Stereo Vision Based Localization of Free Parking Site

Ho Gi Jung[1], Dong Suk Kim[1], Pal Joo Yoon[1], and Jai Hie Kim[2]

[1] MANDO Corporation Central R&D Center, Advanced Electronic System Team, 413-5, Gomae-Ri, Giheung-Eub, Yongin-Si, Kyonggi-Do 449-901, South Korea
{hgjung, greenhupa, pjyoon}@mando.com
http://www.mando.com/eng/main.asp

[2] Yonsei University, Department of Electrical and Electronic Engineering, 134, Sinchon-Dong, Seodaemun-Gu, Seoul 120-749, South Korea
jhkim@yonsei.ac.kr
http://cherup.yonsei.ac.kr

Abstract. This paper describes a novel stereo vision based localization of free parking site, which recognizes the target position of automatic parking system. Pixel structure classification and feature based stereo matching extracts the 3D information of parking site in real time. Parking site marking is separated by plane surface constraint and is transformed into bird's eye view, on which template matching is performed to determine the location of parking site. Obstacle depth map, which is generated from the disparity of adjacent vehicles, can be used as the guideline of the template matching by limiting search range and orientation. Proposed method using both the obstacle depth map and the bird's eye view of parking site marking increases operation speed and robustness to visual noise by effectively limiting the search range.

1 Introduction

Generally novice, female and old driver feels constraint in parking backward between vehicles. J. D. Power's 2001 Emerging Technology Study, which found that 66% of consumers were likely to purchase parking aid, is a good proof [1]. Many upper class cars adopt ultrasonic parking assist system, which warns the driver of close distance to obstacle. Recently, car and component manufacturers started to provide vision based parking assist system. Toyota and Aisin Seiki introduced Back Guide Monitor, which helps the driver by projecting predicted driving course on the image of a rear view camera [2,3]. Aisin Seiki's next generation is expected to include circumstance recognition function to provide an optimistic view to the driver [4]. They use wheel speed sensor, structure from motion technology and virtual camera, i.e. IVR (Intermediate View Reconstruction) technology, to make a virtual rendered image from an optimistic viewpoint.

Automatic parking system automates parking operation with automatic steering control and automatic braking control. Automatic parking system consists of three components : path planning including the localization of target position, automatic steering and braking system used to implement the planned trajectory, HMI (Human

A. Gagalowicz and W. Philips (Eds.): CAIP 2005, LNCS 3691, pp. 231 – 239, 2005.

Machine Interface) used to receive driver's input and provide the visual information of ongoing parking process. The localization of target position can be implemented by various methods, e.g. fully manual designation [2], GPS infrastructure [5] and the vision based localization of free parking site [6,7]. Toyota's IPA (Intelligent Parking Assist) is a semiautomatic parking system, which leaves the braking control as driver's responsibility. Toyota's IPA developed the localization of target position by HMI, which shows a potential target position on the image from rear view camera and enables the driver to change the target position with direction control buttons such as up, down, left, right and rotation [2].

Although semiautomatic parking system becomes commercialized, fully manual designation is too tedious and complicated for daily usage. Therefore, it is natural that the need of the vision based localization of free parking site is increasing rapidly. Nico Kaempchen developed a stereo vision based pose estimation of parking lots, which uses feature based stereo algorithm, template matching algorithm on a depth map and 3D fitting to the planar surface model of vehicle by ICP (Iterative Closest Point) algorithm [6]. The vision system uses the disparity of vehicles but ignores all the information of parking site marking. Jin Xu developed a color vision based localization of parking site marking, which uses color segmentation based on RCE neural network, contour extraction based on least square method and inverse perspective transformation [7]. Because the system depends only on parking site marking, it can be degraded by poor visual conditions such as stain on marking, shadow and occlusion by adjacent vehicles.

