Snow Side Wall Detection using a Single Camera

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Abstract: In the area where it snows heavily, snow removal of a road cannot often catch up with snowfall. Especially, a community road becomes too narrow for vehicles to pass each other since snow removal is insufficient compared with a main street. To obtain this information, this paper presents the novel method to measure the distance between a vehicle and a snow wall of shoulder by a single camera. Our method creates the inverse perspective mapping (IPM) image by projecting an input image to the virtual plane which is parallel to the moving direction of the vehicle and which is perpendicular to the road surface. Then, the distance to the side wall is calculated from the histogram whose bin is the length of an optical flow detected in the IPM image. The optical flow of the IPM image is detected by a block matching and the motion of the side wall is obtained from the peak of the histogram. The narrow way is detected by results measured by several vehicles with a backup camera.Our method is robust to changes in the appearance of the texture on the side wall that occur when a vehicle moves along a road.

1 INTRODUCTION

In the northern part of Japan, there are many areas where it snows heavily. In these areas, snow removal of a road is important for citizens' life. If road width is wide enough, vehicles can pass mutually even if snow is stacked to the road shoulder. However, there are many narrow community roads in the local city of Japan. After snowfall, these roads become too narrow for vehicles to pass mutually as shown in Fig.1 and this situation causes a minor collision or traffic congestion. Since it's difficult to pass through a narrow road, vehicles are gathered in a wide main street. This causes the further traffic congestion. If the road information, such as narrowness of the road, is timely given to drivers, this problem will be improved because drivers can choose the course for bypassing these points. However, it's not easy to know the current situation of community roads because most of them are not equipped with a traffic surveillance camera.

We aim at realizing the system which detects the place through which the road is too narrow for vehicles to pass mutually owing to the snow stacked to the shoulder. In order to estimate narrowness of the road, this system uses the distance between the vehicle and a snow side wall, measured by a lot of vehicles with a backup camera. Since vehicles with a backup camera for parking support increases recently in Japan, our method acquires the distance information from a backup camera. This system assumes that the distance information measured by each vehicle is sent to a base station by a cell phone line with position information obtained from GPS. The road point where many vehicles output short distance is judged to be narrow. Since the distance information collected by many vehicles is used for analysis, it does not become a problem even if some vehicles fail to measure the distance occasionally.

This paper describes the novel method how to measure the distance between the vehicle and the side wall by a single camera, especially a backup camera. Since a backup camera uses a wide-angle lens, image distortion is severe. Therefore, distance measurement is difficult for the usual motion stereo. Our method solves this problem by processing in the inverse perspective mapping (IPM) image. At first, the IPM image is created by projecting an input image to the virtual plane which is parallel to the moving direction of the vehicle and which is perpendicular to the road surface. Then, the distance to the side wall is calculated from the histogram whose bin is the length of an optical flow detected in the IPM image. Our method assumes that a vehicle goes straight along the road in

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a short time. The moving direction and the moving distance are estimated from images of a backup camera. The distance to the side wall is calculated only while a vehicle goes straight. Since corresponding between features is performed by a block matching in the IPM image and the motion vector is estimated from the peak of the histogram, our method is robust to changes in the appearance of the texture on the side wall that occurs when a vehicle moves along a road.

The remainder of this paper is organized as follows. In Sect.2, related works are reviewed briefly. In Sect.3, the outline of the proposed method is described. In Sect.4, the method to calculate the distance to the side wall is explained in detail. In Sect.5, experimental results performed to simulation images and several snow road scenes are discussed. Conclusions are presented in Sect.6.

2 RELATED WORKS

Stereo vision is often used for measuring the distance to an object with cameras(Dhond and Aggarwal, 1989),(Hoff and Ahuja, 1989). Various methods which can acquire a dense depth map have been proposed and used for automobile applications, such as obstacle detection, road boundary detection and so on(Einecke and Eggert, 2013),(Suhr and Jung, 2013),(M. Michael and Schlipsing, 2013),(C. Guo and Naito, 2013),(M. Enzweiler and Franke, 2013). A commercial car with the collision avoidance system using a stereo camera has already been produced(Eyesight, 2013)(K. Saneyoshi and Sogawa, 1993)(Sogawa and Hanawa, 2002). Although stereo vision is effective in distance measurement with a camera, it requires higher cost than monocular vision because it needs calibrated two cameras. Therefore, there are few vehicles which have been equipped with stereo cameras.

