Stereo Vision Based Parking Assist System

Chi Gun Choi, Dong Suk Kim, Ho Gi Jung and Pal Joo Yoon
Mando Corporation

Reprinted From: Intelligent Vehicles & Transportation Systems
(SP-2027)
ABSTRACT
This paper presents semi-automatic parking assist system, which performs stereo vision based recognition of free parking site and parking guidance with automated steering operation. Pixel structure classification and feature based stereo matching extracts the 3D information of parking site. 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 vehicle can be used as the guideline of template matching by limiting the search range and the orientation. Proposed method using both the obstacle depth map and the bird’s eye view of parking site marking increases the operation speed and the robustness to visual noise by effectively limiting the search range. Using this map information, geometrical relation is tested and efficient parking path is generated. Desired steering angle data correspondent with wheel travel is transmitted to electric power steering via serial communication. This system was implemented on real passenger car and tested in practical parking situation.

INTRODUCTION
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 Machine Interface) used to receive the 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]. Otherwise, semi-automatic parking system leaves the braking control as the driver’s responsibility. For example, Toyota’s IPA (Intelligent Parking Assist) localize the target position by HMI, which shows a potential target position on the image of a 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].

For the next stage, the need of the vision based localization of free parking site is increasing rapidly. Nico Kaempchen developed 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]. This vision system uses the disparity of vehicles but ignores all the information of parking site marking. Jin Xu developed 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 semi-automatic parking. 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 the 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. Because the template matching is fulfilled within a limited range, the speed of searching effectively increases and the result of searching is robust to the 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. After localizing the position of the free parking site, parking controller test the parking capable condition using obstacle location and vehicle dimension data. If parking is possible, adequate parking path is generated and guided with automated steering operation.

SYSTEM CONFIGURATION
Figure 1 shows the configuration of semi-automatic parking system used for the experiments. R-EPS (Rack
type Electric Power Steering) is used as an active steering actuator, which controls steering angle by command of parking controller.

![System Configuration Diagram](image)

Figure 1. System Configuration

Stereo vision camera is off-the-shelf product and installed at the back-end of test car like figure 2(a). Driver interface, i.e. HMI, is implemented with touch screen monitor like figure 2(b). Through the driver interface, system informs the progress of ongoing parking operation and shows the backward view.

![Camera Installation and HMI](image)

Figure 2. Test vehicle

Parking controller receives signals of stereo camera and touch screen monitor. And steering command is transmitted to R-EPS ECU (Electronic Control Unit) via CAN serial link. In semi-automatic parking system, ultimate responsibility remains to driver. Driver must pay attention to surrounding situation and controls the parking operation by manual brake handling. Therefore, semi-automatic parking system is different from full automatic parking system not only in the viewpoint of automatic braking but also in the viewpoint of surrounding monitoring.

### STEREO VISION SYSTEM

Figure 3 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. In Figure 3, it is observed that some portion of parking site marking is occluded by adjacent vehicle and trash. Some portion of parking site marking is invisible because of shadow.

![Stereo Image](image)

Figure 3. Stereo image

### PIXEL CLASSIFICATION

<table>
<thead>
<tr>
<th>Pixel Class</th>
<th>d(3)</th>
<th>d(2)</th>
<th>d(1)</th>
<th>d(0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 X 1</td>
<td>1, if g(i)-g(x)&gt; +T</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2, if g(i)-g(x)&lt; -T L</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0, else</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ g(.) : \text{grey value} \]

In the case of automotive vision, it is known that vertical edges are sufficient to detect noticeable objects [9]. Consequently, stereo matching using only the vertical edges drastically reduces the 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. Figure 4 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.

![Pixel Classification Result](image)

Figure 4. Pixel classification result
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 the previous test step will be investigated in the next test step.

