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The Obstacle Detection Method using Optical Flow Estimation at the Edge Image

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Abstract -The purpose of this study is to develop an algorithm for the detection of the obstacle ahead of a host vehicle by image processing using a monocular onboard camera, and to show that this algorithm is able to apply the prevention of the collision accident. It can be supposed that there is some important information on the edge of the image. In this paper we show an obstacle detection method by extracting optical flow along the edge of the image, and estimated result of the three dimensional (3D) information in the world coordinate system from the optical flow.

1. Introduction

In recent years, with the increase of cars, the lack of recognition and miss judgment by drivers causes the increase of traffic accidents. Advanced Safety Vehicle (ASV) [1] project which support drivers' recognition, judgment and control by the machine intelligence has been investigating for the driver safety.

The purpose of this study is to develop an algorithm for the detection of the obstacle ahead of a host vehicle by image processing. The obstacle ought to have three dimensional (3D) information (width, height, and depth) in the world coordinate system. Stereo vision has been used as the method for estimating that. In this study, we use a monocular onboard camera to cut down the cost. Optical flow seems to be useful to estimate the 3D information using that. It has been able to be extracted only using the grayscale image.

In this paper we show an obstacle detection method by extracting optical flow along the edge of the image. The part of the edge in the image seems to be important in outdoors, because it can be extracted clearly even if the brightness is changed by various conditions. Therefore, we extract the optical flow there by assuming the virtual intensity gradient along the edge and centering on the corner point.

The information of the image used in this study are input in the below situation. Fig.1.1 shows that the car with a digital camera is running straight ahead to the motionless car on the roadway. The situation is shot for the animation, and we transform the animation into images of time series every 50m second. In the next section, we explain about the method for the extraction of the optical flow.

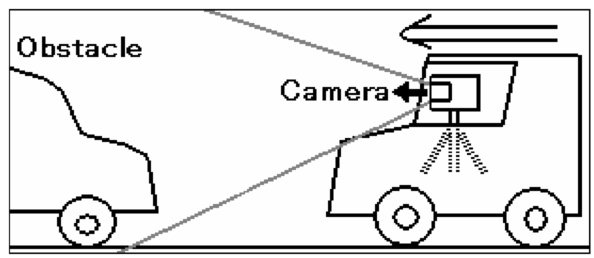

Fig.1.1: Situation

2. Optical Flow

Optical Flow is used to estimate a motion of objects by describing the intensity change at each pixel of the digital image as vectors of the movement. We used the Gradient Method (GM) for detecting optical flow. In the GM, the optical flow can be extracted only the simple calculation compared with previous Matching method even if the camera is shifted by the movement of the car.

2.1. Gradient Method

The GM is one of methods for the extraction of the optical flow. In the GM, it is assumed that the change of times keeps the brightness of the image and only the small movement changes it. The position of the camera is given by x, y in the world coordinate system. Let us assume that each velocity of x, y coordinates of optical flow in the image is u, v, and each gradient (intensity change) of x, y coordinates is Ex, Ey. We also assume the interval t in images of time series and the intensity change by the interval is Et. The constraint equation of the optical flow is defined as:

$$E_x u + E_y v + E_t = 0 \qquad (2.1)$$

We used the Local Method to estimate values of u, v. As getting the equation (2.1) from the interest pixel, it is able to get some constraint equations from its local pixels. This is the method to estimate the value by calculating these simultaneous equations using the Least Square Method.

Fig.2.1 show grayscale images of time series, and Fig.2.2 shows the extraction result of optical flow used the GM to them.

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Fig.2.1: Original Images

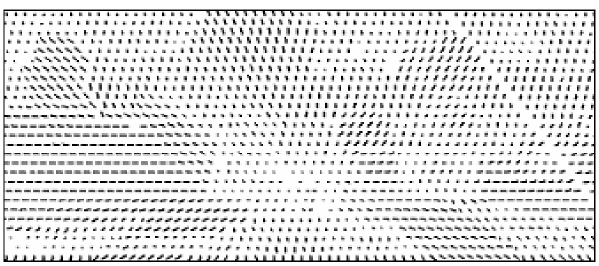

Fig.2.2: Optical Flow by GM

The result shows that the optical flow is extracted to pixels which have unimportant information and it seems to be difficult to get the feature of the object. The cause is that the intensity of all pixels in the grayscale image is changed by the small shift of camera provided that the obstacle is the motionless object. It seems to be difficult to show the obstacle detection method using the GM from the result. Therefore we propose the Virtual Intensity Gradient Method in 2.2

2.2. Virtual Intensity Gradient Method

It is ought to extract the optical flow along the edge of the image to estimate the shift of the object, because the important information of the object exists there. The intensity gradient on the edge of the image is changed suddenly by the shift of the camera in time series. Therefore it is impossible to extract optical flow along the edge of the image using the GM.

