Fast Stereo Matching Using Rectification and Correlation Techniques

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Abstract— This paper presents a new method for matching points of interest in stereoscopic. A self-calibration is realized by using points of interest on both images in order to estimate the fundamental matrix from which we can compute both projected matrices related to each camera. We propose a robust and fast rectification technique for matching points of interest in order to simplify the research on epipolar line. Resemblance measure based on ZNCC (Zero mean Normalized Cross Correlation). Our matching scheme is evaluated using stereo images consisting of many points, with regularization using homography and fundamental matrix. The results obtained clearly show the relevance of our approach.

Keywords— Self-calibration, Rectification, Correlation, Fast Matching, Homography and Fundamental Matrix

I. INTRODUCTION

The correspondence problem remains of central interest in the field of image analysis. Matching feature points between images constitutes a fundamental step in many computer vision applications such as the recovery of 3D scene structures, the detection of moving objects, or the synthesis of new camera views.

Although solutions for the correspondence problem are still being investigated for difficult cases, great advances have been made in establishing correspondence between views generated by an uncalibrated system of cameras. In the recent literature, the following scheme has emerged as the method of choice to perform an effective feature-based view matching [1], [2], [3]:
1. Feature points (corners) are detected [4], [5], [6].
2. Correlation is applied between feature points, then a threshold is applied to obtain a first set of candidate matches.
3. A robust method, such as RANSAC or LMedS, is used to estimate the epipolar or trifocal geometry of the camera system [3], [7].
4. Candidate pairs that are incompatible with the estimated camera geometry are rejected.
5. Guided matching using the estimated geometry is performed to find more matches.

The efficiency and accuracy of this scheme depends greatly on the quality of the candidate match set obtained in Step 2. Although usually robust to some noise, the estimator used in Step 3 requires a candidate match input set with a sufficient number of correct matches to find an accurate solution, and with a low proportion of mismatches to perform efficiently. For these reasons, another step is often added between steps 2 and 3 to filter the candidate match set. This is generally done by the introduction of some basic constraints that allow to eliminate matches that are suspected to be incorrect. These additional constraints are basic in the sense that, at the stage where they are applied, the epipolar or trifocal geometry of the camera system’s geometry is not yet known. Thus image rectification or guided matching is not an option at this point.

Generally, in order to realize the reconstruction procedure, we should follow two steps calibration and matching.

Calibration is to determine the intrinsic and extrinsic parameters of used cameras in receiving the scene to reconstruct. If the parameters related to the camera are given, we can realize this step automatically (self-calibration) by using certain points of interests and the estimation of the fundamental matrix by robust method (RANSAC: Random Sample Consinus) [3], [7]. We can consider the matching procedure as the most important step because it is very complicated step that requires a powerful algorithm to obtain good results. But, in order to facilitate the procedure, we are going to tackle in this paper a new idea of matching based on rectification step and points of interests to realize a propagation in the image. Aiming to determine an avalanche of matched points.

This method doesn’t only give satisfactory results, it facilitate also research for corresponding points in the used image (right, left) depending on rectification step that makes epipolar line horizontal. On the contrary to other methods (dynamic, relaxation, epars, dense,..), this new technique use both constraints epipolar lines and points of interests to accelerate and facilitate the research.

This paper is organized in the following manner: in the second part, we are going to explain the evaluation stages of matrix projection related to every camera using the fundamental matrix. The algorithm of rectification is implanted in the third part. Then, the fourth one describes the new method of the stake in correspondence by a fast matching algorithm. Finally, experimentations are presented in the fifth part and the conclusion in the sixth one.

