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# Light Stripe Projection based Parking Space Detection for Intelligent Parking Assist System

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***Abstract*— This paper proposes a novel light stripe projection based free parking space recognition method in order to overcome the common drawbacks of existing vision based target parking position designation methods in dark indoor parking site. 3D information of parking site is recognized by light stripe projection method. By analyzing the 3D information, system can recognize discontinuous points, pivot, and opposite-site reference point. Experiments show that the proposed method can successfully designate target position in spite of dark illumination condition and the black reflective surface of vehicle. Furthermore, because the proposed method can be implemented just by adding a low-cost light plane projector, it is economically practical solution.**

## I. INTRODUCTION

INTELLIGENT parking assist system is a kind of driver assistant system automating steering maneuver during parking operation. Intelligent parking assist system consists of 6 components: target position designation, path planning, path tracking, active steering, active braking, and HMI(Human Machine Interface) [1].

Target position designation recognizes the 3D information of desired final position of vehicle. For parallel parking, almost all system use range sensor, e.g. ultrasonic sensor [2][3][4] and SRR(Short Range Radar) [5][6], to find free space. For perpendicular parking, vision based method is dominant. Although there is a system using scan-type laser radar [7], the price of scan-type laser radar is too high to be used in mass production case. Because low-cost range sensor such as ultrasonic sensor and SRR has drawback against slanted surface, they often fail to find slanted free space. Furthermore, because driver wants to monitor on-going parking operation visually, backward monitoring camera becomes an essential component of parking assist system [8].

To find free space, various vision technologies are used. Nico Kaempchen used binocular stereo to find the 3D information of adjacent vehicles [9]. Jin Xu [10] and Yu Tanaka [11], and our previous work [12][13][14] developed vision algorithm to designate target position by recognizing parking slot markings. C. Vestri [15] used motion stereo to find the 3D information of adjacent vehicles. With such automatic recognition algorithms, HMI based manual designation methods are incorporated into vision based system [4][16][17].

Although such vision system can find target position in outdoor situation with bright sunlight, they suffer other kinds of problem in dark underground parking site. Dark under ground parking site is very common in urban life, e.g. parking site of apartment, department store, and general downtown buildings. In dark parking site, feature extraction, which is the basic initial operation of binocular stereo and motion stereo, shows bad performance. Furthermore, near lighting bulbs make big moving glints on vehicle's surface, which give bad influence to stereo matching. Parking slot marking recognition also suffers many problems from dark illumination condition and reflective ground surface, which is general for indoor parking site.

This paper proposes light stripe projection based method to provide a target position designation method in dark underground parking site. By adding low-cost light plane projector, system can recognizes 3D information of parking site. Although acquired 3D information is limited, we conclude that it is sufficient to find free parking space. With various experiments, it is shown that the proposed method is a good solution.

## II. LIGHT STRIPE PROJECTION BASED 3D RECOGNITION

### A. System Configuration

Proposed system can be implemented simply by installing a light plane projector at the backend of vehicle as shown in Fig. 1. NIR(Near InfraRed) line laser is used as the light plane projector not to border neighboring people. Because parking assist system should provide backward image to driver,

