Abstract
This paper proposes a parking assist system that fuses around view monitor (AVM) image, ultrasonic sensor, and in-vehicle motion sensor. The proposed system recognizes various types of parking slot markings using AVM image sequences and classifies occupancies of the detected parking slots using ultrasonic sensors. Once a desirable parking slot is selected by a driver, its position is continuously tracked by fusing AVM images and motion sensor-based odometry. Experimental results show that the proposed system can reliably detect and track various types of parking slot markings.

Introduction
Due to the growing interest and demand for automatic parking, a great deal of research on parking assist system is being carried out. Parking space designation is one of the essential parts of the parking assist system. Most of the parking assist systems on the market designate parking spaces by utilizing a user interface-based approach via a touch screen or a free space-based approach via ultrasonic sensors. However, the former has a drawback of repetitive driver operations and the latter highly depends on the existence and poses of adjacent vehicles.

To overcome the drawbacks of the previous methods, this paper proposes a sensor fusion-based parking assist system that is able to recognize and track various types of parking slot markings. The proposed system consists of three stages: parking slot marking detection, parking slot occupancy classification, and parking slot marking tracking. The parking slot marking detection stage recognizes various types of parking slot markings using AVM image sequences. It detects parking slots in individual AVM images by utilizing a hierarchical tree structure of parking slot markings and combines sequential detection results. The parking slot occupancy classification stage identifies vacancies of detected parking slots using ultrasonic sensor data. Parking slot occupancy is accurately determined by calculating weighted sum of ultrasonic sensor outputs in each parking slot region. Weights are determined according to the relative direction between parked vehicle and moving vehicle. The parking slot marking tracking stage continuously estimates the location and orientation of the selected parking slot while the ego-vehicle is moving into it. During tracking, AVM images and motion sensor-based odometry are fused in the chamfer score level to achieve robustness against occlusions caused by the ego-vehicle.
Parking Slot Marking Detection

The proposed system focuses on five types of parking slot markings commonly presented in Korea (rectangular, slanted rectangular, parallel, open rectangular, and diamond types), as shown in Figure 2. Additionally, this paper deals with parallel type slot recognition in comparison with method [1].

Parking slot detection process is conducted by using a hierarchical tree structure-based method [1]. Figure 3 shows a hierarchical tree structure of four types of parking slot markings. In this figure, parallel type is omitted because its structure is the same as the rectangular type except slot width. In Figure 3, four types of parking slot markings consist of four types of slots and each slot is composed of two junctions as shown in the first row. Junctions composed of four types of slots can be categorized into four types and each junction consists of two corners as shown in the second row. These corners can be divided into four types as shown in the last row.

If the hierarchical tree structure-based method is applied to individual AVM images sequentially taken while the ego-vehicle is passing by parking slots, the system inevitably misses several slots due to image degradation at locations far from cameras or partial occlusions caused by adjacent vehicles. To overcome this problem, the proposed system combines sequentially detected parking slots [2]. Parking slot markings that can be detected in a single AVM image are restricted. However, occluded or degraded parking slot markings in one AVM image can be detected in other AVM images since occluded regions and image qualities are changing while the ego-vehicle is moving along the corridor of the parking lot. Figure 4 shows a concept of the image sequence-based method. Red, blue, green, and yellow lines indicate parking slots detected in the first, second, third, and fourth images, respectively. It can be seen that most of the parking slots can be obtained in the fourth image by combining sequential detection results. This system first detects various types of parking slot markings using the hierarchical tree structure-based method. If there are previously detected parking slots, their current positions are predicted using an image registration technique or motion sensor-based odometry. After that, sequential detection results are combined according to slot properness measures, and final parking slots are determined via slot clustering.

Parking Slot Occupancy Classification

Once parking slots are detected in an AVM image sequence, the proposed system classifies occupancies of the detected parking slots by utilizing ultrasonic sensors mounted on both sides of the front bumper. The proposed occupancy classification method calculates weighted sum of ultrasonic sensor data to determine whether the detected slots are vacant or not. As mentioned in [3], a uniform weighting function would be sufficient if ultrasonic sensor output were stable in various situations. However,
ultrasonic sensors give unstable outputs when surfaces of parked vehicles are not perpendicular to heading directions of ultrasonic sensors. Figure 5 shows examples of ultrasonic sensor data. In the left case, an ultrasonic sensor gives stable outputs since surfaces of parked vehicles are almost perpendicular to its heading direction. However, in the right case, it only gives stable outputs on the vehicle surface near to the sensor since its heading direction is not perpendicular to surfaces of parked vehicles.

To deal with these situations, this paper utilizes a method that adaptively changes a weighting function in accordance with the angle between moving direction of the ego-vehicle and surface orientation of a parked vehicle. Figure 6 shows stability of ultrasonic sensor with different angles between moving direction of the ego-vehicle and surface orientation of a parked vehicle. According to this observation, this paper models stability of ultrasonic sensor with Rayleigh function and uses it as a weighting function. Since Rayleigh function changes with different sigma values as shown in Figure 7, a small sigma value is selected when the angle between moving direction of the ego-vehicle and surface orientation of a parked vehicle is large. In the middle case of Figure 6, a reflected shape of Rayleigh function is utilized.