This paper proposes a novel vision system to localize free parking site for automatic parking system. Proposed method is based on feature based stereo matching and separates parking site marking by plane surface constraint. The location of parking site is determined by template matching on the bird's eye view of parking site marking, which is generated by inverse perspective transformation on the separated parking site marking. Obstacle depth map, which is generated by the disparity information of adjacent vehicles, can be used to narrow the search range of parking site center and the orientation. Because the template matching is fulfilled within the limited range, the speed of searching effectively increases and the result of searching is robust to noise including previously mentioned poor visual conditions. Using both obstacle depth map and parking site marking can be justified because typical parking site in urban area is constructed by nation-wide standards.

2 Stereo Vision System

2.1 Pixel Classification

In the case of automotive vision, it is known that vertical edges are sufficient to detect noticeable objects [9]. Consequently, stereo matching using only vertical edges drastically reduces computational load [10,11]. Pixel classification investigates the intensity differences between a pixel and 4 directly connected neighbors so as to assign the pixel a class reflecting the intensity configuration. It is known that the feature based stereo matching with pixel class is fast and robust to noise [11]. Equation (1) shows that a pixel of smooth surface will be classified as zero class and a pixel of edge will be classified as non-zero class. To reduce the effect of threshold T, histogram equalization or adaptive threshold can be used.

	0	
3	x	1
	2	

$$d(i)=\begin{cases}1, \text{ if } g(i)-g(x)> +T\\ 2, \text{ if } g(i)-g(x)< -T\\ 0, \text{ else}\end{cases}$$

d(3)	d(2)	d(1)	d(0)

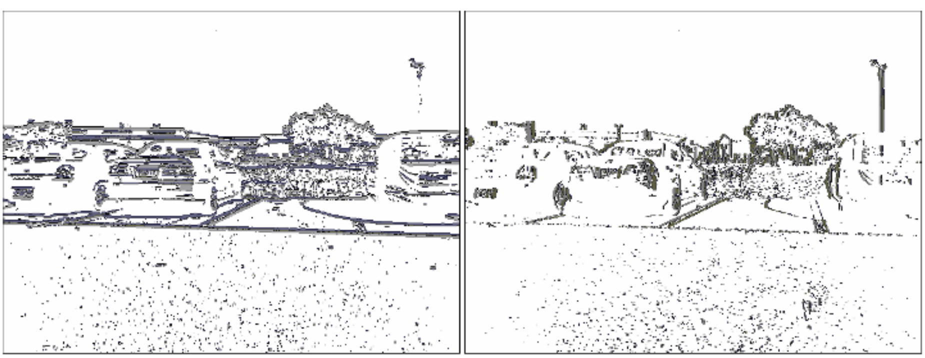
(1)

4 neighbors g(.) : grey value pixel class

(a) left image (b) right image

Fig. 1. Stereo image of typical parking site. Parking site marking is drawn according to corresponding standards. Some portion of parking site marking is occluded by adjacent vehicle and trash. Some portion of parking site marking is invisible because of shadow.

Fig.1 is the stereo image of typical parking site, which is acquired with Point Grey Research's Bumblebee camera installed on the backend of test vehicle. Each image has 640x480 resolution and 24 bits color information. The images are rectified with



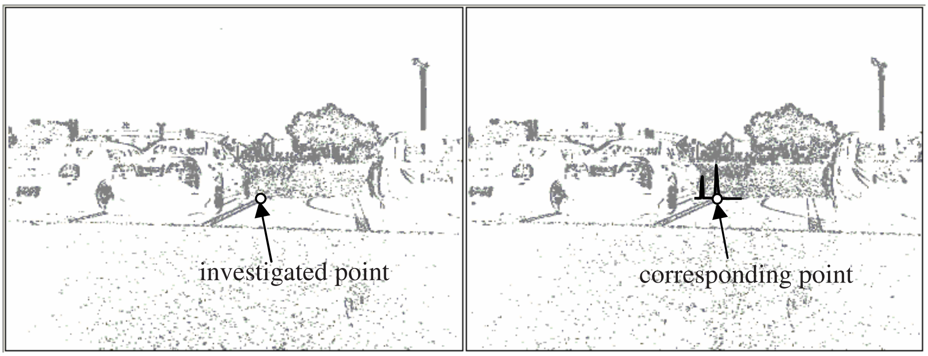
(a) pixels classified as horizontal edge (b) pixels classified as vertical edge

Fig. 2. Pixel classification result

Point Grey Research's Triclops rectification library [8]. Fig.2 shows the result of the pixel classification. 13.7% of total pixels are classified as horizontal edge and 7.8% are classified as vertical edge.