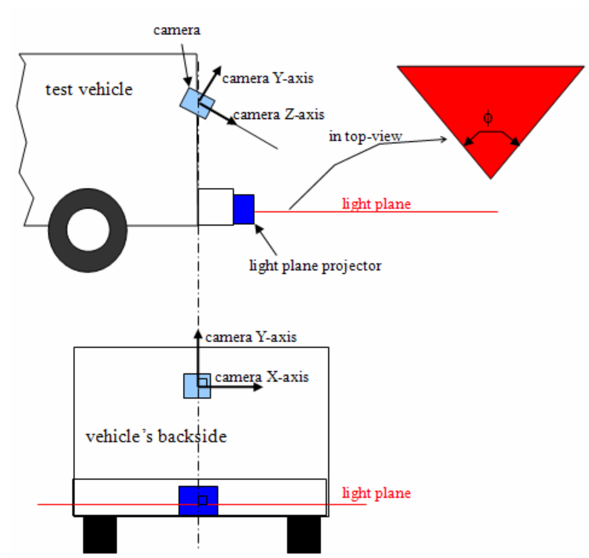
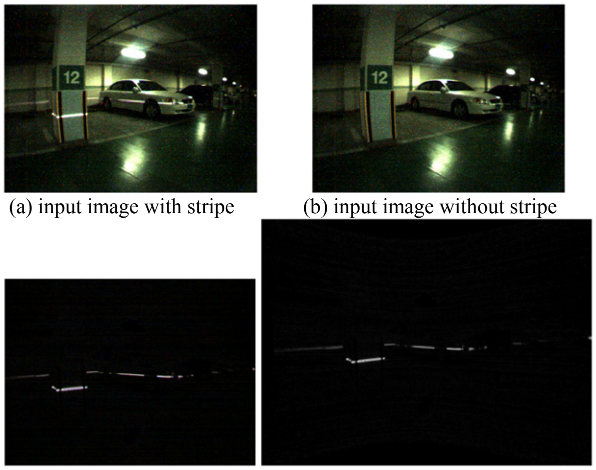



Fig. 1. System configuration.



(a) input image with stripe (b) input image without stripe

(c) difference image (d) rectified difference image

Fig. 2. Rectified difference image.

band-pass filter, commonly used with NIR light source, can not be used. On the contrary, in order to acquire image in NIR range, infrared cut filter generally attached to camera lens is removed. To capture backward image with large FOV(Field Of View), fisheye lens is used. With radial distortion parameters measured through calibration procedure, input image is rectified to be undistorted image.

In order to robustly detect light stripe without band-pass filter, difference image between image with light projector on and image with light projector off is used. Turning the light plane projector on during short period, system acquires backward image including light stripe as shown in Fig. 2(a). Turning the light plane projector off, system acquires visible band image as shown in Fig. 2(b). Difference image between them can extract light stripe irrespective of surrounding environment as shown in Fig. 2(c). Furthermore, because light plane projector is turned on during only short time, it can guarantee eye-safe operation with comparatively high power light source [18].

### B. *Light Stripe Detection*

Light stripe detection consists of two phases. The first phase sets threshold adaptively with the intensity histogram of difference image and detects light stripe pixels having definitely large value. The second phase detects additional light stripe pixels with line detector, of which width is changed with respect to the corresponding distance. In light stripe projection method, the distance of a pixel has one-to-one relation with its y-coordinate value [19].

Existing light stripe detection applications are applied to continuous object surface with little distance variance in near distance. Furthermore, because existing applications use infrared band pass filter to detect light stripe, they can ignore the effect of surrounding environment and easily extract light stripe image. It can be assumed that light stripe pixels on continuous surface are neighboring in consecutive image columns. Because our application in this paper handles searching environment consisting of discontinuous surfaces with large distance difference, we should devise new stripe detection algorithm.

Fig. 3. Detected light stripe.

According to the intensity histogram of difference image, Gaussian noise generated from CMOS image sensor's characteristics and pixels belonging to light stripe exist in different ranges. It is found that if threshold is set to the 6 sigma of histogram, pixels with explicitly large value in the difference image can be easily separated from Gaussian noise. Because light stripe is generated to be orthogonal to camera X-axis, there is only one position corresponding to light stripe in a column. If only one peak is detected in a column, the center of region above the threshold is recognized as the position of light stripe.

The second phase uses peak detector with upstanding rectangular shape. By analyzing the relation between the width and y-coordinate of detected light stripe, it is found that light stripe in near distance generally has large width and light stripe in far distance has small width. For each y-coordinate, the width of peak detector is changed accordingly. The filter summarizes pixel values inside of the rectangle and subtracts pixel values outside of the rectangle.

