15-1

MVA2007 IAPR Conference on Machine Vision Applications, May 16-18, 2007, Tokyo, JAPAN

Free Parking Space Detection Using Optical Flow-based Euclidean 3D Reconstruction

Jae Kyu Suhr, Kwanghyuk Bae, Jaihie Kim
School of Electrical and Electronic Engineering
Yonsei University
Seoul, 120-749, South Korea
E-mail: lfisbf@yonsei.ac.kr

Ho Gi Jung
Central R&D Center
MANDO Corporation
Yongin-Si 446-901, South Korea
E-mail: hgjung@mando.com

Abstract

An automatic parking system provides convenience for drivers by automatically finding free parking spaces and steering automobiles toward them. This paper proposes a vision-based free parking space detection system. The proposed method consists of two stages. First, the automobile rearview is three-dimensionally reconstructed using the optical flow-based method. The metric information is recovered using the scale ratio between the camera heights in the real world and the reconstructed world. Second, the free parking space is detected by estimating the parking space orientation and the reference point in the top-view of the reconstructed 3D structure. Experimental results show that the proposed method successfully reconstructs the 3D structures of the automobile rearview and detects free parking spaces in the different environments.

1 Introduction

An automatic parking system provides convenience for drivers by automatically finding free parking spaces and steering automobiles toward them. Recently, the interest and need for automatic parking have been dramatically increasing [1]. There are many kinds of methods to detect free parking spaces, including the laser scanner-based method, the short range radar network-based method, and the vision-based method. However, the vision-based method is most attractive to drivers because it can depict parking procedures in a visual way. The vision-based method can be categorized into three approaches. The first approach recognizes adjacent vehicles by using the 3D structure of parking lots [2]-[3]. The second approach recognizes parking space markings [4]-[5]. The last approach recognizes both adjacent vehicles and parking space markings [6]-[7]. The proposed method is categorized in the first approach. N. Kaempchen developed a system that can locate free parking spaces by recognizing adjacent vehicles with a stereo vision-based method [2]. K. Fintzel proposed a system that recognizes adjacent vehicles three-dimensionally by using a single camera and odometry and provides a rendered image from a virtual viewpoint for better understanding of the given parking situation [3].

This paper proposes a free parking space detection method which uses the optical flow-based euclidean 3D reconstruction. The proposed method consists of two stages. One is the 3D reconstruction stage and the other is the free parking space detection stage. The 3D reconstruction stage consists of six steps. First, the feature points are tracked by the Kanade-Lucas-Tomasi feature tracker [8]. Second, the relative rotation between the two images is calculated using the fundamental matrix estimated by the MLESAC [9]. Third, the relative rotation between the two images is eliminated by de-rotating the feature points in one of two images. Fourth, the focus of expansion (FOE) is estimated using the de-rotated corresponding points. Fifth, the 3D coordinates of each corresponding point are calculated using the de-rotated optical flow and the estimated FOE. Last, the camera height from the ground plane is estimated in the three-dimensionally reconstructed world. The 3D points are rescaled using the scale ratio between the camera heights in the real world and the reconstructed world, and the 3D points that are too far from the camera are deleted.

The free parking space detection stage consists of four steps. First, the 3D points near the ground plane are deleted and all the remaining points are projected onto the ground plane. Second, the Hough transform is applied to the projected points to estimate the orientation of the parking space. Third, the reference point is detected using two 1D projections. Last, the most appropriate parking space is recognized among four candidates that are determined by the estimated orientation and the reference point. Fig. 1 shows a block diagram of the proposed method.

Experimental results show that the proposed method successfully reconstructs the 3D structures of the automobile rearview and detects free parking spaces in the different environments.

