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Estimating Camera Motion Without Knowledge of Matching Primitives

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Abstract: This study presents a method for estimating the motion of camera, by using only slope of line segments which is feature robust to noises in a system of computer vision in rotation movement. Our method is based only on the formalism of the slope of the segment by using the definition of the projection of points and the relation which exists between the slopes of the segment in various images and this without any knowledge about geometrical models of cameras or of there matching primitives. Experiment showed feasibility as well as robustness of the algorithm.

Key words: Estimation of the structure and the motion, matching, tracking, projective geometry, computer vision

INTRODUCTION

Convergence motion of cameras, similar to the movements of eyes, constitutes a subject of search in artificial vision. The introduction in the algorithms of stereoscopic vision allows to get closer to the human perception which is essentially dynamic[1].

Indeed the estimation of the movement is important for various applications such as: 3D reconstruction, objects tracking and the visual subjection.

Various methods were developed for the estimation of the movement and the structure[2,3]. We distinguish two classes of methods; the first is based on the calculation of the optical flow and the spatio-temporal relations[4]; the second's on the feature matching[5,6].

In this last case, used approaches are based generally on Euclidian's models and require a calibration of cameras[7-9]; uses the matching to resolve the problem of the movement and the structure.

Our goal is to resolve the problem of motion of camera without using the matching primitives and without any knowledge about geometrical models of camera.

This method is based only on the formalism of the slope of the segment, using coordinates of extremities of the segment in the image plane.

Proposed algorithm brings a double solution: resolution of the estimation of the movement and the tracking problem.

In this study, we present at first the theoretical aspects and the algorithmic of estimation of motion of camera, based on the calculation of the slopes of a line segment in the projective space. We also present the experimental results obtained by tested algorithm on synthetically and real images.

POSITION OF THE PROBLEM

Hypotheses

- We have a binocular system of vision not anthropomorphic in convergence motion;
- We suppose that every image was segmented and the contour approximated by line segments.
- Let us note IM_0 , IM_1 , IM_2,.., IM_I,…,IM_N the sequence of images taken with the camera where IM_I is image obtained with the camera after I rotations.
- $IM_I = \{S_{1,i}, S_{2,i}, S_{3,I},..., S_{k,I},... S_{n,I}\}$ where S_{kI} is the segment k in the image I obtained by the camera after the I rotations.
- Every segment is defined with its two point's extremities.

Geometrical model of convergence motion: The camera is placed on a support plan and when it makes a movement of rotation, the centre of projection likened to a point is considered as moving on the same plan.

Because of the uncertainties of the mechanics, we take place in the unfavourable case where the centre of rotation of the camera is not unique (the theoretical optical axes intersect in various points) to see Fig. 1. This has no repercussion on the proposed algorithm because it is independent from the centre of rotation. The geometrical model of the movement of rotation of the camera is illustrated by it Fig. 2.

Where

- IM is projective plan
- P is the intersection of the optical axis with the image plan
- PUV is the theoretical frame in IM

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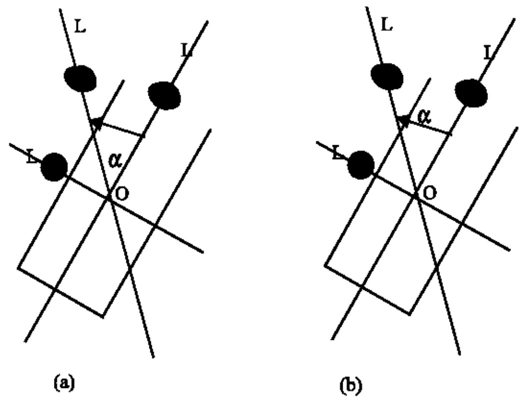

Fig. 1: Example of camera in rotation motion (a) with fixed rotation center (b) variable center of rotation