### C. *Light Stripe Projection Method*

It is possible to assume that light stripe projector at location $L$ is located at virtual position $L'$ because light plane projector makes a light plan as shown in Fig. 4. Normalization of configuration calculates baseline $b$ between camera and light plane project $L'$ located on camera Y-axis and between-angle $\alpha$. The height of camera from ground surface is $c$. The distance between camera and light plane projector in the direction of vehicle axis is $d$. The height of light plane projector from ground surface is $h$. The angle between camera axis and ground surface is $\gamma$. The angle between light plane projector and ground surface is $\beta$. Therefore, $\alpha$=90+$\beta$-$\gamma$. According to the sine law, $b$ is calculated as below:

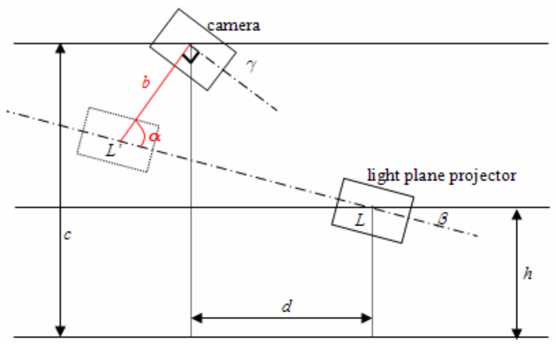



Fig. 4. Normalization of configuration.

$$b : c - h - d \cdot \tan(\beta) = \sin(90-\beta) : \sin(90+\beta-\gamma)$$

$$b = \frac{\sin(90-\beta)}{\sin(90+\beta-\gamma)}\left(c - h - d \cdot \tan(\beta)\right)$$

Finding the intersecting point between plane $\Pi$ and line **Op** can calculate the coordinates of stripe pixel point **P** as sown in Fig. 5. $\Pi$ denotes the plane generated by light plane projector. Line laser projected onto object surface forms a light stripe. **p** ($x$, $y$) denotes the point on image plane corresponding to a point **P** (X,Y,Z) on light stripe.

*1) The equation of light plane* $\Pi$

Light plane $\Pi$ meets Y-axis at point $\mathbf{P_0}$ (0, -$b$, 0). The angle between the plane and Y-axis is $\alpha$ and the angle between the plane and X-axis is $\rho$. Distance between camera and $\mathbf{P_0}$, i.e. baseline, $b$ and the between-angle $\alpha$ are calculated by configuration normalization.

The normal vector **n** of light plane $\Pi$ is calculated by rotating the normal vector of XY plane, (0, 1, 0), by $\pi/2$-$\alpha$ with respect to X-axis and by $\rho$ with respect to Z-axis.

$$\mathbf{n} = \begin{bmatrix} \sin\alpha \cdot \sin\rho \\ \sin\alpha \cdot \cos\rho \\ -\cos\alpha \end{bmatrix} \tag{1}$$

The equation of plane can be obtained with the normal vector **n** in (1) and one point on the plane $\mathbf{P_0}$ like (2).

$$\mathbf{n}(\mathbf{X} - \mathbf{P}_0) = 0 \tag{2}$$

*2) The equation of* **Op**

Optical center **O**, one point on light stripe **P**, and corresponding point on image plane **p** should be on one common line in three dimensional space. With perspective camera model denoted by (3), all points **Q** on the line **Op** can be denoted by parameter $k$ like (4). Here, $f$ denotes focal length of optical system and ($x$, $y$) is the coordinate of **p**.

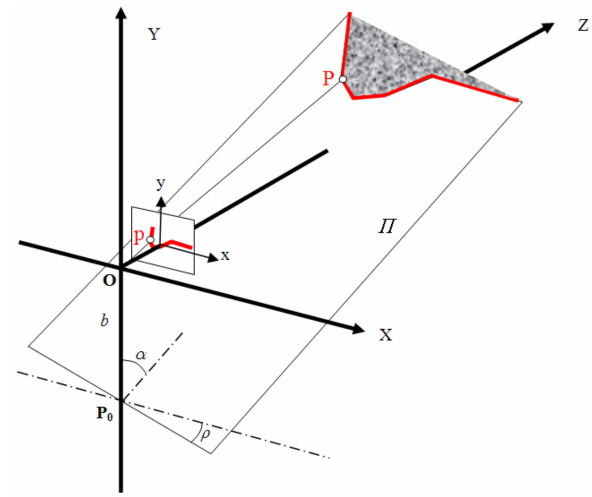



Fig. 5. Relation between light plane and light stripe image.

