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In-Car Video Stabilization using Focus of Expansion

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ABSTRACT

Video stabilization is a very important step for vision based applications in the vehicular technology because the accuracy of these applications such as obstacle distance estimation, lane detection and tracking can be affected by bumpy roads and oscillation of vehicle. Conventional methods suffer from either the zooming effect which caused by a camera movement or some motion of surrounding vehicles. In order to overcome this problem, we propose a novel video stabilization method using FOE(Focus of Expansion). When a vehicle moves, optical flow diffuses from the FOE and the FOE is equal to an epipole. If a vehicle moves with vibration, the position of the epipole in the two consecutive frames is changed by oscillation of the vehicle. Therefore, we carry out video stabilization using motion vector estimated from the amount of change of the epipoles. Experiment results show that the proposed method is more efficient than conventional methods.

Key words: In-car Video Stabilization, Focus of Expansion, Epipole

1. INTRODUCTION

In order to prevent vehicle accidents caused by driver's inattentiveness, DAS(Driver Assistance System) using a camera installed in the vehicle has been extensively studied in the vehicular technology field. FCWS(Forward Collision Warning System), LDWS(Lane Departure Warning System) and PCWS(Pedestrian Collision Warning System) are among the researches that are related to this field. The FCWS is designed to warn the driver or to break the vehicle by force when there is a potential collision with vehicle in front of the host vehicle. The LDWS is a system which prevents dangerous lane departure of the vehicle by sending a warning signal to the driver when the vehicle leaves the lane without turning on the signal light. The PCWS prevents the risk of collision by warning the driver of the danger of an incoming collision with a pedestrian in front of the car. DAS uses camera calibration to estimate the distance between the host vehicle and the vehicle in front of the host vehicle. Camera calibration is also used to get lane information as well. However, the performance of algorithms such as object detection, distance estimation, and tracking are degraded because the extrinsic parameters of the camera are changed by the road condition or the vibration of the vehicle. Therefore, video stabilization is needed as a pre-processing step to improve the performance of DAS using the camera.

EIS (Electronic Image Stabilization) and DIS (Digital Image Stabilization) methods are two major categories of the image stabilization methods which can be applied to the image acquired from camera installed in the vehicle. EIS method estimates motion vector from angular rate sensor and then using the information obtained to compensate

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the image[1]. However, this method faces two main problems that make it undesirable. The first one is an economical problem that arises due to the need to install additional mechanical devices. The second one is a time delay problem which is caused by the mechanical movements of the device. On the other hand, DIS methods use image processing techniques to handle video stabilization. Methods which use information about edge histograms[1], feature points[1], lanes[2], and phase correlations[3] are typical examples of the DIS methods. Due to the zooming effect, it is hard to estimate the precise movements of the vehicle by using edge histogram method. The feature point method fails when the features from two frames don't match each other properly. We can apply the method which uses information about lanes only when lanes exist in the image. The phase correlation method estimates motion by calculating the phase correlation of a predefined ROI (region of interest) of two consecutive frames. This method works fine if the car in front of the host vehicle is fairly stable. However, problem arises when the car in front of the host vehicle experiences shock or vibration due to the unstable road condition or road bumps.

This paper proposed a video stabilization method that uses motion vector estimated from the amount of change of the epipoles of two consecutive frames in order to overcome the side effects such as zooming effects by camera movements, and motion of surrounding vehicles.

This paper is organized as follows. Section Ⅱ explains about the position change of the FOE caused by vibration of the vehicle. Section Ⅲ describes the video stabilization method using the change of the epipole. Section Ⅳ presents the experimental results for demonstrations. Section Ⅴ gives conclusions of this paper.

2. POSITION CHANGE OF FOE BY VIBRATION OF THE VEHICLE

The coordinate of the camera installed in the vehicle is defined as Fig. 1. Z-axis translation occurs when the vehicle moves in the forward direction. Pitch and rolling is caused by either road condition or movement of the vehicle. Yaw is caused by intentionally steering of the vehicle. In this paper, yaw caused by intentionally steering and static state of vehicle are ignored. Rolling is also ignored to simplify calculation. In the case of pure translation toward Z-axis, optical flow between two successive frames obtained by the camera is diffused from an FOE as shown in Fig. 2.