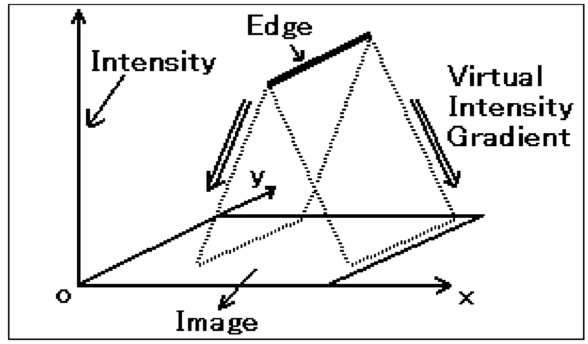

Fig.2.3: Linear Virtual Intensity Gradient

We proposed a Virtual Intensity Gradient Method (VIGM) [2]. The virtual intensity gradient Vx, Vy, Vt are generated by assuming the linear intensity gradient around the edge as shown in Fig.2.3. We can get the constraint equation of the optical flow (2.2) from the intensity change.

$$V_x u + V_y v + V_t = 0 \qquad (2.2)$$

Fig.2.4 show the edge images of time series, and Fig.2.5 shows the extraction result of optical flow used VIGM to them.

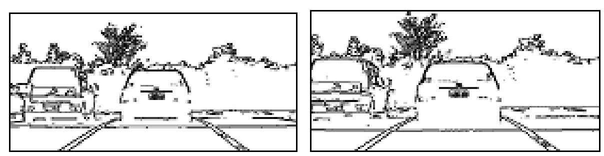

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Fig.2.4: Edge Images

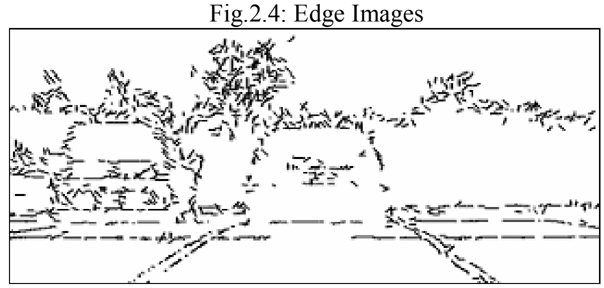

Fig.2.5: Optical Flow by VIGM

This method enables to extract the optical flow along the edge of the image. However, the linear parts cause the aperture problem and the complex edge composition makes the accurate extraction of optical flow difficult. Therefore we propose the method to extract the optical flow accurately along the edge of the image.

3. Proposal Method

We show a method for obstacle detection by extracting optical flow along the edge of the image, and estimating the three dimensional (3D) information in the world coordinate system from the optical flow.

We get a constraint equation of the optical flow using corner points on the edge of the image in the proposal method.

3.1. Harris Corner Detector

Harris Corner Detector (HCD) [3] is the method to detect corners in the image. The image is analyzed every local area by using the feature that the intensity in the corner point is changed by small shift of all directions. Given that the intensity of the interest pixel x, y in image is I(x, y), we can have the approximation E (p, q) of intensity change by small shifts [p, q] to x, y directions of local area as;

$$E(p,q) \cong \begin{bmatrix} p & q \end{bmatrix} \; M \; \begin{bmatrix} p \\ q \end{bmatrix} \qquad (3.1)$$

where

$$M = \sum_{x,y} w(x,y) \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} \qquad (3.2)$$

w(x, y) is the window function, which is Gaussian Filter of local size. Given that λ1, λ2 are the eigenvalue of the matrix M from (3.2), the equation of the threshold R for the corner detection is;

$$R = \det M - k(traceM)^2 \qquad (3.3)$$

where

$$\det M = \lambda_1 \lambda_2, \qquad traceM = \lambda_1 + \lambda_2$$

k = 0.04 ~ 0.07, which is the empirical constant. Fig.3.1 shows the result the corner detection to the edge image.

