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# Offset Vertical Stereo System for Real-Time Range-Finding to Preceding Vehicles

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**Abstract**

We have developed a new real-time range-finding system based on vertical stereo vision for measuring the distance to vehicles in front. In the system, stereo images are inputted from vertical cameras which are placed in the periphery of the windshield. However, the placement causes to the difference of vehicle's size in upper and lower images and missing stereo matching. To solve the problem, we proposed the powerful stereo matching algorithm that increases the missing. The method has two processes; the first process is to select particular characteristics of vehicles as matching candidates. The second process is to correspondence the same characteristic of the vehicles in the candidates using size invariant measure.

To evaluate the accuracy of our algorithm, we compared measured values with actual distance. The result that the measured value is close to the actual one is indicated to few missing matching. Moreover, we implemented the algorithm on our high-speed general-purpose video image processing system, ISHTAR, and processed video data in expressway scenes. We confirmed robustness of the algorithm under environmental changes, such as various vehicles in front, sunlight changes and shadows.

## 1. Introduction

Range-finding systems between vehicles are important to alarm collisions for drivers in traffic congestion. Conventional methods are sensors using microwave, ultrasonic or laser [1]. However, these sensors cannot distinguish preceding vehicles from other objects in the vicinity, such as vehicles in the next lane, or the guardrail. On the other hand, range-finding systems using image sensors can distinguish whether vehicles are in front or not and measure distances to only preceding vehicle.

We propose a new range-finding system based on stereo vision techniques that is one of popular range-finding systems using image sensors. The system realized fine mountability of stereo cameras' vertical arrangement and few miss-matching case in stereo matching. The mountability is ability to place vertical stereo cameras in the periphery of the windshield. And the stereo matching can reduce miss-matching caused from the offset arrangement using correspondence between positions of each vertical projections of long horizontal edges as particular characteristics of vehicles in front.

## 2. Conventional Range-finding System with Image Sensors

In the past, we proposed a vertical stereo system in which two cameras are aligned vertically, as shown in Figure 1. This system had ability of measuring distance in various conditions of vehicle types or sunlight. It could work in real-time with fast and compact algorithm.

In the vertical stereo system, the edge contrasts of horizontal lines are extracted as a characteristic feature of the preceding vehicle. The distance measurement is carried out identifying corresponding lines using a certain comparison criterion with respect to their edge contrast. Using horizontal lines seems a reasonable approach, as the identification of horizontal lines is easier than the identification of points, and the rear views of vehicles have clear horizontal lines, especially near the rear bumpers and license plates.

However, to make the range-finding system practical, the following three points are demanded.

(i) Robustness to environmental change, i.e., the system must work in various conditions of vehicle types, sunlight or weather.
(ii) Fast and compact processing algorithm for real-time measurement and cost reduction.
(iii) Mountability of the system on the vehicle.

The vertical stereo system did not cope with all of those three demanding. That is, considering the mountablity of vertical stereo camera on vehicles, the vertical arrangement leads to following problems.

(a) The lower camera may disturb the view and comfort of drivers.
(b) The hood narrows the view of the lower camera.

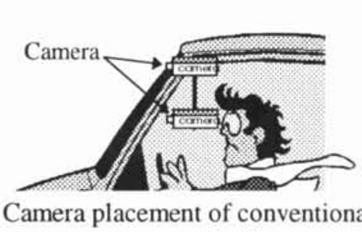


Fig. 1. Camera placement of conventional vertical stereo method.

## 3. Offset Vertical Stereo System for Range-finding

One solution for the problem of mountability may be to position the lower camera closer to the upper camera. However, the distance between the two cameras directly effects on the accuracy of the measurements: a smaller distance between two cameras results in lower accuracy. Therefore, this simple solution is not acceptable.

Our solution to the problem is to move the lower camera nearer to the windshield, as shown in Figure 2. With this arrangement, we can solve the above mentioned problem without narrowing the vertical distance between two cameras. However, this offset arrangement of two cameras causes another problem: the size of the preceding vehicle differs for the individual cameras, as shown in Figure 3. The difference influences the accuracy of measurement, especially in close distance where the accuracy is more important. Therefore, conventional algorithms that simply compare edge contrasts to identify corresponding horizontal lines are unsuitable.

To solve this problem, we try to choose reliable horizontal lines which have conspicuously large value of edge contrasts. While the actual values of edge contrasts are influenced by the offset vertical camera arrangement, the pattern of edge appearance in each image is similar. Moreover, restricting the number of corresponding candidates leads the finding of identical part to be easy. The key strategy is to choose easy recognizable horizontal lines as candidates for the identification of corresponding lines.

