characteristics and in a mathematical description, [1, 2]. In this work we constrain our considerations to cylindrical panorama images, which are the most popular form of the panoramic presentations.
Restitution of the architectural forms from their panoramic images is a reverse process to the panoramic projection. It is very useful for retrieving geometric properties; shape and proportions of the represented forms. Therefore, it can find a lot of applications in reconstruction and documentation of the architectural objects. Reconstruction of 3D forms from their perspective images has been a very developing field recently. Rosebush and Kushner, [3] give overview of the earliest reconstruction methods. Most of the research is concerned with recovering a 3D structure from a set of perspective views [4, 5]. There are also attempts of reconstruction on the basis of the single panoramic images

captured by a rotating sensor-line camera [6]. The proposed methods of reconstruction are usually associated with the optimization process, [7, 8, 9].
The method of reconstruction presented in the paper is an extension of the method described in [10, 11] and shows panorama reconstruction attempt from the single flat image when base elements defining panoramic projection are known or can be determined easily. Whereas, this paper will show possibility of reconstruction of an architectural form from a flat panoramic image when base elements of perspective are unknown. Especially, it will prove that the accurate location of the base line/ground line for the reconstruction process is not necessary. This method of reconstruction is a combination of the descriptive way of reconstruction with the computer aid.

2. Geometrical aspects of a panoramic representation

According to descriptive geometry definition, cylindrical panorama projection is a projection onto a cylindrical surface τ or on the fragment of this surface from a real point S being a center of this projection, see Fig.1. The image of any point is a pricing point of the projection ray passing thought this point with the projection surface. For the restitution purpose it is necessary to treat cylindrical panoramic representation as a kind of vertical perspective on a cylindrical surface. Usually, in the case of vertical perspective onto a flat projection plane we project not only the point, which is to be represented but also the orthographic projection of this point received on so-called base plane $\pi \perp \tau$. In this way the image of any point F is a pair of two projections: the main F^S and the auxiliary F^{OS}, see Fig.1.

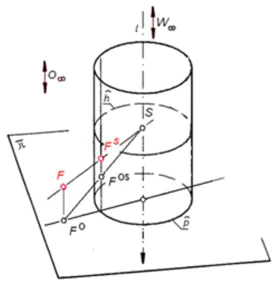

Figure 1. Panoramic image of a point *F*

Cylindrical perspective is a kind of nonlinear projection, therefore most of projected lines are represented as curved lines. Only vertical lines are represented as vertical and straight lines. Due to this fact most of geometrical properties of the presented figures are lost during projection, however, cross ratio of quadruple of collinear points included in any projected vertical line is preserved during projection. This property enables graphical and analytical connection between projections F^S and F^{OS} of a given point F included in the surface and their counterparts received on the unrolled projection surface. Such an approach was presented in [10]. Moreover, the projective relations occurring between projected points enabled creation of analytical algorithms for drawing cylindrical panoramas on a flat unrolled surface with the computer aid [10].

3. Reconstruction

Geometric restitution of cylindrical perspective is an inverse process to the cylindrical perspective projection. The reconstruction process that is restitution three-dimensional models; their real shape, size and position in space on the basis of their flat two-dimensional image is not easy. That is due to the fact that during projection onto a curved surface and next during transformation onto a flat surface, many of the clues about three-dimensional nature of the presented forms are lost. However, like in the case of the linear perspective, the information about real models lies encoded in their distortion occurring in the 2D image [12]. Therefore, in order to retrieve this information and reconstruct a complete 3D structure we base on geometrical knowledge about the theory of projection.

2.1. Reconstruction formulas

Due to the fact that reconstruction of cylindrical perspective is a reverse process to cylindrical perspective projection. We derive formulas for calculating the 3D location of the characteristic points of represented figures on the basis of their perspective 2D image by transformation of the algorithms for the perspective creation presented in [10]. For the restitution purpose we place a spatial Cartesian coordinate system of axis x, y, z as shown in Fig. 2 and a Cartesian coordinate system of axis v, d on the unrolled surface as shown in Fig.3.