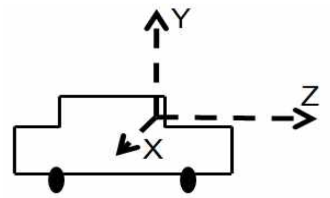


Fig. 1. Camera coordinate.

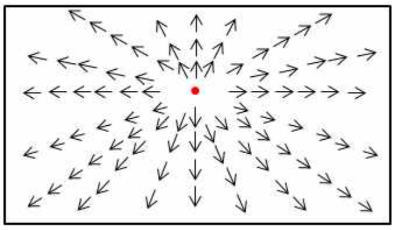


Fig. 2. Optical flow and FOE

Fig. 3(a) shows the case when the vehicle purely moves in the forward direction. When this happens the FOE positions of the two consecutive frames will be equal as shown in Fig. 3(c). When pitch occurs due to vibration, such as Fig. 3(b), the FOE positions at the two consecutive frames will be different as shown in Fig. 3(d). The FOE is always equals to the epipole in a frame[4]. So in this paper, we calculate the epipole in a frame to get the FOE and estimate the motion vector from the amount of change of the epipole at the two consecutive frames. The projection matrix and the epipole can be expressed as Eq. (1) and Eq. (2), respectively[4]. Where K is the intrinsic parameter, R is the rotation parameter and t is the translation parameter.