## 4. Design of the Range-Finding System

As shown in Figure 4, our new range-finding system consists of two TV cameras with offset vertical arrangement and three processing parts for (I) lane identification, (II) vehicle identification, and (III) stereo matching, respectively. First, in lane identification part, white or yellow lines that indicate the boundary of the cruising lane is estimated by edge detection. Next in vehicle identification part, the preceding vehicles are characterized by horizontal lines and they are extracted in identified cruising lane by means of edge histogram. Finally in stereo matching part, the identical parts of preceding vehicles are found by correspondence of conspicuous horizontal line and the distance is calculated from the positional difference of matched line in image.

These processing parts are detailed in the following subsections.

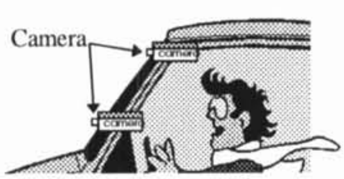


Fig. 2. New camera placement.

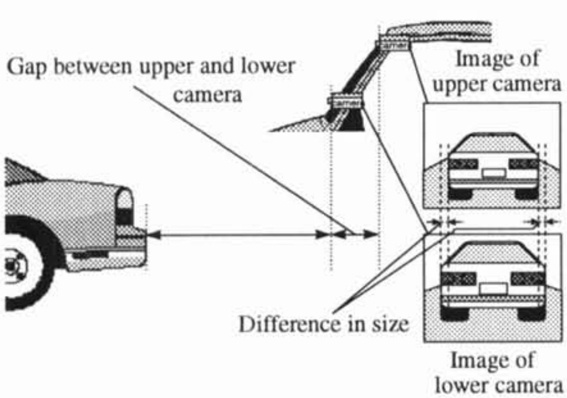


Fig. 3. Discrepancy caused by new camera placement.

### 4.1 Lane Identification Stage

The regions of the cruising lane as shown in the upper and lower images are determined in this stage. These left and right boundary of the lane is usually defined by solid or broken white, or solid orange lines. These two lines converge on a point in the image plane. For this reason, the region of the cruising lane is determined by identifying these two boundary lines. Assuming that the cruising lane can be approximated to be straight, the convergence point of the lines is the vanishing point. Consequently, the cruising lanes in the upper and lower images are determined by the following three steps also shown in Figure 5.

(i) Determination of left boundary: Using an edge operator, the constituent points of the left boundary line are determined and a straight line is calculated on this base as the left boundary line.

(ii) Detection of vanishing point: The vanishing point is calculated as the intersection point of vanishing line and left boundary line.

(iii) Estimation of right boundary: The right boundary line is calculated based on the vanishing point, known road width, and some camera parameters.

Here, it is assumed that the position of the vanishing line

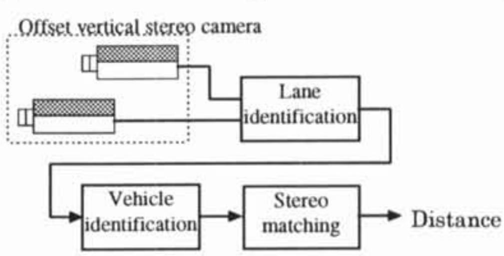


Fig. 4. Configuration of the range-finding system.

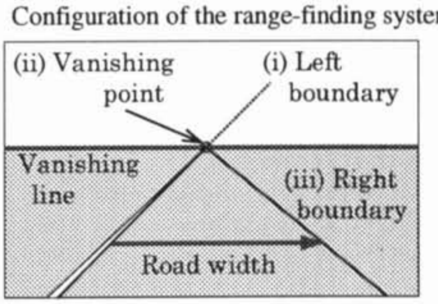


Fig. 5. Lane identification

and the width of cruising lane are known.

In the following parts, only the region which was determined as the cruising lane is considered. This is effective for avoiding the detection of irrelevant objects outside the cruising lane, and for reducing the processing load.

### 4.2 Vehicle Identification Stage

In this stage, preceding vehicles in the cruising lane are identified by the form of edge characteristics features. In the rear view of a vehicle, there are clearly defined horizontal lines, especially near the rear bumper or the license plate. As shown in Figure 6, the edge characteristics feature of the preceding vehicles is extracted by following steps.

(i) Detection of horizontal lines: The edge contrasts of horizontal lines are extracted by edge operation.

(ii) Horizontal projection of edge values: Summing up the values of edge contrasts, the characteristic features of preceding vehicles are determined.