$$\frac{X}{x} = \frac{Z}{f} = \frac{Y}{y} \tag{3}$$

$$\mathbf{Q} = \left(k \cdot x,\ k \cdot y,\ k \cdot f\right) \tag{4}$$

*3) 3D Recognition from the Intersecting-Point*

Because a point on light stripe **P** is the intersecting point of the light plane $\Pi$ and the line **Op**, it should satisfy (2) and (4) simultaneously. By substituting (4) and (1) into (2), parameter $k$ can be solved like (5).

$$k = \frac{b \cdot \tan\alpha \cdot \cos\rho}{f - \tan\alpha\left(x \cdot \sin\rho + y \cdot \cos\rho\right)} \tag{5}$$

By substituting (5) into (4), the coordinate of **P** can be calculated like (6), (7), and (8) [19].

$$X = \frac{x \cdot b \cdot \tan\alpha \cdot \cos\rho}{f - \tan\alpha\left(x \cdot \sin\rho + y \cdot \cos\rho\right)} \tag{6}$$

$$Y = \frac{y \cdot b \cdot \tan\alpha \cdot \cos\rho}{f - \tan\alpha\left(x \cdot \sin\rho + y \cdot \cos\rho\right)} \tag{7}$$

$$Z = \frac{f \cdot b \cdot \tan\alpha \cdot \cos\rho}{f - \tan\alpha\left(x \cdot \sin\rho + y \cdot \cos\rho\right)} \tag{8}$$

*4) Transform to Vehicle Coordinate System*

Vehicle coordinate system is defined such that the foot of a perpendicular of optical center **O** with respect to ground surface is the origin and XZ plane is parallel to the ground surface. By rotating a point **P** in camera coordinate system by

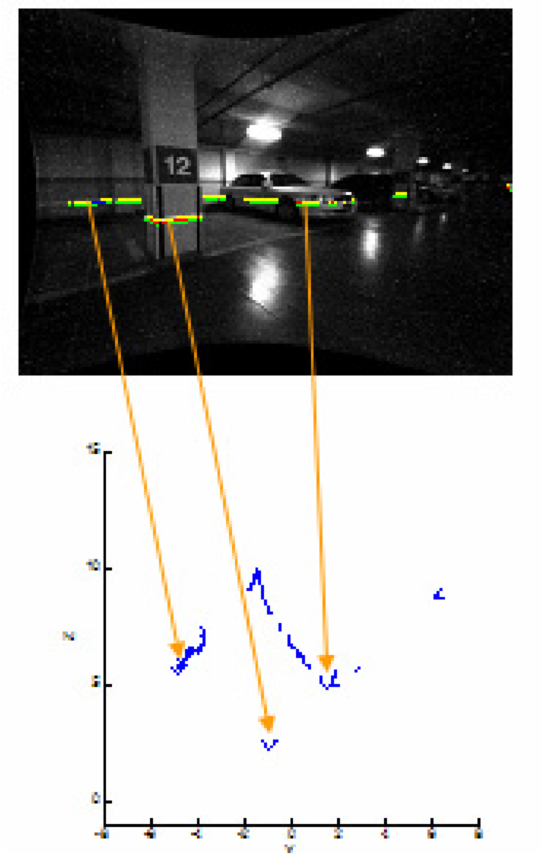



Fig. 6. 3D recognition result.

-$\gamma$ with respect to X-axis and translating it by camera height $c$ in the direction of Y-axis, the corresponding point **P'** in vehicle coordinate system can be calculated like (9).

$$\mathbf{P}' = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\gamma & -\sin\gamma \\ 0 & \sin\gamma & \cos\gamma \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} 0 \\ c \\ 0 \end{bmatrix} \quad (9)$$

3D information of detected light stripe is calculated by (6) ~ (9). Fig. 6 shows the recognized 3D information by projecting them onto the XZ plane of vehicle coordinate system.