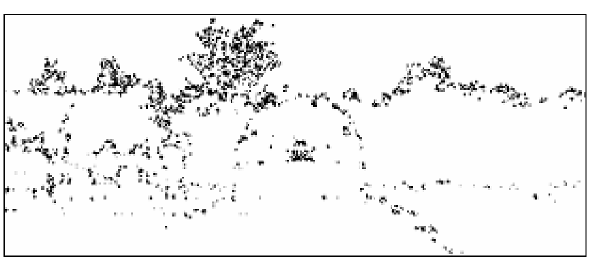

Fig.3.1: Corner Detection

3.2. The proposal of conic gradient

Fig.3.2 shows the assumption of the conic virtual intensity gradient centering on the corner point detected by HCD.

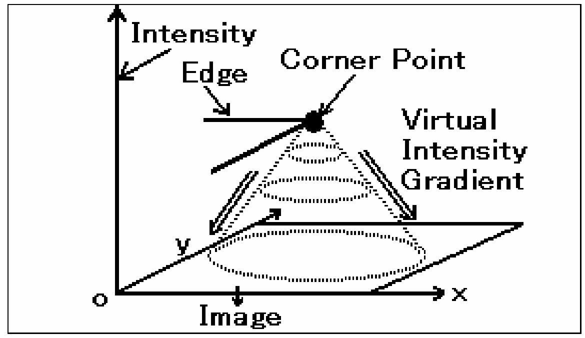

Fig.3.2: Conic Virtual Intensity Gradient

The new virtual intensity gradient Cx, Cy, Ct are generated by this assumption, and we can get a constraint equation of optical flow (3.5) from the intensity change.

$$C_x u + C_y v + C_t = 0 \qquad (3.5)$$

3.3. Simultaneous Equations of constraint conditions

It is assumed that the simultaneousness equations of constraint conditions make an accuracy of the optical flow better. We calculate the simultaneous equations of three constraint conditions by the conic gradient centering on the corner point (3.5), the linear gradient along the edge (2.2), and the GM (2.1).

$$\begin{aligned} E_x u + E_y v + E_t &= 0 \\ V_x u + V_y v + V_t &= 0 \\ C_x u + C_y v + C_t &= 0 \end{aligned} \qquad (3.6)$$

The proposal method enables to have the information of three times as much as that of previous method to one interest pixel. Results of the calculation are Fig.3.3. From this figure, we succeeded in the extraction of accurate optical flow compared with previous method.

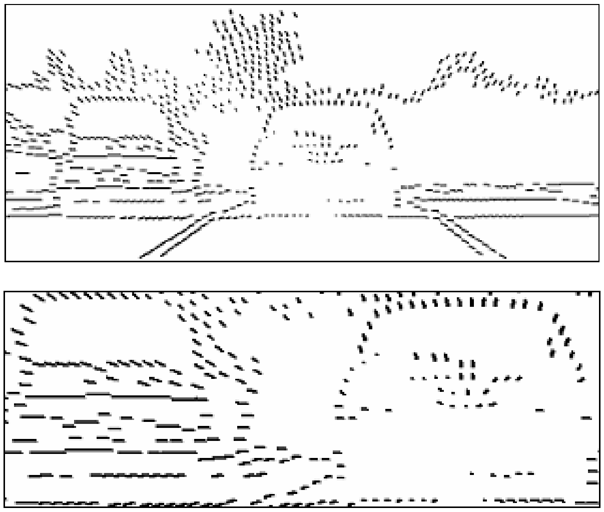

Fig.3.3: Optical Flow by Proposal Method

3.4. The estimation of 3D information

We estimated 3D information such as depth and height in the world coordinate system using the optical flow by proposal method. It is difficult to estimate 3D information accurately as using stereo vision because of using a monocular camera in this study. If it can estimate the height information of obstacle, the obstacle detection should be possible from the position relationship of the flow in the world coordinate system.

Firstly, let us assume that the image is described by the perspective projection, and X, Y, Z are the world coordinates after the estimation of 3D information. We also estimate the value of the depth Z from the position relationship between the height of FOE (Focus Of Expansion) and that of edge by the distance information image, and X, Y from Z.

(1) FOE estimation

In this section, we estimate the FOE position in the image. FOE is the point which is the occurrence source of the motion in the image.