2.2 Feature Based Stereo Matching

Stereo matching is performed only on pixels classified as vertical edge. Furthermore, stereo matching is composed of step-by-step test sequences through class comparison, class similarity, color similarity and maximum similarity detection. Only correspondence candidates passing previous test step successfully will be investigated in the next test step.



(a) left image (b) right image

Fig. 3. Stereo matching result of a pixel. Graph on the right image shows the total similarity of pixels within search range. A pixel with highest total similarity becomes corresponding point.

Assuming that the vertical alignment of Bumblebee is correct, the search range of a pixel is limited to a horizontal line with –35 ~ 35 displacement. First, correspondence test is performed on pixels with the same class as the investigated pixel. Class similarity is the measure of how the candidate pixel is similar to the investigated pixel in the sense of 3x3 class window. Color similarity is the measure of how the candidate pixel is similar to the investigated pixel in the sense of 5x5 color window. Total similarity is the product of the class similarity and the color similarity. If highest total similarity is lower than a certain threshold, the investigated pixel fails to find corresponding point and is ignored.

$$\begin{aligned} &\mathrm{ClassSimilarity}(x,y,s) = \frac{1}{3x3}\sum_{u=-1}^{1}\sum_{v=-1}^{1} f(\mathrm{Class}_{left}(x+u,y+v),\mathrm{Class}_{right}(x+u+s,y+v)) \\ &\text{where} \quad f(\mathrm{Class}_{left},\mathrm{Class}_{right}) = \begin{cases} 0, & \mathrm{Class}_{left} \neq \mathrm{Class}_{right} \\ 1, & \mathrm{Class}_{left} = \mathrm{Class}_{right} \end{cases} \end{aligned} \tag{2}$$

$$\text{ColorSimilarity}(x,y,s) = 1 - \frac{1}{256}\sqrt{\frac{\text{ColorSSD}(x,y,s)}{5x5}}$$

$$\text{where ColorSSD}(x,y,s)=\sum_{u=-2}^{2}\sum_{v=-2}^{2}\begin{Bmatrix}(R_{left}(x+u,y+v)-R_{right}(x+u+s,y+v))^2+\\(G_{left}(x+u,y+v)-G_{right}(x+u+s,y+v))^2+\\(B_{left}(x+u,y+v)-B_{right}(x+u+s,y+v))^2\end{Bmatrix} \quad (3)$$

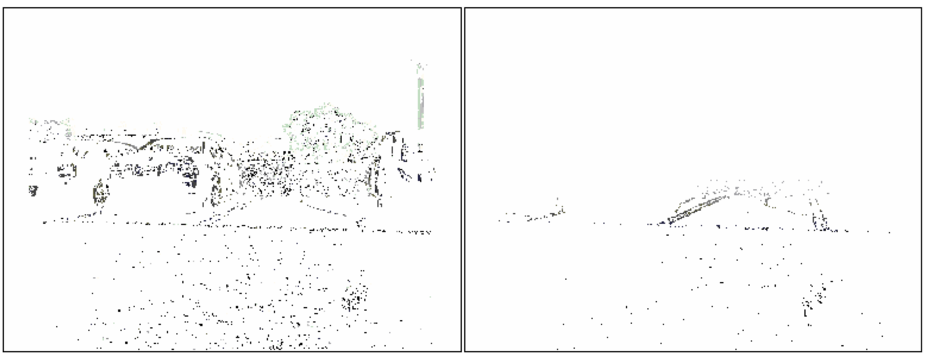
$$\text{Similarity}(x,y,s)=\text{ClassSimilarity}(x,y,s) \times \text{ColorSimilarity}(x,y,s) \quad (4)$$

