Synthesis of Top View Image and the Detection of Obstacles Using Multiple Cameras for Monitoring rea Around a Truck

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ABSTRACT

We propose a system that supports truck drivers. It can be used to prevent collisions between trucks and obstacles such as humans, bikes, or cars. This is accomplished by using a top view image and a function for the detection of obstacles around a truck based on their height. Our system requires only color cameras.

1. INTRODUCTION

Automobile manufacturers have previously attempted to develop systems to prevent collisions between cars and obstacles. For example, Nissan developed a top view system known as the "Around View Monitor"[1] for ordinary vehicles. However, developing a top view system for trucks is more difficult than creating such a system for ordinary vehicles because of their size. Trucks are larger, so the synthesis of the top view image is much more difficult. In addition, a previous study[2] indicated that more than half of all incidents caused by trucks are related to collisions with obstacles when parking or turning, so any system that supports truck drivers must be efficient. Therefore, our objective is to support truck drivers by showing them top view images around their truck and detecting obstacles based on their height. We can achieve this using only color cameras.

To assess our system's effectiveness, we conducted two tests, a simulation test and a practical test (Fig. 1). The former was carried out using a model truck that is one-fourteenth the size of a real truck, while the latter was carried out using a real truck. As a result of these tests, we can prove that our system would support truck drivers.

(a) Simulation **(b) Practical**

Fig. 1 Equipment

2. RELATED WORK

There are two projects closely related to this study, namely Toyota's "Toyota Safety Sense"[3] and Clarion's "SurroundEye"[4]. The "Toyota Safety Sense" is a system that detects obstacles located in front of a car by using a color camera and a millimeter wave radar. "SurroundEye" is a system that creates top view images of trucks using four color cameras. It enables drivers to see the area around their trucks, including the rear of the truck, although it cannot detect obstacles.

There are some other related works. For example, one prior study was able to generate top view images without the accurate intrinsic parameters of the attached cameras[5]. Another study created top view images using cameras attached to the signals at a junction rather than cars[6]. Additionally, a previous study made top view images of a junction using cameras attached to cars located near to that junction[7].

3. SYSTEM OVERVIEW

Our system involves three core algorithmic components:

1. Synthesis of top view images.
2. Detection of obstacles around the truck.
3. Calculation of the obstacles' height.

4. TECHNICAL DETAILS

We will now describe the components of our system in detail. We attach ten color cameras to a truck, with four cameras being attached to each side and two cameras to the rear of the truck. The area around the truck is overlapped by two cameras, which is an important element of this system. First, we will describe how we synthesize the top view images.

4.1 Synthesis of top view images

To synthesize the top view images, we calculate the homography matrices of each camera. In the simulation test, we calculate these values using a checkerboard. In the practical test, we use tiles on the earth (Fig. 2(b)). We regard the tiles as a checkerboard. When converting the images, two pixel values are calculated for each area because they are overlapped by two cameras. Then, we determine the values by considering the distance to the two cameras that cover the pixel area, and we calculate a weighted average. The top view image becomes clearer using this method.

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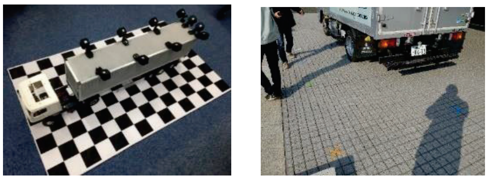


(a) Simulation **(b) Practical**

Fig. 2 Aspect of calibration

4.2 Detection of obstacles around the truck

We will now describe how to detect obstacles around a truck. In this paper, the term “obstacles” includes humans and objects such as bikes and cars.

First, we calculate the difference in the pixel values of the overlapped area. The difference becomes greater if an obstacle is present, since the obstacle’s color is different to that of the plane. To remove any noise on the difference map, we apply binary coded processing, expansion processing, and contraction processing. Then, we can create a “obstacle map” like Figure 3. Each white area on the map is a candidate for being an obstacle. To distinguish between obstacles and noise, we retain the following information for each area:

- Barycentric coordinates
- Pixel values
- Size

If the size of an area is too small, it is judged to be noise; otherwise, it is an obstacle. However, it is possible for an area to be split into two or more even though the different areas indicate the same obstacle. In the case of splitting, the size of the areas becomes smaller. Then, they would be judged to be noise. To avoid missing such areas, we compare information concerning all the areas, and we determine the split areas to be the same obstacle by setting conditions regarding the information. If the areas’ pixel values and barycentric coordinates are similar, they are judged to be the same obstacle.

In addition, we apply a tracking method to ensure the system is more robust. We compare the information concerning each previous frame’s areas with those of the current frame, and if the difference between them is small, they are judged to be the same obstacle.

Using these methods, we can robustly detect obstacles in the top view images.

