# Study of free space detection for narrow roads driving support system

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## Abstract

Free space detection is one of the techniques for constructing safe driving support and autonomous driving. In this paper, we focus on narrow roads and describe the free space detection algorithm for constructing a narrow road driving support system. By installing the stereo camera in front of the vehicle, it is possible to perform object recognition and distance measurement without other external sensors. The installation position of the camera and the pitch angle of the camera are also used for detection of free space. The evaluation method is performed by comparing the detection result image with the previously prepared correct answer image. We are considering two kinds of evaluation methods based on the area and contour of free space.

**Keywords**: Automobile, Free space, Stereo camera.

## 1. Introduction

In residential areas and narrow roads connected to there, drivers have to have precise driving behavior compared with other traffic scenes for collision avoidance and smooth traffic. It is necessary to continuously recognize and judge the surrounding environment and the state of the host vehicle, these are heavy burden for unskilled drivers, and elderly drivers whose cognitive function declines. Therefore, driving support systems focusing on narrow roads have been researched and developed(1).

In such systems, a functions of detecting obstacles and free space from traffic scenes is used. By detecting these, it is possible to judge a collision with others or to judge whether the vehicle travels on an appropriate driving road. In general, the free space detection function is realized by using a three-dimensional estimation method for the traffic environment. There is a method(2) using LiDAR as an external sensor, it is an issue to install and popularize it in a general vehicle because LiDAR is expensive. On the other hands, in-vehicle cameras are inexpensive compared to LiDAR and they are spreading because they are easy to mount on general vehicles. Among in-vehicle cameras, stereo cameras are increasingly used for emergency braking functions and are becoming popular in general vehicles. It can also be used for three-dimensional estimation of traffic scenes, so it is used for various driving support functions(3). So, a free space detection function(4-6) using this has been proposed.

In this research, we aim to detect the free space in front of vehicle to support driving on narrow roads. Although it is difficult to construct functions for all narrow road environments using machine learning and deep learning, our proposed method can realize the free space detection by using disparity value obtained from stereo camera and positional relationship between stereo camera and vehicle instead of learning method.

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This paper is organized as follows: Section 2 introduces the existing method of free space detection. Section 3 shows the assumed traffic situations and devices used in the experiment. Section 4 explains the free space detection method which we used. In Section 5, the evaluation method of this function and its result are shown. Finally, we state a conclusion.

## 2. Existing methods

Keiji SANEYOSHI mentioned the advantages of stereo cameras and proposed a method of detecting three-dimensional objects from traffic scenes[4]. The image obtained from the stereo camera includes disparity information. This image is called a disparity image, and he detected a three-dimensional object from this image. At first, the disparity image is divided into vertical regions composed of small widths. For each of the divided regions, a histogram is created from the disparity value and the number of pixels. If most of the three-dimensional object is put vertically from the ground and the optical axis of the stereo camera is substantially horizontal with the ground, the disparity value of the three-dimensional object area becomes a substantially constant value, and a clear peak appears in the histogram. Obstacle regions can be detected by extracting pixels in the disparity image representing the disparity values around this peak. Finally, it is possible to detect the free space by extracting pixels between the bottom row of the detected object regions and the bottom row of the disparity image. He proposed this method for obstacle region detection and implemented it on the FPGA.

NAITO et al. used v-disparity and u-disparity to detect indoor floor[5]. The former is an image showing the frequency of occurrence of disparity values in the vertical direction and the latter is an image denoting the frequency of occurrence in the horizontal direction. Fig. 1 shows an example of a traffic scene on a narrow road. The disparity image for Fig. 1 generated by ZED stereo camera and the v-disparity and u-disparity image are shown in Fig. 2. In their research, the obstacle regions and the free space area are divided by detecting line segments meaning object regions using Hough transformation from each image. By using Hough transformation which is robust to noise, they showed that the road surface can be extracted even if the disparity image is not high quality. This is a method that can be used indoors and outdoors, and vehicles with stereo cameras can use it.

Fig. 1. Example of a traffic scene on a narrow road.

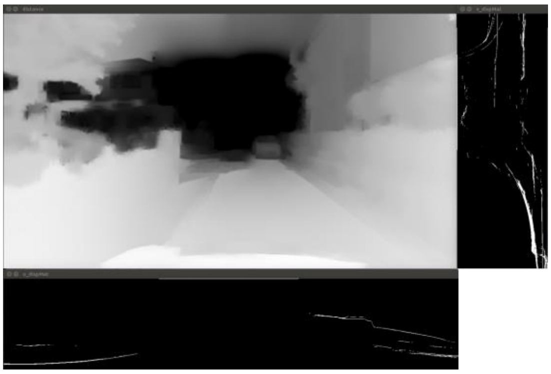

Fig. 2. The disparity image is shown in the upper left. The v-disparity image is shown in the upper right the u-disparity image in the lower row.

## 3. Assumed traffic situations and devices

Table 1 shows the assumed traffic situation, and Table 2 shows the list of used devices. The camera is installed on the roof of the vehicle and it is at a height of about 1.65 [m] from the ground. For safe driving on a narrow road with poor visibility, we set the assumed maximum vehicle speed to be slower than the vehicle speed on a wide road.