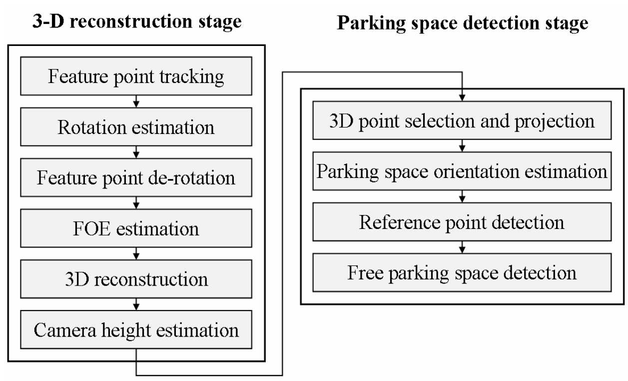


Figure 1. Block diagram of the proposed method.

2 Optical Flow-based 3D Reconstruction

2.1 Rotation estimation

Once the corresponding points are found by the Kanade-Lucas-Tomasi feature tracker [8], the fundamental matrix can be estimated by a robust estimation algorithm. In this case, the MLESAC is used [9]. The essential matrix is calculated using the fundamental matrix and the camera intrinsic parameter matrix. Finally, the rotation matrix is calculated using the singular value decomposition of the essential matrix [10].

2.2 De-rotation and FOE estimation

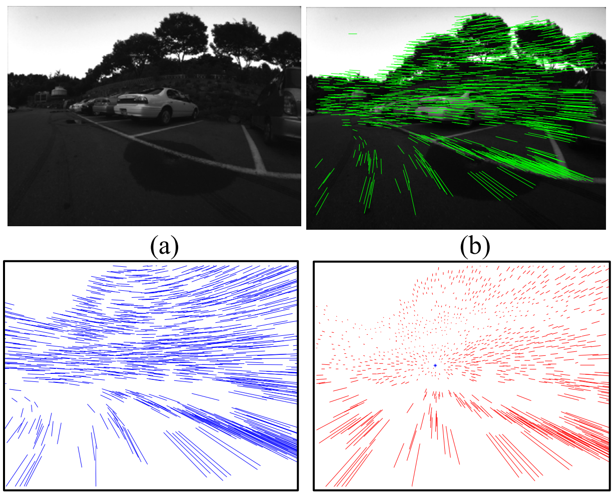
The feature points in the second image are de-rotated to make two images related with pure translation. Rotation between the corresponding points is eliminated by transforming the feature points in the second image using a homography, H defined as

$$H = KR^{-1}K^{-1} \tag{1}$$

Here, K and R are the camera intrinsic parameter matrix and the rotation matrix, respectively. The fundamental matrix, F is re-estimated using the de-rotated feature points. Two epipoles (e_1, e_2) are calculated as the null spaces of F and F^T in (2) [10].

$$Fe_1 = 0\ , \quad F^T e_2 = 0 \tag{2}$$

Because the two epipoles are the same as the FOE when the two images are related with pure translation, the FOE is estimated as the middle point of the two epipoles. Figure 2 (a) and (b) show an example image of the parking space and the optical flow of the feature points, respectively. Figure 2 (c) and (d) are the radial distortion free optical flow and the de-rotated optical flow, respectively. The FOE location is indicated by a blue dot in Figure 2 (d).



(c) (d)

Figure 2. (a) a parking space image (b) optical flow (c) radial distortion free optical flow (d) de-rotated optical flow with the FOE shown by a blue dot.

2.3 3D reconstruction

Once the feature points in the second image are de-rotated, the corresponding points are related with pure translation. If the Z-axis translation is not zero (which always happens in the automobile rearview camera), the 3D coordinates of feature points are calculated using the de-rotated optical flow and the FOE [11]. When the optical axis is the Z-axis, the motion field of pure translation is described as

$$v_x = \frac{T_z x - T_x f}{Z}, \qquad v_y = \frac{T_z y - T_y f}{Z} \tag{3}$$

v_x and v_y are the lengths of optical flow in the X-axis and the Y-axis, respectively. T_x, T_y, T_z are the X-axis, the Y-axis, and the Z-axis translations, respectively. x and y are the X-axis and the Y-axis coordinates of the image point in the camera reference frame, respectively. Z is the Z-axis coordinate of the 3D point and f is the focal length of the camera. In this case, the location of FOE (x_{foe}, y_{foe}) is defined as

$$x_{foe} = f\frac{T_x}{T_z}, \qquad y_{foe} = f\frac{T_y}{T_z} \tag{4}$$

Using (4), (3) can be rewritten as

$$v_x = (x - x_{foe})\frac{T_z}{Z}, \qquad v_y = (y - y_{foe})\frac{T_z}{Z} \tag{5}$$

