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Discrimination of an Approaching Vehicle at an Intersection Using a Monocular Camera

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Abstract— **A method of discriminating an approaching vehicle was devised for the purpose of constructing a visual driver assistance system at an intersection using a monocular camera. When a monocular camera is used, it is basically difficult to acquire distance information, so vehicle detection and discrimination of approaching vehicles without the use of distance information are associated issues. In this research, the presence of a vehicle at an intersection is detected by classifying the region on the image that has the shape of the vehicle, and the degree of the vehicle approach is discriminated by comparing the motion vector of the vehicle with the subject vehicle's direction of movement. By performing a test using this method, it was confirmed that it is possible to discriminate approaching vehicles.**

I. INTRODUCTION

In recent years in Japan, the number of traffic accident fatalities tends to have fallen, but conversely the number of traffic accident casualty has been increasing. Of traffic accidents involving two vehicles, the most numerous are rear-end collisions, followed by intersection collisions [1]. The greatest cause of intersection collisions has been the failure of the driver to see the other vehicle approaching. Consequently, we considered that a visual driver assistance system which detects an approaching vehicle and informs the driver should be effective in reducing traffic accidents. Also, if a monocular camera is used with such a visual driver assistance system, the system can be made compact, relatively easily, and its cost can be kept low, thus enabling it to be applied to a wide range of vehicle models. Accordingly, in this research, a monocular camera was used to construct a system that can discriminate the approach of another vehicle at an intersection. The effectiveness of this system was verified empirically.

The remainder of this paper is organized as follows. In Section 2, we introduce the approach to this research, and section 3 describes the detection method of vehicles and the method of discriminating an approaching vehicle. Section 4 indicates and examines the test results obtained using this system. Finally, section 5 summarizes the results of the research.

II. THE APPROACH

The goal of this research is to construct a visual driver assistance system that discriminates an approaching vehicle at an intersection, such as that shown in Fig.1, using a monocular camera. Until now, a front camera that could acquire images in a single visual field over a range of 190 degrees in the front of the vehicle has been put to practical use for systems using a monocular camera to provide visual assistance at intersections [2]. However, the visual assistance that this system provides to the driver is only an image display, and the driver must search for an approaching vehicle from these images. Consequently, it is considered that to provide more effective support for visual recognition to the driver, the system should be able to discriminate an approaching vehicle, and inform the driver of it.

In this research, we devise the following method of changing over the method of providing assistance to the driver for visual recognition according to the particular vehicle. First, at an intersection, a vehicle that has a high possibility of approaching the subject vehicle must be recognized by the driver as quickly as possible. For this reason, the driver is informed of the existence of the vehicle by means of an explicit alarm. Regarding a vehicle having a high possibility of passing through the intersection before the arrival of the subject vehicle at the intersection, it is also possible that the motion of the vehicle may change, causing the vehicle to approach the subject vehicle, so that the system captures the attention of the driver of the subject vehicle. On the other hand, regarding a stationary vehicle, although the system must recognize the existence of the vehicle to detect any change of motion without delay, the possibility of the vehicle approaching the subject vehicle is considered to be low, so there is no need for the system to take action in relation to the driver.

For the perspective of the above, the following method of carrying out vehicle discrimination in three states in relation to the possibility of the approach of the vehicle at an intersection is constructed as the target of this research.

(1) Degree of approach = Low level:
Stationary vehicle

(2) Degree of approach = Middle level:
A vehicle with a high possibility of passing in front of the subject vehicle

(3) Degree of approach = High level:

A vehicle with a high possibility of approaching the subject vehicle

In this research, an approaching vehicle is defined as a vehicle whose degree of approach is either high or meddle level.

Fig. 1 Target Intersection

III. Method of Discriminating an Approaching Vehicle

This section describes the methods of vehicle detection and motion vector extraction, which are necessary for discriminating an approaching vehicle, and the method of discrimination by comparing an approaching vehicle with the subject vehicle's direction of movement. The general monocular camera used in this research can not easily acquire data concerning the distance between the subject vehicle and an object in its vicinity. Consequently, the construction of a method of vehicle detection without using distance data and discriminating an approaching vehicle are issues involved in realizing a visual driver assistance system [3][4]. In this research, a vehicle is detected by classifying a region on the image that has the shape of the vehicle, and the degree of approach of the vehicle is discriminated by comparing the motion vector of the vehicle with the subject vehicle's direction of advance. Figure 2 shows the discrimination flow of approaching vehicles.