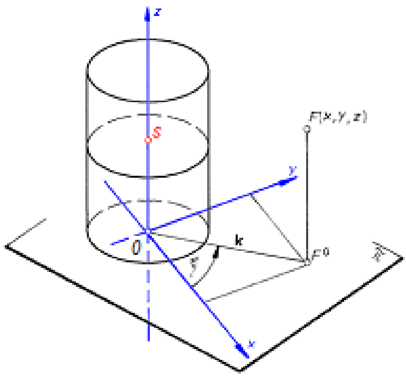

Figure 2. The way of the location of the Cartesian coordinate system of axis x, y, z towards the projection surface

The calculation of the spatial location of any point F determined on the unrolled projection surface τ by its main projection $F^S(v, d)$ and supplemental projection $F^{OS}(v, do)$ shown in Fig.3 can be established by means of the following parameters :

$$w(v, d_o, d) = \frac{h \cdot (d - d_0)}{h - d_0} \tag{1}$$

$$k(v, d_o, d) = \frac{h \cdot r}{h - d_0}, \tag{2}$$

where $k(v, d_o, d)$ it is a distance between point F^O and the centre of the base circle O. The parameter $w(v, d_o, d)$ determines the coordinate z whereas on the basis of $k(v, d_o, d)$ and v polar coordinates for the given point F^O are calculated. The variables r and h are respectively: the radius of the base circle and the height of the horizon line h that is the distance of the horizon line from so called base line/ground line p.

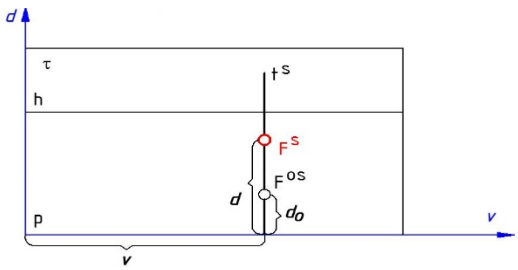

Figure 3. Parameters defining the position of the image of point $F(F^{OS}, F^S)$ on the unrolled projection surface

According to formulas (1) and (2) we can state that the high h of the horizon line, as well as the value of the radius r of the base circle are the crucial parameters in the above formulas.

2.2. Establishing base elements of the panoramic representation

The base elements of the panoramic projection are: the horizon line, the base line and the radius of the base circle. The horizon line and the base line are circles included in the projection surface respectively on the level of a station point and on the level of the ground. However, after the development of the surface on the plane, they are two straight lines the distance of which equals the height h of horizon. Both lines can be established in the descriptive way on the unrolled image. In the case of the horizon line location, the concept of so-called ‘vanishing points’ can be used, to which all parallel lines converge at the level of horizon - the eye level. The determination of the vanishing points on the unrolled projection surface is not as easy as in the case of the classical perspective onto a flat projection plane. Due to the fact that the projected straight lines appear as curved lines, their intersection points can be established approximately in a descriptive way. Therefore, it is recommended to find vanishing points of the lines whose projections are similar to the straight lines. The horizon line joining vanishing points should be perpendicular to the vertical lines, however, the correctness of its location can be improved in the further reconstruction process. Considering formulas (1) and (2) for calculating position of the characteristic points of the presented figure, we can state that expressions h-d_o and d-d_o are constant independently on the position of the base line. However, parameters k and w change relatively to the value of h. Therefore, by changing the value of h we do not change the proportions of the reconstructed figure.