According to (5), the Z-axis coordinates of the 3D point can be calculated by using one of two equations in (6) up to an unknown scale T_z.

$$Z = (x - x_{foe})\frac{T_z}{v_x}, \qquad Z = (y - y_{foe})\frac{T_z}{v_y} \tag{6}$$

For improving the 3D reconstruction accuracy, the optical flow lengths in the X-axis (v_x) and the Y-axis (v_y) are compared and the longer one is used for the Z-axis coordinate calculation. The X-axis and the Y-axis coordinates of the 3D points are calculated using (7).

$$X = Z\frac{x}{f}, \qquad Y = Z\frac{y}{f} \tag{7}$$

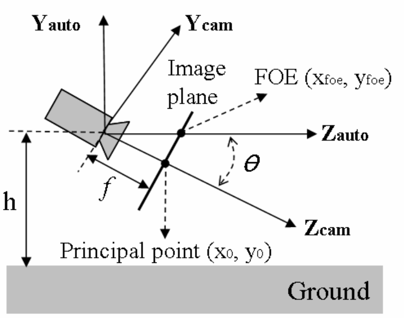


Figure 3. Camera configuration

2.4 Camera height estimation

For the euclidean 3D reconstruction, the known camera height from the ground plane is used. If it is assumed that there is only an X-axis rotation between the automobile coordinates (Y_{auto}, Z_{auto}) and the camera coordinates (Y_{cam}, Z_{cam}) as shown in Figure 3, the X-axis rotation angle θ can be estimated by (8) [12].

$$\theta = \arctan\left(\frac{y_{foe} - y_0}{f}\right) \tag{8}$$

After rotating the 3D points in the X-axis by θ, the ground plane becomes parallel to the XZ-plane of the automobile coordinates. Therefore, the ground plane in the reconstructed world is estimated using the Y-axis value histogram of the 3D points as shown in Figure 4. The peak of the Y-axis value histogram is chosen as the location of the ground plane. The metric information is recovered using the scale ratio between the camera heights in the real world and the reconstructed world. After scaling all the 3D points, the points that are too far from the camera are eliminated. Figure 5 shows the euclidean 3D reconstruction result of the parking space in centimeters.

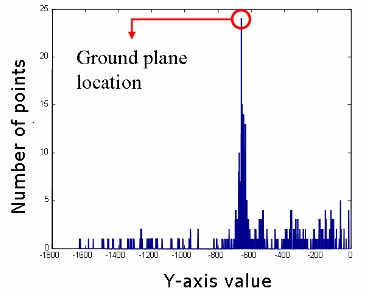
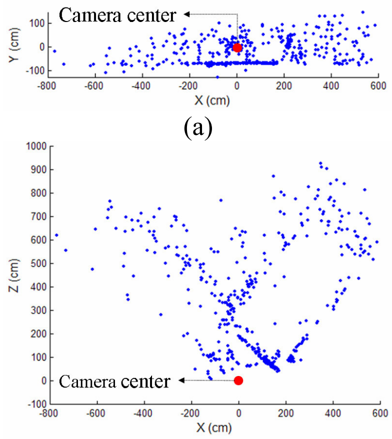


Figure 4. Y-axis value histogram of the 3D points



(a)

(b)

Figure 5. Euclidean 3D reconstruction result (a) view from the camera (b) view from the top

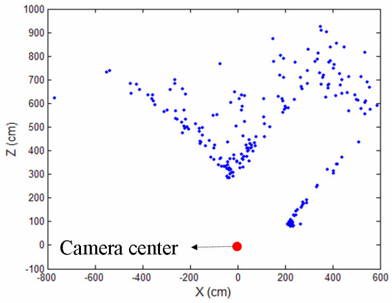


Figure 6. Top-view of the parking space after deleting the points near the ground plane

3 Parking Space Detection

3.1 3D point selection and projection

Once the ground plane location is estimated, the 3D points near the ground plane are deleted and then the remaining points are projected onto the XZ-plane. Figure 6 shows the point projection result after deleting the points near the ground plane. It can easily be seen that the 3D points on the obstacles are retained.