II. ESTIMATION OF PROJECTED MATRIX RELATED TO EACH CAMERA

In this part, we are going to estimate both projected matrices M1 (right camera) and M2 (left camera) depending on the fundamental matrix F [8], [9], [10] which will be computed based on the points of interest used by RANSAC method [3], [7].
A. Estimation of the fundamental matrix

The estimation of the fundamental matrix is based on the well determination of point of interest given by Harris’s algorithm [11] to determine the local maxima in the image following the coming steps: to every point in the image.
- Calculate the following matrix:

\[
H = \begin{pmatrix} \frac{\partial I}{\partial x} & \frac{\partial I}{\partial y} & \frac{\partial I}{\partial y} \\ \frac{\partial I}{\partial x} & \frac{\partial I}{\partial y} & \frac{\partial I}{\partial y} \end{pmatrix}
\]

(1)
- Calculate the following measure:

\[
R = \text{det}(H) - k \left( \text{trace}(H) \right)^2 \quad \text{with} \quad k = 0.04
\]

(2)

If \( R \geq 0 \) so this point is a local maxima.

After this step, we are going to match the local maxima by measures ZNCC [12] (Zero mean Normalized Cross Correlation):

\[
\text{ZNCC}(P) = \frac{\sum (I(P) - \bar{I}(P))(I(P+\Delta) - \bar{I}(P+\Delta))}{\sqrt{\sum (I(P) - \bar{I}(P))^2 \sum (I(P+\Delta) - \bar{I}(P+\Delta))^2}}
\]

(3)

With \( P = (x, y) \) is a point in the image, \( \Delta = (\Delta_x, \Delta_y) \) is the shift, \( T(P) \) and \( T'(P) \) are the means of pixel luminances for the given window centered at \( P \).

Then, we are going to apply RANSAC method [3], [7] to estimation the fundamental matrix \( F \) based on points of interest.

B. Estimation of epipoles

Let’s consider \( e \) and \( e' \) the two epipoles of the left and right image, we can compute \( e \) and \( e' \) by the following relation [9]:

\[
e \sim (r_1 \land r_2) + (r_1 \land r_3) + (r_2 \land r_3)
\]

\[
e' \sim (c_1 \land c_2) + (c_1 \land c_3) + (c_2 \land c_3)
\]

(4)

With \( c_i \) the cols of \( F \) and \( r_j \) its rows.

C. Estimation the projected matrix related to each camera

In this part, we are going to find the two projected matrix \( M_1 \) and \( M_2 \) based on the fundamental matrix \( F \) previously estimated by canonical realization proposed by Hartely [8]:

\[
P \sim \begin{pmatrix} I & 0 \end{pmatrix}
\]

\[
P' \sim (H, \gamma e')
\]

(5)

Where \( H \) is 2D homography called reference homography, \( e' \) the second epipole and \( \gamma \) is a factor of echelle between \( H \) and \( e' \). Two possible solutions present themselves, the first one is called singular canonical realization as: \( P' \sim (H \ e') \) with \( H = [e'] \land F \), the second one is called non singular canonical realization as:

\[
P' \sim (H \ e') \text{ with } H = \frac{[e'] \land F + e'e' e'}{\left\| e' \right\|}
\]

(6)

III. RECTIFICATION

Epipolar line plays an important role in the reconstruction procedure we can limit the research of the correspondent of a point of the left image on this epipolar line on the other image. The objective therefore is to simplify the equation of the line.

Rectification step

Detailed description of this step is given by Radu Horaud and Olivier Monga [10].
- Calculate the extrinsic parameters \( R \) and \( t \) of the left camera (in the same way we calculate \( R' \) and \( t' \) of the right camera) based on the projection matrix previously estimated.
- Calculate the coordinate of \( N \) (the origin of the reference of the left camera) and \( N' \) (the origin of the reference of the right camera) by the following relations:

\[
R \ ON + t = 0, \quad R' \ ON' + t' = 0
\]

(7)

with \( O \) the origin of the reference of the scene.
- Calculate the direction of the \( NN' \) line that is not modified at the time of rectification by the following formula:

\[
NN' = ON' - ON = R\vec{t} - R^{-1} t
\]