Here, to improve the robustness of the extraction of horizontal lines, a wide edge operator is which is more sensitive to long horizontal lines is applied. This is because, when the operating point is a component point of a long horizontal line, the neighborhood points shall be the component. Making the edge operator wide, the output values of edge operator are interfered to be emphasized in horizontal lines, and not in the other point.

### 4.3 Stereo Matching Stage

In this stage, the corresponding horizontal lines in upper and lower images are specified and the distance to preceding vehicles is calculated from the parallax of them. Influenced by the offset arrangement of stereo camera, the corresponding characteristic features of horizontal lines are not same. Therefore, we selected longer horizontal lines for the candidate of stereo matching. Horizontal lines are chosen as if they have sufficiently larger edge contrasts compared to the other lines. In other words, as shown in Fig. 7, let the smallest value of selected horizontal lines' edge

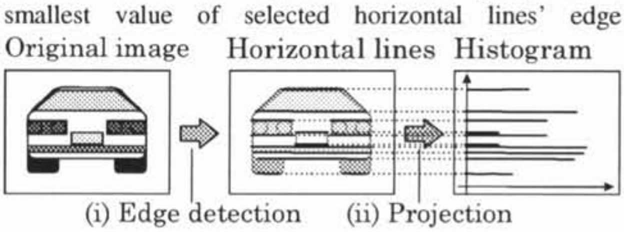


Fig 6. Vehicle identification

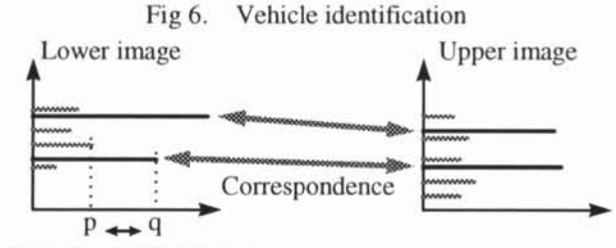


Fig 7. Correspondence of matching candidate

characteristic feature be p, and the largest value of unselected be q, the ratio of p and q must be greater than a threshold. After selecting candidates for corresponding horizontal lines from the images of the upper and lower cameras, the identification process is carried out by matching candidates from bottom to top within the list of candidates. Finally, the distances to the preceding vehicles are calculated based on the parallax of the identified corresponding horizontal lines.

Here, both the distance and height of the matched lines are calculated to distinguish preceding vehicles from traffic signs on the road. Matching of horizontal lines makes the stereo matching process easier and more accurate than what could be achieved with matching points.

In this algorithm, the values of edge contrasts are taken into account only when choosing the candidates for corresponding horizontal lines, but they are not used for the identification itself. We defined the border for line selection in such a way that the number of selected lines in the upper and lower images is identical.

## 5. Evaluation of the System

To evaluate the performance of our method, we made experiments for checking measurement accuracy and robustness to environmental change in real situations.

### 5.1 Evaluation of measurement accuracy

To evaluate the measurement accuracy, we compared measured distance of new range-finding system with actual distance using a test setting as shown in Figure 8(a). In the test setting, we mounted two cameras in offset vertical stereo arrangement onto a tripod. A target vehicle was moved in front of the stereo camera, and the actual distance between target vehicle and stereo camera was measured with a measuring tape.

Figure 8(b) shows the result of the comparison. In the figure, the bar chart means the measured distance of our method and the dotted points mean the correct distance. The line charts are the margin of estimated error which correspond to one pixel shift of the horizontal line in image plane. From this figure, it is clear that our system have the ability of measuring distance accurately within a reasonable range of error even in the close distance where the influence of the offset arrangement is severe.

### 5.2 Real-time simulations

To evaluate the robustness to environmental change, we made real-time simulations with actual setting as shown in Figure 9(a). We mounted the offset vertical stereo camera on a vehicle, and implemented the proposed algorithm on ISHTAR[3] which is our high-speed video processing system with digital signal processors. Using this system, we measured distance between vehicles for real expressway scenes.

Figure 9(b) shows the results of the measurement under various conditions summarized in Table 1. The number in each picture is the measured distance and the white lines shows the positions of the estimated corresponding horizontal lines of upper and lower images. The results indicate that our method works successfully in various conditions that are typical situation in practical use.

## 6. Conclusions

We proposed a new system characterized by offset vertical stereo vision which measures the distance between two vehicles as driver supporting system. To avoid the problems caused by mounting two cameras vertically, we arranged them in offset arrangement peripheral to the windshield. However, to compensate the new problems caused by this unique camera placement and to improve the accuracy of the measurement, we introduced a new selection algorithm that uses easily recognizable horizontal lines for identifying corresponding lines.