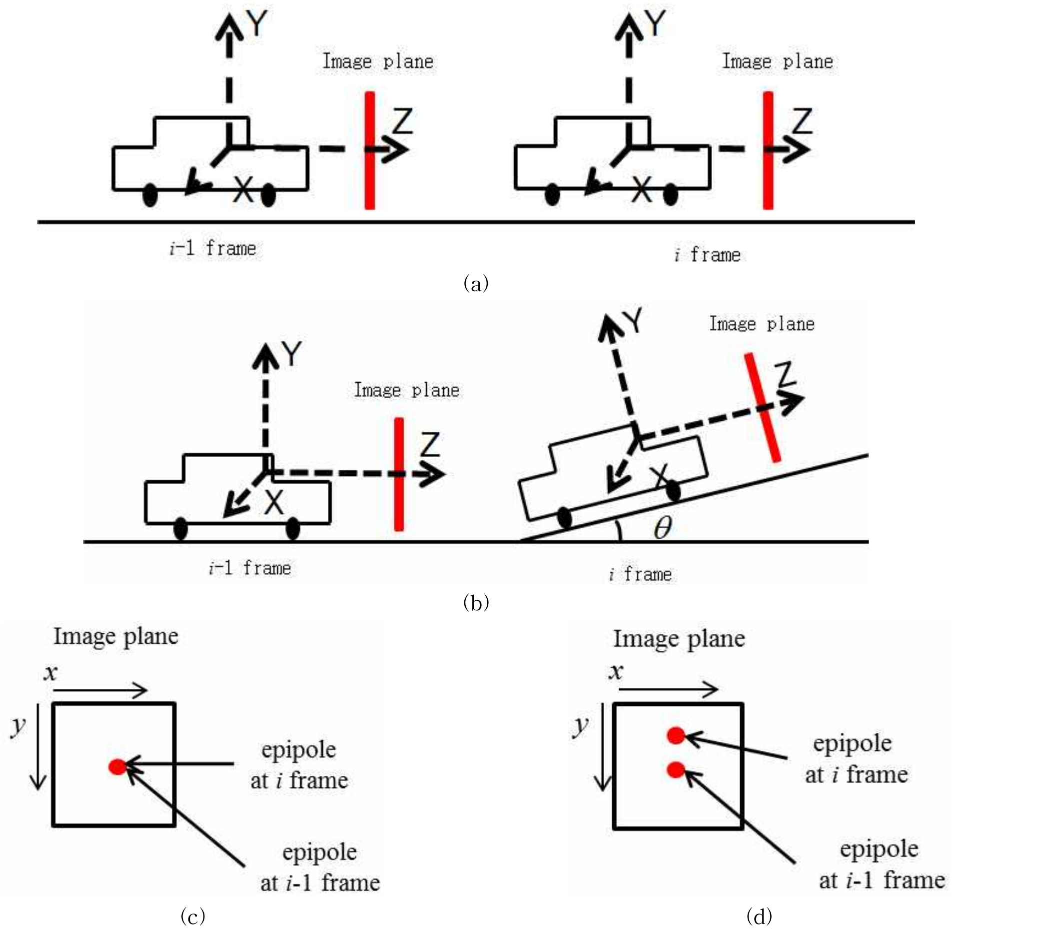


Fig. 3. Position change of the epipole by camera translation and rotation (a) pure translation by *Z*-axis, (b) pure translation by *Z*-axis and rotation by *X*-axis, (c) position change of the epipole at (a), (d) position change of the epipole at (b).

Then, the amount of change of the epipole is expressed by Eq. (3). We can assume $K=K'=I$, because intrinsic parameter at the camera installed in the vehicle has not changed. In the case of pure translation like Fig. 3(a), the epipole position has not changed because R is equals to I. In the case of pitch, motion vector is estimated by the amount of change of the epipole in the y-axis of the frame. Fig. 4 shows the relation between a motion vector estimated by the amount of change of the epipoles in the y-axis of the frames and degree of X-axis of camera coordinate. If degree of X-axis increases, the amount of absolute change of the epipole will also increase.

$$P=K[I\,|\,0],\ P'=K'[r\,|\,t] \tag{1}$$

$$e=KR^{T}t,\ e'=K't \tag{2}$$

$$e'-e=K't-KR^{T}t \tag{3}$$

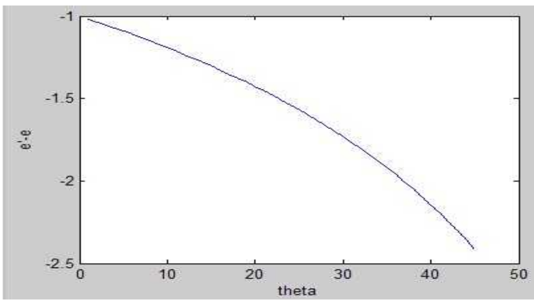


Fig. 4. The change of the epipole by degree of *X*-axis

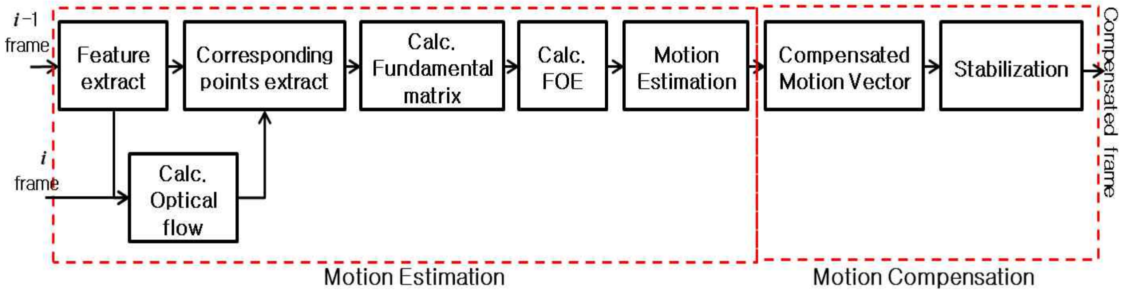


Fig. 5. Flow chart of the proposed method.

3. VIDEO STABILIZATION USING CHANGE OF THE EPIPOLE

Fig. 5 shows a flow chart of the proposed stabilization method. We can divide the flow chart into two parts: the motion estimation part and the motion compensation part. The motion estimation part calculates a motion vector. This will be explained in section 3.1. We then perform video stabilization using compensated motion vector which is obtained from the motion vector calculated earlier.

