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Estimation of FOE Without Optical Flow for Vehicle Lateral Position Detection

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Abstract

In this paper, we propose a new method to estimate the FOE (Focus of Expansion) from moving camera image sequence for vehicle motion understanding, which does not rely on optical flow vectors. Motion understanding of the camera is very important in many applications. Most of the conventional methods for detection and estimation of the position of FOE rely on estimation of optical flow vector in the input image sequence. However, errors in estimating optical flow vector result in inaccurate estimation of FOE. In our method, we synthesize the input image and create an expected image of the next frame by using optical flow vectors. Optical flow vectors are obtained from the hypothesis of position of FOE and global constraint of optical flow. We evaluate the position of FOE by SAD (Sum of Absolute Differences) value between the warped and the real image. The proposed method estimates the position of FOE by minimizing SAD. For demonstrating the efficacy of the proposed method, we apply the proposed FOE estimation method for detecting lateral position of a vehicle. The experimental results show advanced performance comparing with FOE estimation based on a commercial optical flow vector field estimating software.

1 Introduction

Understanding the motion of the camera is very important in many applications, such as vehicle driver's support, robot navigation, etc. Position of Focus of Expansion (FOE) in an image sequence of a moving camera provides rich information on the motion of the camera. Many researchers have developed methods to understand the motion form position of FOE in a motion sequence.

In most of the method for estimating the position of FOE, the optical flow vector field is first estimated from the input motion image sequence [1]. Detection and tracking of image feature points are also used to estimate FOE from motion image sequence [2, 3, 4, 5]. In some of such techniques, position of FOE is estimated as an intersecting point of all of the optical flow vectors. However, estimation of optical flow is not easy and accurate task, especially in the case of poor texture in the input image sequence. For example, road image sequence taken with a camera on a vehicle usually does not include rich texture because the road surface is made of homogenous materials. Even if the lines are painted on the road surface, the texture of the line does not give accurate optical flow because the intensity edge is almost parallel to the direction of the optical flow. Such inaccuracy in estimation of optical flow makes estimating FOE difficult task.

In this paper, we propose a method for estimating the position of FOE, which does not rely on optical flow estimation. We focus on detecting vehicle lateral position on a road, whether the white line is drawn or not. White lines are not always seen because of bad road condition. Our method is composed from 4 steps. 1.Calculate the Optical Flow Constraint Equation (OFCE) in the image. 2.Synthesize a warped image both from hypothesis of FOE and OFCE. 3.Evaluate the hypothesis of FOE position by comparing the warped image with the real image of the next frame and calculate the Sum of Absolute Differences (SAD) value. 4.Repeat 2–3 for all of the hypothesis position of FOE, and we estimate the position of FOE, which gives the minimum SAD value as a FOE.

2 Estimation of FOE

Our method estimates the FOE by evaluating the adequacy of hypothesis of the position of FOE and maximizes the adequacy. We use the value of sum of absolute differences for the evaluation of adequacy.

2.1 Optical flow constraint equation

Optical Flow Constraint Equation (OFCE) are given as

$$I_x V_x + I_y V_y \quad I_t = 0 \tag{1}$$

where (I_x, I_y, I_t) shows the gradient of intensity at position (x, y) at time t and (V_x, V_y) shows the flow vector at position (x, y).

2.2 Calculation of flow vector

We define a *Sample Searching Pixel* in our method. Since some textures are needed in the image to obtain I_x, I_y in Eq. (1), we find and select some pixels that contain rich textures in its neighbors as a *Sample Searching Pixel*. We use LoG filter to select *Sample Searching Pixel*. We obtain *N Sample Searching Pixels* by choosing *N* pixels from the image that contain rich texture after processing it by LoG filter,

We now express the *Sample Searching Pixel* as SSP_i where $1 \le i \le N$. Flow vector is computed at each *Sample Searching Pixel* according to the OFCE and a hypothesis of the position of FOE.

In Eq. (1), I_x , I_y , I_t can be obtained from consecutive two input images. Let us consider $V_x - V_y$ coordinate with the origin at SSP_i on the input image plane. On this coordinate, Eq. (1) should be satisfied, so we can consider the $Line_{OFCE}$ as shown in Fig. 1. On the other hand, the flow vector should be along with the line $Line_{FOE}$ from the hypothesis of the position of FOE to SSP_i . Therefore, the end of the flow vector from SSP_i must be the intersection of $Line_{OFCE}$ and $Line_{FOE}$. By computing the intersection, we can estimate the position of SSP_i at the next frame.

