Robust License-Plate Recognition Method for Passing Vehicles Under Outside Environment

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***Abstract*—In this paper, novel methods to recognize license plates robustly are presented. A sensing system with a wide dynamic range has been developed to acquire fine images of vehicles under varied illumination conditions. The developed sensing system can expand the dynamic range of the image by combining a pair of images taken under different exposure conditions. In order to avert blurring of images against fast passing vehicles, a prism beam splitter installed a multilayered filter, and two charge-coupled devices are utilized to capture those images simultaneously. Furthermore, to extend the flexibility of camera placement, a recognition algorithm that can be applied to inclined plates has been developed. The performance of recognizing registration numbers on license plates has been investigated on real images of about 1000 vehicles captured under various illumination conditions. Recognition rates of over 99% (conventional plates) and over 97% (highly inclined plates) showed that the developed system is quite effective for license-plate recognition.**

***Index Terms*—Character recognition, image processing, license-plate recognition, wide dynamic range camera.**

I. Introduction

IMAGE-BASED vehicle recognition is categorized into detection, classification, and identification. These have been adopted widely to various applications during the past two decades. The detection of vehicles is applied to advisory of congestion, occupancy management of parking areas, and surveillance of illegally parked vehicles. The classification is utilized for the electronic toll-collection system (ETC) and to display available parking spaces to vehicles. The identification is also employed for managing parking facilities, monitoring and analysis of traveling time, and security systems such as observation of stolen vehicles and monitoring of unauthorized vehicles entering private areas.

One of the most effective and useful techniques of vehicle identification is the recognition of license plates from images captured with TV cameras. The application fields of license-plate recognition have become widespread. For instance, to achieve comprehensive applications being developed intensively under the framework of Intelligent Transport Systems [1], license-plate recognition is one of the key functions. Moreover, demands to apply license-plate recognition in small-scale facilities [2], such as for managing a private parking lot and monitoring vehicle entry and exit at a factory, are increasing.

License-plate recognition is realized by acquiring images of either the front or the rear of vehicles with TV cameras and then by image processing to identify license plates. Therefore, the sensing system for taking images and the recognition algorithms are the most significant roles.

Recognition algorithms reported in previous research are generally composed of several processing steps, such as extraction of a region of a license plate, segmentation of characters from the plate region, and recognition of each character. As to extraction of the plate region, techniques based upon binary image processing [3], neural network, and Markov Random Field [4] have been proposed. A number of techniques to segment each character after localizing the plate in the image have also developed. In [5], histograms generated by projection of edges onto vertical and horizontal axes were used. Neural network and fuzzy logic were adopted in [6]. For recognizing segmented characters, numerous algorithms exploited mainly in optical character-recognition applications [7], [8] utilized template matching methods [9], [10], statistical approaches [11], [12] (e.g., Mahalanobis distance), and neural networks [13], [14].

Not only recognition algorithms, as described above, but also the property of a sensing system should be a considerable issue in practical use. The sensing system utilized for license-plate recognition under outside environment has to be capable of capturing fine images under varied illumination conditions, i.e., from low brightness at twilight up to high brightness at noon, and simultaneously of capturing nonblurring images for fast passing vehicles.

In order to make a sensing system robust for the change of illumination conditions, it is required to expand a dynamic range of the sensing system. One approach to expand the dynamic range is to improve the property of the sensing device itself. The other is to obtain an image with a wide dynamic range by applying image processing to the images captured with a conventional TV camera.

Some imaging devices have been developed in the former approach. A typical example is the charge-coupled device (CCD) camera, whose device is forced to cool at a low temperature to suppress thermal noise. In addition, logarithmic conversion CCD sensors [15]–[17] and a hyperdynamic range CCD [18] have been reported. On the other hand, several studies based on the latter approach also have been proposed [19]–[21]. Those studies indicate that an image with a wider dynamic range than that of a TV camera can be obtained by composing the images taken under different exposure conditions. However, an integrated sensing system has not yet been developed that satisfies requirements for license-plate recognition, such as a wide dynamic range, resolution [17], [18], frame rate [21], and cost.

Furthermore, to capture fine images against quickly passing vehicles, a sensing system is required to avert blurring of images. A conventional technique to overcome this problem is to

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control a shutter speed of a TV camera (e.g., 1/1000 s). In this solution, usually a supplementary lighting source such as an infrared lamp is utilized to preserve brightness; therefore, an entire system for license-plate recognition tends to be massive and costly.

