SEMI-AUTOMATIC FLOOR-PLAN RECONSTRUCTION FROM A 360^{O} PANORAMIC IMAGE

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Abstract: The ease of panorama creation has made it very popular. Although it is a very convenient way to convey the environment, panoramic images can often be confusing. This discomfort has major influence in a 360 degree indoor panorama, where the viewer is forced to look in all the directions at the same time. In this paper we propose an alternative approach for visualization of the indoor environment. Instead of using the panorama directly, our method reconstructs a floor-plan from it and displays the created 3D model. During the reconstruction the user is only required to mark the corners in the original image. For the wall planes we use unwrapped texture mapping. Our experiments show that the proposed approach copes very well with the complex environments that include large spaces and corridors.

1. INTRODUCTION

Scene visualization using 360^{o} panoramic images has become very popular and simpler than ever before. The advent of inexpensive photographing equipment and the progress in detecting and matching informative image features (Brown and Lowe, 2003) have made it possible for any amateur photographer to produce high quality panoramic mosaics. However, while the panoramic image shows an impressive view of the environment, it may cause a great deal of confusion when displaying confined spaces. Many people find it difficult to understand the spatial scene arrangement in 360^{o} panoramic views because it makes the viewer to look in all the directions at the same time. Furthermore, in the process of the panorama generation, the images are projected on different surfaces (Brown and Lowe, 2007) and then flattened onto the image plane causing some forms of distortions that may increase the viewer's disorientation in the indoor scene.

There are several commonly used ways to display panoramic images. The first approach suggests displaying the panoramic image through an *interactive image browser* which shows the user a sub-view of the scene. The panorama is projected onto a cylinder surface, allowing the user to control the viewing direction by changing the viewing sector inside the virtual cylinder. However it is not possible to get a quick overview of the whole scene from a single point of view.

In (Zelnik-Manor, et al., 2005), several projections of the panoramic images are compared in purpose of increasing the visual quality for the viewer. It is proposed to use perspective multi-plane projection, where the walls are projected onto different planes. This panoramic image editing approach eliminates the geometric distortion and results in better viewing experience than the distorted original panoramas. However, in the case of 360^{o} panoramas the user will be still confused by looking in all the directions at the same time.

A preferable approach is to present the indoor scene using a 3D model of the environment reconstructed from the panoramic images. This approach provides a very convenient and realistic visualization of the scene, since it enables the observer to orientate within the space. Moreover, it enables the viewer to obtain an overview of the whole scene by viewing it from an outside point, or to see the details from an inside location.

Algorithms for this approach can either require or not some pre-knowledge about the scene, such as the geometric model. The methods that use such pre-knowledge, like in (Farin, et al., 2005, 2007; Shum, et al., 1998) usually can only adjust the sizes in the model based on the panoramic image. This semi-automatic technique requires an initial sketch of the floor-plan which affects drastically the final results. However, one can use the approaches without the a-priori model (Pollefeys, et al., 2000). They are usually not robust enough and unreliable due to the complexity of the scenes and the fragility of the vision techniques.

In this paper we propose an algorithm that estimates the floor-plan and reconstructs a 3D model of the room from a panoramic image with only minor user assistance. Furthermore, the original camera position is estimated for further applications (Farin, et al., 2007). This algorithm does not require a full geometric model of the scene. As a matter of fact, it generates the floor-plan using only the user's corner-marks in the panorama. Compared to (Farin, et al., 2007; Shum, et al., 1998) our algorithm requires less external user intervention and usage of priori-knowledge about the scene. In addition, the necessary user intervention is less complicated.

The rest of the paper is organized as follows. Section 2 gives a general overview on the creation of panoramic images. Section 3 describes the floor plan reconstruction technique along with the required user assistance. In Section 4 we present the method for estimation of the camera location. The experimental results are shown in Section 5 and conclusions are drawn in Section 6.