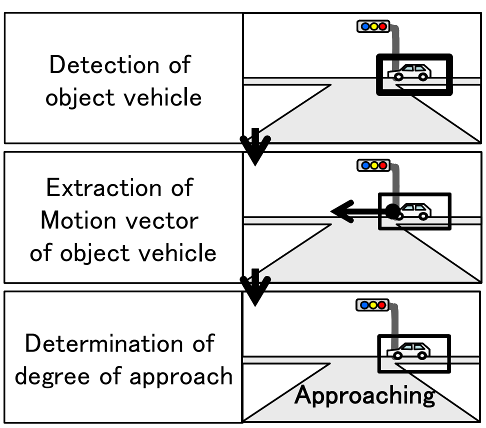


Fig. 2 Discrimination flow of approaching vehicles

A. *Detection of a Vehicle*

Because a passenger vehicle is the most common type of vehicle in use, this paper describes the case of a passenger vehicle as the type of vehicle to be detected. Note, however, that in this research the vehicle to be detected is facing sideways as seen from the subject vehicle. At present, there is a great variety of passenger vehicles (hereafter called "vehicles"), each with a unique shape. Consequently, it is conceivable that classification of a vehicle through learning can be realized by either learning the shapes of representative models, or learning the common features of a large number of kinds of vehicles [5]. The former method is impractical because it necessitates coping with new vehicles in the future and a large number of variations due to body fittings such as ski carriers, etc. Consequently, it is necessary to use the latter method, that is, to extract the common features of a large number of automobiles and carry out learning. As a result of observing vehicles based on this viewpoint, attention was paid to the fact that the lower half of the sideways-facing body of various passenger vehicles, that is, the undercarriage and the wheels are of similar appearance, as shown in Fig.3. In the selection of vehicle features that are the object of classification, there is a difference in appearance between the image acquired at a relatively short distance from the vehicle to be detected, and the image acquired at a long distance from it, so it is also necessary to take into account the appearance of the vehicle with distance. For example, in the case of the undercarriage, the greater the distance from the vehicle, the smaller the vehicle image becomes, and hence it is only possible to classify rough features such as the wheels and body shape. Conversely, the shorter the distance from the vehicle the larger the vehicle image becomes, enabling detailed features such as the lighting devices to be acquired. However, this results in an excessively large quantity of data concerning vehicle features, which conversely makes it difficult to detect the vehicle. As a result of a study using a camera, which is described later, it was found that when the Entire undercarriage and front part (hereafter called the "nose") of the vehicle are observed from a relatively short distance (about 0 to 20 m), individual features such as the lighting devices are noticeable. When these parts are observed from a long distance (about 20 m or more), however, they appeared to be the same shape, even for different kinds of vehicles. For this reason, the entire undercarriage and nose are classified by observation from a long distance. In contrast, the change in the appearance of the wheels with distance is relatively small compared to that of the undercarriage and nose, so the wheels are classified at a short distance. From the foregoing, the following three parts of the undercarriage are classified.

(1) Entire undercarriage : Long distance
(2) Nose (front edge of vehicle) : Long distance
(3) Wheels : Short distance

The relationship between the appearance of the image and distance differs depending upon the resolution of the image. In this research, the distance at which the object features are imaged at a resolution of at least 30 × 30 pixels is defined as short distance, and other distances as long distance. Because it is conceivable that a difference in appearance may arise in the above vehicle features depending upon the body color, the edge of each feature, which is affected by the body color to a relatively small degree, is extracted and used for classification. Figure 4 shows an example of the edge appearance of each vehicle features extracted by using of Sobel operator .

To classify the above vehicle features, AdaBoost using Haar- features[6], which is a statistical learning method, is used to configure a classifier. In this research, the vehicle features for learning were extracted from a small car, sedan, hatchback and mini-van, which are the main types of passenger vehicles currently in existence (Fig.4). Also, even when a vehicle exists in the image, it does not necessarily mean that all features are classified. Consequently, in this research, each feature is searched for simultaneously, and the vehicle is discriminated when one of the features is classified.