## III. Parking Space Detection

### *A. Occlusion Detection*

Occlusion is defined as a 3D point pair, which is located in adjacent column in stripe image and is far more than a certain threshold, e.g. ego-vehicle's length, from each other in XZ plane. Occlusions are detected by checking the above mentioned conditions on detected light stripe. Two 3D points belonging to an occlusion have a property about whether it is left-end or right-end of consecutive stripe pixels. Fig. 7 shows detected occlusion points. Occlusion point recognized as

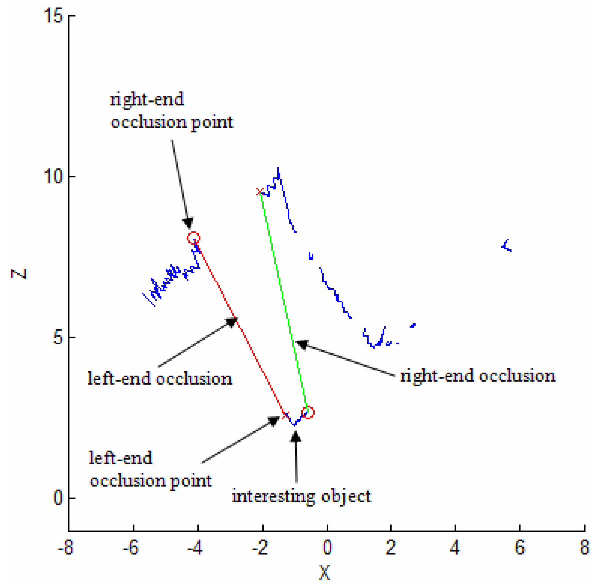



Fig. 7. Detected occlusion points and occlusion.

left-end is denoted by 'x' marking and occlusion point recognized as right-end is denoted by 'o' marking. Here, left-end occlusion point and right-end occlusion point make one occlusion. If the left-end occlusion point of an occlusion is nearer than the right-end occlusion point from camera, the pair is supposed to be on the left-end of interesting object. In this application, the interesting object means object existing on the left or right side of free space. If the left-end occlusion point is further than the right-end occlusion point from camera, the occlusion is supposed to be on the right-end of interesting object. Such characteristic is attached to occlusion as directional information. In Fig. 7, the occlusion at the left-end of interesting object is drawn by red line and the occlusion at the right-end of interesting object is drawn by

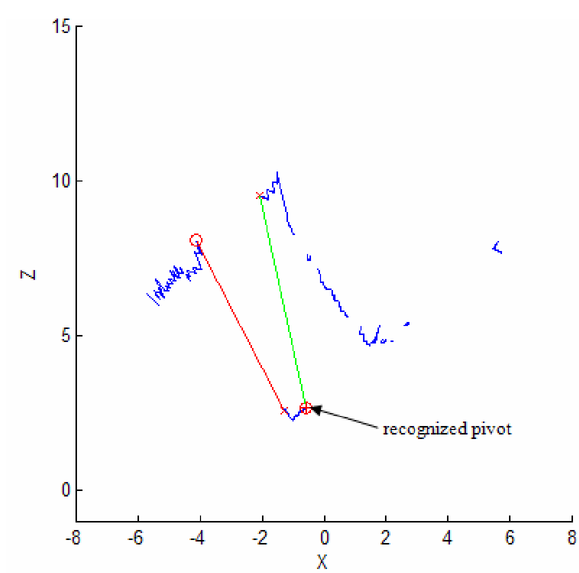
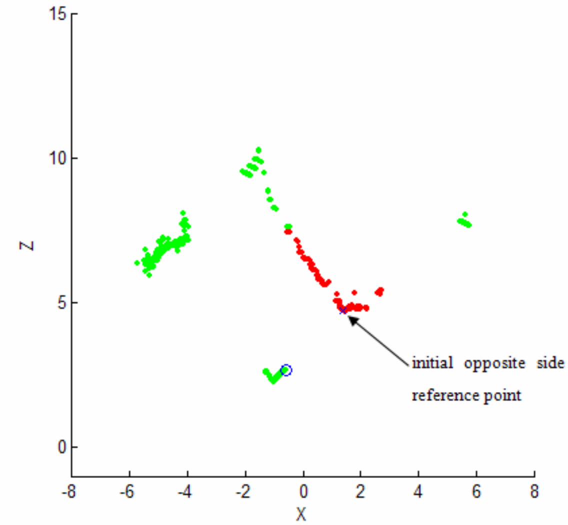



Fig. 8. Pivot detection result.