On the other hand, vehicles with a single camera for rear view monitor or drive recorder are increasing. Especially, vehicles with a backup camera for parking support are rapidly increasing in Japan as the car navigation system spreads widely. For this reason, we proposes the method which measures the distance to the snow side wall by a single camera, especially a backup camera. Although a lot of methods have been proposed for distance measurement with a single camera, motion stereo is generally used in automobile applications(Huang, 1994)(A. Wedel and Cremers, 2006)(A.J. Davison and Stasse, 2007). Motion stereo needs to search corresponding points between two frames taken at different points or it needs to track feature points between frames. However, an image of

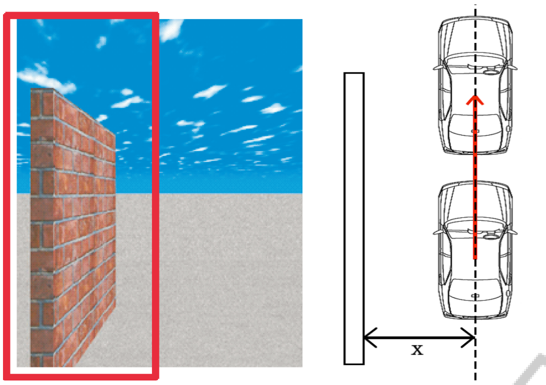
Figure 1: Snow wall of shoulder.

a backup camera has a severe distortion. In addition, appearance of the texture on the side wall changes a lot as the vehicle moves forward since the side wall is parallel to the moving direction of the vehicle. In addition, a lot of similar texture exist on the snow side wall. Therefore, it's difficult to estimate the distance to the snow side wall stably by conventional methods.

3 OUTLINE OF THE PROPOSED METHOD

Figure 2 shows the model of the driving environment which the proposed method assumes. The distance x between the on-vehicle camera and the side wall along the road is calculated from the moving distance of a vehicle and the movement of the side wall in the IPM image when a vehicle moves forward. The proposed method calculates the distance to the side wall near a vehicle. Therefore, it is assumed that the side wall consists of planes perpendicular to a road surface.

Figure 3 shows the procedure of the proposed method. At first, the motion of ego-vehicle is estimated from image sequences of a backup camera. The motion vector is estimated from optical flows detected on a road surface. Our method decides that an ego-vehicle moves straight when the motion vector shows the upward direction in a certain period of time. When a vehicle moves straight, the inverse perspective mapping (IPM) image is created and optical flows are detected in the IPM image by the block matching. If the wall is close to a vehicle, the movement of the wall in the IPM image is large as shown in Fig. 4(a) and the magnitude of the optical flow is also large. If the wall is far from a vehicle, the movement of the wall in the IPM image is small as shown in Fig. 4(b) and the magnitude of the optical flow is also small. Then, a histogram whose bin is the magnitude of the optical flow is created. The magnitude



(a) Side wall (b) Relation between a vehicle and a wall

Figure 2: Model of driving environment.

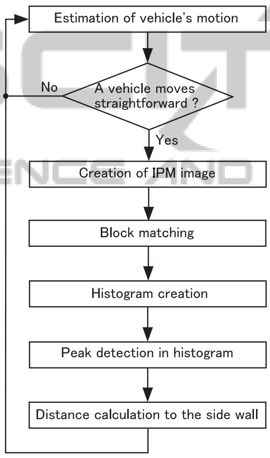
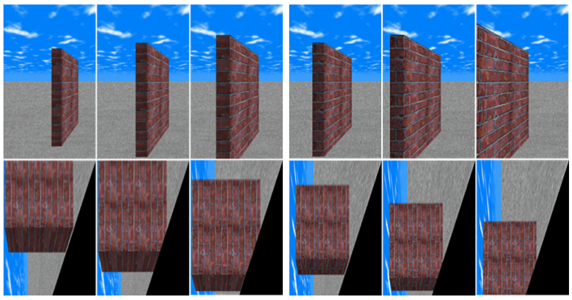


Figure 3: Outline of the proposed method.

with the maximum peak in this histogram is selected as the movement of the side wall in the IPM image. Finally, the distance between a vehicle and the side wall is calculated from this movement and the motion of an ego-vehicle.