3.2 Parking space orientation estimation

To find a free parking space, the orientation of the parking space has to be estimated. The Hough transform is used for detecting the strongest line and the orientation of this line is considered to be the parking space orientation. This is based on the fact that the side of automobile forms a line in the top-view of the 3D structure. Figure 7 shows the result of the line detection.

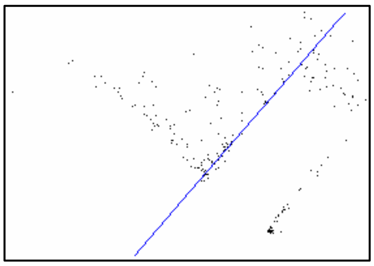
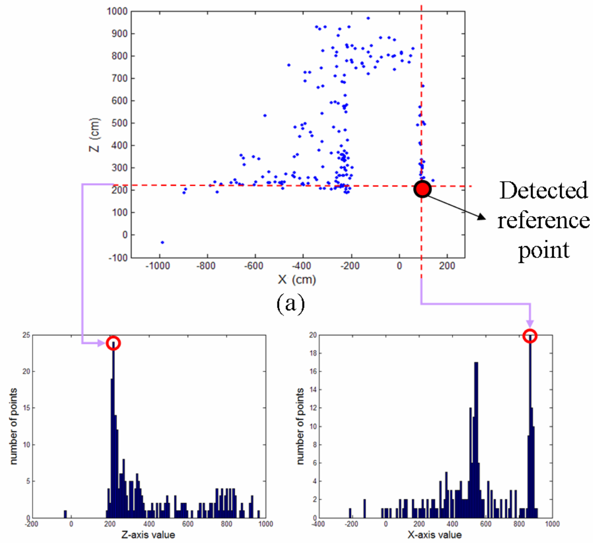


Figure 7. Parking space orientation estimation result

3.3 Reference point detection

After estimating the orientation, the projected points are rotated according to the parking space orientation. The reference point that is considered to be the corner of a free parking space is detected by using vertical and horizontal projections of the rotated points. The largest peaks in the vertical and the horizontal projection results are searched to estimate the Z-axis and the X-axis coordinates of the reference point. Figure 8 (a) shows the rotated points and the detected reference point. Figure 8 (b) and (c) show the vertical and the horizontal projections which are used to detect the reference point.



(b) (c)

Figure 8. (a) Rotated points and the detected reference point (b) vertical projection (c) horizontal projection

3.4 Parking space detection

Once the reference point is detected, there are four candidates for a free parking space as shown in Figure 9. In this figure, the only upper left rectangle is recognized as the most appropriate parking space because the upper right rectangle includes an occluded region and the lower right and the lower left rectangles are located behind the camera. Figure 10 shows the final result of free parking space detection. In this figure, the size of the rectangle is 190cm×480cm.

