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Finding the Epipoles of a Sequence of Images for Forward Moving Camera

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ABSTRACT

Finding epipoles of a sequence of images has been an important topic of considerable research in the field of computer vision. Epipole is the main feature in epipolar geometry which has enormous demand in computer vision. In most of the cases epipole is estimated from two images and the images are taken by two stationary cameras or by one stationary camera from two different locations. But if the images are taken from a moving camera, the constraints of images are changed and finding epipoles becomes very difficult. A better performance can be achieved by capturing a sequence of images for a small translation of the camera in pure forward direction then the epipole can be found for each image. The implementation of our technique deals with the estimation of epipoles for a sequence of images for the pure forward moving camera.

Index Terms—*Camera Motion, Epipolar Line, Epipole, Fundamental Matrix, SIFT.*

I. INTRODUCTION

The epipole is an essential parameter to determine the center of the projection of the camera. This center of the projection of the camera is very much useful for autonomous robot vehicle and many other applications. It is also very helpful parameter to know the 3D information or 3D structure of a scene. There are many algorithms like Linear-self Calibration method, Point-Line Corresponding method etc., to find the epipoles of images which are captured from two stationary cameras. However it is not possible to use two stereo cameras in some medical treatments (especially inside the ear) and robotic applications (where only one camera is used) because of space scarcity.

In this paper, an algorithm has been implemented using only one camera which moves straight forward direction to take a sequence of images and this algorithm can estimate the epipoles of a sequence of images based on matching points searching between two consecutive images. This method needs no prior data, no camera internal parameters except only images.

II. SURVEY OF RELATED WORKS

To find the epipole we must need epipolar line and to find epipolar line we must need fundamental matrix. There are several methods to compute the fundamental matrix. If the internal camera parameters or intrinsic camera parameters are known, then it is easy to find the fundamental matrix. On the other hand, fundamental matrix can be calculated by using corresponding points between two images of the same scene. But the method for estimation of epipoles does not depend on the method of computing fundamental matrix of two images. Farhoosh Alghabi and Mohsen Soryani have computed epipoles directly from four corresponding points of two stereo images [1]. Ziangbin and Wenbo have proposed epipoles by using RANSAC algorithm [2]. Papadimitriou and Dennis proposed to find an epipolar plane first and then to find the epipolar line [3]. Zohn Lim and Nick Barnes have found epipole using Optical Flow at antipodal points [5].

III. PROBLEM STATEMENT AND MAIN CONTRIBUTION

In most of the cases, two cameras in parallax position or one camera from two distinct positions are used to capture two images for estimating the epipole. But if we want to use only one camera then this method is not sufficient to estimate the epipole.

Our research question is if one can estimate the epipole of a sequence of images captured by a single camera moving in pure forward direction?

We take a sequence of images of a real scene using a pure forward moving camera and all the images are stored in our image database in a sequential order. We select any two images at a time from the storage and find the matching points between them using SIFT algorithm [4]. By applying Eight-point algorithm, we find the fundamental matrix between those two images from which we can estimate the epipolar lines. All the epipolar lines must intersect at a point, called epipole.

Our main contribution is to implement the proposed algorithm using MATLAB to estimate the epipoles of a sequence of images captured from a forward moving camera. We simulated the algorithm using real life images and validated algorithm.

III. PROBLEM SOLUTION

A. Modeling:

We use Scale-invariant Feature Transform (SIFT) algorithm to find the matching points between two images [4]. These matching points are the local features of the images. These image features are invariant to any kind of image transformation such as image scaling, rotation, translation etc. But the feature must be sufficiently distinctive to identify objects. That is why we eliminate a number of image features to get accuracy to find the fundamental matrix. From those corresponding points of the images, we selected the best eight points to apply in Eight-Point algorithm to find the Fundamental matrix though it is also possible to find the fundamental matrix by seven corresponding points. These eight points of the both images are shown in Figure [1].

If $\boldsymbol{X_i}$ is a set of points on one image then the set of corresponding points on the other image is $\boldsymbol{X_i'}$ where $\boldsymbol{i}$ represents the point number. Of course the image should be of the same scene where the projection of the points from the scene can occur in both images. There is a good relationship between these set of points and the fundamental matrix.