Figure 5. Examples of ultrasonic sensor data

Figure 6. Stability of ultrasonic sensor

Parking Slot Marking Tracking

If a parking slot is detected in an AVM image, its 3-D position can be reconstructed using camera parameters estimated from the calibration procedure. However, if the assumptions of the AVM system, that is, the fixed camera configuration (height and angle) and flat road surface, are broken, the reconstructed 3-D position will be distorted. Additionally, if a 3-D position is updated using only motion sensor-based odometry, its accuracy will be degraded by a cumulative error of odometry.

To alleviate this problem, this paper continuously tracks and updates the position of the selected parking slot in sequential AVM images while the vehicle is moving into it. This approach is useful because the parking slot position in an AVM image becomes more accurate when the ego-vehicle is getting closer to it.

Since parking slot markings are composed of multiple lines with different orientations, this paper generates templates using multiple directional lines and estimates positions of parking slot markings using directional chamfer matching (DCM) in sequential AVM images. DCM-based tracking using AVM images properly works in cases where parking slot markings are slightly occluded. However, it can be failed when parking slot markings are severely occluded by the ego-vehicle. To overcome this drawback, this system tracks a parking slot by fusing AVM images and motion sensor-based odometry in chamfer score level. Their weights are adaptively chosen according to the degree of occlusion caused by the ego-vehicle.

Figure 8 shows edge templates automatically generated from parking slot detection results. In this figure, green lines in the first row and blue lines in the second row indicate detected parking slots and automatically generated edge templates, respectively. Figure 9 shows a result of parking slot marking tracking in case of a rectangular type parking slot. It can be seen that the parking slot is accurately tracked in spite of severe occlusion caused by the ego vehicle.
Experimental Results

Parking slot detection performance was evaluated with 100 image sequences which include 588 various types of parking slots. The proposed system achieves 96.3% of recall and 93.4% of precision as shown in Table 1. Figure 10 shows parking slot detection and occupancy classification results. In this figure, green and red lines indicate vacant and occupied parking slots, respectively, and yellow dots are ultrasonic sensor data.

Parking slot occupancy classification performance was evaluated with 566 correctly detected parking slots, and the proposed system shows 97.5% of classification rate. This means that there are only four misclassified slots.

Parking slot tracking performance was evaluated with 50 image sequences (ten situations for each type of parking slot marking). Table 2 shows location and orientation errors of three methods: fusion-based, image-based, and odometry-based methods. It can be notice that the proposed fusion-based method outperforms the other two methods by showing 3.1cm of location error and 1.0° of orientation error on average. Figure 11 shows snapshots of parking slot marking tracking results.

Table 1. Parking slot marking detection performance

<table>
<thead>
<tr>
<th>Slot type</th>
<th>Recall</th>
<th>Precision</th>
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<tbody>
<tr>
<td>Rectangular</td>
<td>99.4%</td>
<td>96.8%</td>
</tr>
<tr>
<td>Open rectangular</td>
<td>93.7%</td>
<td>99.0%</td>
</tr>
<tr>
<td>Diagonal</td>
<td>98.5%</td>
<td>87.8%</td>
</tr>
<tr>
<td>Slanted rectangular</td>
<td>93.5%</td>
<td>93.5%</td>
</tr>
<tr>
<td>Parallel</td>
<td>90.7%</td>
<td>84.8%</td>
</tr>
<tr>
<td>Total</td>
<td>96.3%</td>
<td>93.4%</td>
</tr>
</tbody>
</table>

Table 2. Parking slot marking tracking performance

<table>
<thead>
<tr>
<th>Tracking method</th>
<th>Location error (cm)</th>
<th>Orientation error (degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>max</td>
</tr>
<tr>
<td>Fusion-based</td>
<td>3.1</td>
<td>10.3</td>
</tr>
<tr>
<td>Image-based</td>
<td>12.7</td>
<td>444.4</td>
</tr>
<tr>
<td>Odometry-based</td>
<td>11.2</td>
<td>40.3</td>
</tr>
</tbody>
</table>
Summary/Conclusions

This paper proposes a sensor fusion-based parking assist system. Since the proposed system provides vacant parking slots, drivers only need to select one of the provided slots. This makes the proposed system more convenient than the previous systems that ask drivers to point out relatively precise locations of parking slots. This system can also successfully detect slated rectangular and diamond parking slots that are unable to be handled by ultrasonic sensor-based systems. Furthermore, the proposed system can reduce 3-D parking slot position errors caused by non-flat road surfaces and slight changes in camera positions by continuously tracking selected parking slots. However, because the proposed method is based on junction combination, when the junction is unclear by shadow, snow, reflected light and so on, the recognition accuracy is degraded. Therefore we are planning to develop the robust parking slot recognition algorithm for solving the problem from obscured markings (by snow, leaves, rains or worn out marking) and light source change. Consequently, we are aiming to use the developed parking assist system in any parking environment (day/night, indoor/outdoor, etc.).

References


Definitions/Abbreviations

AVM - Around view monitoring
DCM - Directional chamfer matching