4 ESTIMATION OF VEHICLE'S MOTION

The motion of an ego-vehicle is estimated from the optical flow detected on a road plane by the Lucas-Kanade method(Lucas and Kanade, 2008). Figure 5(a) shows flow vectors detected in an image of a backup camera. Extremely long flows are deleted as incorrect ones. Since lens distortion is large in the far area, the optical flow is detected only on the road surface near the camera. An image is divided into square blocks, as shown in 5(b) and an average flow is calculated in each block. Then, a histogram of flow direction is created by voting the length of each average flow. A direction in a histogram is quantized every 10 degrees. Figure 5(c) shows the example of a histogram. In an image of a backup camera, let the leftward direction be 0 degree, let the downward direction be 90 degrees, let the rightward direction be 180 degree and let the upward direction be 270 degrees. When a vehicle moves straightforward, the maximum peak of a histogram appears around 270 degrees because a backup camera takes a rear-view. When the maximum peak of a histogram is observed around 270 degrees in a certain period of time, our method decides that an ego-vehicle moves straightforward. When an ego-vehicle moves straightforward, flow vectors in the camera coordinate system whose direction are around 270 degrees are converted to the vehicle coordinate system. Conversion parameters are determined in advance by the camera calibration. We use a mat on which the square grid pattern is drawn for calibration. This mat is set on the ground in front of a backup camera. In both the camera coordinate system and the vehicle coordinate system, the position of the grid corner is manually measured and the table corresponding between these coordinate systems is created. The conversion parameter is calculated by solving the perspective projection matrix using this table. The average length of converted flow vectors is used as the moving distance of an ego-vehicle.

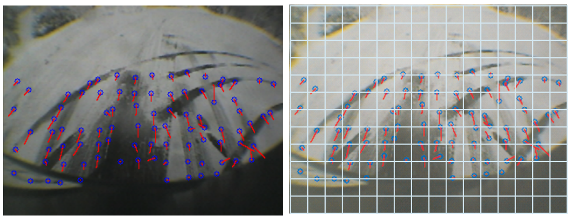


(a) Near (b) Far

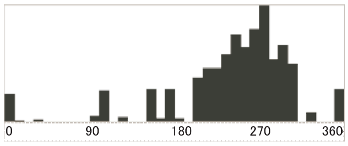
Figure 4: IPM image.

5 CREATION OF IPM IMAGE

The inverse perspective mapping (IPM) usually converts the coordinate system of the image plane to the coordinate system of the road surface to create a bird's-eye view image which looks down a road from the sky(Bertozzi and Broggi, 1997). Our method converts an image to the virtual plane which is parallel to the moving direction of the vehicle and perpendicular to the road surface. This vertical plane is set between



(a) Optical flow (b) Square blocks



(c) Histogram of flow direction

Figure 5: Optical flow from the backup camera.

(a) Input image (b) IPM image mapped on the virtual plane

Figure 6: Example of IPM image.

the side wall and an on-vehicle camera. The homography matrix(Onoguchi, 1998) is used for projecting an input image to the virtual plane. In the IPM image, the region distant form a vehicle has low resolution. However, this problem does not affect subsequent processing since the proposed method uses only the region near a vehicle. Figure 6 shows the example of the inverse perspective mapping. Figure 6(a) shows an input image. The rectangular ROI is set in the left side of an input image for creating the IPM image. Figure 6(b) shows the IPM image created from the image of the ROI. The position and the shape of the ROI is fixed manually when a camera is installed.

6 DISTANCE CALCULATION TO THE SIDE WALL

We explain the method which calculates the distance between an on-vehicle camera and the side wall by using Fig.7.

In Fig.7, a camera mounted on a vehicle moves Δy from right to left. Let P_1 denote the focus of a camera at the right position and let P_2 denote the focus of a camera at the left position. At P_1, the point k on the side wall is projected to p_1 on the image plane and at P_2, k is projected to p_2 on the image plane. The point k_1 (k_2) is an intersection of the virtual plane and the straight line connecting k and p_1 (p_2). Let Δx denote the distance between the virtual plane and the focus of a camera and x denote the distance between the side wall and the focus of a camera. The angle θ_1 (θ_2) between the virtual plane and a straight line connecting k and p_2 (p_1) is given by

$$tan\ \theta_1 = \frac{\Delta x}{b-\Delta y} = \frac{x}{y-\Delta y} \tag{1}$$

$$tan\ \theta_2 = \frac{\Delta x}{a} = \frac{x}{y}, \tag{2}$$

where a is the distance on the virtual plane from P_1 to k_1 and b is the distance on the virtual plane from P_2 to k_2.