Table 1. Assumed traffic situations

| | |
|---|---|
| Configuration of Narrow road | Line, Curve, Parking Lot and Curb |
| Obstacle | Telephone pole, Fence, Oncoming car and Pedestrian |
| Vehicle speed | Slow moving ~ 20[km/h] |
| Verification time | Daytime |

Table 2. Devices list

| | |
|---|---|
| Camera | ZED stereo camera, STEREOLABS |
| Laptop PC | Intel® Core™ i7-6700HQ Processor, 2.60 GHz |
| | 32.0 [GB] memory |
| | Ubuntu 14.04 LTS |

## 4. Free space detection on narrow roads

Fig. 3 shows the flow of processing. First, we take a traffic scene while driving on a narrow road with a parallel stereo camera. The left and right cameras are calibrated beforehand. The image on the left side is shown in Fig. 1. Next, we will generate disparity images. After removing the area including the bonnet from each camera image by the trimming processing, the disparity image is generated by the Semi-Global Block Matching method. An example of implementation by OpenCV, one of open source computer vision library, is shown in Figure 4. By using the Semi-Global Block Matching method for disparity calculation, it is possible to calculate disparity value smoothly even for objects that is strong against noise and has a small texture. A pixel close to white has a large disparity value and represents that the distance from the installation position of the camera to the target point is close.

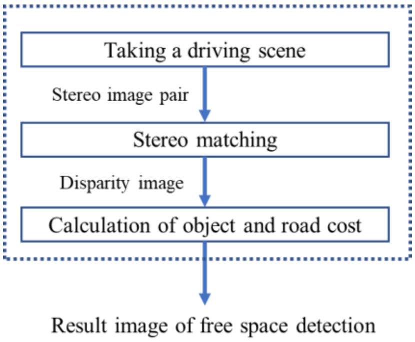


Fig. 3. The flow of processing.

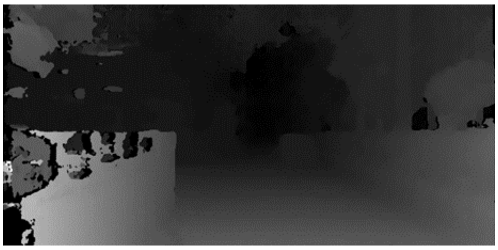

Fig. 4. Generation of disparity image using OpenCV.

After generating the disparity image, the cost of the obstacle and the road surface is calculated, and the region division is performed. We consider the model shown in Fig. 5 for the generated disparity image. In this model, the obstacles are installed perpendicular to the horizontal ground. From the above, two assumptions can be set as follows: One is that if the boundary between the road surface and the lower end of the object is defined as $v_b$ and the row at the lowermost end of the disparity image is

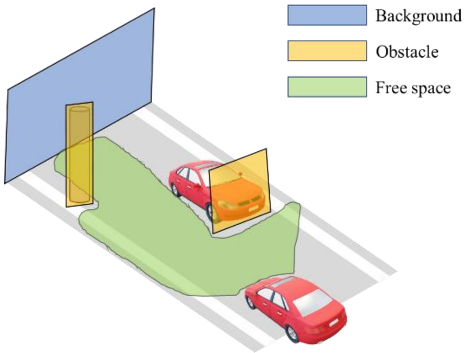


Fig. 5. Model of three regions.
( This figure was made based on Ref. (6) )

$$\Gamma_v = \alpha_1 \Gamma_v^R + \alpha_2 \Gamma_v^O \tag{1}$$

$$\Gamma_v^R = \Sigma_{v=v_b}^{V} |d_R(v) - d_v| \tag{2}$$

$$\Gamma_v^O = \Sigma_{v=v_b-h_v}^{v_b} |d_R(v_b) - d_v| \tag{3}$$

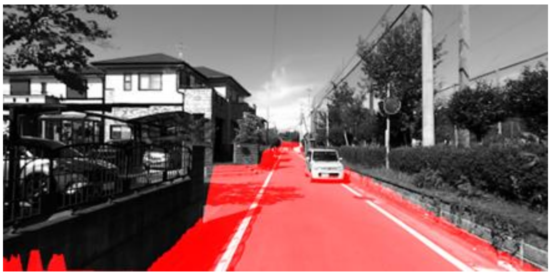

Fig. 6. Result of free space detection.

defined as $V$, $v$ satisfying $[v|\ v_b \leqq v \leqq V]$ is within the free space regions, and its disparity value is represented by $d_R(v)$. Second is that If $h_v$ is defined as the height of the object (measured in pixels), $v$ satisfying $[v|\ v_b\text{-}h_v \leqq v \leqq v_b]$ is within the obstacle region, and its disparity value is constant at $d_R(v_b)$.