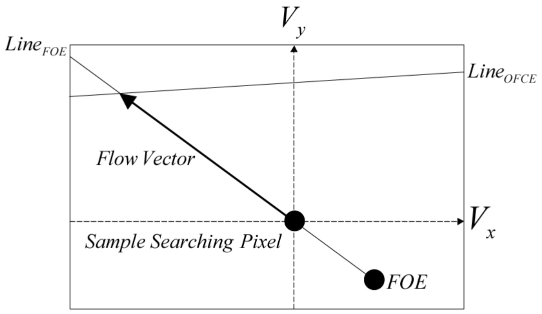

Figure 1. The intersection of $Line_{OFCE}$ and $Line_{FOE}$ provides the flow vector of *Sample Searching Pixel,* SSP_i . $Line_{OFCE}$ is the line expressed by $I_x V_x + I_y V_y + I_t = 0$

In some situation, the intersection of $Line_{OFCE}$ and $Line_{FOE}$ can't be calculated due to the next 3 reasons.

$$I_x = I_y = 0 \quad (2)$$

$$Line_{FOE} \, // \, Line_{OFCE} \quad (3)$$

$$Line_{FOE} \, // \, Line_{OFCE} \quad (4)$$

Eq. (2) shows that no texture exists at SSP_i . We avoid this situation by using LoG filter to choose SSP_i . In the case of Eq. (3) and Eq. (4), the intersection of the two lines can't be obtained. In these cases, the computation at SSP_i is rejected.

2.1 Image warping

For evaluating the hypothesis of the position of FOE, the input image is warped as the expected image at the next frame. To synthesize a warped image, the flow vectors computed at each SSP_i are used. Fig. 2 shows how to warp the image.

Each pixel of the warped image corresponds to flow vector, which are obtained from input image. Position of the pixel in the warped image corresponds to the position of flow vector in the input image.

Our method creates two warped images. We obtain the first warped image *F* by copying the pixel of the present frame at SSP_i . We also obtain the second warped image *G* by copying the pixel of the next frame at the end of the flow vector.

Some flow vectors are not obtained from the input image according to Eq. (2) – (4). The pixel of warped image, which does not have a flow vector to correspond, is except from the process.

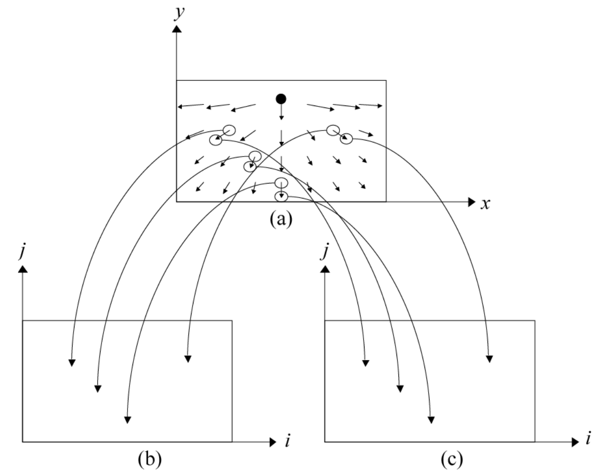

Figure 2. (a) Flow vector in the input image.
(b) Warped image *F*, signifies the expected next frame. Each pixel is copy of SSP_i .
(c) Warped image *G* signifies the real next frame.

The first warped image *F* signifies the expected next frame and the second warped image *G* signifies the real next frame. If the FOE is correct, two images should be completely identical since we assume that objects shown in image do not move. SAD between F and G are computed for evaluating the adequacy of the assumed FOE as the following section.

2.2 Evaluation of adequacy

SAD value between the warped image *F* and *G* are used to evaluate the adequacy of the position of FOE. We compute the difference of intensity per each pixel in *F* and *G*. The calculation is shown in Eq. (5).

$$SAD_{xy} = \frac{|F - G|}{N_{xy}} \quad (5)$$

N_{xy} is the number of flow vector obtained from the input image when the position of the FOE is assumed at (*x*,*y*).

