ANGLES ESTIMATION OF ROTATING CAMERA

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Abstract: We address the problem of camera motion from points and line correspondences across multiple views. We investigate firstly the mathematical mathematical formula between slopes of lines in the different images acquired after rotation motion of camera.
Assuming that lines in successive images are tracked, this relation is used for estimating rotation angles of the camera.
Experiments are conducted over real images and the obtained results are presented and discussed.

1 INTRODUCTION

There are many applications of computer vision and pattern recognition where the camera orientation is controlled by a computer. For example, in order to track and center the object of attentive focus, the camera is rotating once the object is near from the image border. The amount of rotation depends on the velocity of the object and its depth.

When a camera is rotated by a certain angle relative to a stationary scene, different projected images are seen on the image plane. Consequently, the extracted low-level features (interest points, segments of contour, etc) on images change their attributes so as position, intensity, etc).

From these low-level features, if a set of invariants are computed in the sense that their new values are completely determined by the original values and the amount of the camera rotation, we can then predict the values of these invariants which would be obtained if the camera were rotated by a given amount.

Conversely, if we are given two views of the same scene obtained from different camera orientations, and if we know the point-to-point correspondence, we can reconstruct the amount of camera rotation which would transform the values of these invariants to prescribed values.

When the camera is fixed, the analysis of different views permits to understand the structure and the motion of moving objects. We can consider this case as equivalent to camera rotation.

Camera motion estimation is important for various computer vision applications such as: 3D reconstruction, objects tracking and so on. Various methods were developed and can be classified as optical flow methods and direct methods, which are global, and features correspondences-based approaches, which are local. From the interesting methods we cite (R. Ewerth and Freisleben, 2004), (C. Jonchery and Koepfler, 2008), (A. Yamada and Miura, 2002), (A. Biswas and Venkatesh, 2006) for optical flow methods well-adapted to small motions and (B. Rousso and Pelegz, 1996), (Bartoli and Sturm, 2003), (Urfalioglu, 2004) for feature correspondence-based methods that are well-adapted to high motions of the camera giving well separated views of the scene. In this paper we address the problem of camera motion from lines and points correspondences across multiple views. We investigate firstly the mathematical formula between slopes of lines in the different images acquired after rotation of the camera. Assuming that lines in successive images are tracked, computed relation is used for estimating rotation angles of camera. Our contribution in this works is the extraction from low-level features invariants that permits the estimating of motion rotation of

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the camera knowing the correspondence of the features. Experiments are conducted over real images and the obtained results are presented and discussed.

2 POSITION OF THE PROBLEM

In this work, we assume that the camera performs horizontal rotational movement. The proposed geometrical model is illustrated by figure 1. After each rotation of the camera, a new image is acquired and noted IM^i, where i refers to the position number of the camera. We assume that in each image some of line segments or interest points defining segment lines are extracted. The geometrical model of image formation is defined by (see figure 1):
- O^i is the impact point of the image IM^i defined as the intersection of the optical axis with the image plane
- L is the center of projection of the camera, O^iL represent the focal length f
- $\overrightarrow{O^iU^iV^i}$ is the internal referential associated to IM^i
- The theoretical external referential $\overrightarrow{(OXYZ)}$ is defined so as the origin O is the rotation center of the camera, $\overrightarrow{OX}$ is parallel to $\overrightarrow{O^iU^i}$, $\overrightarrow{OY}$ is parallel to the optical axis, the axis of rotation $\overrightarrow{OZ}$ is parallel to $\overrightarrow{O^iV}$.
- The camera is fixed so as the rotational axis passes through the optical axis. Due to the uncertainty of the mechanics, the $\overrightarrow{OZ}$ axis is somewhere not far from the impact point whose coordinates relatively to $\overrightarrow{(OXYZ)}$ are (d_x, d_y, d_z).
- ex, ez define the dimensions of the pixel

We suppose that none of the defined parameters is known. Our aim is to develop a mathematical relation that permit to compute the amount of the angle rotation of the camera. This relation must be independent of the camera model and will use only the coordinates of image points in the different views.
We can see in figure 1 that when the camera is rotating around the origin O, the projection center L and image plane IM^i are rotating also with the same angle.

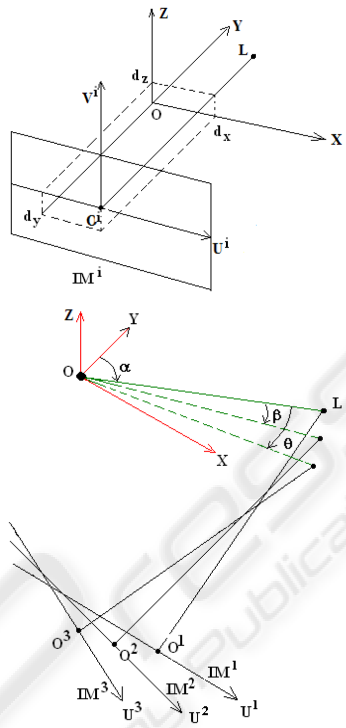

Figure 1: Geometrical models for image formation and camera rotation.