As reviewed above, although a number of techniques on both recognition algorithms and sensing systems have been proposed, they are not adequate in applications of license-plate recognition, which will spread over various fields, especially in small-scale facilities.

This paper presents novel methods to recognize license plates of vehicles. The contributions of this work are:

1) a new sensing system having a couple of remarkable characteristics: 1.5×10^4 wide dynamic range, and elimination of image blurring against quickly passing vehicles;
2) an algorithm to recognize registration numbers of vehicles robust for inclined plates.

Section II describes problems inherent in license-plate recognition. In Sections III and IV, the sensing system and the recognition algorithm developed for the solution of those problems are presented. In Section V, experimental results are demonstrated. This paper concludes with the performance of the developed system for license-plate recognition.

II. Problems in License-Plate Recognition

The main problems to be solved in license-plate recognition application, especially for small-scale facilities, are the following:

1) to realize a sensing system capable of capturing fine image under greatly varied illumination conditions from twilight up to noon in the sunshine;
2) to realize a sensing system capable of capturing non-blurred images against quickly passing vehicles;
3) to develop recognition algorithms flexible for sensor placement that is adequate for inclined plates.

Fig. 1 shows brightness of objects under outside environment. This figure indicates that brightness is distributed from one up to 1.5×10^4 cd/m^2 under any lighting source. Thus, a dynamic range of 1.5×10^4 is required for a sensing system to capture images of license plates without loss of information. This also indicates that the dynamic range of a conventional CCD video camera, approximately 300–500, is insufficient for the sensing system under required conditions.

For applications of license-plate recognition, it is necessary for a sensing system to handle passing vehicles, although unnecessary in special cases when vehicles are forced to stop. For example, if a speed of a vehicle is 100 km/h, a filed of view is 2.7 m wide $\times$ 2 m high, and this view is framed in 640 $\times$ 480 pixels with a camera. The motion of a plate in the image is approximately three pixels during 1/600 s. Although the limitation of this motion depends on the size of characters to be recognized, a shutter speed of 1/600 s is sufficient for the sensing system to recognize registration numbers of Japanese license plates [22].

A shape of a license plate observed in an image depends on relative placement between a sensor and a vehicle. Horizontal and vertical distortion of the plate arises from pan/tilt angles of the sensor toward passing directions of the vehicle. Fig. 2 shows

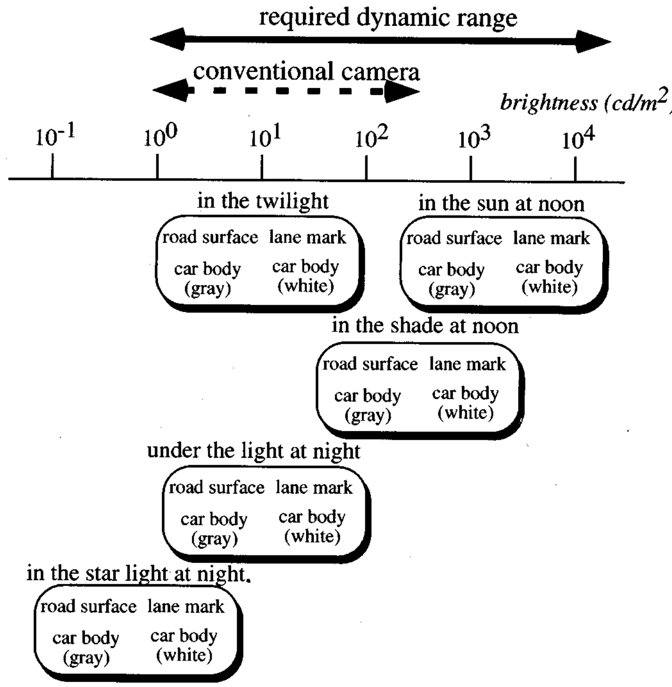


Fig. 1. Various brightness measured on the road and the dynamic range required for a camera.

examples of plate images, where sensor placement is changed. The range of sensor placement (pan/tilt) reported in previous works is mostly restricted to less than 20 $\sim$ 25° [22], [23]. In order to expand the application of license-plate recognition into various fields, it is necessary to develop an algorithm qualified to handle more deformable plates. Notice that, as shown in Fig. 2, it is difficult to read the registration numbers from the images at pan and tilt over 40°. Therefore, in our research, we specify the range of sensor placement up to 40°, which is about twice as wide as that of the previous studies.