It is possible to estimate the FOE position from the optical flow, but in case using a monocular onboard camera in this paper, slight difference by the pitching and the direction of the brightness axis and the car's path causes the violent change of the FOE position in time series to affect the optical flow. Therefore, given that minute difference of brightness axis and the car's pitching can be ignored, and there are straight lines of depth direction such as traffic lane in the image, we estimate the FOE position using Hough-transform from the edge image, and supposed that the position of the FOE is the intersection of lines. Fig.3.4 shows the estimated result.

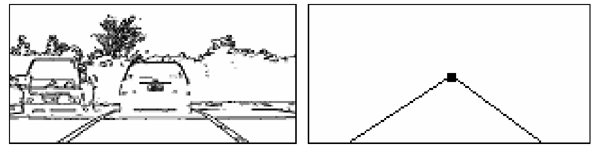

Fig.3.4: FOE estimation

Fig.3.5 shows the comparison of the FOE position estimated by the edge image and the optical flow in time series.

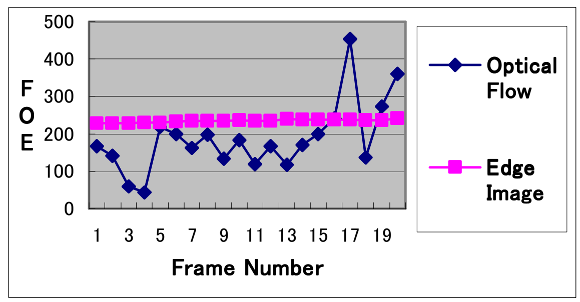

Fig.3.5: Transition of FOE

From this graph, the result of FOE estimation by the edge image is stable, while those by the optical flow are not stable. Therefore it seems to be difficult to estimate the 3D information by the optical flow

(2) The estimation of distance information

We generate the simple distance information using the edge. The boundary between the background and the object is called Jump Edge and the boundary between the ground and the object is called Roof Edge. The Jump Edge corresponds to the distance from the viewpoint which changes stepwise, and the Roof Edge to the parts which sticks convexly or concavely. We carry out the threshold processing using the shade of the object as shown Fig.3.6, and extracted only the bottom line of the shade area as the Roof Edge from the result. Fig.3.7 illustrates the distance information image by Jump Edge and Roof Edge.

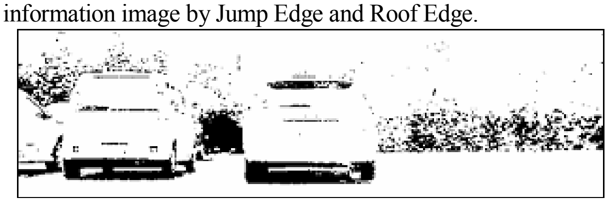

Fig.3.6: Candidate Area of boundary

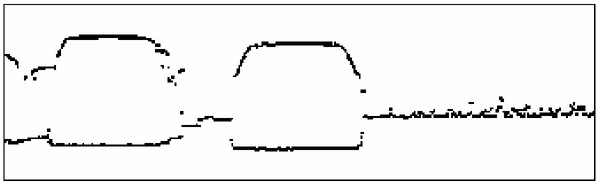

Fig.3.7: Jump Edge and Roof Edge

(3) Inverse Projection

We project the 3D information to the world coordinate system X, Y, and Z using the FOE and the distance information estimated from (1) and (2).

Firstly, we estimate the value of depth Z from each flow. Given that the viewpoint position of observer is equal to that of FOE. Fig.3.8 shows that O (Xo, Yo, Zo) is the observer position in the world coordinate system, D is the distance moved through the interval, r is the start point of the optical flow, r' is the closing point, and f is the distance of focus. The value of Z is changed by two conditions. If the flow exists below the Roof Edge in the image, the equation for calculating Z is;

$$Z = \frac{L}{r' - r} f \qquad (3.8)$$

where $r = \sqrt{x^2 + y^2}$ $r' = \sqrt{(x+u)^2 + (y+v)^2}$

u, v are values of the optical flow. L is the height to the viewpoint position of observer from the point O. If the optical flow exists above the Roof Edge in the image, the equation for calculating Z is;

$$Z = \frac{D}{r' - r} - f \qquad (3.9)$$

If the flow exists above the Jump Edge, we assume that it is the background and set it as the very large distance.