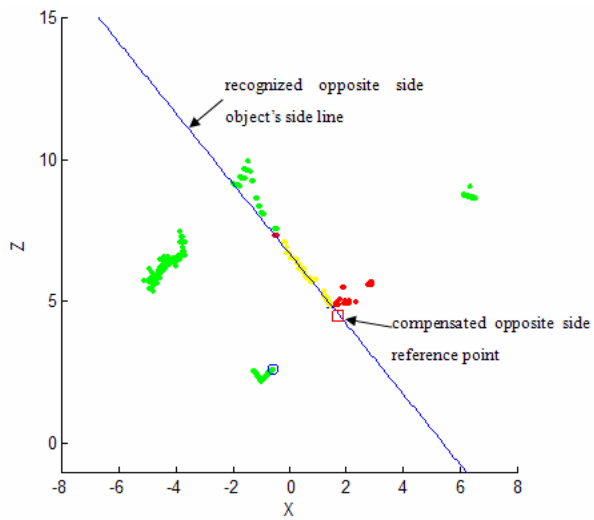




Fig. 9. Opposite-side reference point detection result.

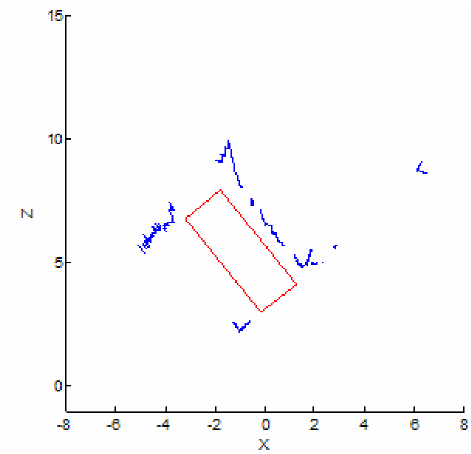



Fig. 10. Established target position.

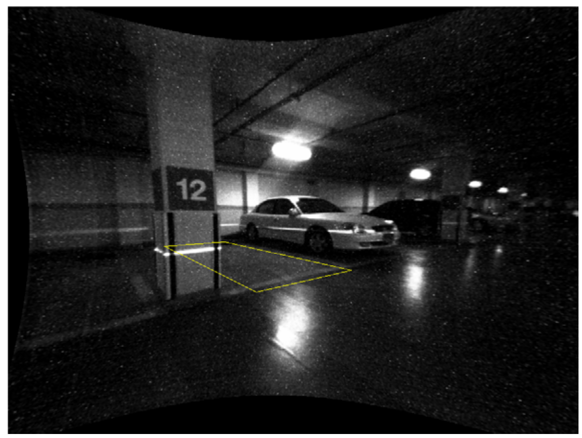



Fig. 11. Target position projected on input image.

green line.

### B. Pivot Detection

Pivot occlusion is defined as an occlusion which satisfies the below conditions: 1) There is free space in the direction of occlusion. The region of free space checking is semicircle, of which straight side is the line between occlusion points and of which radius is ego-vehicle's width and of which center is the nearer occlusion point. 2) It is far from FOV border by sufficiently large distance, e.g. ego-vehicle's width. 3) It is nearer than any other candidates from optical axis. Pivot, center of rotation, is the nearer occlusion point of pivot occlusion. Fig. 8 shows recognized pivot with '+' marking.