2. PANORAMA CREATION

To create a 360^o panoramic image without special equipment one should take a series of overlapping still images in all directions and then stitch them together into a single image. Simply appending the images usually creates ghosting in the resulting image because the same object in different images can be seen from different perspectives. To prevent this, all the images are projected onto a single plane (Brown and Lowe, 2007). For indoor environments this is not good enough because the objects in the image are relatively close to the camera. In such cases a cylinder is used instead of a plane. Unfortunately, this creates an additional distortion in the panoramic image, long horizontal lines are transformed into curves as can be seen in Figure 1.

3. FLOOR-PLAN RECONSTRUCTION

Before presenting the proposed technique we describe several assumptions. First, we assume that the panoramic image is taken from a single location (rotation only, without translation). Second, all the room's corners are visible on a single panoramic image. Third, the walls of the room are planar and perpendicular to each other. Forth, the ceiling should be at the same height in the whole room. These conditions are met in most of the spaces and can be approximated to, in the others.

Under the assumptions above, a floor-plan can be described as a planar polygon with corners of 90^o (outward pointing, convex) or 270^o (inward pointing, concave). Such a polygon can be built based only on the lengths of the edges and the orientation of the corners. If we assume that we have all the corners marked from the floor to the ceiling in the panoramic image we can automatically obtain these parameters. Corners that are close to the camera look higher than distant ones. The orientation of the corner can be determined by comparing its vertical size to the neighbors'. The length of a wall is estimated using the difference in height of its two corners.

3.1 User Interaction

As opposed to a computer, it is easy for the human eye to differ between wall corners and windows or furniture. Thus the user is asked to mark each corner of the room in the panoramic image with a line that starts at the junction of the corner with the ceiling and ends at the floor.

Because of the distortion created by the projection onto a cylinder some walls usually appear curved. For such cases, the user is asked to mark vertical lines along the curved wall. These lines are treated as flat (180^o) corners. The number of such flat corners is determined by the user so that the curved wall is divided into relatively flat sections. It is to be noted that the order of marking the corners is unimportant. Also, the described technique determines automatically whether the corner is inward (convex), outward (concave) or flat.

3.2 Wall length estimation

At the first step of our algorithm we calculate the lengths of all the walls. A rectangular wall that is viewed from an angle will appear trapezoidal due to the projection onto the image plane. The original length of a wall can be calculated from the form of that trapezoid by using the projection matrix (Szeliski, 2010). This matrix describes the relation between the 3D scene coordinates and the pixel coordinates in the panoramic image:

$$\begin{pmatrix} \bar{x}_P \\ \bar{y}_P \\ w_P \end{pmatrix} = \begin{pmatrix} f & 0 & C_x \\ 0 & f & C_y \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_S \\ y_S \\ z_S \end{pmatrix} \quad (1)$$

The notations used here are:

- (x_s, y_s, z_s) for 3D coordinates of the scene
- (X_p, Y_p, W_p) for homogenic coordinates
- $(x_p = X_p / W_p, y_p = Y_p / W_p)$ for pixel coordinates in the panoramic image
- Subscript numbers are used to note the different corners.
- f is the focal length of the camera
- C_x is the mean of x_{p1} and x_{p2}, C_y is the mean of y_{p1} and y_{p2}.

To find the 3D scene coordinates, the system of equations is solved for x_{s1}, x_{s2}, z_{s1}, z_{s2}. The solution is given by:

$$x_{S1} = y_S \frac{x_{P1} - C_x}{y_{P1} - C_y} \qquad x_{S2} = y_S \frac{x_{P2} - C_x}{y_{P2} - C_y}$$
$$z_{S1} = \frac{y_S \times f}{y_{P1} - C_y} \qquad z_{S1} = \frac{y_S \times f}{y_{P2} - C_y} \quad (2)$$

Assuming that all the walls have the same height y_s, the length of the wall is proportional to:

$$L = \sqrt{(x_{S2} - x_{S1})^2 + (z_{S2} - z_{S1})^2} \quad (3)$$

This calculation is repeated for every pair of corners, regardless of their orientation. This way, walls that are affected by the cylindrical curving are treated as several shorter walls.