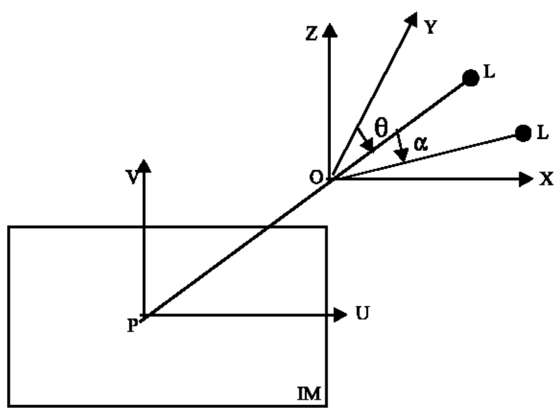

Fig. 2: Geometrical model of cameras's motion

- L is the centre of projection
- PL = f (focal length)
- θ is the initial angle between the optical axes PL and OY
- α is the angle of rotation of the camera
- O is the theoretical centre of the rotation of the camera, obtained as intersection of the optical axes corresponding to the two states of the camera
- PO = d
- (OXYZ) is a external orthonormal frame of the camera; it can be fixed such as OX //PU, OY coincides with the optical axis and OZ // PV
- ex, ez define the dimensions of the pixel

In our theoretical study none of these parameters are supposed known.

For any point M (x, y, z) of the 3D space, it projective coordinates u_M, v_M on IM are[10]:

$$u_M = ex.f.\frac{-\mathrm{Cos}(\theta).x + \sin(\theta).y}{\sin(\theta).x + \cos(\theta).y + d - f}$$

$$v_M = ez.f.\frac{-z}{\sin(\theta).x + \cos(\theta).y + d - f}$$

After rotation motion of α, the new projective coordinates of M become

$$u_M = ex.f.\frac{-\mathrm{Cos}(\theta+\alpha).x + \sin(\theta+\alpha).y}{\sin(\theta+\alpha).x + \cos(\theta+\alpha).y + d - f}$$

$$v_M = ez.f.\frac{-z}{\sin(\theta+\alpha).x + \cos(\theta+\alpha).y + d - f}$$

We have only projective coordinates of line segment's extremities in images sequences and their mathematical formulations.
The method of line segment matching is based only on the formalism of projective point's extremities of segments.

BASIC PRINCIPLE OF THE METHOD

Choice of the primitive: We use in this method the slope of the segment as feature tracking.

This choice is justified by the fact that the slope of the segment is robust to the noise and also it is independent from the used frame[11].

Theoretical aspects of the method:

- $S_{i,0}$ line segment i of IM_0.
- $S_{i,1}$ line segment i of IM_1 obtained after rotation of an angle α of the camera.

Let us note $v_0 = a_{i0}.\ U_0 + b_{i,0}$ the equation of $S_{i,0}$ with regard to the frame (PUV).

Projective coordinates on IM_0 of every point Mi(xi, yi, zi) of the scene 3D are :

$$u_0 = ex.f.\frac{-X_{i,0}}{Y_{i,0} + d - f}\ ;\ v_0 = ez.f.\frac{-Z_{i,0}}{Y_{i,0} + d - f}$$

$$\begin{cases} Y_{i,0} = X_i.\sin(\theta) + Y_i.\cos(\theta) \\ X_{i,0} = X_i.\cos(\theta) - Y_i.\sin(\theta) \\ Z_{i,0} = Z_i. \end{cases}$$

Equation $v_0 = a_{i,0}.\ U_0 + b_{i,0}$ of the segment $S_{i,0}$ become:

$$Z_{i,0} = a_{i,0}.\frac{ex}{ez}.X_{i,0} - \frac{b_{i,0}}{ez.f}.\left(Y_{i,0} + d - f\right) \quad (1)$$