### C. Recognition of Opposite-Side Reference Point

It is assumed that recognized 3D points, whose distance from pivot is smaller than a certain threshold, e.g. ego-vehicle's length, in the direction of pivot occlusion, belong to opposite-side object. Fig. 9 shows detected 3D points belonging to opposite-side object. Among these 3D points, one point nearest to pivot becomes the initial opposite-side reference point.

Using points whose distance from opposite-side reference point is smaller than a certain threshold, e.g. 2/3 of ego-vehicle's length, in the direction going away from camera and perpendicular to pivot, the direction of opposite-side object's side can be estimated. Fig. 9 shows the estimated direction of opposite-side object's side based on 3D points marked by yellow color. Estimated side of opposite-side object is marked by blue line.

Opposite-side reference point is compensated by projecting pivot onto the estimated side of opposite-side object. In Fig. 9, compensated opposite-side reference point is denoted by rectangular marking. When the left side object and the right side object of free parking space has different distance from the border between parking area and roadway, for example nearer side object is pillar and the opposite-side object is a vehicle parked deeply, the initial opposite-side reference point will be located at the position more inner than pivot. Consequently, if system establishes target position with pivot and initial opposite-side reference point, the attitude of target position has great risk to be misaligned.

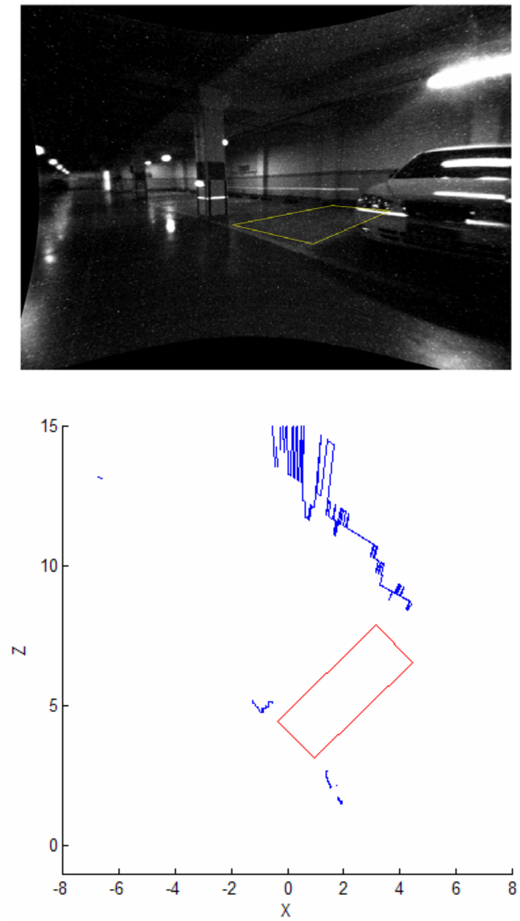



Fig. 12. Target position when neighboring side is a vehicle.

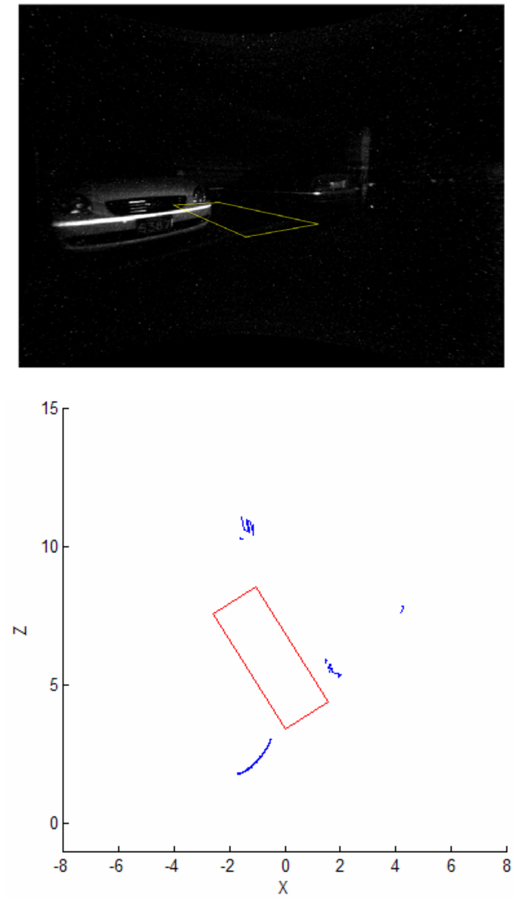



Fig. 13. Recognized target position between vehicles.