After calculating the original length of the wall, the trapezoid wall from the panoramic image can be transformed into a rectangle. This unwrapped image is used as a texture in the 3D rendering of the room. Flat corners provide a solution for texturing "curved" walls by transforming them part by part.

3.3 Corner orientation detection

The next step is to estimate the orientation of each corner. A corner that points out of the room (convex) is more distant from the camera than its neighbors. Thus, the height of such a corner is much smaller than that of the neighbors. A corner that points into the room (concave) is closer to the camera than its neighbors and thus its height is much larger. A flat corner is closer to the camera than one of its neighbors and more distant than the other and thus its height is between those of its neighbors. The orientation of a corner is determined by calculating the angle defined by the corner's highest point and those of its neighbors. The corner is outward (convex) if the angle is smaller than 170^o, and inward (concave) if the angle is larger than 210^o. If the angle is between 170^o and 210^o then it is a flat corner. The margin is larger on the positive side because the curvature of the walls is always positive. In Figure 1, outward (convex) corners are marked in green, inward (concave) corners are marked in red and flat corners are marked in blue.

3.4 Sketch Generation

After obtaining the approximate lengths of the walls and the orientations of the corners, the floor plan is built step by step. The length of each step is the approximated length of the corresponding wall. The direction of each step is found by turning the direction of the previous step by $+90^o$ or -90^o according to the corner's orientation (convex or concave) or continuing in the same direction for the flat corners. The direction of the first step is arbitrary.

The approximation of the lengths of the walls is not perfect. This creates an accumulative error in the

Figure 1 – A panoramic image with marked corners and numbered walls. Convex corners appear in green, concave corners in red and flat corners in blue. Note that the user is only required to mark the corners; the orientation and the wall numbering are automatic.

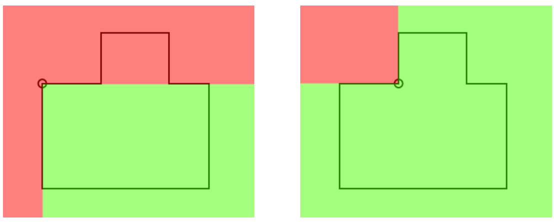
sketch. Because of this error, the resulting polygon is not closed, in the other words, the end of the last step does not meet the beginning of the first step. To make a closed sketch, the first step is extended backwards and the last step is extended forward until a crossing point is reached. In Figure 1, walls 1 and 20 are extended to their shared corner closing the polygon and completing the floor-plan generation. An additional example can be found in Figure 4.

4. CAMERA POSITION ESTIMATION

An approximation of the position of the camera in the scene can be useful for some applications, including correction of the floor-plan (Farin, et al., 2007).

The estimation is based on the assumption that all the corners of the room that were marked in the panoramic image must be seen from the camera position. The coordinates of the corners of the room had already been estimated to create the floor-plan. Thus, they are a convenient set of points to create a constraint for the position of the camera.

Finding the area in the floor-plan from which all the corners can be seen is a form of a linear programming problem for which there are numerous efficient algorithms (De Berg, et al., 2008). Under the assumption that all the corners are of ±90 degrees, the problem is largely simplified. For an inward corner (concave), a quarter of the 2D space can be discarded as an area from which the corner cannot be seen (Figure 2, (b)). For an outward corner (convex), three quarters of the 2D space can be discarded as an area from which the corner cannot be seen (Figure 2, (a)).



(a) (b)

Figure 2 – Camera position estimation steps. A convex (a) and a concave (b) corners allow to discard parts of the plane (red).