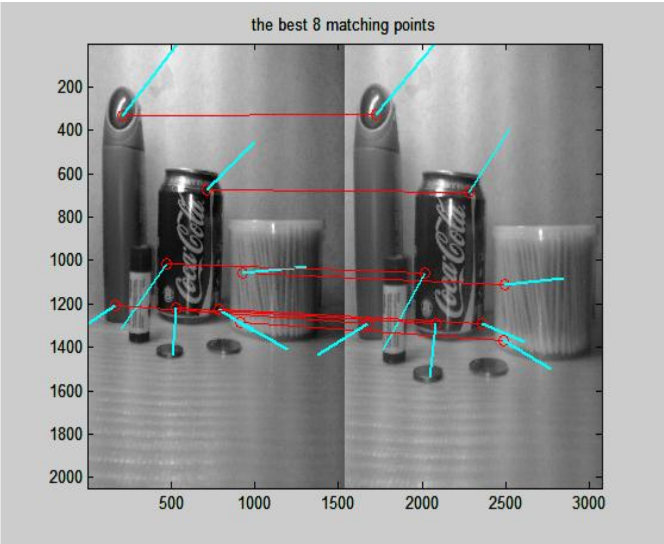

Fig.1: Eight corresponding points between two images

The fundamental matrix is a 3×3 matrix of rank 2. It is independent of the scene structure and it depends on the internal parameter of the camera and relative pose. However, fundamental matrix can be calculated from only corresponding points of two images of same scene without knowing the internal parameter of the camera. In our case we use only the corresponding points of two consecutive images.

If the corresponding points of two images are $\boldsymbol{X_i}$ and $\boldsymbol{X_i'}$, then fundamental matrix $\boldsymbol{F}$ can be calculated from:

$$\boldsymbol{X_i'} \boldsymbol{F} \boldsymbol{X_i} = 0 \qquad (1)$$

Let an image point on the first image be [x, y, 1] and the corresponding point on the second image be [x', y', 1]. The fundamental matrix can be calculated from this equation:

$$\begin{bmatrix} x & y & 1 \end{bmatrix} \begin{bmatrix} F_{11} & F_{12} & F_{13} \\ F_{21} & F_{22} & F_{23} \\ F_{31} & F_{32} & F_{33} \end{bmatrix} \begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = 0 \qquad (2)$$

According to the Eight-point Algorithm, we need at least eight corresponding points between two images. The concept of fundamental matrix is closely related to the concept of epipolar line. If the fundamental matrix between two images is $\boldsymbol{F}$ and if $\boldsymbol{X}$ is any point on the first image, then the epipolar line $\boldsymbol{l}$ on the second image is the cross multiplication of $\boldsymbol{F}$ and $\boldsymbol{X'}$ and it is written as

$$\boldsymbol{l} = \boldsymbol{F} \times \boldsymbol{X'} \qquad (3)$$

For each point on the first image, we have an epipolar line on the second image and all epipolar lines intersect at a point which is the epipole. If any two points $\boldsymbol{x}$ and $\boldsymbol{x'}$ are corresponding points, then $\boldsymbol{x'}$ lies on the epipolar line $\boldsymbol{l'}=\boldsymbol{Fx}$ corresponding to the point $\boldsymbol{x}$. In other words, if image points satisfy the relation $\boldsymbol{x'} \boldsymbol{F} \boldsymbol{x}=0$ then the rays defined by these points are coplanar. This is a necessary condition for points to correspond.