2.3 Position of FOE

By assuming many position of FOE, many pairs of position of FOE and its adequacy are obtained. The position of FOE, which gives the minimum SAD value, could be the best position for FOE, but from some pilot experiments, the position of minimum value is very unstable. Instead of the position of the minimum value, we estimate the position of FOE by next equation.

$$\begin{bmatrix} FOE_x \\ FOE_y \end{bmatrix} = \frac{\sum_x \sum_y \begin{bmatrix} SAD_{xy} \times x \\ SAD_{xy} \times y \end{bmatrix}}{\sum_x \sum_y SAD_{xy}} \quad (6)$$

Eq. (6) is the calculation of the centroid of SAD value. Only 5 percentile of pixels from the smallest SAD value, are used to calculate.

2.4 Vehicle movement estimation

If the position of FOE is known, the movement of the camera can be calculated. Optical flow is known as follows [6].

$$v_x = \frac{T_z x - T_x f}{Z} - \omega_y f + \omega_z y + \frac{\omega_x xy}{f} - \frac{\omega_y x^2}{f} \quad (7)$$

$$v_y = \frac{T_z y - T_y f}{Z} - \omega_x f + \omega_z x + \frac{\omega_y xy}{f} - \frac{\omega_x y^2}{f} \quad (8)$$

In Eq. (7) and Eq. (8), (v_x, v_y) expresses the flow vector from position (x, y), f expresses the focal length, (T_x, T_y, T_z) and $(\omega_x, \omega_y, \omega_z)$ shows the translation velocity movement and the rotation velocity movement of the camera, respectively.

As a running vehicle does not rotate so much, all of the rotation can be ignored and Eq. (7) can be rewritten as

$$v_x = (x - x_0)\frac{T_x}{Z} \quad (9)$$

where

$$x_0 = \frac{fT_x}{T_z} \quad (10).$$

Thus, the lateral movement of the vehicle T_x is expressed only by x_0. Focal length f is previously known. The vehicle speed, which is expressed by T_z, can be obtained by a sensor of vehicle. Therefore, we can obtain lateral position of the vehicle from the position of FOE.

3 Experiments

We show some results from the experiments using our image based FOE estimation method. We test our method by both synthetic image and real image. We synthesized the images by using POV–Ray and captured real images from a camera on a vehicle. Also, in the experiment using the real images, we compared our result to the real movements of the vehicle and to the FOE estimate method, which are based on optical flow.

3.1 Experiments on synthetic image

We synthesized the input images to estimate the FOE. The vertical level of camera is fixed at 2 meter, and horizontal position moves as shown in Fig. 3. The camera axis goes through the point 14 meter ahead on the ground, and it moves straightforward parallel to the ground.

The horizontal movements of the camera estimated by the proposed method in various conditions are compared with the correct motion as shown in Fig. 3. Our method in the case of using 5000 SSP_i shows close result compared to the correct movement. The estimated error of the closest result is 0.85 meter. However, if the number of the SSP_i is small, the result is not so close to the correct movement. This is because the information, which is obtained from the image, is not enough.

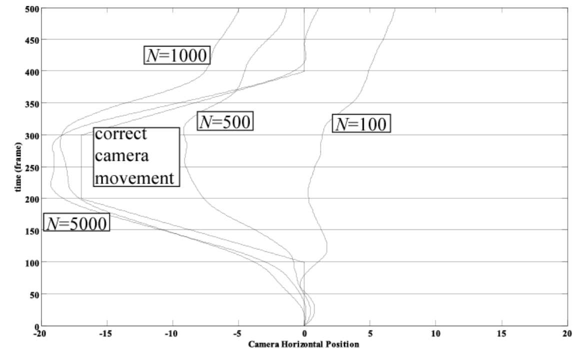

Figure 3: Real movement of the camera. Each line shows the result obtained by proposed method using 100, 500, 1000 and 5000 SSP_i.

3.2 Comparison of the proposed method with optical flow estimation–based method

Three lines in Fig. 4 show the movement of the vehicle obtained by detecting the horizontal position of the white line on the road, by computing cross section of all optical flow vectors that are obtained by a commercial software that provides optical flow vector field, and by our method. The software we used for the optical flow vector field is “Flow-vec” which is created by Library Corporation

In this experiment, we consider that the result obtained from horizontal position of the white line is the true measurement of lateral vehicle position as a reference. Since the result of our method is closer to the result from the white line, the proposed method for FOE estimation is more accurate than the optical-flow estimation–based method.