Generally, stripe on the corner and side of opposite-side object is expected to be robustly detected. Therefore, it is reasonable that target position can be more correctly established with compensated opposite-side reference point, which can be estimated with 3D points belonging to opposite-side object's side.

### *D. Target Parking Position*

Rectangular target position is established at the center between pivot and opposite-side reference point. Target position's short side is aligned to the line between pivot and opposite-side reference point. The width of target position is the width of ego-vehicle and the length of target position is the length of ego-vehicle. Fig. 10 shows the finally established target position. Fig.11 shows the established target position projected on input image.

## IV. Experimental Results

Fig. 12 shows that proposed method successfully recognize free parking space even when the nearer side of parking space is occupied by vehicle.

Fig. 13 shows that proposed method successfully recognize free parking space between vehicles in spite of dark illumination condition. Especially, it is noticeable that although the vehicle on the further side of free parking space has black color, proposed method can detect light stripe on the vehicle's corner and side surface and successfully designate target parking position.

Fig. 14 shows the case when the depth of parked adjacent vehicle is considerably different from the depth of adjacent pillar. Because proposed method estimates the side line of opposite-side object and establishes opposite-side reference point by projecting pivot onto the line, it can comparatively successfully designate target position.

## V. Conclusion

This paper proposes a novel light stripe projection based free parking space recognition method in order to overcome the common drawbacks of existing vision based target position designation methods in dark indoor parking site. The proposed method is expected to be practical solution because it can be implemented simply by installing a low-cost light plane projector on existing parking monitoring system and it uses simple mathematics and computation to recognized 3D information of parking site. Various experiments show that the proposed method can successfully recognize target parking position in spite of various illumination conditions. Future research topics include the extension of proposed

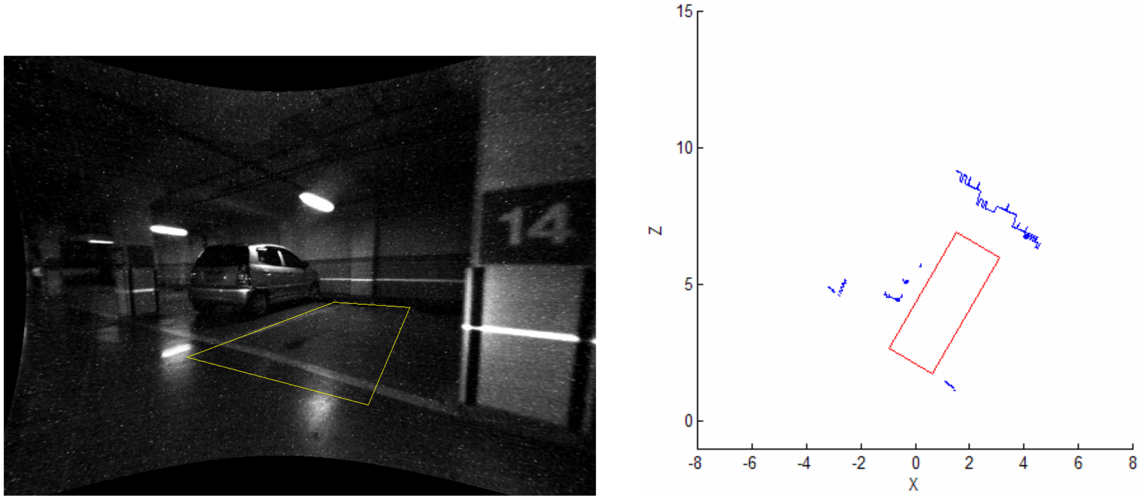



Fig. 14. Recognized target position when adjacent objects have large difference in depth.

method to outdoor parking site in nighttime and the improvement of stripe detection which determines the precision of recognized 3D information.

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