Repeating this process for each corner leaves only the area from which all the corners are visible. The center of this area is a good approximation for the camera position in the floor-plan.

5. EXPERIMENTS

For the experimental validation of the proposed approach we created panoramic images of several indoor environments. The rooms we have used include both large areas and long corridors. They have only planar constant height walls, and perpendicular corners. We placed a Nikon D70s digital camera at the point from where all the corners are visible and stabilized it on a tripod. The images were taken using camera rotation only with an about 50% overlap. Then we created a 360^o panorama using a demo version of Autostitch(TM) software (Brown, 2011). An example of such panorama of a hall with the connected corridor is shown on Figure 3.

To enable user interaction with the panoramic image we have built a MATLAB GUI that loads the panorama and asks the user to mark all the corners. Optionally, the "flat corners" can be easily marked as well. Having the image and the corners, the floor plan is reconstructed automatically together with the estimated camera location (Figure 4).

For better visualization we add an arbitrary (but reasonable) height to all the walls and color them using texture mapping. The texture for each wall is created by unwarping the wall's image to the corresponding rectangle. The rendered 3D model of the room can be viewed from a bird's eye camera for overview (Figure 5, (a)), or from any inside point for detailed view (Figure 5, (b)).

Figure 3 – A 360^o panoramic image of a hall connected to a long corridor.

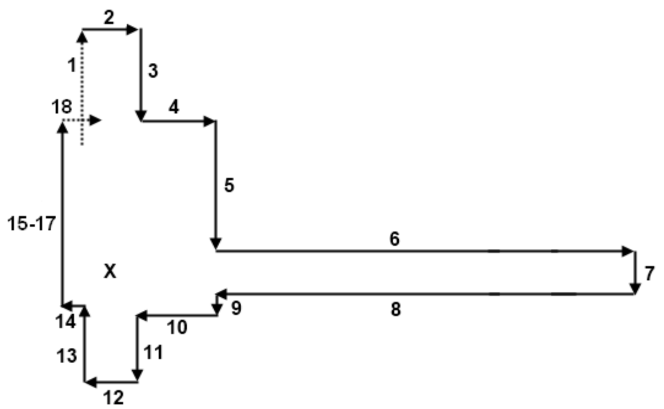


Figure 4 – Sketch generation process with numbered steps. The dashed lines represent the extension of the first and last vectors. The 'X' marks the estimated camera position.

As we can see for this space our algorithms managed to reconstruct both the large hall in the middle with all the corners and the long corridor.

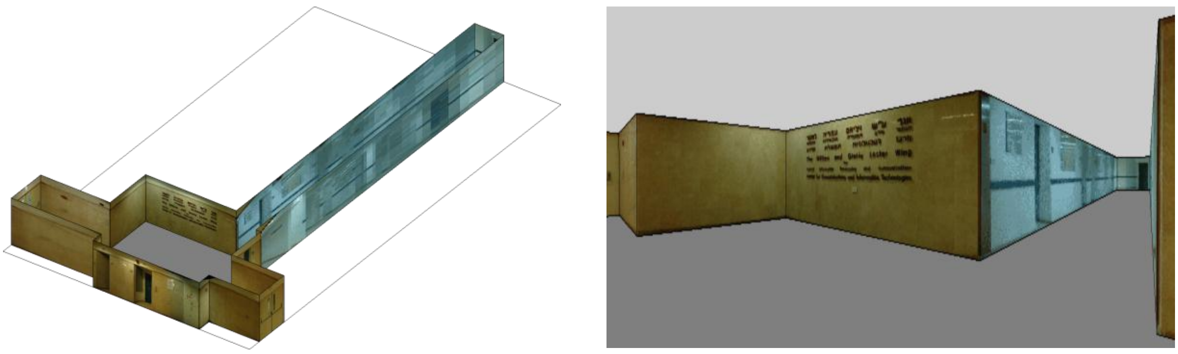
Additional results are shown on Figure 6. On the left (a) there is the reconstructed hallway from the panorama and the corners of the Figure 1. It can be seen that our approach handled the long and curved wall as well as the short distant ones. On the right (b) the T-junction of two corridors is reconstructed, with both close and far away objects.