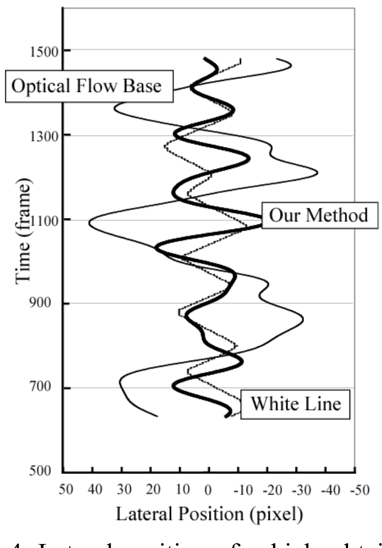

Figure 4: Lateral position of vehicle obtained from each method.

The movements of FOE, which are obtained from method based on optical flow and our method, are shown in Fig. 5. The input image shown in Fig. 6 is one frame of the image sequence when the vehicle is running at the road, which is curving to left. The position of FOE is expected to exist around the left upper side of the image. The result of our method shows reasonable position of FOE, while the result of the optical flow based method shows unstable and unnatural position.

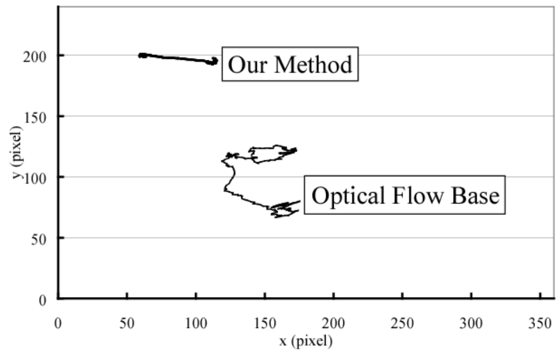

Figure 5: Movement of FOE of the input sequence.

Figure 6: Vehicle on a curve. The small lines drawn in the image show the optical flow vector, which are computed by using the position of FOE obtained from our method. The result of the optical flow shows a reasonable movement of the camera.

3.3 Experiment on bad condition

We show a result of our method on bad condition. Fig. 7 shows the movements of FOE on a road, which is covered by snow. As shown in Fig. 8, the road is straight and white line can't be seen. The position of FOE is expected to exist near the center of the image. Our method shows the straight line while the result obtained by the optical flow estimation fluctuates along the centerline. This means that the optical flow estimation is not accurate because of the snow on the road.

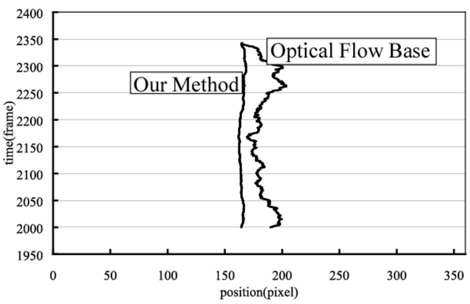

Figure 7: Lateral position of FOE on a snow road.

Figure 8: Vehicle on a snow road. The small lines drawn in the image show the optical flow vector, which are computed by using the position of FOE obtained from our method. The result of the optical flow shows a reasonable movement of the camera.

4 Conclusions

In this paper, we have proposed a method for estimating the position of FOE, which does not rely on optical flow estimation. Our method estimates the FOE by evaluating the adequacy of hypothesis of the position of FOE and maximizes the adequacy. We use the value of SAD for the evaluation of adequacy. We demonstrate this effectiveness of the proposed method by showing the experiments results using various road images.

References

[1] Didi Sazbon, Hector Rotstein and Ehud Rivlin, “Finding the focus of expansion and estimating range using optical flow images and a matched filter,”

[2] Zezhi Chen, Nick Pears, John McDermid and Thomas Heseltine, “ Epipole Estimation under Pure Camera Translation, ” Proc. VIIth Digital Image Computing: Techniques and Applications, Sun C., Talbot H., Ourselin S. and Adriaansen T. (Eds.), pp. 849–858, 10–12 December. 2003, Sydney.

[3] Negahdaripour, S., “Direct Computation of the FOE with Confidence Measures,” Compute Vision and Image Understanding, Vol. 64, No. 3, pp. 323–350, November 1996.

[4] Ramesh Jain, “Direct Computation of the Focus of Expansion” IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 5, No. 1, pp. 58–64 , January 1983.

[5] Sridhar Srinivasan, “Extracting Structure from Optical Flow Using the Fast Error Search Technique” International Journal of Computer Vision, Vol. 37, Issue 3, pp. 203–220, June 2000.

[6] Berthold Klaus Paul Horn: “Robot Vision” The MIT Press McGraw– Hill Book Company (1986)