Paper

A Study on Discrimination of Forward Objects on the Road Using Laser Radar and a Camera

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This paper describes a new method for distinguishing objects on and alongside the road using a scanning laser radar (SLR) and a vehicle-mounted camera. Objects are detected on the basis of SLR digital signal data and the types of objects are distinguished by using their movement vectors and positions relative to white lane markers. For object detection, a new two-step grouping method is proposed for improving detection accuracy. The movement vectors of objects are adjusted properly based on the steering angle and speed of the host vehicle. The proposed method has been validated on a simulator using data recorded at a velocity of more than 40km per hour on Japanese expressways. The expected discrimination of vehicles, delineators and overhead signs in the forward view was successfully achieved in the simulation.

Keywords: object detection, discrimination of forward objects, scanning laser radar, lane recognition, ITS

1. Introduction

Vigorous activities are under way to research and develop forward environment recognition technologies in order to achieve applications such as driving-assistance systems [(1)]. Significant progress has been achieved especially with regard to measurement of the distance between the host vehicle and a preceding vehicle. Some of the resulting technologies have been implemented on production vehicles, for example, as the sensing system for Adaptive Cruise Control (ACC) [(1) (2)].

Meanwhile, various driving-assistance systems, such as a lane-keeping support system and a driving environment information system, have been proposed as a result of R&D work on Intelligent Transport Systems (ITS) [(3) (4) (5)]. These advanced systems require more sophisticated environment recognition technologies not only for measuring distance but also for distinguishing objects around the host vehicle.

Scanning laser radar (SLR) is often employed as an onboard sensor in such systems. This is because vehicles are often equipped with rear reflectors that can be sensed by SLR. Its reasonable price and suitable size for vehicle application are also other reasons. An SLR unit is able to measure the distance and direction of objects, but it is difficult to distinguish the types of detected objects with SLR data alone. Many methods have been proposed for detecting forward vehicles using points sensed by SLR. With one method, a vehicle is detected as a set of two sensed points having the same relative vector [(6)], based on the physical features of vehicles. With another method, vehicles are detected using an integration of the histogram of sensed points and some groups of which they consist [(7)]. Some methods have also been reported for detecting objects by integrating SLR and the recognition of lane markers by image processing [(6) (8)]. However, the main aim of these proposed methods is just to detect a preceding vehicle. It is difficult with these methods to detect objects in adjacent lanes or forward objects other than vehicles.

We propose an object detection/discrimination method that can handle not only preceding vehicles but also other objects on and alongside the road ahead. This method combines an SLR unit and image processing.

An SLR unit can basically measure the relative locations of laser-reflective objects. Objects detectable by SLR around the host vehicle on expressways include moving objects such as cars, motorbikes and trucks and stationary objects such as roadside reflectors, traffic signs, billboard signs and so on. This paper presents a method for distinguishing these SLR-detectable objects and sorting them into three categories: (1) vehicles, that is, moving objects on the road ahead, (2) delineators, that is, roadside reflectors and (3) overhead signs. Motorbikes, trucks and ordinary vehicles are in the first category. Overhead signs that the host vehicle's lane pass under are in the third category.

In order to categorize objects properly, each object must be separated from the other types and detected as one object. A novel way of grouping SLR sensed points is proposed for improving object separation accuracy. This method is characterized by the use of a two-step grouping procedure based on the positional relations among the points and the movement of the groups. In the first step, points located close together are collected and merge into a small group. In the second step, small groups are merged further as an object according to the movement vector of each small group. Without this consideration of movement vectors in the second step, a delineator is often misrecognized as a part of a vehicle when the latter passes near the delineator.

A method of judging whether objects are stationary or moving is also proposed which takes both the direction of movement and the speed of an object into consideration. Since this approach uses not only the speed but also the direction in making a judgment, it achieves better accuracy in distinguishing between a stationary object and a moving one in some difficult cases, for example, when the host vehicle is on a curve, or an object crosses in front of the host vehicle.

Image processing is used to detect white lane markers on the road ahead. This detection result is used in judging whether detected objects are obstacles in the host vehicle's lane or not.

In this study, the applied scenes are limited to the ones where the host vehicle runs at a velocity of more than 40km/h on Japanese expressways. This paper explains the proposed method and shows the results of an experiment conducted with a simulator using data recorded on Japanese expressways.