- Let’s consider \( OX, OY, OZ \), the axes of rectified left camera, we calculate the leading vectors of these axes by the following relations:

\[
j_i = \frac{NN'}{\left\| NN' \right\|} \quad k_i = \frac{K_i}{\left\| K_i \right\|} \quad i_i = j_i \land k_i
\]

with \( K_i = (\vec{ON} \land \vec{ON'}) \land NN' \)
- Calculate the rotation matrix between the reference of the camera left in the initial position and the reference of the rectified camera left by the following formula:

\[
R_i = R_i R^{-1}
\]

- Calculate the rectified coordinates of each point by the following relations:

\[
(x', y', 1)^T = R_i \begin{pmatrix} x \\ y \\ 1 \end{pmatrix}
\]

IV. FAST MATCHING

After the rectification step, we are going to detect new points of interest realizing local maximal of in plans of images, these points are invariant in both images that will be used like starting points in the matching procedure, all pairs of corresponding points of interests are added in a global list L according to the ZNCC value.

Let’s consider \( x \) and \( x' \) two invariant correspondents respectively of the right and the left image. To realize the propagation in the image, we are going to define the two neighborhoods \( V \) and \( V' \) respectively of \( x \) and \( x' \) in which we are going to research the corresponding. These neighborhoods are 3x3, if \( y \) is a point of the left image belongs to the neighborhood of \( x \), its corresponding \( y' \) will be research in the right image on the same epipolar line like \( y \) and in neighborhood \( V' \) size 1x3 centered in a point which have the same position like \( y \) in the neighborhood of \( x' \).
The research in $v'$ will be based on correlation technique ZNCC, and the point that realize maximum of the ZNCC function will be consider as the corresponding of $y$, the pairs $(y, y')$ will be added in a list of global $L$, this procedure is continued until the end of the list $L$.

V. EXPERIMENTATIONS

All the parts previously detailed will be tested now on several pairs of images.

A. Estimation of the fundamental matrix

The estimation of the fundamental matrix is tested on the following pairs of images:

![Fig. 1](image1.jpg)

Fig. 1. (a) the left image and (b) the right image

![Fig. 2](image2.jpg)

Fig. 2. The application of Harris's algorithm gives the results: (a) Left image and (b) Right image

In order to obtain the points of interests, we have applied RANSAC method which gives the following points:

![Fig. 3](image3.jpg)

Fig. 3 The matching of Harris's points gives the results: (a) Left image and (b) Right image

The fundamental matrix is computed based on points previously found:

$$F = \begin{pmatrix}
-0.0000 & 0.0000 & -0.0015 \\
-0.0000 & -0.0000 & 0.0144 \\
0.0017 & -0.0143 & -0.1374
\end{pmatrix}$$

B. Rectification

The algorithm of rectification explained previously is tested on the following images:

![Fig. 4](image4.jpg)

Fig. 4: The matching of Harris's points with RANSAC method gives the results (a) in the left image and (b) in the right image

![Fig. 5](image5.jpg)

Fig. 5 (a) Left image and (b) Right image
The rectification result gives the following images:

![Fig. 6 (a) Left image and (b) Right image](image)

C. Reconstruction

Fast matching algorithm previously detailed is tested on the following pairs of images:

![Fig. 7 (a) Left image and (b) Right image](image)

The following images present the results of RANSAC method applied on Harris's points:

![Fig. 8 Results of RANSAC method applied on Harris's points: (a) in the left image and (b) in the Right image](image)

The propagation result after rectification is done in the following images Fig 9:

![Fig. 9 (a) Left image and (b) Right image](image)

VI. CONCLUSION

In this paper, we implanted a new algorithm of matching based on two stages: the rectification and the correlation. The objective of the first stage is to simplify research on a given neighborhood. The second stage is based on the ZNCC method to match points found on the epipolar line. Starting points of the propagation are points of interests detected by Harris and matched by the RANSAC method. The results of the last section show the relevance of our approach; the percentage of correct matches is very high (approximately 95%) and the recovered epipolar very accurate.

Using this matching scheme, we are able to match a large number of points rapidly and we are consequently able to implement efficient methods for dense depth maps computation.

REFERENCES