The distance a and b on the virtual plane are given by

$$a = \frac{y}{x}\Delta x. \tag{3}$$

$$b = \Delta y + \frac{y}{x}\Delta x - \frac{\Delta x \Delta y}{x}. \tag{4}$$

Therefore, the difference $b-a$ is given by

$$b - a = \Delta y - \frac{\Delta x \Delta y}{x} = \Delta y(1 - \frac{\Delta x}{x}). \tag{5}$$

Figure 8 shows IPM images obtained by projecting the side wall to a virtual plane at the position P_1 and the position P_2. The distance D between corresponding points is given by

$$sD = a - (b - \Delta y) = -(b-a) + \Delta y = \frac{\Delta x \Delta y}{x}, \tag{6}$$

where s is the constant magnification which changes the distance on an IMP image into the distance on an virtual plane. In order to estimate s, we put the calibration board on which the square grid pattern is drawn on the position of the virtual plane. Let B denote the size of the square grid and let B_{IPM} denote the size of the square grid in the IPM image. s is given by

$$s = \frac{B}{B_{IPM}} \tag{7}$$

Because the moving the distance Δy of a vehicle is given by Sec. 4 and the distance Δx between a camera and the virtual plane is constant, the distance x to the side wall is given by

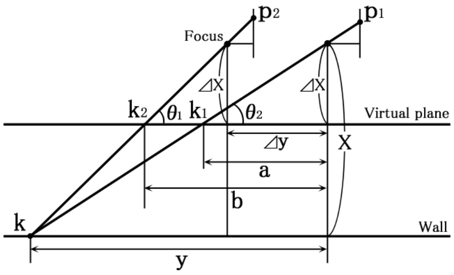


Figure 7: Inverse perspective projection to virtual plane.

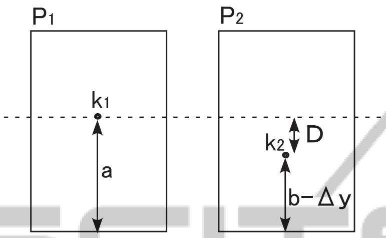


Figure 8: IPM image at P_1 and P_2.

$$x = \frac{\Delta x \Delta y}{sD}. \quad (8)$$

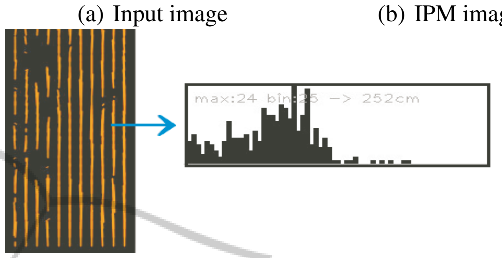
7 CORRESPONDING BETWEEN IPM IMAGES

The distance D between corresponding points are estimated by the block matching in IPM images created at P_1 and P_2. In the IPM image, the texture around the corresponding point at P_1 is similar to the texture around it at $P2$ because the appearance of textures on the side wall is not subject to influence of the perspective projection. Thus, our method uses the cross-correlation for searching corresponding points between IPM images.

Figure 9(b) shows the IPM image of Fig.9(a) and Fig. 9(c) shows optical flows detected in Fig.9(b). The optical flow is detected by the block matching. Since the distance to the side wall is calculated only when the vehicle moves straightforward, the direction of the optical flow is almost vertical and the vertical length is similar in the IPM image. Therefore, the histogram whose bin is the vertical length of the flow vector is created to estimate the distance D, as shown in Fig.9(c). The vertical length of the bin with the maximum peak is selected as the distance D. The vertical length in the IPM image can be converted to the actual distance D on the virtual plane because the distance Δx between the camera and the virtual plane is constant. The conversion parameter is beforehand estimated by the calibration.

(a) Input image

(b) IPM image



(c) Histogram estimated in the IPM image

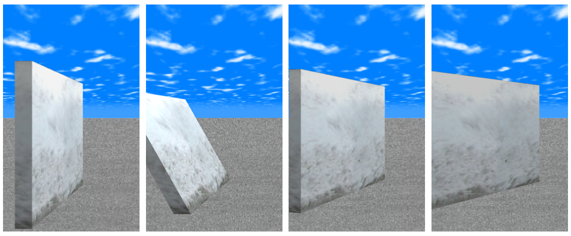
Figure 9: Movement of the side wall in the IPM image.

8 EXPERIMENTS

We conducted experiments which estimated the distance to the side wall in simulation scenes and real road scenes. An image size is 320×240 pixels and the processing time is $30fps$ on PC with Xeon 2.67GHz CPU.