2. Sensor Configuration

2.1 Block Diagram Figure 1 shows a simplified block diagram of the proposed method. In the grouping block, forward objects are detected based on SLR sensed points, and a detection history that forms the paths of the objects is stored in memory. A judgment is then made as to whether detected objects are stationary or moving. A CCD camera is used for recognizing white lane makers. At the final stage, the types of detected objects are judged by integrating all of all this information.

2.2 Sensor Configuration Figure 2 shows the sensor configuration used with this method. Consisting of an SLR unit and a camera, this is one of the most commonly used configurations for forward environment recognition. The SLR unit is installed in the front bumper and a forward-looking camera is located behind the rearview mirror. The basic scanning direction of the SLR is parallel to the axis of the camera lens. The SLR beam scans the forward direction horizontally, in other words, parallel to the road surface.

The coordinate system is defined as shown in Figure 2. The Z-axis is the center line of the scanning plane of the SLR, the X-axis corresponds to the direction at a right angle to the Z-axis and parallel to the road surface, and the Y-axis is perpendicular to the road surface.

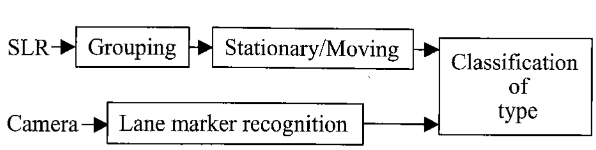


Fig. 1. System block diagram.

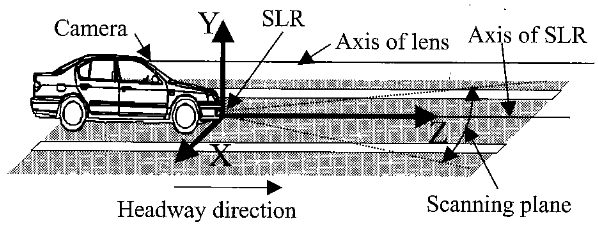


Fig. 2. Sensor configuration.

3. Proposed Method of Object Discrimination

3.1 Two Step Grouping Method for Object Detection Figure 3 illustrates object detection by SLR. The small circles in the figure indicate the SLR detected points (SDPs). Since SDPs are distributed around small reflective surfaces, a grouping process for collecting the SDPs that are part of the same object is required in order to detect objects accurately.

All SDPs belonging to one object should be measured at almost the same distance by SLR. However, accurate object detection may not be accomplished if only this distance information is used in the process. For example, moving vehicle A and delineator D in Figure 3 may be regarded as belonging to the same object when both of them are very close. To avoid such error, a new two-step grouping method is proposed that uses not only the distance but also the movement vector of the groups.

One reflective surface usually consists of a number of SDPs, as indicated in Figure 3. In the first step of the grouping operation, the system recognizes a small group of SDPs as a reflective surface. They are shown as the dashed line ellipses in the figure. The system gathers the points that are at almost the same distance and have almost the same movement vector. The results of this second step of the grouping process are shown as the solid line ellipses in Figure 3. This achieves higher object detection accuracy than traditional grouping methods thanks to the consideration of movement vectors. This procedure outputs the position and the width of each detected object. The position is calculated in reference to the central position of a detected object, and the width is calculated from the SDPs of the object on both sides (for example, object-B in Figure 3).

After this detection process, the detection reliability of each object is checked by referring to some previous detection results and searching for an identical object. An object is identified if its current position matches the position estimated from previous observations. The estimated position is calculated assuming the object moves as it has previously moved. The result of this process is also used to calculate the path of the object as seen from the SLR unit.

3.2 Stationary/Moving Judgment

3.2.1 Basic principle Judgment of whether detected objects are stationary or moving represents important information for distinguishing types of objects.