In the same way, equation $v_1 = a_{i,1}.u_1 + b_{i,1}$ of the segment $S_{i,1}$ (homologue of $S_{i,0}$ after camera's rotation of an angle α) is as follows:

$$Z_{i,1} = a_{i,1}.\frac{ex}{ez}.X_{i,1} - \frac{b_{i,1}}{ez.f}.\left(Y_{i,1} + d - f\right) \quad (2)$$

where

$$\begin{cases} X_{i,1} = x_i.\cos(\theta+\alpha) - y_i.\sin(\theta+\alpha) = \\ X_{i,0}.\cos(\alpha) - Y_{i,0}.\sin(\alpha) \\ Y_{i,1} = x_i.\sin(\theta+\alpha) + y_i.\cos(\theta+\alpha) = \\ X_{i,0}.\sin(\alpha) + Y_{i,0}.\cos(\alpha) \\ Z_{i,1} = z_i. = Z_{i,0} \end{cases}$$

Expressing $X_{i,0}$ and $Y_{i,0}$ according to $X_{i,1}$ and $Y_{i,1}$:

$$Z_{i,1} = X_{i,1}\left[\frac{ex}{ez}a_{i,0}.\cos(\alpha) + \frac{b_{i,0}}{f.ez}.\sin(\alpha)\right]$$
$$- \frac{Y_{i,1}}{f.ex}\left[f.ex a_{i,0}.\sin(\alpha) - b_{i,0}.\cos(\alpha)\right] \quad (3)$$
$$- \frac{b_{i,0}}{f.ez}\left[d - f\right]$$

Using the Eq. 2 and 3, we obtain:

$$\frac{ex}{ez}a_{i,1} = \frac{1}{f.ez}\left[f.ex a_{i,0}.\cos(\alpha) + b_{i,0}.\sin(\alpha)\right]$$

where

$$\frac{a_{i,1} - a_{i,0}.\cos(\alpha)}{\sin(\alpha)} = \frac{b_{i,0}}{f.ex} \quad (a)$$

In the same way, by considering the segment $S_{i,2}$ (homologue of $S_{i,0}$ after camera's rotation of an angle β) expression (a) is:

$$\frac{a_{i,2} - a_{i,1}.\cos(\beta)}{\sin(\beta)} = \frac{b_{i,0}}{f.ex} \quad (b)$$

The report (a) / (b) lead us to the following formula:

$$\frac{a_{i,1} - a_{i,0}.\cos(\alpha)}{a_{i,2} - a_{i,0}.\cos(\beta} = \frac{\sin(\alpha)}{\sin(\beta)} = \sigma \quad (c)$$

Note that σ is constant for all segment considered in the sequence of images IM_0 , IM_1 and IM_2.

If we consider two other segments $S_{j,0}$, $S_{j,1}$ and $S_{j,2}$; expression (c) is written as:

$$\frac{a_{j,1} - a_{j,0}.\cos(\alpha)}{a_{j,2} - a_{j,0}.\cos(\beta} = \frac{\sin(\alpha)}{\sin(\beta)} = \sigma \quad (d)$$

We see that (c) = (d) then after some transformation, we obtain this equation:

$$(a_{i,1}.a_{j,0} - a_{j,1}.a_{i,0}) \cos(\beta) + (a_{i,0}.a_{j,2} - a_{j,0}.a_{i,2}) \cos(\alpha) = (a_{i,1}.a_{j,} - a_{j,1}.a_{i,2})$$

The Eq can be written as:

$$C_1 . \cos(\beta) + C_2 . \cos(\alpha) = C_3$$

This Eq is linear with two (2) unknowns that correspond to the movement values made by the camera. Resolution requires two other segments S_m and S_n in three images of the sequence.

The second equation is:

$$(a_{m,1}.a_{n,0} - a_{n,1}.a_{m,0}) \cos(\beta) + (a_{m,0}.a_{n,2} - a_{n,0}.a_{m,2}) \cos(\alpha) = (a_{m,1}.a_{n,2} - a_{n,1}.a_{m,2})$$

$$C'1 . \cos(\beta) + C'2 . \cos(\alpha) = C'3$$

The resolution of the system supplies the movements of the camera as well as the matches segments in the three images of the sequences.