3 ESTIMATING OF THE ROTATION OF THE CAMERA

3.1 Basic Principle

In general case where the camera is rotating by an angle α, any point $M_i(x_i, y_i, z_i)$ of the $3D$ space is projected into m_i^1 where its projective coordinates on the image plane IM^1 are (Duda and Hart, 1988)(O. Faugeras and Papadopoulo, 2000):

$$u(m_i^1) = f.ex.\frac{-x_i'.cos(\alpha) + y_i'.\sin(\alpha)}{x_i'.\sin(\alpha) + y_i'.\cos(\alpha) + D} \quad (1)$$

$$v(m_i^1) = f.ez.\frac{(-z_i')}{x'.\sin(\alpha) + y_i'.\cos(\alpha) + D} \quad (2)$$

where: $x_i' = x_i - d_x$, $y_i' = y_i - d_y$, $z_i' = z_i - d_z$ and $D = d_y - f$.

As the referential $\overrightarrow{(OXYZ)}$ is attached to the initial position of the camera, the angle α may be considered as equal to zero. The equations 1 and 2 will serve us for the writing of the new coordinates of points after two rotations of the camera. Let S_i be a line segment in the $3D$ scene and let S_i^1 be the image of S_i on the image IM^1 whose equation relatively to $(O^1U^1V^1)$ is $v = a_{i,1}.u + b_{i,1}$.

The coordinates of m_i^1 image on IM^1 of any point $M_i(x_i, y_i, z_i)$ of the segment S_i are:
$u(m_i^1) = \frac{f.ex.X_{i,1}}{Y_{i,1}+D}$, $v(m_i^1) = \frac{f.ez.(-Z_{i,1})}{Y_{i,1}+D}$ where:
$X_{i,1} = -x_i'.\cos(\alpha) + y_i'.\sin(\alpha)$
$Y_{i,1} = x_i'.\sin(\alpha) + y_i'.\cos(\alpha)$
$Z_{i,1} = z_i'$

As $v(m_i^1) = a_{i,1}.u(m_i^1) + b_{i,1}$, we can write:

$$Z_{i,1} = a_{i,1}\frac{ex}{ez}X_{i,1} - \frac{b_{i,1}}{f.ez}(Y_{i,1} + D) \quad (3)$$

After a second rotation of the camera with an angle β, the segment S_i will be projected on IM^2 as S_i^2. Let $v = a_{i,2}.u + b_{i,2}$ be the equation of S_i^2.

Following the same steps described above, we obtain:

$$Z_{i,2} = a_{i,2}\frac{ex}{ez}X_{i,2} - \frac{b_{i,2}}{f.ez}(Y_{i,2} + D) \quad (4)$$

where:
$X_{i,2} = -x_i'.\cos(\alpha+\beta) + y_i'.\sin(\alpha+\beta)$
$Y_{i,2} = x_i'.\sin(\alpha+\beta) + y_i'.\cos(\alpha+\beta)$
$Z_{i,2} = Z_{i,1}$

A set of transformations will give us:

$$v(m_i^2) = a.u(m_i^2) + b \quad (5)$$

where: $a = (a_{i,1}.\cos(\beta) + \frac{b_{i,1}.\sin(\beta)}{f.ex})$ and $b = C_2\frac{Y_{i,2}}{Y_{i,2}+D}$.

Knowing that the equation (5) is valid for any point m_i^2 of the segment S_i^2 whose equation is $v(m_i^2) = u(m_i^2).a_{i,2} + b_{i,2}$, we obtain:

$$\frac{a_{i,2} - a_{i,1}.\cos(\beta)}{\sin(\beta)} = \frac{b_{i,1}}{f.ex} \quad (6)$$

The equation 6 is also valid for any segment S_j. The use of two equations written for S_j and S_j gives us:

$$\frac{a_{i,2} - a_{i,1}.\cos(\beta)}{a_{j,2} - a_{j,1}.\cos(\beta)} = \frac{b_{i,1}}{b_{j,1}} \quad (7)$$

For another rotation movement of the camera with angle θ, a new equation is obtained for segments S_i and S_j where $v = a_{i,3}.u + b_{i,3}$ and $v = a_{j,3}.u + b_{j,3}$ are the equations of S_i^3 and S_j^3 on the image IM^3.

$$\frac{a_{i,3} - a_{i,1}.\cos(\theta)}{a_{j,3} - a_{j,1}.\cos(\theta)} = \frac{b_{i,1}}{b_{j,1}} \quad (8)$$

From 7 and 8, we obtain:

$$k_1.\cos(\beta) + k_2.\cos(\theta) + k_3 = 0 \quad (9)$$

where:
$k_1 = a_{i,3}a_{j,1} - a_{i,1}a_{j,3}$
$k_2 = a_{i,1}a_{j,2} - a_{i,2}a_{j,1}$
$k_3 = a_{i,2}a_{j,3} - a_{i,3}a_{j,2}$

The use of a third segment S_k with the segment S_i gives us the relation:

$$k_1'.\cos(\beta) + k_2'.\cos(\theta) + k_3' = 0 \quad (10)$$

where:
$k_1' = a_{i,3}a_{k,1} - a_{i,1}a_{k,3}$
$k_2' = a_{i,1}a_{k,2} - a_{i,2}a_{k,1}$
$k_3' = a_{i,2}a_{k,3} - a_{i,3}a_{k,2}$

The linear resolution of the equations 9 and 10 gives us the values of the angles β and θ.