3.1 Motion Estimation

In order to estimate motion vector in the video, we extract feature points from the previous frame using KLT algorithm[5], and then[6,7]. Mismatched feature we get the corresponding points in current frame using optical flow of the feature point problem arises when the feature points located on the boundary of the frame disappear. In order to solve this problem, we exclude the feature points extracted from boundary of the frame. Fig. 6 shows a mismatched feature point problem and a feature extraction region.

We then calculate the fundamental matrix from the remaining corresponding points using normalized 8-point algorithm using RANSAC[4]. From Eq. (4), we are able to calculate the epipole, where F is the fundamental matrix and e is the epipole. We can obtain the motion vector by solving Eq. (5), where $FOE.y(i)$ is the y coordinate of the epipole in current frame and $FOE.y(i-1)$ is the y coordinate of the epipole in previous frame.

$$Fe = 0 \tag{4}$$

$$MV(i) = FOE.y(i) - FOE.y(i-1) \tag{5}$$

3.2 Motion Compensation

In order to stabilize the video sequence of an in-car camera, we need to find the compensated motion vector $CMV(i)$ in the opposite direction of mo-

(a) (b)

Fig. 6. (a), (b) Mismatched problem and feature extraction region

tion vector and we use kalman filter[8] to obtain a stable motion vector.

The kalman filter provides an estimate to the state of a discrete-time process defined as a linear dynamical system in the form of $X(i+1) = A \times X(i) + W(i)$, where $W(i)$ is the process noise. The kalman filter operates using measurements defined by $Y(i) = H \times X(i) + V(i)$, where $V(i)$ is the measurement noise. Process and measurement noise are assumed to be independent, white, and with normal probability distributions.

In this paper, the state of the image stabilization system is represented by vertical position of image coordinate and velocity. So, the transition matrix is defined by

$$A = \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix} \quad (6)$$

The measurement matrix is defined by

$$H = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \quad (7)$$

4. EXPERIMENTAL RESULT

In this section, the performance of the proposed method is evaluated and compared to the other existing method based on the compensated motion vector. To do this, we installed camera in the vehicle as shown in Fig. 7, and captured real video sequences by an in-car camera.

We manually find the vanishing line of the extracted frames, and then we can get the ground truth by finding the difference of the vanishing line in the y-axis between previous frame and current frame. The ground truth is given by

$$CMV(i)' = vanish.y(i-1) - vanish.y(i) \quad (8)$$

where $vanish.y(i-1)$ is the y coordinate of the vanishing line in the previous frame and $vanish.y(i)$ is the y coordinate of the vanishing line in the current frame. The performance is evaluated based on the root mean square error($RMSE$) between the phase correlation method and the proposed method. The $RMSE$ is given by

$$RMSE = \frac{1}{N}\sqrt{\sum_{i=1}^{N}(CMV(i) - CMV(i)')} \quad (9)$$

where $CMV(i)$ is the compensated motion vector generated from the proposed method at i frame, $CMV(i)'$ is the motion vector of ground truth at i frame and N is the number of frame. The proposed method is compared to the phase correlation [3].

Fig. 7. Installed camera in the car.

The $RMSE$ results of these two methods are summarized in Table 1. The performance of the proposed method is equal to the phase correlation method in most cases. However, if the vehicle in front of the host vehicle experienced vibration due to the crossing of a speed bump as shown in Fig. 8, the phase correlation method gives a wrong motion vector because this method estimates motion vector based only on a predefined ROI. However, the proposed method ignores the motion of the vehicle in front of the host vehicle due to RANSAC algorithm. In this case, The $RMSE$ results of these two methods are shown in Table 2. Fig. 9 shows the comparison of ground truth and the compensated motion vectors by two different methods which are the proposed method and the phase cor-

Table 1. *RMSE* comparisons of phase correlation and the proposed method(When the vehicle in front of the host vehicle did not experience vibration)