Through experiments in actual settings, we confirmed that our system provides sufficient accuracy within a reasonable error range and is robust against changes in the environment.

## References


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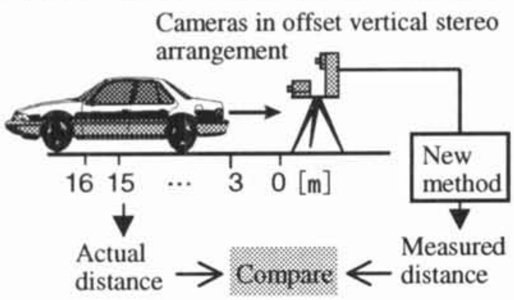
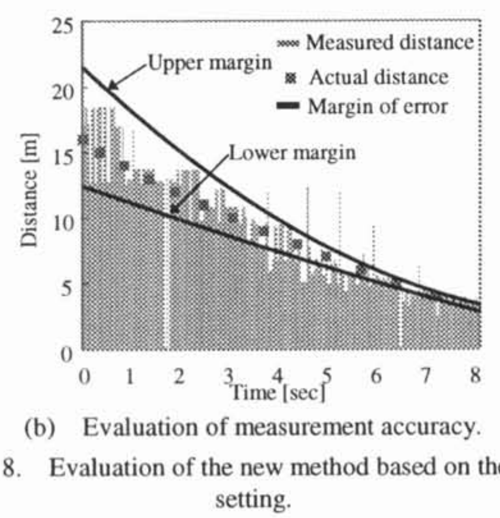
[2] M.Shiohara et al., "Real-Time Stereo Vision System for Rangefinding Between Vehicles, " Proc. of 4th World Congress on Intelligent Transport Systems (Oct. 1997).

[3] M.Shiohara et al., "Real Time Optical Flow Processor ISHTAR," Proc. ACCV'93, pp.790-793 (1993).


(a) Situation of test setting.

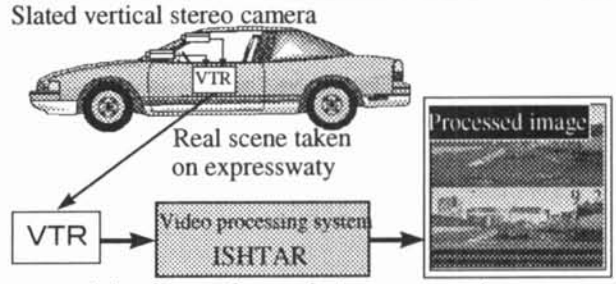



(b) Evaluation of measurement accuracy.

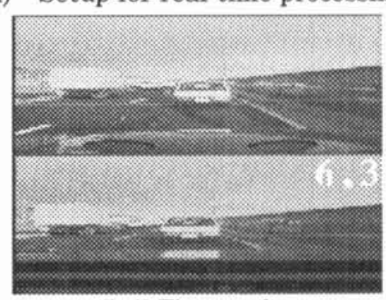
Fig. 8. Evaluation of the new method based on the test setting.

Table 1. Various conditions of real-time simulation

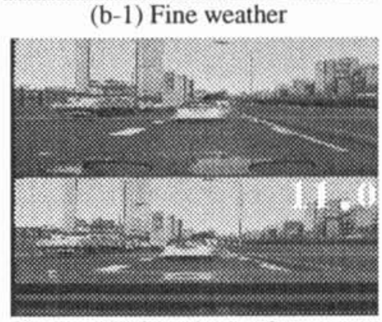
| | Truck | Small car | Motorcycle |
|---|---|---|---|
| Fine | ○ | ○ | ○ |
| Cloudy | ○ | ○ | ○ |
| Rain | ○ | ○ | ○ |
| Night | — | ○ | — |



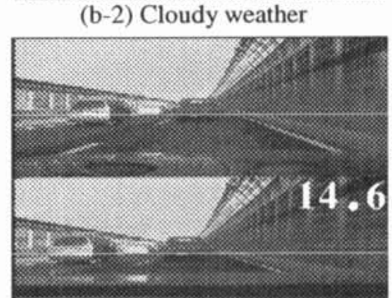

(a) Setup for real-time processing.




(b-1) Fine weather




(b-2) Cloudy weather




(b-3) In the shade

(b) Results under varying conditions.

Fig. 9. Real-time processing.