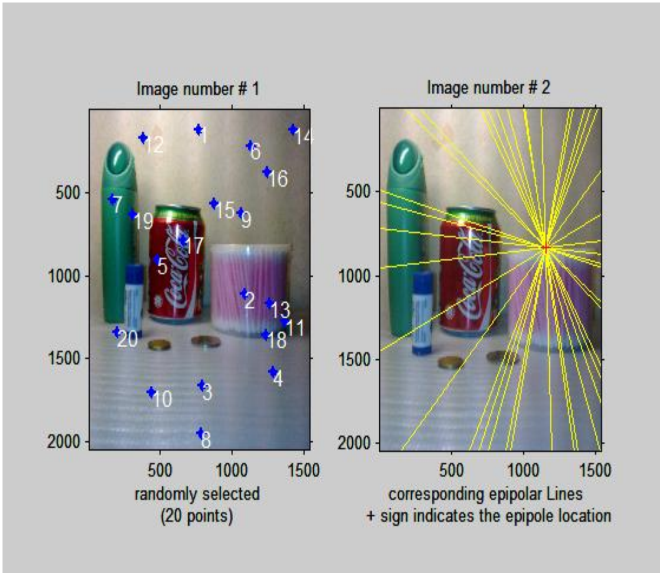

Fig.2:The epipole on image 2 based on image 1

B. Implementation and validation:

We have taken five images in a sequential order from a forward moving camera. After taking the first image, we moved the camera in pure forward direction and then we took the second image. The distance between the two camera positions is the camera translation $\boldsymbol{t}$. We take any two images together from the database in sequential order and we find eight corresponding points between those two images by applying SIFT method and then we find fundamental matrix by applying eight point algorithm. For every point of the first image we draw a line in the second image with the help of fundamental matrix. This line is the epipolar line. This epipolar line is actually the projection of any one point of the first image to the second image through the center of the camera. In this way we draw a number of epipolar lines on the second image with the help of fundamental matrix and all the epipolar lines intersect at a point which is called the epipole. The overall procedures are shown in Fig. 3.

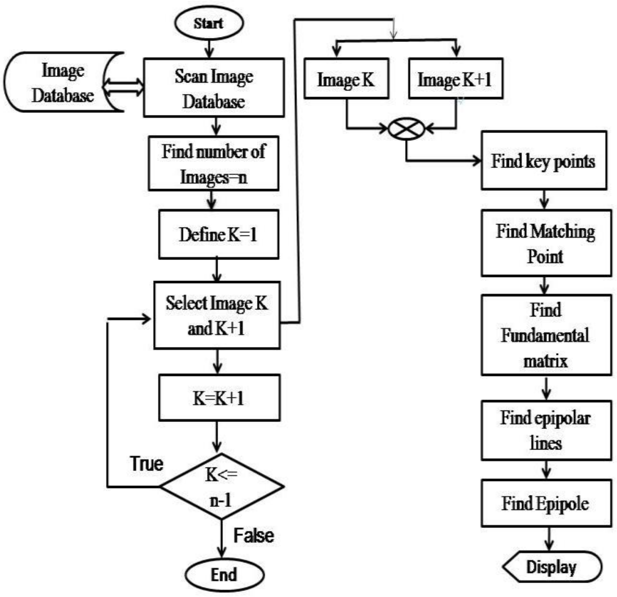

Fig.3: Flow Chart of Epipole Estimation Algorithm

We can also estimate epipoles using camera parameters. This is called theoretical results. In order to validate our algorithm, we compared the practical results with the theoretical results.

The focal length of the camera is *25* mm and it is denoted by *f* and the location of the principal point was (500, 500*)* and it is denoted as (*p1*, *p2*) pixel which are calculated using camera calibration technique. Then the camera matrix ***K*** is given by

$$\boldsymbol{K}=\begin{bmatrix} f & 0 & p_1 \\ 0 & f & p_2 \\ 0 & 0 & 1 \end{bmatrix} \quad (4)$$

For the forward movement, t was defined as camera translation and then the epipole ***E*** is

$$\boldsymbol{E} = \boldsymbol{K.t} \quad (5)$$

The results are compared with our practical results in Table I.

Table I: Epipole Position in Pixel for the Image Pairs

Images	Epipole location in pixel		
	Using Camera parameters	Using images	Absolute error
1 and 2	(1136,820)	(1140,825)	(4,5)
2 and 3	(1138,822)	(1142,820)	(4,2)
3 and 4	(1140,825)	(1145,816)	(5,9)
4 and 5	(1139,824)	(1143,826)	(4,2)

IV. Conclusion

We presented an algorithm to estimate epipoles using a sequence of images for a forward moving camera. At first, we find the matching points between two images using SIFT algorithm and then we use Eight-point algorithm to find the fundamental matrix and finally we estimate the epipole on the second image based on the first image for every image pair. We use only a sequence of uncalibrated images as input and we get epipoles as output. This algorithm can be used in medical treatments and robotic application to recover 3D structure of a scene using only images.

Our algorithm is valid only for pure forward translation of the camera. An extension of this algorithm can be achieved for the angular movement of the camera. Also another extension of the algorithm can be proposed to find epipoles using image brightness instead of using matching points.

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