2.3 Road / Object Separation

Generally, pixels on the road surface satisfy plane surface constraint, i.e. the y coordinate of a pixel is in linear relationship with the disparity of the pixel, d(x,y), like equation (5) [11]. Consecutively, the pixels of obstacles, e.g. adjacent vehicles, do not follow the constraint. Therefore, the disparity map which is the result of stereo matching can be separated into two disparity maps : the disparity map of parking site marking and the disparity map of obstacle.

$$d(x,y)=\frac{B}{H}f_x\left(\frac{y}{f_y}\cos\alpha+\sin\alpha\right), \text{ with } y \rangle f_y \tan\alpha \quad (5)$$

where B : baseline, H : Height, f_x, f_y : focal length, α : tilt angle



(a) disparity map of obstacle (b) disparity map of parking site marking

Fig. 4. Road / Object separation result

The distance between camera and object, Z_{world}, is inverse proportional to the disparity like equation (6-1). Previously mentioned plane surface constraint can be simplified like equation (6-2). P_1 and P_2 is the constant parameter of camera configuration. Consequently, the relationship between the y coordinate of a pixel on road surface and Z_{world} can be summarized like equation (6-3), (6-4). The relationship between X_{world} and the x coordinate of a pixel can be defined like (6-5) by triangulation. Using the relationship, the disparity map of parking site marking is transformed into the bird's eye view of parking site marking. The bird's eye view is constructed by copying values from the disparity map to the ROI (Region Of Interest) of X_{world} and Z_{world}. Pixels with different color from parking site marking are ignored to remove the noise of textures such as asphalt and grass.

$$z_{world} = \frac{B \cdot f}{d(x,y)} \tag{6-1}$$

$$d(x,y) = P_1 y + P_2 \text{, where } P_1 = \frac{B}{H}\frac{f_x}{f_y}\cos\alpha \text{ , } P_2 = \frac{B}{H}\frac{f_x}{f_y}\sin\alpha \tag{6-2}$$

$$z_{world} = \frac{B \cdot f}{P_1 \cdot y + P_2} \tag{6-3}$$

$$y = \frac{1}{P_1}\left(\frac{B \cdot f}{z_{world}} - P_2\right) \tag{6-4}$$

$$X_{world} : Z_{world} = x : f \quad \Rightarrow \quad x = \frac{f \cdot X_{world}}{Z_{world}} \tag{6-5}$$

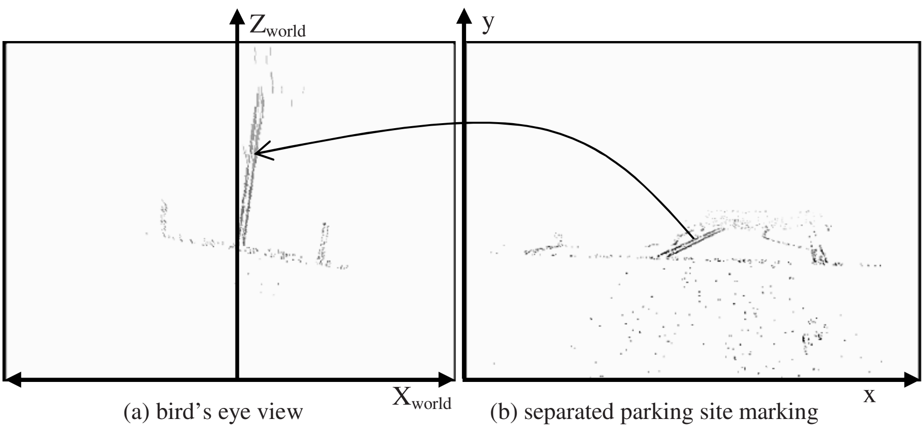
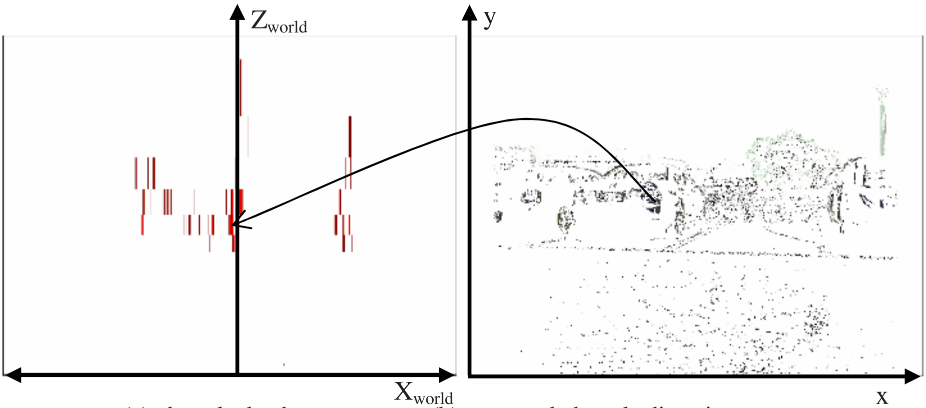