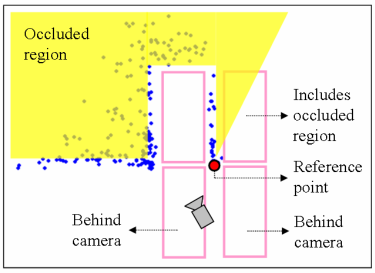


Figure 9. Candidates of free parking space

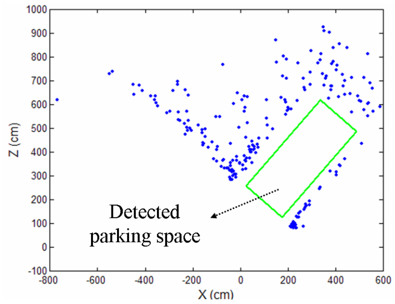


Figure 10. Final parking space detection result

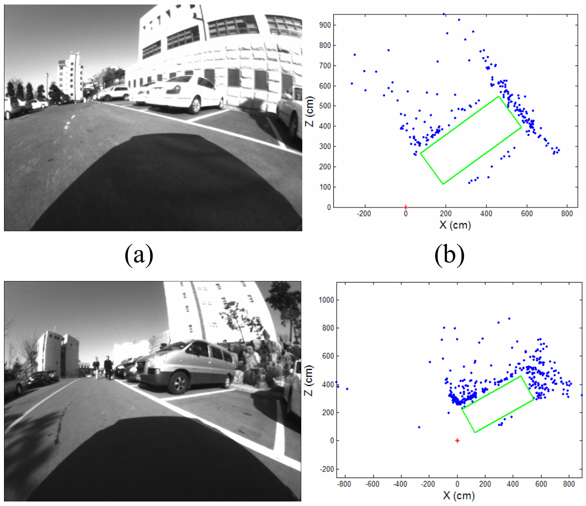
4 Experimental Results and Conclusions

The proposed method is tested in 22 different outdoor parking sequences which include buildings, trees, stones, shadows, moving people, sloping road, or standing water. Three of them are shown in Figure 2 (a), Figure 11 (a) and (c). This method succeeds in 20 sequences and fails in 2 sequences. These failures are caused by mainly two reasons. First, the sun is strongly reflected on the surface of automobile so that the feature tracking is failed. Second, the road is not flat so that the ground plane is erroneously estimated.

The proposed method reconstructs the automobile rearview using the optical flow-based 3D reconstruction. The metric information is recovered using the scale ratio between the camera heights in the real world and the reconstructed world. The free parking spaces are detected using the top-view of the reconstructed structures. In future works, we plan to improve the camera height estimation method and the free parking space detection method because the metric information and the free parking space location have to be very accurate for parking safety.

Acknowledgments

This work was supported by the Korea Science and Engineering Foundation (KOSEF) through the Biometrics Engineering Research Center (BERC) at Yonsei University.



(a) (b)

(c) (d)

Figure 11. Two other experimental results
(a), (c) parking space images. (b), (d) parking space detection results

References

[1] R. Bishop: Intelligent Vehicle Technology and Trends, *Artech House Pub*, 2005.

[2] N. Kaempchen, et al.: Stereo Vision Based Estimation of Parking Lots Using 3D Vehicle Models, *IEEE Intell. Veh. Symp.*, vol.2, pp.459-464, 2002.

[3] C. Vestri, et al.: 3D Parking Assistant System, *IEEE Intell. Veh. Symp.*, pp.881-886, 2004

[4] J. Xu, et al.: Vision-Guided Automatic Parking for Smart Car, *IEEE Intell. Veh. Symp.*, pp.725-730, 2000

[5] H. G. Jung, et al.: Parking Slot Markings Recognition for Automatic Parking Assist System, *IEEE Intell. Veh. Symp.*, pp.106~113, 2006.

[6] H. G. Jung, et al.: Stereo Vision Based Localization of Free Parking Site, *Computer Analysis of Images and Patterns (LNCS)* vol.3691, pp.231-239, 2005.

[7] H. G. Jung, et al.: 3D vision system for the recognition of free parking site location, *International Journal of Automotive Technology*, vol.7 no.3, pp.351-357, 2006.

[8] B. D. Lucas, et al.: An iterative image registration technique with an application to stereo vision. *In Proc. Int. Joint Conf. on Artificial Intelligence*, pp.674-679, 1981.

[9] P. H. S. Torr, et al.: MLESAC: A new robust estimator with application to estimating image geometry, *Comp.Vision and Imag. Underst*, vol.78, pp.138− 156, 2000.

[10] R. Hartley, et al.: Multiple View Geometry in Computer Vision, *Cambridge University Press*, 2000.

[11] E. Trucco, et al.: Introductory Techniques for 3-D Computer Vision, *Prentice Hall*, 1998.

[12] W. Burger, et al.: Estimating 3-D egomotion from perspective image sequences", *IEEE Trans. on Patt. Anal. and Mach. Intell.*, vol.12, no.11, pp.1040-1058, 1990