6. CONCLUSIONS

In this paper we have proposed a visualization algorithm for 360^{o} panoramic images of indoor environments. Our algorithm reconstructs a 3D model of the room and projects the panoramic image onto the virtual walls. In addition, the camera position is estimated for further applications. The algorithm is user friendly and requires very small user assistanse. Our experimental results show that it is able to reconstruct a visualy accurate and realistic model of the rooms in the panoramic images thus helping the observer orient and understand the spatial arrangement of the scene.

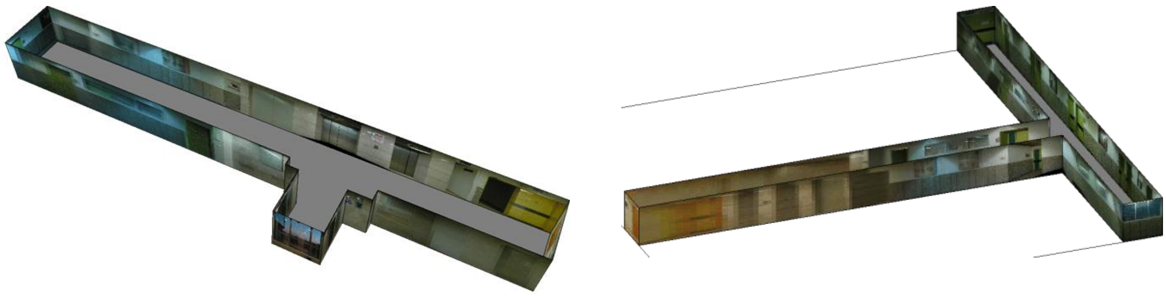
However, as mentioned in Section 2, the panoramas are created by projecting the scene onto a cylinder. The curvature imposed by this nonlinear projection can interfere with some of the calculations described in this work. This effect is unnoticeable for walls that take only a small portion of the panorama and the calculations are correct. However, walls that capture a wide angle of view appear curved in the image and the calculations deviate from the truth. Our solution for these cases is to ask the user for additional information in the form of flat corners. Another approach may be finding the correct inverse cylindrical transformation. Given the inverse transformation the curved walls can be transformed back into straight ones and the calculations mentioned above are correct.

Another limitation is that the algorithm requires



(a) (b)

Figure 5 – The reconstructed room and corridor model from the 360^{o} panorama in Figure 3. It is possible to receive an overview of the whole scene from a distant point of view (a) or a partial view from within the room model (b).



(a) (b)

Figure 6 – Additional 3D room models reconstructed from a single panorama.

all the walls and corners to be visible on one panoramic image. This makes the algorithm not suitable for the reconstruction from several panoramas that were shot from different locations and cover the whole scene when combined. For example, a "U" shaped room cannot be captured by a single panorama. A possible solution is to manually combine the panoramic images into a single, longer, image covering all the walls of the room. The obtained panorama will contain all the needed data for the reconstruction of the scene. However, the camera position would be estimated separately for each of the original panoramic images.

Inevitably, using pre-knowledge assumptions about the room layout such as perpendicular walls and constant ceiling height, limits the algorithm's universality. Nevertheless, the assumptions taken in this paper hold for most standard room layouts and allow a semi-automatic reconstruction with very small user assistance.

In addition, since the algorithm generates the floor-plan, it can be integrated with algorithms of the second class mentioned in Section 1. Having a relatively accurate initial geometric model of the room and the camera position it is possible to optimize the model ratios using the approach of (Farin, et al., 2007) without any additional user assistance. Another possibility is to use (Shum, et al., 1998) for results optimization by employing camera calibration and additional user assistance.

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