Based on these assumptions, a cost function that minimizes at the boundary line between the road surface and the lower end of the object is defined. The definition of each cost is shown in Eqs. (1) to (3). Eq. (2) is the Road score, and Eq. (3) is the Object score. $d_v$ used in each expression is a disparity value obtained from a disparity image. $d_R(v)$ and $d_R(v_b)$ are calculated from the internal camera parameters and height and pitch angle of the camera[5]. Eq. (1) is the cost of each pixel in the disparity image and is calculated by the weighted sum of Eqs. (2) and (3). Finally, cost is calculated for each column of the disparity image. By extracting the interval between the row with the lowest cost and the bottom row of the image, the result of free space detection shown in Fig. 6 is obtained.

## 5. Evaluation method

We are considering two evaluation methods. The first is evaluation by area[7]. We count the number of pixels representing free space from the two images of the correct answer image shown in Fig. 7(Top) and the extraction result image of free space. Thereafter, evaluation is performed by calculating each parameter represented by Eqs. (4) to (6). Eq. (4) means the ratio of pixels detected as a free space region by mistake and Eq. (5) means the proportion of pixels detected erroneously as non-free space regions. Eq. (6) shows an indicator of correctness.

The second is to compute the deviation of boundary between the two images, the correct answer image shown in Fig. 7(bottom) and result image. We detect the row that becomes the boundary of free space from each column of each image. After that, calculate the deviation of the row for each corresponding column. If this deviation is close to 0, it means free space was detected accurately. Conversely, if the deviation becomes large, it means the free space is not sufficiently detected, and the obstacle or background area is detected as free space.

$$FalsePositiveRate = \frac{FP}{FP + TN} \quad (4)$$

$$FalseNegativeRate = \frac{FN}{FN + TP} \quad (5)$$

$$Precision = \frac{TP}{TP + FP} \quad (6)$$

*TP* : Number of pixels correctly detected free space
*TN* : Number of pixels correctly detected as non-free space
*FP* : Number of pixels detected as free space by mistake
*FN* : Number of pixels detected erroneously as non-free space

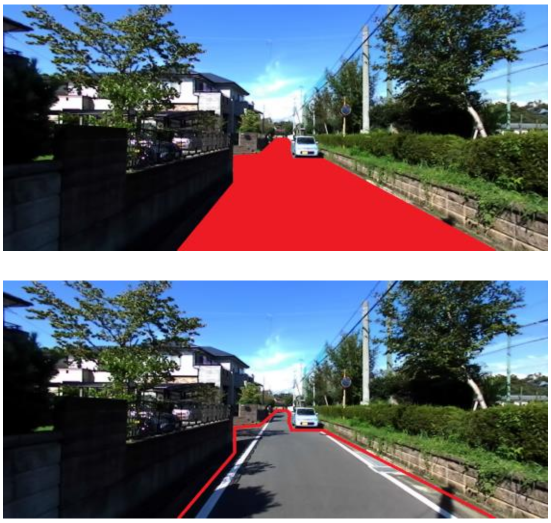

Fig. 7. Correct answer images

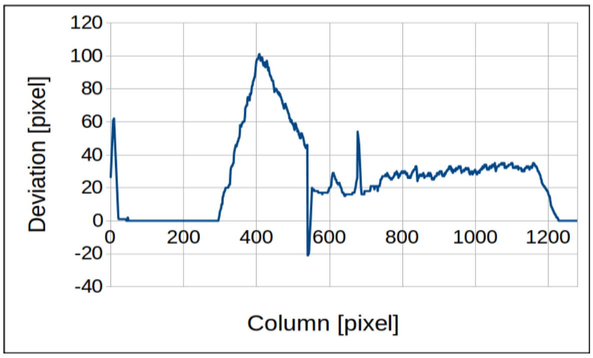


Fig. 8. Result of evaluation based on boundary deviation

We evaluated the extraction of free space using a video taken beforehand in the assumed environment described in Section 3. First, in the evaluation by area, the results of Eqs. (4) to (6) were 4.97[%], 0.11[%], and 76.93[%], respectively. Evaluation based on the deviation of the boundary is shown in Fig. 8. From the above results, it can be said that there is a calculation error because the implemented free space detection method did not accurately detect the line of the boundary between the obstacle and the road surface. The cause is presumed to be that the edge became ambiguous due to generating disparity image by Semi-Global Block Matching method. Finally, we describe the processing time. The video used in the evaluation contains 360 images. Processing to generate disparity images from one pair of left and right images is about 175 [msec], and processing to extract free space from the obtained disparity image is about 50 [msec].

## 6. Conclusions

In this paper, we described a method of free space detection using a stereo camera for narrow road driving support system. Also, we explained the evaluation method. We implemented the proposed method on a laptop computer and evaluated the free space extraction using a video showing the actual traffic scene.

We will improve the accuracy of the detection algorithm and summarize the evaluation results in various environments on the narrow road. Especially, we would like to try the local matching method of the conventional method and u-v-disparity as a method to emphasize the edge from the disparity image. For practical application, high-speed processing is indispensable. It is necessary to reduce the calculation load by generating disparity images only for the lower half of the image in which many boundaries of the road surface and obstacles appear, or to implement by FPGA or GPU in the future.

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