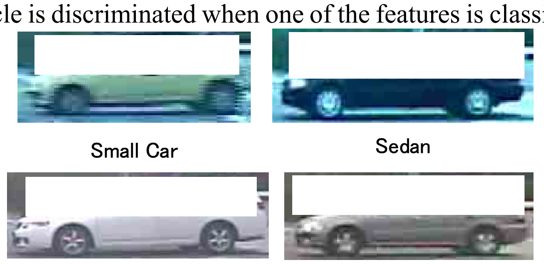


Fig. 3 Features of each vehicle

B. *Extracting the Vehicle Motion Vector*

In this research, the motion vector is obtained as the trajectory of the feature point of images. The sampling interval for the image is defined as Δt, and from the image at time:t and the next image at time:$t + \Delta t$, the feature point of each image is extracted using a Harris corner detector [7]. Next, the direction and magnitude of the motion between these images, that is, the optical flow, is extracted using the Lukas-Kanade method [8] [9]. The optical flow of the vehicle detected in advance is the motion vector required. Figure 5 shows an example of a motion vector extraction.

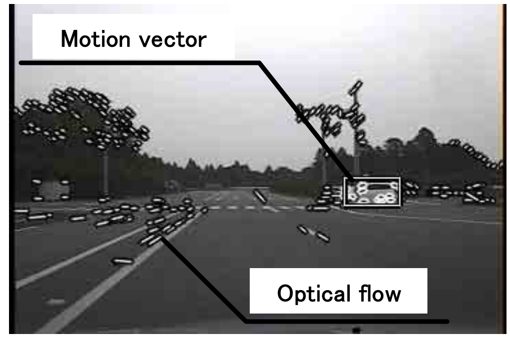


Fig. 5 Motion vector

C. *Discrimination of an Approaching Vehicle*

By comparing the motion vector of the vehicle obtained by means of the above processing with the direction of movement of the subject vehicle, the degree of approach of the vehicle is discriminated in three stages. The direction of movement of the subject vehicle in the image can be expressed as the Focus of Expansion (hereafter called FOE) [10]. With regard to discriminating the degree of approach of a vehicle in this research, attention is focused on the image region containing the detected vehicle (hereafter called "vehicle region"), and the discriminating value of approach is obtained as shown below, from the average values of the starting point and end point for all of the motion vectors in the vehicle region, the number of motion vectors per unit area in the vehicle region, and the position of the FOE.

- Position of FOE: $P_{foe} = (x_{foe}, y_{foe})$
- Number of motion vectors in the vehicle region: N
- Motion vectors in the vehicle region:

$$V_n = (x_{1n} - x_{0n}, y_{1n} - y_{0n}), (n = 0,1,\ldots,N-1)$$

- Average value of the starting point of the motion vectors:

$$P_0 = (P_{0x}, P_{0y}) = (\sum_0^{N-1} x_{0n} / N, \sum_0^{N-1} y_{0n} / N) \qquad (1)$$

- Average value of the end point of the motion vectors:

$$P_1 = (P_{1x}, P_{iy}) = (\sum_0^{N-1} x_{1n} / N, \sum_0^{N-1} y_{1n} / N) \qquad (2)$$

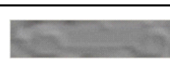
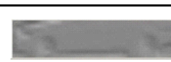
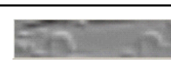
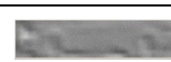
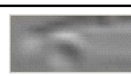
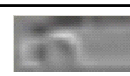
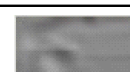
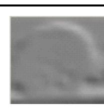
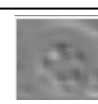
Model		Small car	Sedan	Hatchback	Mini-ban
Raw Image					
Features for learning (Edge)	Undercarriage				
	Nose				
	Wheel				

Fig. 4 Features for learning of each vehicle

・Area of the vehicle region : S

・Discrimination value of approaching : D_v

When $P_{1x} < P_{0x} < x_{foe}$, or $x_{foe} < P_{0x} < P_{1x} : D_v = -N/S$ (3)

When $P_{0x} < P_{1x} < x_{foe}$, or $x_{foe} < P_{1x} < P_{0x} : D_v = N/S$ (4)

1) Stationary Vehicle

A vehicle that has a low possibility of approaching the subject vehicle is a stationary vehicle at an intersection. In this case, although the vehicle is in a stationary condition, an apparent motion vector is generated due to the motion of the subject vehicle. This is shown in Fig.6. Consequently, a detected vehicle with a motion vector that moves away from the FOE is judged to be a vehicle that has a low possibility of approaching, and the degree of approach is discriminated to be low level (see eq.3).