Method	*RMSE*
phase correlation [3]	0.22
proposed method	0.22

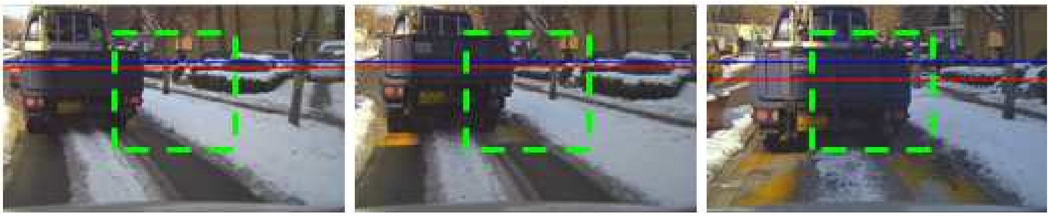
Table 2. *RMSE* comparison of phase correlation and the proposed method(When the vehicle in front of the host vehicle experienced vibration)

Method	*RMSE*
phase correlation [3]	6.63
proposed method	1.09

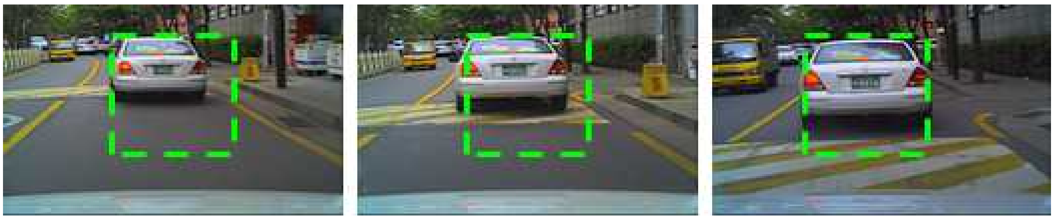
relation method. The x-axis represents frame numbers and the y-axis represents the compensated motion vector. From the result shown in Table 2 and Fig. 9, we can conclude that the proposed method is more efficient than phase correlation method.

V. CONCLUSION

In this paper, we proposed a novel video stabilization method used by in-car cameras. We get an epipole using corresponding points in two consecutive frames, and then we estimate a motion vector by the amount of change of the epipoles. The compensated motion vector which is used to carry out video stabilization can be obtain from the estimated motion vector. Experiment results have shown that the proposed method is more efficient than the conventional method because of its property to eliminate mismatched corresponding points and motion of surrounding vehicles.



(a)



(b)

Fig. 8. (a), (b) Motion which generated at vehicle in front of the host vehicle.

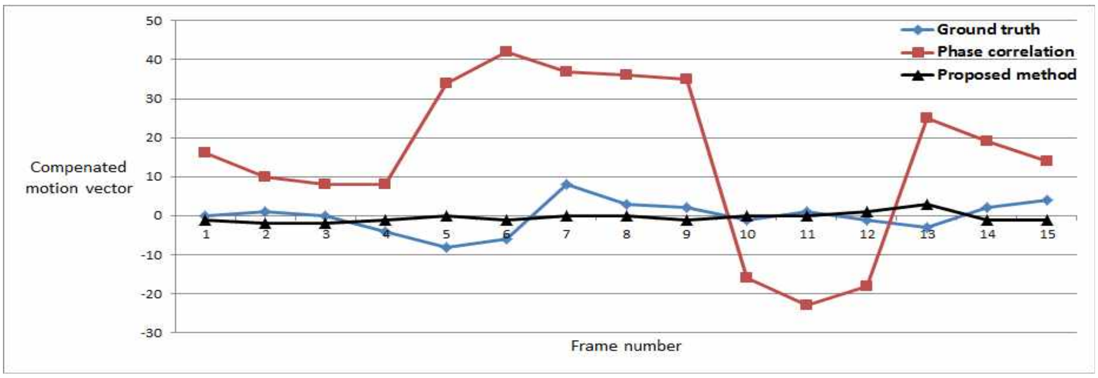


Fig. 9. Compensated motion vector comparison.

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