Fig. 5. Bird's eye view of parking site marking

Obstacle depth map is constructed by projecting the disparity information of pixels unsatisfying the plane surface constraint. World coordinate point (X_{world}, Z_{world}) corresponding to a pixel in the obstacle disparity map can be determined by equation (6-1) and (6-5) [10]. Because the stereo matching does not implement sub-pixel resolution for real time performance, a pixel in the disparity map contributes to a vertical array in the depth map. The element of depth map accumulates the contributions of corresponding disparity map pixels. By eliminating the elements of depth map under a certain threshold, noise on the disparity map can be removed. In general, the noise of the disparity map does not make a peak on the depth map.

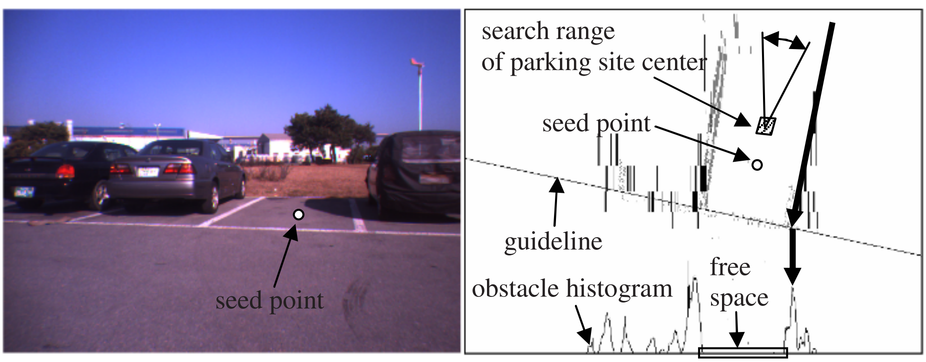


(a) obstacle depth map (b) separated obstacle disparity map

Fig. 6. Obstacle depth map

3 Localization of Parking Site

Free parking site is localized using both the depth map of obstacle and the bird's eye view of parking site marking. Localization algorithm consists of 3 steps : 1) finding the guideline, which is the front line of parking area, by the Hough transform of the bird's eye view of parking site marking, 2) obstacle histogram which is generated by projecting the obstacle depth map onto the guideline, 3) template matching within the search range limited by the obstacle histogram.

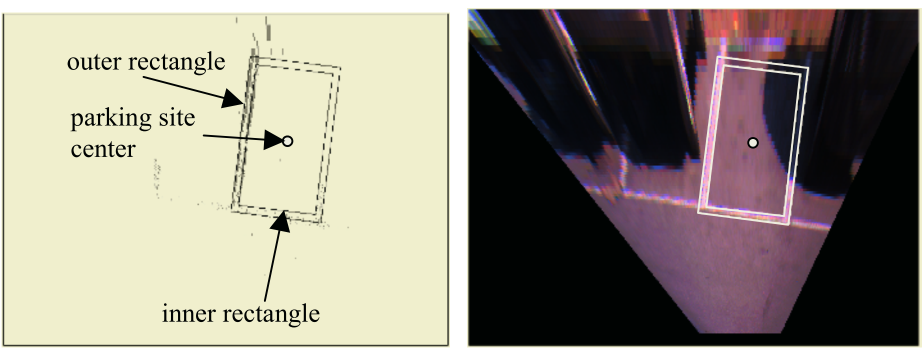


(a) seed point for localization (b) guideline and obstacle histogram

Fig. 7. Search range reduction by guideline and obstacle histogram. HMI displays the image of rear view camera during parking process and user can set target position by clicking on touch screen. User's input is seed point and is used to restrict initial search range.