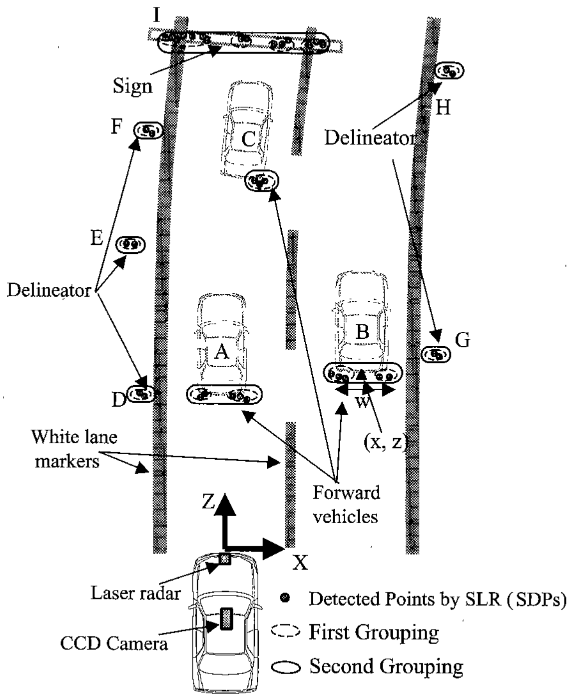


Fig. 3. Results of object detection using SLR.

This judgment is generally made by comparing the speed of the host vehicle with the observed speed of an object. The observed speed is usually calculated from the change in position of the detected object. However, one drawback of this simple method is that the system can not estimate the object's speed correctly when it moves laterally or when the host vehicle is on a curve(Figure 4).

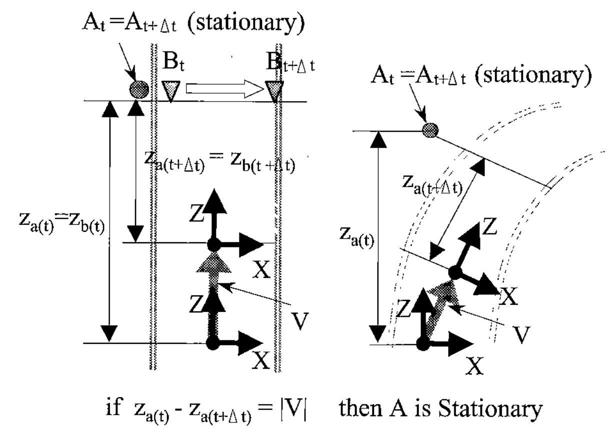
Therefore, we propose an improved method which takes both the speed and direction of movement into consideration. An overview of this method is given here in reference to Figure 5.

Consider that there is a stationary object denoted as object-A. Figure 5 shows the change in position of object-A as seen from the vehicle-mounted SLR unit. When the SLR unit moves in parallel by (x_c, z_c) and its axis rotates on the Z-axis by θ from time t to time $t+\Delta t$, Eq. (1) gives the observed position of the object at time $t+\Delta t$. Therefore, the apparent movement vector of each detected object assumed to be in this coordinate system can be estimated with this equation.

$$\begin{bmatrix} x_{a(t+\Delta t)} \\ z_{a(t+\Delta t)} \\ 1 \end{bmatrix} = \mathbf{T_c}\mathbf{T}_\theta \begin{bmatrix} x_{a(t)} \\ z_{a(t)} \\ 1 \end{bmatrix} \cdots\cdots\cdots\cdots (1)$$

$$\mathbf{T_c} = \begin{bmatrix} 1 & 0 & -x_c \\ 0 & 1 & -z_c \\ 0 & 0 & 1 \end{bmatrix}$$

$$\mathbf{T}_\theta = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$



(a) Object moves left to right (b) Vehicle on a curve

Fig. 4. Problems in an ordinary stationary/moving judgment method.

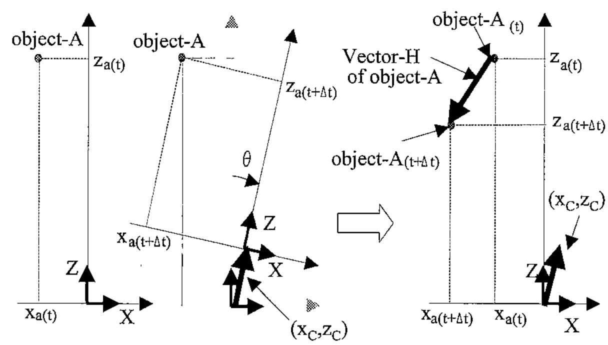


Fig. 5. Positions of stationary object.