III. Sensing System

By combining a pair of images captured with two CCDs at the same time and under different exposure conditions, an image with a wide dynamic range and without blurring would be obtained. In this section, the methods to attain those features are described and the structure of the developed sensing system is presented.

A. Methods

Fig. 3 shows the optical principle of the sensing system. A prism beam splitter splits incident rays into reflected and transmitted lights having different intensities. The intensity ratio of split rays $(\lambda_1 : \lambda_2)$ is controllable with a multilayered filter in the beam splitter. The rays with different intensities are framed in a pair of CCDs synchronously. In this figure, transmitted light is stronger than reflected; thus CCD1 frames a high exposure image in comparison with CCD2. This structure allows the sensing system to capture a pair of images corresponding to different exposure conditions simultaneously. To realize 1.5×10^4 dynamic range, the intensity ratio of the transmitted light to the reflected is selected as 45 : 1, which is described later.

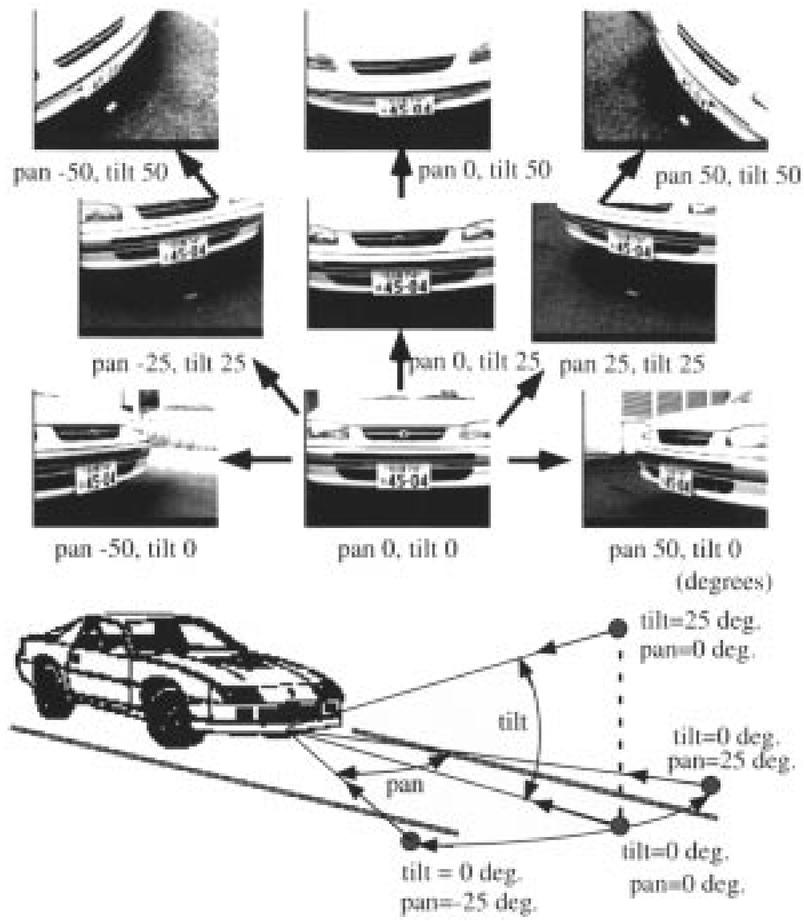


Fig. 2. Difference of images of license plates when camera placement (pan/tilt) is changed up to $\pm 50^\circ$. It is difficult to read the registration numbers at pan and tilt over 40°.

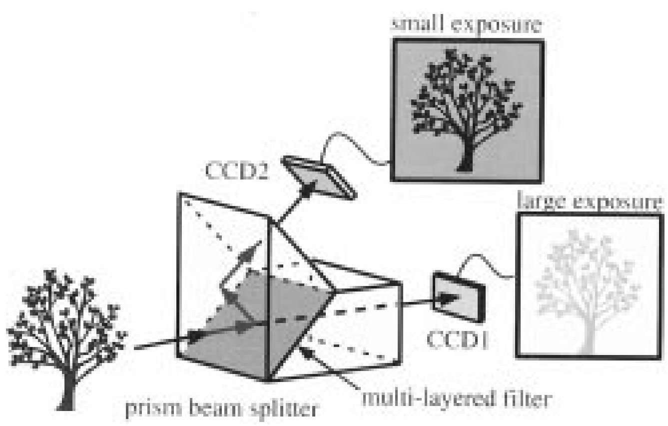


Fig. 3. The principle of the proposed optical system.