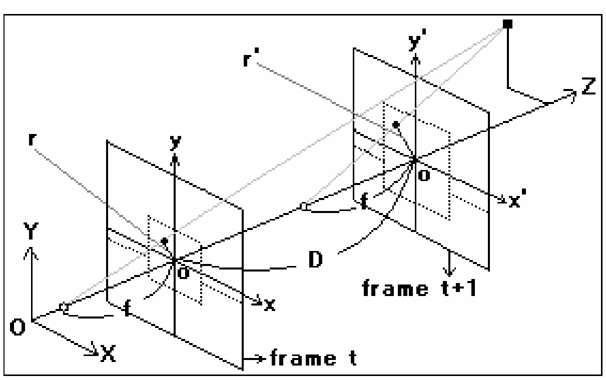

Fig.3.8: Inverse Projection

The equations (3.10) also give values of X, Y in the world coordinate system using estimated Z,

$$X = \frac{x}{f}(Z - Z_o) + X_o$$
$$Y = \frac{y}{f}(Z - Z_o) + Y_o \qquad (3.10)$$

(4) 3D-information reconstruction

We can get the image of 3D representation by re-projecting the value of X, Y, and Z to the image. We assume the condition [a(0<a<X_SIZE), b(0<b<Y_SIZE), c(0<c<Y_SIZE-b)] using the image which consists of the size of the side X_SIZE and the length Y_SIZE. a, b, and c are parameters to set the angle for the show of the result of the 3D information. The point P (xp, yp) by the projection to the image is;

$$xp = \frac{a}{X\_SIZE} X + \frac{X\_SIZE - a}{Z\_SIZE} Z$$
$$yp = b - \frac{b}{X\_SIZE} X + \frac{Y\_SIZE - c - b}{Y\_SIZE} Y + \frac{c}{Z\_SIZE} Z \qquad (3.11)$$

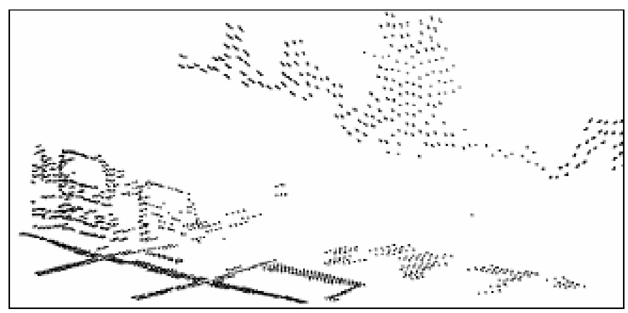

Fig.3.9: 3D Information

3.5. Experimental Result

The height information of the obstacle appears in the world coordinate system from the 3D information. Therefore we determine the threshold to the height. The part of flows shown Fig.3.10 has the height more than the threshold in the world coordinate system. From the result, we can see the distinction between the road and the body of cars.

Fig.3.10: Solid Parts

Fig.3.11 shows that only flows which show the color in Fig.3.10 are extracted in the image. Finally, Fig.3.12 shows the result, which applied Fig.3.11 to the grayscale image using white rectangular frames.

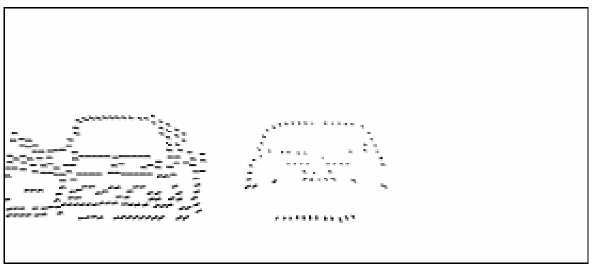

Fig.3.11: Solid Parts in image

Fig.3.12: Obstacle Detection Result

4. Conclusion

In this paper we showed the obstacle detection method by extracting optical flow along the edge of the image, and estimated result of the 3D information in the world coordinate system from the optical flow. The method in this paper has two originalities. One is that we use the corner point on the edge of the image for the generation of the virtual intensity gradient, another is that we calculated simultaneous equations of different restraint conditions of optical flow. The calculation time of the proposed method is about 1 in 32 compared with previous Matching method. Therefore, it seems to be able to react the general speed of driving.

Fig3.12 shows that the result can output most areas of cars as the obstacle. We could show that the proposal method in this study has usefulness from the result.

In future, we will study more accurate estimation of 3D information without the additional information, and try to apply the application in different condition.

5. Reference

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