Panoramic Mosaics Minimizing Overlappings in the Azimuthal Field-of-View

João Vitorino, José Gaspar
Instituto Superior Técnico, Instituto de Sistemas e Robótica, Lisboa, Portugal

***Abstract*—In this paper we describe the construction of an accurate panoramic mosaic from multiple images using a unique information from each image taken with a rotating camera.**

The novelty of the approach lies in the technique of estimating the size and shape of the stripe that is used to make panoramas.

I. Introduction

Panoramic image mosaicing combines the information of multiple images into a single mosaic image, typically for obtaining very wide fields-of-view. Normally, mosaicing involves extracting vertical stripes from images and stitching them side by side. This process implies therefore defining the stripes' shape and location within the images. The stripes' shape and location depends on the intrinsic and extrinsic imaging parameters.

In this work we consider the case of a camera at the end of an arm rotating with a constant low-speed, hence having constant (incremental) extrinsic parameters (see Fig.1). The low-speed implies larger overlapping of the image data and thinner stripes thus having less perspective effects. The stripes' width must be carefully selected in order to avoid repeated viewing of the same scene part.

The intrinsic imaging geometry of the camera is assumed to be central, which includes the case of interest of fisheye lenses [3]. The use of fisheye lenses introduces a large radial distortion factor implying that stripes are no longer rectangular. This paper approaches therefore both the aspect of selecting unique information and finding the shape of stripes.

II. Related work

There are many commercial packages for creating panoramic images. One of the best known is *QuickTime Virtual Reality* [2]. It works on the principle of sewing together a number of standard images by matching image information captured while rotating the camera. In order to deal with less constrained camera motion allowing e.g. to hand-held the camera [1], most of these works are however limited to standard perspective cameras.

Considering professional applications, is acceptable to use mechanical setups guaranteeing precise motion of the camera while allowing for more general camera geometries [3]. Researching the properties of these devices is certainly an enabling key for their widespread use.

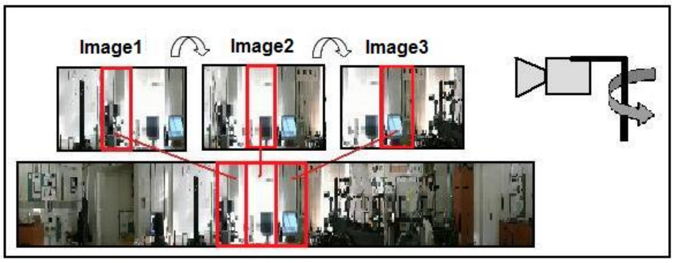


Fig. 1. Panoramic image being created using images captured with a regular camera rotating about an axis behind it.

III. Making panoramas

Definition: ***Rotating camera*** is a camera that rotates around the z-axis of the world coordinate system, Oz, describing a circle with radius r, in angular steps of δ. The optical axis is kept orthogonal to Oz. Hence the camera passes through $N = 360^o/\delta$ poses and is described by the projection function:

$$m = K_i \; \mathcal{F}\left(R_i M + t_i\right), \quad i = 0..N-1 \tag{1}$$

where M is a 3D point, m is the imaged point, K_i is an intrinsic parameters matrix, R_i and t_i set the rotation and translation (functions of r, δ and i), and in the case of a perspective camera $\mathcal{F}(M) = M$, with $M = [x\ y\ z]^T$. In the case of a fisheye lense, we use Hynek and Pajdla's model [3], where $\mathcal{F}$ is a non-linear function introducing radial distortion with (a, b) parameters:

$$\begin{aligned} \mathcal{F}(M) &= [k.x\ k.y\ 1]^T \\ k &= a/r.sin(b^{-1}atan(r/z)) \end{aligned} \tag{2}$$

where $r = \sqrt{x^2 + y^2}$. $\diamondsuit$

As previously referred, each image acquired by the rotating camera gives one stripe for the panoramic mosaic. While with perspective cameras the shape of the stripe is rectangular (vertical stripe), with other geometries like fisheye lens [3] [4] the stripes become more crescent-moon-like shaped. In the following section we detail how to extract the stripes minimizing the azimuthal overlappings.

IV. Finding the stripes

Finding a stripe in each image acquired by a rotating camera, involves defining a reference azimuth and then computing the shape of the stripe. The *camera reference azimuth*, θ is in essence a preferred direction of seeing in each image which is

(a) (b)

Fig. 2. Fisheye image and stripe that was estimated to generate a panorama (a). The panoramic image (b).

fixed in the camera local coordinate system, and thus variable in the world coordinates, ${}^{w}\theta = \theta + i\delta$, for $i = 0..N-1$. The most common mosaics are built with $\theta = 0$, but by choosing two different reference azimuths, one builds two mosaics that have parallax information and thus allow estimating scene-depth [1]. In order to maintain the generality, we keep θ in our formulation.

Property: ***Non-overlapping azimuth ranges*** - Given the rotating camera, Eqs.1 and 2, and a camera reference azimuth, θ, then the azimuth range in the camera local coordinate system

$$\Theta = [\theta - \delta/2, \quad \theta + \delta/2] \tag{3}$$

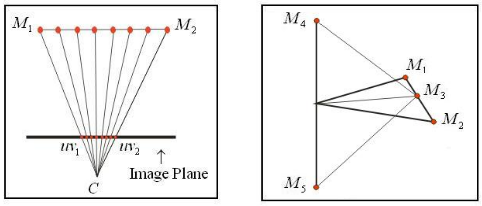
define mutually-exclusive (non-overlapping) 3D fields-of-view for all the camera poses. ♢

The method to calculate the stripe is described by the following algorithm:

1) Define two unit norm 3D points, M_1 and M_2 with zero elevation and that are the left and right azimuthal boundaries of the stripe as given by Eq.3.
2) Do an horizontal line sweep from M_1 to M_2 finding one 3D point for each pixel in the image, Fig.3a.
3) Define a sphere centered at $(0, 0, 0)$ with M_1 and M_2 in the equator. Compute the middle point, M_3 between M_1 and M_2. Do a vertical sweep from M_3 to the north and south poles of the sphere (resp. M_4 and M_5). These sweepings are made until reaching the limits of the image or lacking image resolution. The sweeping-step is regulated to obtain image points separated by one pixel distances. See Fig.3b.
4) Make one *3D surface grid* given the horizontal and vertical directions $M_1 \rightarrow M_2$ and $M_4 \rightarrow M_3 \rightarrow M_5$, and the respective sweeping steps. Projecting the 3D grid defines the pixels necessary to make the stripe.

V. Results

Our mosaicing algorithm was tested with a sequence of images taken with a rotative camera equipped with a fisheye lens, used in the BeNoGo EU-project (see the acknowledgments section). The image sequence has 263 images covering the 360deg and the fisheye lens has a 180deg field of view. Figure 2a shows one image of the sequence and the stripe that is extracted from it. Figure 2b shows the panoramic image resulting from the combination of the stripes taken from the different images.



(a) (b)

Fig. 3. Horizontal sweep from M_1 to M_2 finding one 3Dpt for each pixel in the image plane (a). Vertical sweep passing at the middle point M_3 (b).

VI. Conclusion

In this paper we introduced an accurate geometrical method for constructing panoramic mosaics. The stripe extracted from each image of the sequence is found based on the intrinsic and extrinsic parameters of the system.

Future work will focus on modeling the image brightness on rotating cameras. The brightness of each stripe of a panorama can be adjusted to match exactly with the preceding one, by comparing the overlapping area on consecutive images. Simple brightness-matching optimization-methods will allow then to obtain precise depth estimates from mosaics acquired with different reference azimuths.

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