3.2 Algorithm

The following algorithm gives the steps to be performed in order to compute the angles of rotation of the camera knowing the correspondence between the set of lines extracted in the three images. The theoretical study presented above allows estimating the two rotation angles of camera using only images of three lines.

In order to increase the accuracy in the computation of the values of (β, θ), we will use all combinations of all triplets of lines in the three images.

Let: $IM^1 = \{S_1^1, S_2^1, \ldots, S_n^1\}$, $IM^2 = \{S_1^2, S_2^2, \ldots, S_n^2\}$, $IM^3 = \{S_1^3, S_2^3, \ldots, S_n^3\}$ be the set of located straight lines respectively in the first, second and third image. We assume that each triplet (S_i^1, S_i^2, S_i^3) defines three matched segment lines in the three images.

The steps of the Algorithm consist to select $((S_i^1, S_j^1, S_k^1), (S_i^2, S_j^2, S_k^2), (S_i^3, S_j^3, S_k^3))$ from $(IM^1 \times IM^1 \times IM^1)^3$ and to compute the correspondent slopes. For each one of these triplets, we compute the values of β and θ by resolving the linear equations 9 and 10

This step is repeated until all triplets should be selected. At the end, the average values of (β, θ) is computed.

The number of possible triplets of (S_i^1, S_j^1, S_k^1) in $(IM^1 \times IM^1 \times IM^1)$ is equal to $C_n^3 = \frac{1}{3!} \times n \times (n-1) \times (n-2)$, and it is identical to the number of triplets $((S_i^1, S_j^1, S_k^1), (S_i^2, S_j^2, S_k^2), (S_i^3, S_j^3, S_k^3))$. To reduce the complexity of this algorithm, we will use a restricted number corresponding to triplets of segments giving better results.

4 EXPERIMENTAL RESULTS

In the first we generated randomly (x, y, z) coordinates of six points, and we computed their projections on the three images corresponding to three positions of the camera (initial, first and second rotation). Nine (09) values of rotation angles were used for the new positions of the camera $(10°, 15°, 20°, \ldots, 60°)$. Knowing the points correspondence, the application of the algorithm 3.2 computes the values of (β, θ) for each group of six generated $3D$ points. We repeated this process (100) times and the computed values of (β, θ) are grouped relatively of the orientation of segment lines in the image. We distinguish seven categories of absolute slopes $(C_i, i = 1..7)$ representing the line segments whose absolute slopes are respectively in the intervals: $C_1 = [0, 0.1]$, $C_2 =]0.1, 0.5]$,

$C_3 =]0.5,1]$, $C_4 =]1,5]$, $C_5 =]5,20]$, $C_6 =]20,200]$, $C_7 =]200,\infty[$. From the obtained results, we can conclude that the high value of rotation angles are better estimated than the low values, the better estimation are obtained respectively by the line segments of the categories C_5, C_6, C_4 and C_3. However, It is necessary to avoid the line segments of the first and seventh categories.

We studied also the influence of the noise on the uncertainty estimation of rotation angles. The great noise decrease the accuracy in the estimation of rotation angles. However, we can conclude that the slopes of categories C_4, C_5 are more robust to noise. A set of images of interior 3D scene are taken by the camera after two rotations. The extraction of interest points is done using Harris detector (Harris and Stephens, 1988). Some of these interest points are chosen to define three line segments (S_1, S_2, S_3). We used many combinations of interest points in order to define the three segments. We applied our algorithm for these images. Many combinations of the six interest points are used but eliminating the combinations for which the slopes are near from zero (category C_1) or having high values (category C_7). We selected only the combination of interest points defining segment lines of categories C_4, C_5, C_3 and C_6. The average of calculated values of β and θ by this algorithm are considered as the estimated values. In our case, the error in estimated values from the three images are $(1.59^\circ, 0.93^\circ)$.

5 CONCLUSIONS

In this paper we addressed the problem of camera motion from lines and points correspondences across multiple views. We investigated in the first the mathematical formula between slopes of lines in the various images acquired after the movement of rotation of the camera.
Assuming that lines in successive images are tracked, we used the found relation for estimating rotation angles of camera.

The advantage of the proposed method is that does not require any knowledge about the geometrical models of the camera; they use only the slope of line segment as 2D primitive.
The obtained results from experiment conducted over synthetic and real images are promising and will encourage us for their use in different applications so as head pose estimation where the interest points of the head are moving around the fixed camera.

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