・Discrimination condition: $D_v < -D_{threshold}$

Where $D_{threshold}$ is the threshold value

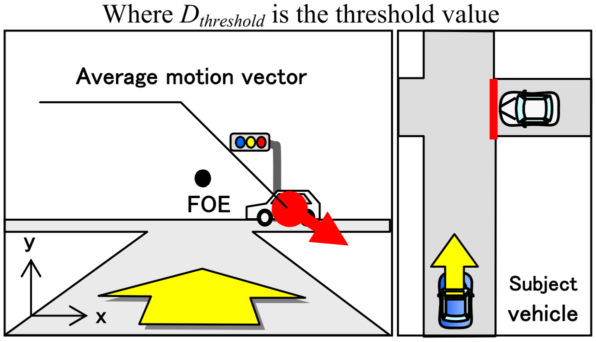


Fig. 6 Stationary vehicle

2) Vehicle that has the possibility of passing in front of the subject vehicle

Among vehicles that pass through an intersection in front of the subject vehicle, it is possible that some vehicles pass through the intersection without necessarily approaching the subject vehicle, or that the subject vehicle passes through the intersection before the approaching vehicle reaches it, as shown in Fig.7. In such a case, the motion vector of the vehicle is generated in the direction toward the FOE, as shown in Fig.7. Consequently, this is the case where the degree of approach is discriminated to be middle level. The discrimination condition is shown below (see eq.4).

・Discrimination condition: $D_v > D_{threshold}$

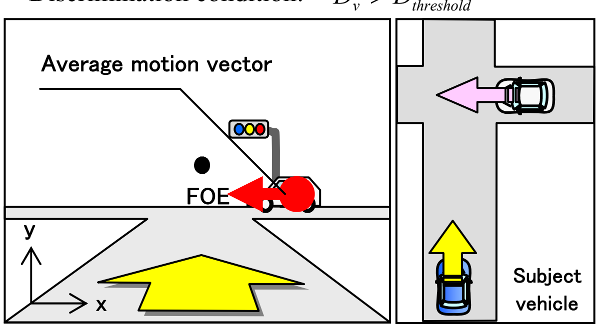


Fig. 7 Vehicle that has the possibility of passing

3) Vehicle having a high possibility of approach toward the subject vehicle

At an intersection, even among detected vehicles, particularly when a vehicle is traveling in such a way that it maintains a constant angle relative to the subject vehicle, as shown in Fig.8, it is considered highly probable that when the vehicle reaches the intersection it will approach the subject vehicle. In this case, the vehicle appears to become enlarged at a constant position on the image. For this reason, a motion vector is not generated in the image. Consequently, when the number of motion vectors per unit area of the vehicle region is no more than the threshold, the degree of approach is discriminated to be high level.

・Discrimination condition: $D_v \approx 0$

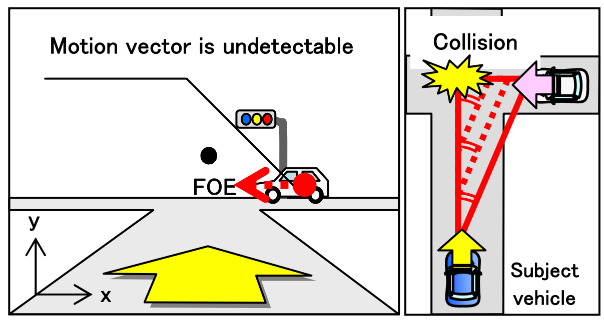


Fig. 8 Vehicle that has the high possibility of approach

IV. EXPERIMENTS

This section describes experimental results in which the vehicle is detected and the degree of approaching is discriminated using this method. The specifications of the CCD camera used are; NTSC output, 640 × 480 pixel resolution, and 48 × 36° field angle. In this system, an image reduced to 320 × 240 pixel resolution is used to reduce the computation cost. Classifiers of each feature were constructed using data sets shown in Table 1.

This experiment was performed at an intersection on a test course with good visibility. A camera mounted on the subject vehicle was used to obtain moving images of a vehicle approaching the same intersection as the subject vehicle, which was moving in a straight line.

A. Vehicle Detection

Figure 9 shows the detection results of each feature of vehicles by the classifier that was configured using this method. The test image data used in the experiment were captured at the test course and within an urban district shown in Table 1. From these, it was found that the entire undercarriage, nose and wheels, which were the object of classification, have been classified. In contrast, Fig.10 shows an example of a detection failure. This is described later in "Consideration". Fig.11 shows a ROC curve of vehicle detection using classifier constructed from each classifier of three features as follows.