2.3. Application of restitution formulas for reconstruction of a building given in a photo

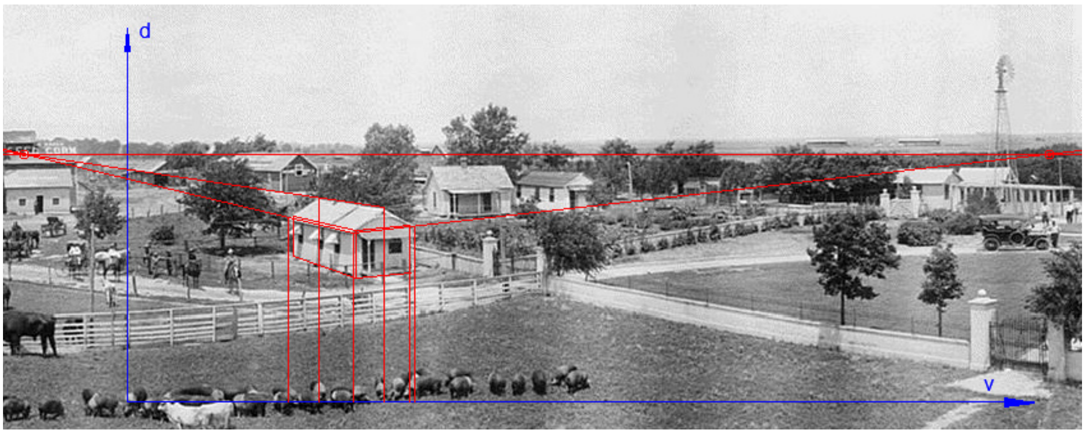

Figure 4. Reconstruction process-establishing base elements of perspective

The first step in our restitution is establishing base elements of perspective in a descriptive way, see Fig.4. The intersection points of the straight lines containing parallel eaves and the ridge of the building determine vanishing points, which in turn establish a horizon line *h*. We locate the ground line parallel to the horizon line and beneath the ground contour of the presented building. Next, we measure the distance between the horizon line and the ground line, which are necessary to use in our formulas. We place the orthogonal coordinate system *v*, *d* as in Figure 4, and establish *v*, d_o and *d* for every characteristic point of the building. Finally, we calculate the position of the points in 3D coordinate system of axis *x*, *y*, *z*, by means of Mathcad software, which defines the shape of the building (Fig.5). If any additional assumption or measure of building is known, it can be scaled the model and achieve its real size.

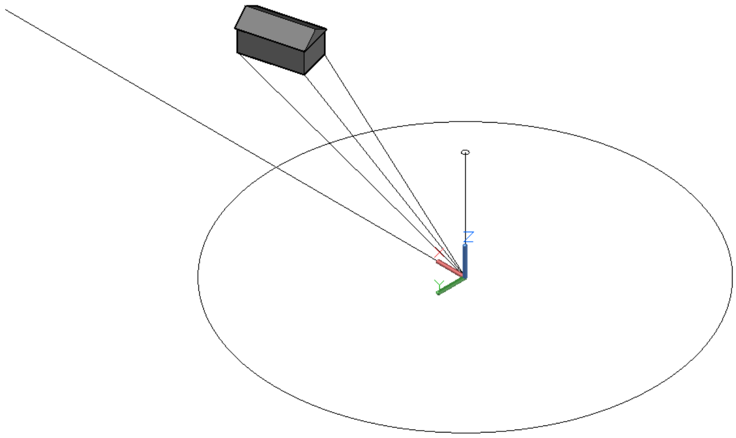

Figure 5. Restitution effect – location of the building towards the station point and the ground line

4. Results and discussions

The above example of reconstruction of a simple building given in the panoramic image shows that our method of reconstruction works well, although slight correction during reconstruction process was necessary. We checked performance of this method in the case of two simple architectural building photographs. The received results were similar as far as accuracy is concerned. The measure of angle between any two horizontal and mutually perpendicular straight lines was 90-94 degree in reconstructed models. The difference in length between any two horizontal or vertical straight lines supposed to be equal was 20 mm.

Moreover, we have repeated reconstruction process for the same building with the different location of the base line. The proportion of length: width: height of the cuboid forming the main walls of the building was similar in the first and in the second case. It proves our assumption that the base line can be freely located beneath the object reconstructed from the panoramic image. The application of the presented method depends on the content of the panoramic image as well as accuracy of establishing coordinates (v, d) of represented points. Birds view panoramic picture is the best for reconstruction process of the architectural forms as their shape and ground plan can be established easily.

5. Conclusions

In the hereby paper, we focused on reconstruction of the architectural objects from a single panoramic image when base elements of panoramic projection are unknown. It has been proved, that reconstruction process, as far as the shape and proportions of the reconstructed building are concerned, does not depend on the location of the ground line. On the basis of the algorithms for drawing panoramic image presented in the previous work, we derived formulas for calculating the space location of the characteristic points of objects represented in the panoramic 2D image, which determines 3D edge models. The presented method of reconstruction can find application in reconstruction of architectural forms from the single image, especially in the case of architectural heritage. The study shows that reconstructing architectural environment from the single panoramic image mostly depends on the image's content and an initial assumption. It is not always an easy process, however, possible in some cases.

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