\[
\text{ColorSimilarity}(x, y, s) = 1 - \frac{1}{256} \sqrt{\frac{\text{ColorSSD}(x, y, s)}{5 \times 5}} \tag{3}
\]

where \( \text{ColorSSD}(x, y, s) = \sum_{u=1}^{3} \sum_{v=1}^{3} \left( \frac{R_{\text{left}}(x+u, y+v) - R_{\text{right}}(x+u+s, y+v)}{R_{\text{left}}(x+u, y+v) + R_{\text{right}}(x+u+s, y+v)} \right)^2 + \left( \frac{G_{\text{left}}(x+u, y+v) - G_{\text{right}}(x+u+s, y+v)}{G_{\text{left}}(x+u, y+v) + G_{\text{right}}(x+u+s, y+v)} \right)^2 + \left( \frac{B_{\text{left}}(x+u, y+v) - B_{\text{right}}(x+u+s, y+v)}{B_{\text{left}}(x+u, y+v) + B_{\text{right}}(x+u+s, y+v)} \right)^2 \]

\[
\text{Similarity}(x, y, s) = \text{ClassSimilarity}(x, y, s) \times \text{ColorSimilarity}(x, y, s) \tag{4}
\]

Class similarity defined by equation (2) is the measure of how the candidate pixel is similar to the investigated pixel in the sense of 3x3 class window. Color similarity defined by equation (3) is the measure of how the candidate pixel is similar to the investigated pixel in the sense of 5x5 color window. Total similarity defined by equation (4) 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. Figure 5 shows the stereo matching result of a pixel. Graph on right image is the total similarity of pixels within search range. The pixel with highest total similarity is corresponding point.

ROAD / OBJECT SEPARATION

Generally, pixels on the road surface satisfy the 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) \[d(x, y) = \frac{B}{H} f_\gamma (\frac{y}{f_\gamma} \cos \alpha + \sin \alpha), \quad \text{with} \ y \ f_\gamma \ tan \alpha \tag{5}\]

where B : baseline, H : Height,

\( f_x, f_y \) : focal length, \( \alpha \) : tilt angle

Class similarity defined by equation (2) is the measure of how the candidate pixel is similar to the investigated pixel in the sense of 3x3 class window.
\[ z_{\text{world}} = \frac{B \cdot f}{d(x,y)} \]  
\( d(x,y) = P_1 y + P_2 \) \( L \) \( (6-1) \)

where \( P_1 = \frac{B \cdot f}{H y} \cos \alpha, P_2 = \frac{B \cdot f}{H y} \sin \alpha \)

\[ z_{\text{world}} = \frac{B \cdot f}{P_1 y + P_2} \] \( (6-3) \)

\[ y = \frac{1}{P_1} \left( \frac{B \cdot f}{z_{\text{world}}} - P_2 \right) \] \( L \) \( (6-4) \)

\[ X_{\text{world}} \cdot Z_{\text{world}} = x : f \quad \Rightarrow \quad x = \frac{f \cdot X_{\text{world}}}{Z_{\text{world}}} \] \( L \) \( (6-5) \)

The distance between camera and object, \( Z_{\text{world}} \), 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 \( Z_{\text{world}} \) can be summarized like equation (6-3), (6-4). The relationship between \( X_{\text{world}} \) 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 \( X_{\text{world}} \) and \( Z_{\text{world}} \). Pixels with different color from parking site marking are ignored to remove the noise of textures such as asphalt and grass. Obstacle depth map is constructed by projecting the disparity information of pixels unsatisfying the plane surface constraint. World coordinate point \( (X_{\text{world}}, Z_{\text{world}}) \) 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.

Figure 7. Bird’s eye view of parking site marking

Figure 8. Obstacle Depth Map

**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: finding guideline, obstacle histogram and template matching.

Guideline, which is the front line of parking area, is found by the Hough transform of the bird’s eye view of parking
site marking. 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 as depicted in figure 9.

Obstacle histogram determines the free range of the guideline. Adjacent vehicles are expected to be located in the direction orthogonal to the guideline because parking area is divided in such a way. Therefore, accumulating the occurrence of meaningful depth map points in that direction can separate occupied parking site from free parking site. Obstacle histogram is implemented as an integer array having the same size as the length of guideline. Inner product between the guideline vector and the meaningful depth map point vector produces a scalar value, which is used as the index of histogram array. Then, array element designated by the index increases. Figure 10 shows the resultant obstacle histogram. It can be observed that free parking site has very low value in the obstacle histogram.

Free space is the continuous portion of the obstacle histogram under a certain threshold and is determined by bidirectional 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 guideline direction, is the position distant from the guideline by the half size of template length. The search range in the orthogonal direction is 10 pixels and the angular search range is 10 degrees.