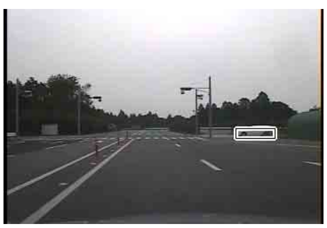
$$Vehicle = Entire\ undercarriage \cup Nose \cup Wheel \quad (5)$$

The final detection rate was more than 90% (Fig.11).

By using this classifier, the frequency that an approaching vehicle was advancing to an intersection with good visibility at a speed of between 10 and 30 km/h was classified from the subject vehicle, which was moving in a straight line toward the same intersection at a constant speed of between 40 and 60 km/h, was obtained. This trial was repeated 30 times, and the results obtained from the sum of these trials are shown in Fig.12. From Fig.12, it can be seen that in the section between 15 and 40 m away from the intersection, the frequency of classification of the entire undercarriage and nose is high, but the wheels are not classified. In contrast, in the range between 15 m and a point immediately before the vehicle, the classification frequency of the entire undercarriage and nose falls, and that of the wheels increases.

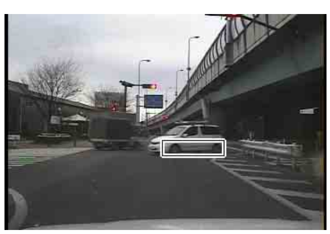
Table 1 Size of data sets

	Positive data	Negative data	Cascade
Entire undercarriage	1783	3800	20
Nose	1936	3800	20
Wheel	971	3800	20
Test image data	2069		




(a) Entire undercarriage (b) Nose


(c) Wheel (d) Nose and Wheel

(e) Nose (f) Entire undercarriage

Fig. 9 Detection results of each feature of vehicles

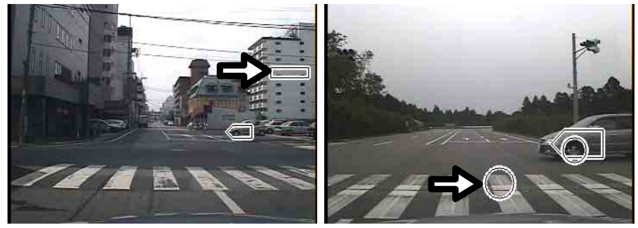


Fig. 10 Example of detection failures

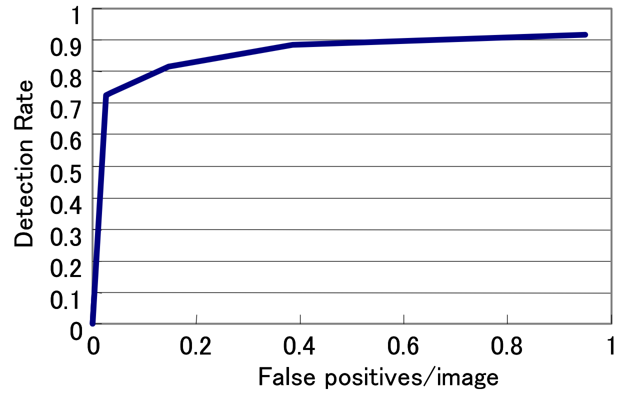


Fig. 11 ROC curve of vehicle detection

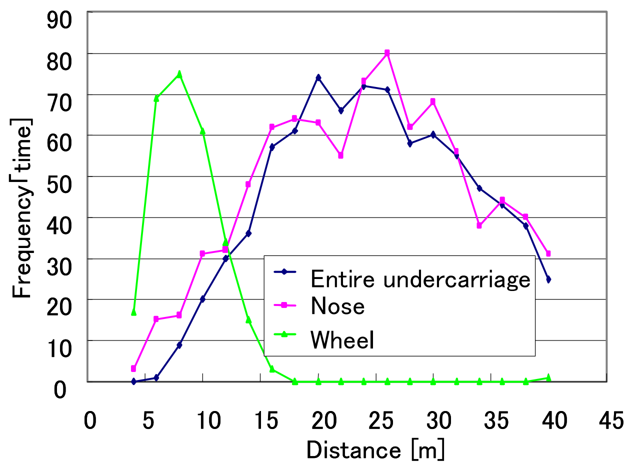


Fig. 12 Detection frequency of each feature

B. Discrimination of Degree of Approach

Discrimination of the approach of the passing vehicle shown in Fig.7 and the vehicle shown in Fig.8, which has a high possibility of approach toward the subject vehicle, that is, vehicles that approach the subject vehicle while maintaining a constant angle relative to it, was performed. The results are shown in Figs.13 and 14. Regarding the vehicle with a high possibility of approach toward the subject vehicle, the variation in the discrimination value of approach increases in proportion to distance, as shown in Fig.13. Conversely, the variation in the discrimination value of approach for a passing vehicle is small, as shown in Fig.14. Also, in both cases, when the degree of approach is low, a stationary condition was successfully discriminated.