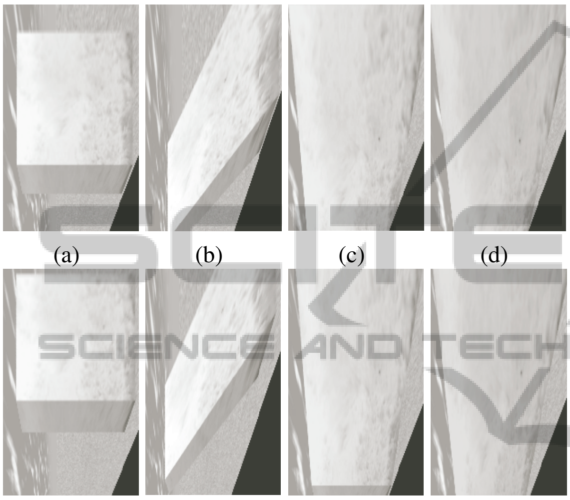
8.1 Experiments on Simulation Scenes

The accuracy of the distance to the side wall is evaluated by using simulation images. Figure 10 shows images of snow side walls created by CG software. The side wall in Fig.10 (a) is parallel to the moving direction of a vehicle and perpendicular to the road surface. The side wall in Fig.10 (b) is parallel to the moving direction of a vehicle but slant to the road surface. The side walls in Fig.10 (c) and (d) are not parallel to the moving direction of a vehicle. In Fig.10 (c), the angle between the side wall and the moving direction is 15 degree. In Fig.10 (d), the angle between the side wall and the moving direction is 30 degrees. Figure 11 shows the IPM image obtained from Fig.10. The distance to the snow side wall is estimated from the movement between the upper image and the lower image. Figure 12 shows estimation results when the distance to the side wall is $70cm$, $90cm$, $110cm$, $130cm$ or $150cm$. Figure 12 (a) shows that the proposed method can estimate the distance to the side wall correctly because a measurement value is almost equal to a true value. In Fig.12(b), a true value shows the the distance to the ground position of the side wall. Since the side wall leans outside, a measurement value is



(a) (b) (c) (d)

Figure 10: The result of a simulation scene (Input image).



(a) (b) (c) (d)

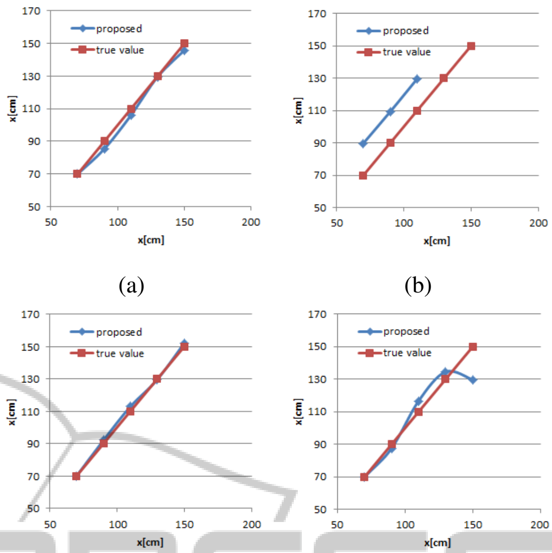
(e) (f) (g) (h)

Figure 11: The result of a simulation scene (IPM image).

slightly larger than the true value. In Fig.12(b), the measurement value of 130*cm* and 150*cm* is missing because most of the side wall is out of the IPM image. Fig.12 (c) shows the result similar to Fig.12 (a). This result shows the proposed method can estimate the distance to the side wall even if the moving direction of a vehicle is shifted about 15 degree with the side wall.

8.2 Experiments on Real Road Scenes

Experiments were conducted using images taken at a snowy road by a backup camera and a front camera. Figures 13 - 18 show results of the backup camera. In these figures, the upper image shows the input image and the lower left image shows the IPM image. The lower right graph shows the distance to the snow side wall. In this graph, a horizontal axis shows time (the number of frames) and a vertical axis shows the distance between a vehicle and the side wall. The origin is the upper left. The upper horizontal grey line shows 100*cm* distance and the lower horizontal grey line shows 200*cm* distance. Input images were captured by the same backup camera. Therefore, the



(a) (b)

(c) (d)

Figure 12: The result of a simulation scene (Accuracy of distance).

shape and the position of a rectangular region for creating the IPM image were same in Figs.13 - 18. Because in these scene, the ego-vehicle almost moves straight along a snow wall at a fixed speed, we estimated the distance to the snow side wall from the cross line between a road and a snow wall, which was manually extracted in each scene. The relation between the distance and the lower endpoint of the cross line was beforehand obtained by the calibration that was performed in advance.