At the same time, the movement vector of object-A is also obtained by the path of the objects in the grouping process (3.1). A comparison of these two vectors is used in judging whether the object is stationary or not. Vector-H is defined as a vector that is estimated with Eq. (1), and Vector-D as another vector which is based on the object detection history.

3.2.2 Calculation of Vector-H The information needed to estimate vector-H is the path of the host vehicle. It can be calculated from the host vehicle's speed and steering angle. The path is obtained based on the Newton equation for the motion of the vehicle [9].

3.2.3 Calculation of Vector-D Vector-D can be calculated from the path of the SLR detected object. However, obtaining the lateral position x of the object accurately is more difficult than obtaining the distance z. The reason is that, for example, either the right or left reflector may be missing in the case of wide objects. Overlapping objects or a small change in the direction of the reflector can also be reasons. Since these conditions are basically unavoidable, an interpolation mechanism is proposed here that uses the object detection history in order to reduce the effects caused by unstableness

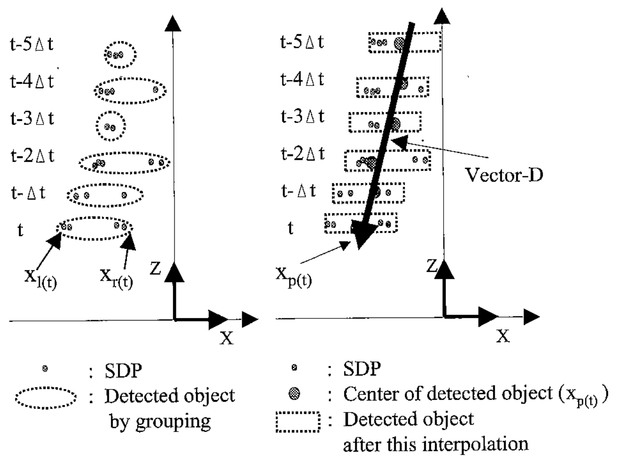


Fig. 6. Calculation of vector-D.

(Figure 6).

(1) The detected right and left points of the object are interpolated by the least squares method using the previous detection history.

(2) The center position between the right and left edges after the interpolation is taken as the representative position of the object.

(3) Vector-D is calculated as a straight line of which the square error of the current and previous representative position is minimum.

3.2.4 Stationary/moving judgment Judgment of whether an object is stationary or moving is based on the following two equations with vector-H and vector-D. Eq. (2) is for similarity of speed and Eq. (3) is for similarity of direction. If both equations are satisfied, the object is judged as being stationary.

$$C \times |\overrightarrow{\mathrm{H}}| < |\overrightarrow{\mathrm{D}}| \cdots\cdots\cdots\cdots (2)$$

$$\frac{\overrightarrow{\mathrm{H}} \cdot \overrightarrow{\mathrm{D}}}{|\overrightarrow{\mathrm{H}}||\overrightarrow{\mathrm{D}}|} > R \cdots\cdots\cdots\cdots (3)$$

where C and R are constants for judgment of differences in speed and direction.

3.3 Lane Detection by Image Processing Many methods have been proposed for detecting white lane markers. We use a method [10] to obtain the road curvature ρ, yaw angle relative to the tangent of the lane γ, and the distance between SLR and the center of the lane xg in reference to the detected lane markers (Figure 7).

3.4 Object Classification Using the result obtained in the processes above, this system distinguishes the types of detected objects, which are categorized roughly as (1) vehicles, (2) delineators and (3) signs. The detection result for white lane markers is used for objects at medium to short distances from the host vehicle because detection accuracy decreases with increasing distance in the case of white line detection by image processing.

The specific conditions for judging types of objects

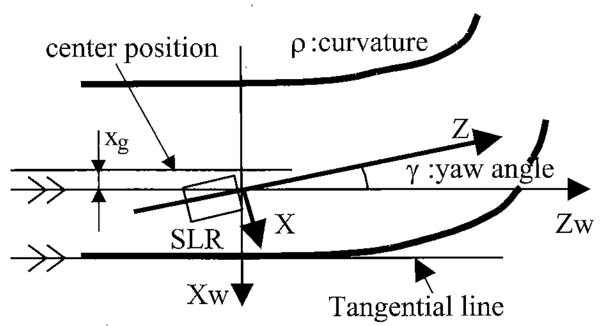


Fig. 7. Road model for white lane marker recognition.