The pose of ego-vehicle is limited to –40~40 degrees with respect to the longitudinal direction of parking area. Therefore, the peak of Hough transform in this angular range is the guideline depicted in Fig. 7(b). Free space is the continuous portion of the obstacle histogram under a certain threshold and is determined by bi-directional search from the seed point. The search range of parking site center in the guideline direction is central 20% of the free space. The initial guess of parking site center in another direction, i.e. orthogonal to the guideline direction, is the position distant from the guideline by the half size of template length. Search range in the orthogonal direction is 10 pixels and angular search range is 10 degrees.

Final template matching uses a template consisting of 2 rectangles derived from standards about parking site drawing. The template matching measures how many pixels of parking site marking exist between 2 rectangles, i.e. between inner and outer rectangle. Fig. 8(a) shows the result on the bird's eye view of parking site marking and Fig. 8(b) projects the result on the bird's eye view of input image. Because the search range is narrowed by the obstacle depth map, template matching successfully detects correct position in spite of stain, blurring and shadow. Furthermore, template matching, which is the bottleneck of localization process, consumes little time. Total computational time on 1GHz PC is about 400~500 msec. Once the initial position is detected successfully, the next scene needs only template matching with little variation around the previous result.



(a) result on parking site marking (b) result on input image

Fig. 8. Detected parking site

4 Conclusion

This paper proposes a stereo vision based 3D localization of the target position of automatic parking system. Obstacle depth map establishes the search range of free parking site and simple template matching finds the exact location of free parking site. By using both parking site marking and obstacle depth map, the search range of template matching is drastically reduced and the result is robust to noise such as stain, waste and shadow. Hereafter, to make practical system, research on the variation of parking site marking is needed.

References

1. Randy Frank : Sensing in the ultimately safe vehicle. SAE Paper No. : 2004-21-0055, Society of Automotive Engineers (2004)
2. Masayuki Furutani : Obstacle detection systems for vehicle safety. SAE Paper No. : 2004-21-0057, Society of Automotive Engineers (2004)
3. Shoji Hiramatsu, etc. : Rearview Camera based parking assist system with voice guidance. SAE Paper No. : 2002-01-0759, Society of Automotive Engineers (2002)
4. K. Fintzel, etc. : 3D vision system for vehicles. In : Proceedings of IEEE Intelligent Vehicle Symposium 2003 (2003) 174-179
5. Massaki Wada, etc. : Development of advanced parking assistance system. IEEE Transaction on Industrial Electronics, Volume 50, No. 1, February 2003 (2003) 4-17
6. Nico Kaempchen, etc. : Stereo vision based pose estimation of parking lots using 3D vehicle models. In : Proceedings of IEEE Intelligent Vehicle Symposium 2002 (2002) 459-464
7. Jin Xu, Guang Chen, Ming Xie : Vision-guided automatic parking for smart car. In : Proceedings of IEEE Intelligent Vehicle Symposium 2000 (2000) 725-730
8. Point Grey Research http://www.ptgrey.com
9. Dariu M. Gavrila, etc. : Real-time vision for intelligent vehicles. IEEE Instrumentation & Measurement Magazine, Volume 4, Issue 2, June 2001 (2001) 22-27
10. U. Franke, A. Joos : Real-time stereo vision for urban traffic scene understanding. In : Proceedings of IEEE Intelligent Vehicle Symposium 2000 (2000) 273-278
11. U. Franke, I. Kutzbach : Fast stereo based object detection for stop&go traffic. In : Proceedings of IEEE Intelligent Vehicle Symposium 1996 (1996) 339-344