The snow side walls of Figs.13, 14, 15, 16, 17 and 18 are away from a backup camera about 140*cm*, 180*cm*, 180*cm*, 180*cm*, 130*cm* and 130*cm* respectively. In the lower right graphs of Figs.13 - 18, most of the measurements show the values near these estimates. These results show that the proposed method can measure the distance to the side wall stably from the low resolution image captured by a backup camera.

Since we aim at realizing the system which determines the road situation by the distance information collected by a lot of vehicles with a backup camera, some error which occurred by the individual vehicle is not a problem. Because the average of measurement error is important, we evaluated it in two scenes where the ego vehicle moves straight along a snow wall, while keeping the distance to a snow wall at 100*cm* and 150*cm*. As a result of evaluation using the image of $1,000$ frames, the measurement error was -1.8*cm* in 100*cm* and it was 10.2*cm* in 150*cm*. This result shows that the proposed method is effective in the system which we are going to realize although the

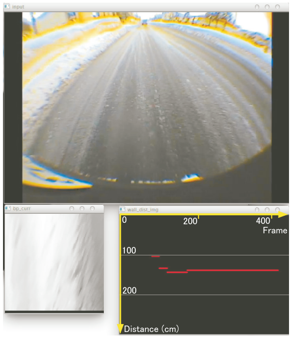


Figure 13: The result of a real road scene 1(Backup camera).

Figure 14: The result of a real road scene 2(Backup camera).

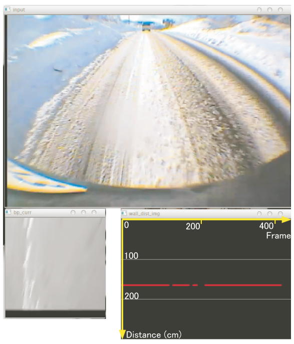


Figure 15: The result of a real road scene 3(Backup camera).

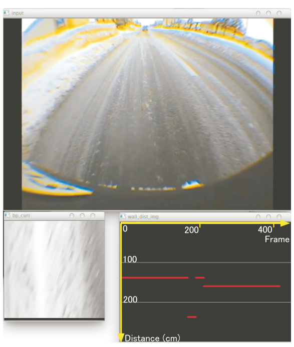


Figure 16: The result of a real road scene 4(Backup camera).

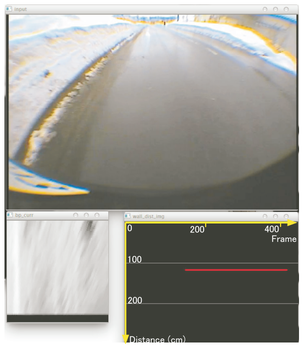


Figure 17: The result of a real road scene 5(Backup camera).

Figure 18: The result of a real road scene 6(Backup camera).

Figure 19: The result of a real road scene 1 (Front camera).

Figure 20: The result of a real road scene 2 (Front camera).

accuracy is not better than the conventional method using a standard lens or a range sensor.

Figures 19 and 20 show results of the front camera. The snow side walls in Figs. 19 and 20 are away from a front camera about 180*cm* and 50*cm*. A vehicle kept the almost same distance from the side wall. In the lower right graphs of Figs. 19 and 20, most of measurements are plotted around correct values. Since the focal length of the front camera is longer than that of the backup camera, the side wall in the IPM image of the front camera is clearer than that of the backup camera. Thus, the distance to the snow side wall can be estimated more accurately.

9 CONCLUSIONS

This paper presented the method which can measure the distance between a vehicle and the snow wall of shoulder by a single camera, especially a backup camera. Our method corresponds features in the IPM image and estimates the motion vector from the peak of the histogram whose bin is the magnitude of the optical flow. Therefore, it is robust to the change in the appearance of the feature on the side wall, which occurs when a vehicle moves along a road. Experimental results using simulation scenes and snow road scenes show the effectiveness of the proposed method.

In the future, we will evaluate the accuracy of the distance in real road scenes by comparing with the measured value of a laser sensor and develop the system which estimate passing difficulty points by integrating the distance information obtained from a lot of vehicles with GPS data. It is also a future work to measure the influence of the error included in moving distance Δy.

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