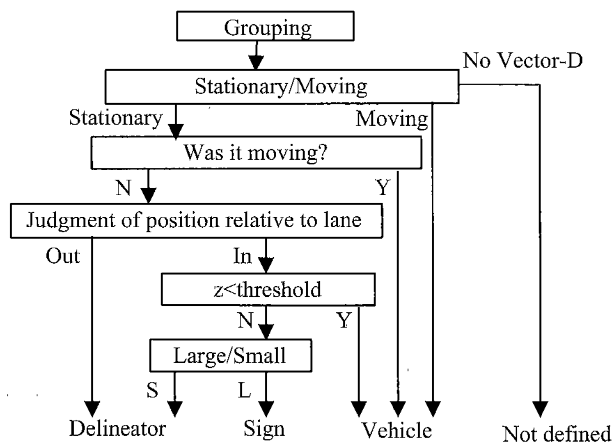


Fig. 8. Flowchart of object discrimination.

are as follows.

(1) Vehicle
- a moving object
- an object which had been detected as a moving object for a certain period of time
- a close stationary object in the host vehicle's lane

(2) Delineator
- an object at a short to medium distance and outside the host vehicle's lane
- a far and narrow stationary object

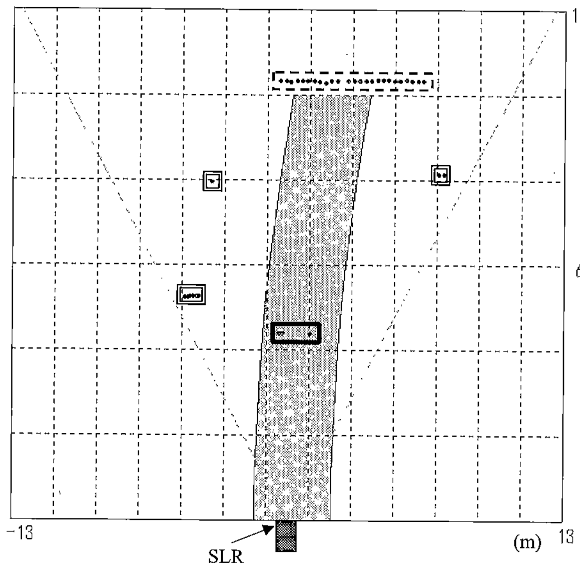
(3) Sign
- a far object in or above the host vehicle's lane

Figure 8 shows a flowchart of the judgment process. No judgment is made for an object without vector-D.

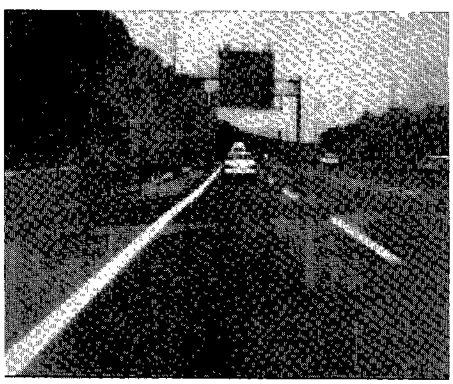
4. Experiment

The proposed method was evaluated on a simulator developed on a PC, using image data and SLR data recorded on Japanese expressways. The evaluation was limited to the following conditions.

- under suitable weather conditions for SLR
- radius of curvature is more than 200 m
- host vehicle's velocity is more than 40km/h
- on a road with a fixed number of lanes marked with white markers (except for merging or divid-