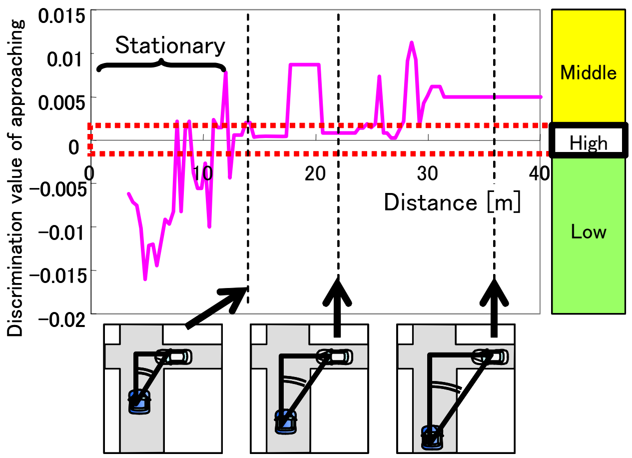


Fig. 13 Approach possibility = High level

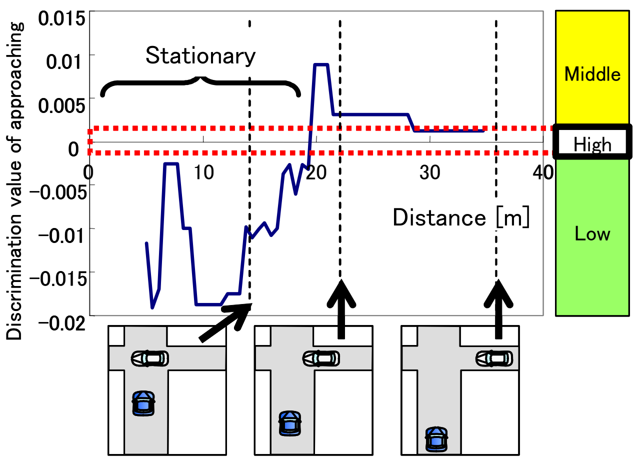


Fig. 14 Approach possibility = Middle level

C. Consideration

By classifying the features of a vehicle in this system, it was confirmed that the vehicle could be detected without using distance information, as shown in Fig.9 and Fig.12. Detection of a vehicle from a long distance is possible by classifying the entire undercarriage and nose of the vehicle, which are of simple shape. Consequently, it is considered that a vehicle can be detected even in an image that has a relatively low resolution. It was confirmed that the classification accuracy of the wheels increases at a short distance. From these facts, it can be said that by setting the object features according to distance it is possible to perform vehicle detection that is stable with respect to variations in distance. However, several detection failures occurred. Representative failures are misdetection of road signs and objects that resemble the shape of a vehicle, as shown in Fig.10.

In discrimination of an approaching vehicle, a distance section in which there is both a high and middle possibility of approach exists for a vehicle that has a high degree of approach, as shown in Fig.13. It is thought that this is due to the fact that the number of motion vectors of the approaching vehicle varies according to the acceleration or deceleration of the subject vehicle or the approaching vehicle. Regarding a vehicle for which there is a middle possibility of approach, it is possible to discriminate a relatively stable degree of approach, as shown in Fig.14. Also, in both cases, there is a tendency for both a high and middle possibility of approach to stabilize with decreasing distance. For the foregoing reasons, it is considered that in the medium to short distance range the degree of approach of a vehicle should be presented to the driver, and outside this range the existence of a vehicle should be presented.

V. Conclusion

A system that uses a monocular camera to discriminate an approaching vehicle at an intersection for visual driver assistance was constructed. Concerning the discrimination of a vehicle that has a possibility of approach toward the subject vehicle at an intersection, a number of features of the vehicle were defined as the object of classification, indicating that it was possible to detect the vehicle with respect to variations in distance as well. By using this result to compare the motion vector of a vehicle obtained from the optical flow with the subject vehicle's direction of movement, it is possible to discriminate the possibility of approach of the detected vehicle in three stages: for a stationary vehicle, for a vehicle that has a high possibility of passing in front of the subject vehicle, and for a vehicle that has a high possibility of approach toward the subject vehicle.

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