4.3 Calculation of the obstacles’ height

Finally, we will describe how to calculate the height of the detected obstacles. Using this method, we can calculate the height if the obstacle’s area within the obstacle map is split in two. Previously, we calculated the perspective projection matrices of each camera using a checkerboard as well as homography matrices.

First, we detect the top of the obstacle. It is the farthest point from the car in the obstacle map (two points in Fig. 4(a)). Figure 4(b) demonstrates where the points are

Fig. 3 Obstacle map

indicated in the input images. Then, we can calculate the height using the triangulation method. We set the (u, v) and (u', v') coordinates of the two points in Figure 4(a), and we express the projection matrices of the two cameras that capture the two points as follows.

$$P = \begin{pmatrix} p_{11} & p_{12} & p_{11} & p_{11} \\ p_{21} & p_{22} & p_{23} & p_{24} \\ p_{31} & p_{32} & p_{33} & p_{34} \\ p_{41} & p_{42} & p_{43} & p_{44} \end{pmatrix}$$

$$P' = \begin{pmatrix} p'_{11} & p'_{12} & p'_{13} & p'_{14} \\ p'_{21} & p'_{22} & p'_{23} & p'_{24} \\ p'_{31} & p'_{32} & p'_{33} & p'_{34} \\ p'_{41} & p'_{42} & p'_{43} & p'_{44} \end{pmatrix}$$

In addition, we set the 3D coordinates of the two points as (Xw, Yw, Zw). Then, the formula written below is established.

$$\begin{pmatrix} p_{31}u - p_{11} & p_{32}u - p_{12} & p_{33}u - p_{13} \\ p_{31}v - p_{21} & p_{32}v - p_{22} & p_{33}v - p_{23} \\ p'_{31}u' - p'_{11} & p'_{31}u' - p'_{11} & p'_{31}u' - p'_{11} \\ p'_{31}u' - p'_{11} & p'_{31}u' - p'_{11} & p'_{31}u' - p'_{11} \end{pmatrix} \begin{pmatrix} X_w \\ Y_w \\ Z_w \end{pmatrix} = \begin{pmatrix} p_{14} - p_{34} \\ p_{24} - p_{34} \\ p'_{14} - p'_{34}u' \\ p'_{24} - p'_{34}v' \end{pmatrix}$$

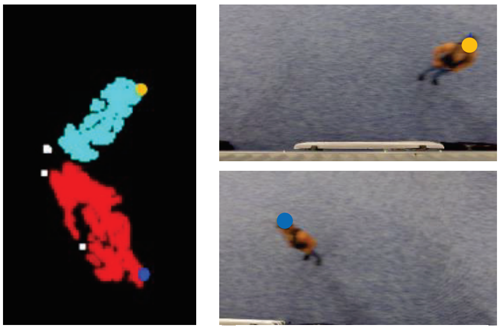
Solving (4.3) about Z_w equals calculating the height of an obstacle. This is therefore an appropriate method for calculating height.

However, there might be a case where we cannot set the corresponding points accurately. For an accurate calculation, if the height of the obstacle was calculated in previous frames, we calculate the weighted average between the height calculated in previous frames and the height calculated in the newest frame.

5. EXPERIMENT

We conducted two tests, a simulation test and a practical test. The former was carried out using a model truck one-fourteenth the size of a real truck, while the latter was conducted using a real truck. We used ten color “GoPro Hero4 Session” cameras (Fig. 5) in each test.

Figure 6 indicates some of the input images for the simulation test. Figure 7 indicates the result of the synthesis of the top view images and the detection of obstacles using their height. The green colored zones in Figure 7(b) indicate an obstacle’s existence, while the red



(a) Obstacle (b) Input image

Fig. 4 Top of an obstacle

colored zone indicates an obstacle that is close to the truck. The numbers in Figure 7(c) indicate the height of the obstacles. Figure 8 is an extended image of Figure 7(b). It shows whether the red and green zones indicate the correct obstacle position or not. The trash bin's color is similar to the color of the plane, so it was not detected well. Figures 9, 10, and 11 indicate the flow of the results when the truck was moving upward in the practical tests. The accuracy of the obstacle detection is worse than that of the simulation tests. One cause of this difference could be the method used for calculating the homography matrices. As stated above, we regarded the tiles on earth as a checkerboard, although they were not perfect because of their tilt. If we could better prepare the calibration environment, the accuracy would be improved. Table 1 indicates the accuracy of the calculations of the obstacles' height. It shows that the result for a tall object, for example, a human, is more accurate than the result for a flat object such as a car. This is because we calculate obstacles' heights by detecting the top of them, and the top of a tall object is more obvious than the top of a flat object.