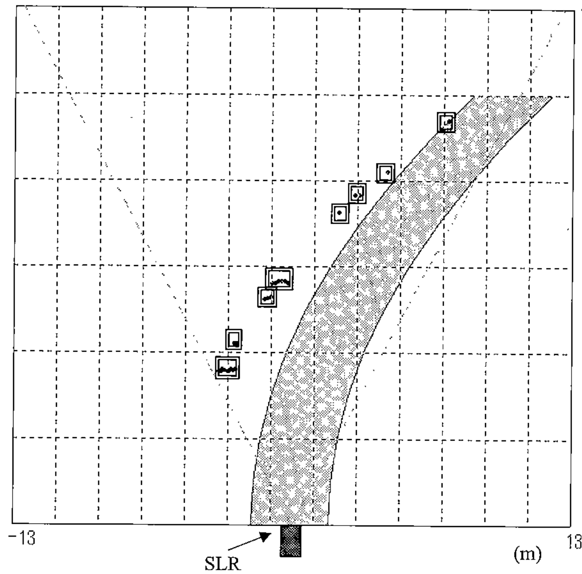


(a) SLR detection results

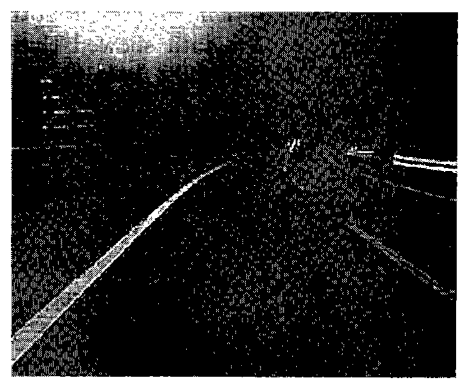


(b) Forward image

Fig. 9. Detection of three types of objects.



(a) SLR detection results



(b) Forward image

Fig. 10. Detection of delineators.

ing points)

The constants in Eqs. (2) and (3) that are necessary for a stationary/moving judgment were set at C=0.8 and R=0.95. Limits were put on the range for object detection. The range for detecting signs was set at z ≧ 70 m and that for detecting positions relative to the white lane markers was set at z ≦ 60 m. Recorded data for 10 minutes of driving were used in the evaluation.

Figures 9 and 10 present examples of object detection by SLR and object discrimination. In both cases, figure (a) shows SDPs and figure (b) is an image recorded at the same time. In (a), rectangles enclosed by a solid line denote detected vehicles, those enclosed by double lines signify delineators and those in dashed lines represent signs.

The results of distinguishing between vehicles, delineators and signs can be seen in Figure 9. Figure 10 is for a situation with no other vehicles. In such situations, delineators are apt to be misrecognized as vehicles because they appear sequentially in front of the host vehicle as if they were vehicles. With the proposed method, these delineators can be recognized correctly as delineators based on a stationary/moving judgment.

Table 1 Distinction Accuracy

Result \ Object	Vehicles	Delineators	Signs
Vehicles	100%	1%	0%
Delineators	0%	99%	36%
Signs	0%	0%	64%

Table 1 shows the discrimination accuracy of the detected objects in this particular driving situation. For all objects detected in 100-ms intervals in the experiment, a comparison was made of their actual types and how they were categorized by the system. The values in the table indicate the results of this comparison and are given as the percentages of correct categorization.

It is clear from the table that vehicles and delineators were accurately distinguished in this experiment. Also, signs weren't misrecognized as vehicles. It is very important for forward vehicle recognition systems on expressways that vehicles and the other objects are correctly distinguished. In this point, the expected discrimination of vehicles and the others in the forward view was successfully achieved in the simulation.

On the other hand, the system often misrecognized signs as delineators. The main reason for this error was the overlapping of objects. This isn't problem for obstacle detection system on the applied scenes in this experiment. However, the discrimination is also expected to be improved for brushing up this method to include more complicated scenes.

5. Conclusion

This paper has proposed a method of distinguishing vehicles, delineators and signs through a process that integrates three components: object detection based on a two-step grouping operation, a stationary/moving judgment of detected objects in reference to their movement vectors, and white lane marker detection using image processing. Experimental results obtained with a simulator using recorded data showed that vehicles and delineators were successfully distinguished. However, some problems remain regarding sign recognition. An object categorization method for resolving occlusion problems based on positional relations among detected objects or sign recognition based on image processing can be applied to overcome these problems.

Further experimental study involving various complicated situations is needed to improve this object discrimination technology for practical use.

(Manuscript received June 6, 2001, revised October 9, 2001)

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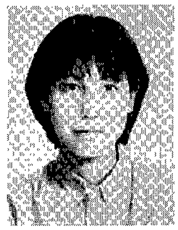

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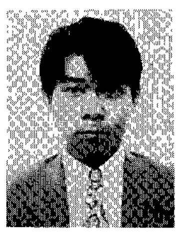

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