If one of aside parking sites is not occupied, free space will be too long compared with the width of parking site template. In this case, free space is modified to a range having the same length as the width of parking site template from the detected obstacle.

Final template matching uses a template consisting of 2 rectangles derived from the 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. Figure 12(a) shows the result on the bird’s eye view of parking site marking and figure 12(b) projects the result on input image. Because the search range is narrowed by the obstacle depth map, template matching successfully detects the 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 100~200 msec. Once the initial position is detected successfully, the next scene needs only template matching with little variation around the previous result.
It is assumed that the reference point of the vehicle movement is located on the rear axle. Proposed semi-automatic parking assist system can be implemented both perpendicular (or garage) parking and parallel (or street) parking situation. But parking site marking is more common in perpendicular parking situation. So test of this paper was mainly executed on perpendicular parking site. For the perpendicular parking case, parking path generator allows –90 to 90 degree range approach angle to the parking site. But camera angle of present system is not so wide that test was available in the range of –40 to 40 degree of approach angle. When human driver do parking, if steering angle is insufficient to park, usually the driver stops the vehicle and move forward a little and try another turn. But this semi-automatic parking assist system does not consider the multi turn parking trial situation yet. So parking capability condition was tested before guidance. If generation of the parking path is successful, it is converted from Cartesian coordination to vehicle travel – steering angle space for steering control.

### Table 1. Test vehicle dimension

<table>
<thead>
<tr>
<th>Item</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheelbase</td>
<td>2.76m</td>
</tr>
<tr>
<td>Track</td>
<td>1.64m</td>
</tr>
<tr>
<td>Vehicle Length</td>
<td>4.75m</td>
</tr>
<tr>
<td>Vehicle Width</td>
<td>1.80m</td>
</tr>
<tr>
<td>Rear Overhang</td>
<td>1.05m</td>
</tr>
<tr>
<td>Minimum Turning Radius</td>
<td>5.12m</td>
</tr>
</tbody>
</table>

**VEHICLE GUIDANCE SYSTEM**

**PARKING PATH GENERATION**

After recognition of the position of free parking space, parking controller generates parking path for semi-automatic guidance. To make vehicle model, vehicle data was used such as wheelbase, track, length, overhang and maximum steering angle. The vehicle model is popular Ackerman (or bicycle) model, assuming that no slip of wheels occurred due to low speed.

**EXPERIMENTS**

To evaluate the feasibility and the performance of the semi-automatic parking system, test vehicle was built on a mid-size sedan. Experiment was executed for the perpendicular parking case on a plane surface. Deviation from target parking point to semi-automatic parking guidance end point was measured repeatedly in various parking conditions. The result direction error is also
measured for each test case. As a result, the average of deviation is about 20cm and the standard deviation is about 5cm. The average deviation of the orientation is about 1.0 degree.

<table>
<thead>
<tr>
<th>Parking Site Dimension</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Width</td>
<td>2.30m</td>
</tr>
<tr>
<td>Depth</td>
<td>5.00m</td>
</tr>
<tr>
<td>Deviation from Target Point</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>19.49cm</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>5.99cm</td>
</tr>
<tr>
<td>Deviation of Orientation</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>1.0 degree</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.4 degree</td>
</tr>
</tbody>
</table>

When the deviation occurs in depth direction of parking lot, the value of 20cm is negligible. But if it occurs in width direction of parking lot, it may cause a collision to adjacent vehicle or uncomfortable feeling to driver. Just 1 degree of deviation angle is small value. But it also make uncomfortable feeling to some drivers.

When 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. In reference of map information, parking path is generated and delivered to steering actuator via serial link. Automated steering guidance helps the driver to park the vehicle easily. From the perpendicular parking experiment, the performance of the system was studied. It is known that the need of more accurate recognition and guidance, especially angular and lateral direction.

REFERENCES


CONCLUSION

This paper proposes a stereo vision based 3D localization of the target position of automatic parking system. Pixel classification and feature based stereo matching produces disparity map in real time. Road and object are separated by plane surface constraint, then transformed into bird’s eye view and depth map respectively. 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. In reference of map information, parking path is generated and delivered to steering actuator via serial link. Automated steering guidance helps the driver to park the vehicle easily. From the perpendicular parking experiment, the performance of the system was studied. It is known that the need of more accurate recognition and guidance, especially angular and lateral direction.