Fig. 5 Camera we used in the tests

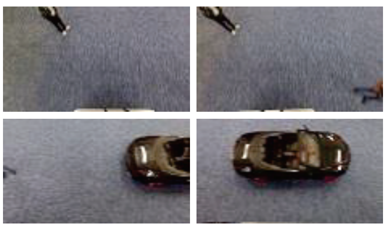
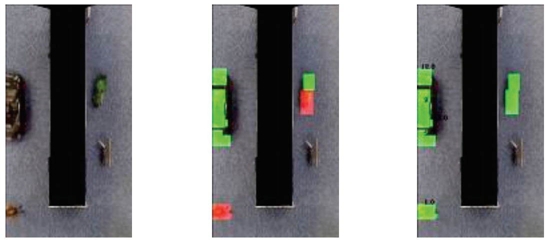
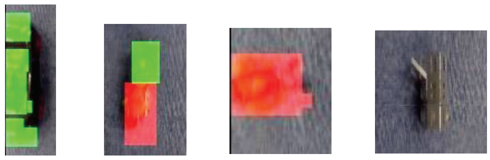


Fig. 6 Input images (Simulation test)



(a) Top view (b) Detecting obstacles (c) Obstacles with their height

Fig. 7 Result images (Simulation test)



(a) Car (b) Bike (c) Human (d) Trash bin

Fig. 8 Accuracy of detection

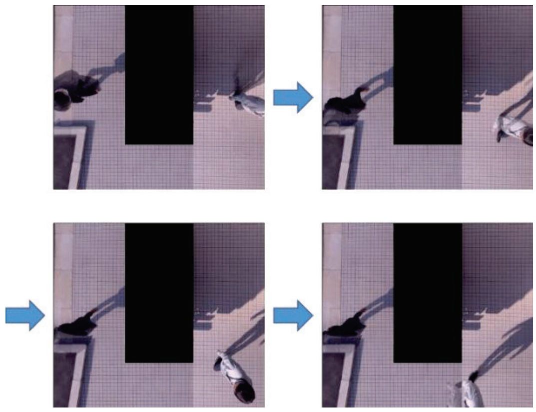


Fig. 9 Flow of images
(Top view, Practical)

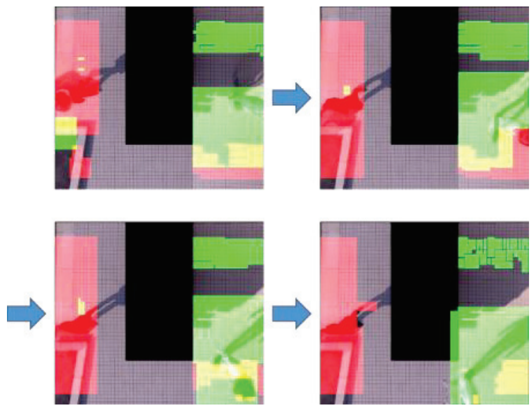


Fig. 10 Flow of images
(Detection of obstacles, Practical)

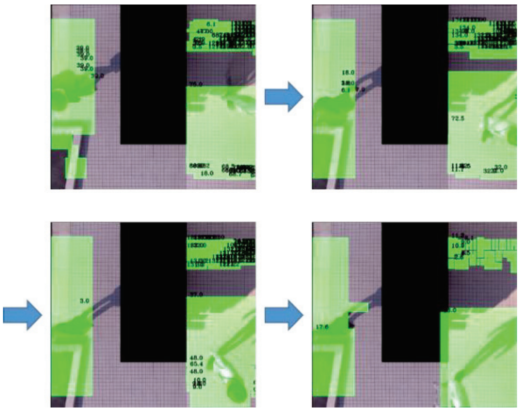


Fig. 11 Flow of images (Obstacles with their height, Practical)

Table 1 Accuracy of obstacles' height

	Car	Bike	Trash bin	Human
Actual height (cm)	6.5	7.0	7.5	14.5
Result height (cm)	10.8	11.2	9.7	14.1
Error rate (%)	66	37.5	21.8	3.4
Standard error	4.0	10.2	6.9	6.5

6. CONCLUSION

In this paper, we propose a system that supports truck drivers.

When using the system for the synthesis of top view images, we could generate images of the area around the truck without distortion by calculating the weighted average of the two pixel values.

We enabled the system for the detection of obstacles by densely attaching the cameras and creating an overlapped area. We could robustly detect obstacles by applying the tracking processing. However, in the practical test, we could not accurately detect them due to the homography matrices including many errors, although we could show the practicability of the proposed system.

We enabled the system for the calculation of the obstacles' height by determining the top points of the obstacles. The results depended on the shape of the obstacles, and we proved that we can accurately calculate the height of tall objects.

We believe that this system could help truck drivers and hence decrease the number of truck incidents.

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