The resolution of the problem requires 4 line segments in three sequences of images: We can that express the following proposition:

Proposition: A necessary condition to estimate the motion of the camera, it is enough that the resolution of the system of equations composed by 4 segments can give identical values.

The solution we propose has a way similar to that current in Hough's transformed[12]: it is a question of engendering all the possibilities for the correspondence constants (α,β) and keeping those that collect the maximum of votes.

α and β represent the motion of the camera and the matching factor.

RESULTS

The algorithm tested on synthetically data generated by computer gives e xpected results on noisy and not

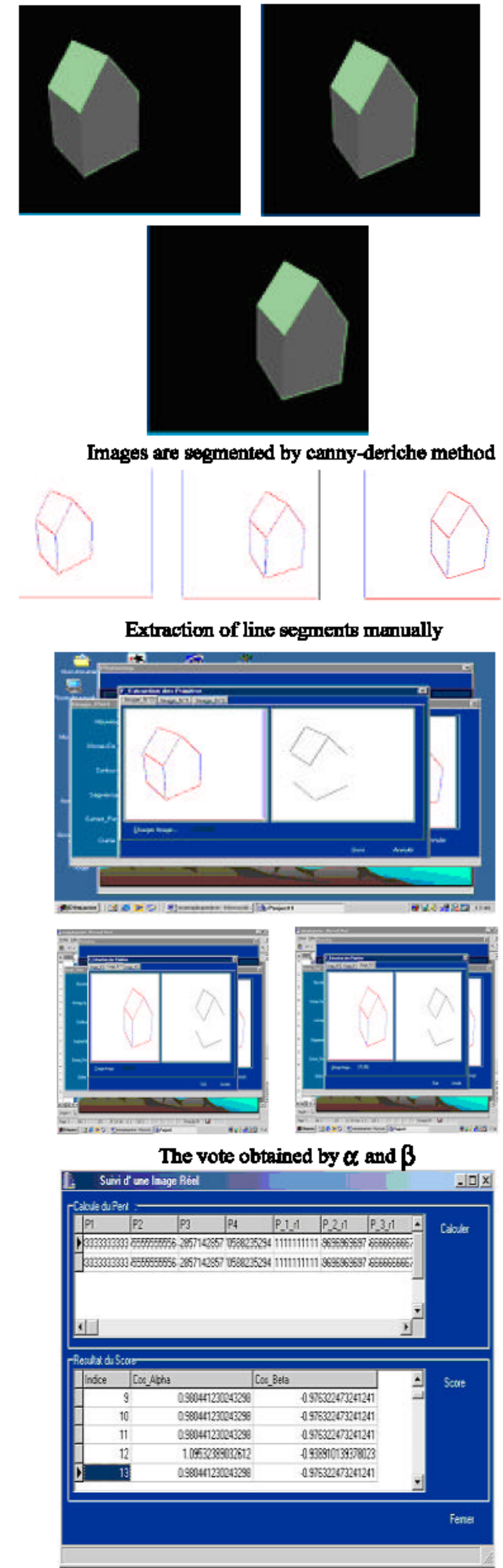

Fig. 3: Example of the sequence of 3images

noisy data. Applied also to real images segmented by Canny-Deriche's method, the proposed algorithm gives suitable results (Fig. 3).

In this method, we remind that:

- The extremities of segments are indicated manually.
- The vertical segments are eliminated; then to be matched by using the constraints of order and neighbourhood.

Furthermore, experiment shows that algorithm gives better results for the oblique segments (< = 45°) and for the long segments with regard to the short segments.

The value of cos(α) = 0,98044 and cos(β) = -0,9763 have the big vote of apparition. These values represent the motion of camera. The line segments witch have engendered this values are in correspondence.

CONCLUSION

We have proposed a method of estimating the motion of camera by using as primitive the slope of the segment which is a robust feature. This method does not require any knowledge of matching primitive or of the geometrical models of the camera. It allows also determining the matching segments as well as intrinsic parameters (focal length, size of the pixel), returning so possible work in the theoretical frame.

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