By synthesizing a pair of images with different intensities, an image whose dynamic range is wider than an original image can be generated. The details can be found in [21]. Fig. 4 illustrates the synthesizing algorithm. As $\lambda_1 > \lambda_2$, we have the following relation:

$$0 \le f_2(x, y) \le f_1(x, y) \le L_{\mathrm{sat}} \tag{1}$$

where $f_1(x, y)$ and $f_2(x, y)$ represent gray levels at a pixel coordinate (x, y) in each image framed by CCD1 and CCD2 and L_{sat} denotes a saturation level. In our study, signal output from a TV camera is digitized with 8 bits; thus $L_{\mathrm{sat}} = 255$. From f_1 and f_2, a synthesized image f_{sync} with an expanded dynamic range is calculated by the following equation for each pixel:

$$f_{\mathrm{sync}}(x, y) = \begin{cases} f_1(x, y), & \text{if } f_1(x, y) < L_{\mathrm{sat}} \\ \left(\dfrac{E_2}{E_1}\right)^{\gamma} f_2(x, \ y), & \text{if } f_1(x, y) = L_{\mathrm{sat}} \end{cases} \tag{2}$$

where E_1 and E_2 are the coefficients determined by exposure conditions $(E_1 > E_2)$ and γ is also the coefficient for gamma compensation. Fig. 4 depicts the idea of synthesizing a pair of images. Consequently, the image with a dynamic range, which is E_1/E_2 times as wide as one of the cameras, itself can be composed by calculating f_{sync}.

Finally, the way to settle the intensity ratio of λ_1 to λ_2 is described. The dynamic range of the sensing system D is calculated from

$$D = \left(\frac{L_{\mathrm{sat}}}{L_{\mathrm{noi}}}\right)^{1/\gamma} \left(\frac{E_1}{E_2}\right) \tag{3}$$

where L_{noi} represents the noise intensity of the camera; thus $L_{\mathrm{sat}}/L_{\mathrm{noi}}$ represents the signal-to-noise ratio (S/N) of the camera. The S/N of the CCD camera (SONY XC-7500) used in our system is approximately 1000; however, it is specified from the quantization error on digitization. Thus, $L_{\mathrm{sat}}/L_{\mathrm{noi}}$

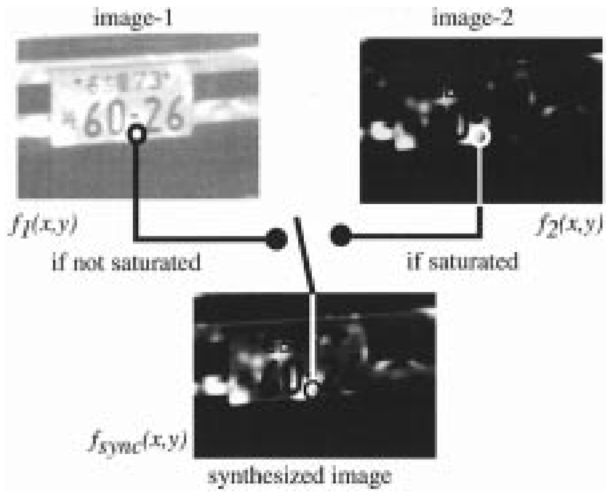


Fig. 4. Synthesis of a pair of images captured under different exposure conditions.

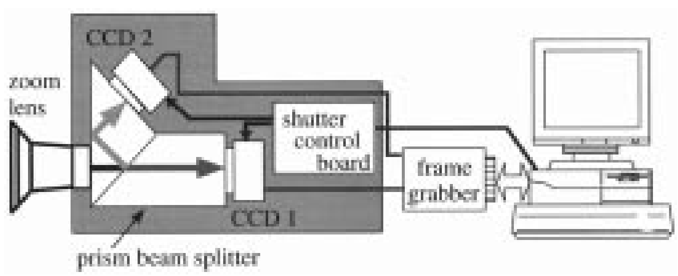


Fig. 5. The structure of the developed sensing system.

Fig. 6. The photo of the developed sensing system.

is derived as 255. Moreover, γ was approximately 0.95 from our experimental estimation. In consequence, using these parameters and (3), E_1/E_2 must be 43.9 to realize the dynamic range of $D = 1.5 \times 10^4$. Therefore, as described above, $(\lambda_1 : \lambda_2)$, which represents the intensity ratio of transmitted light to reflected, is selected as $45:1$.

B. Structure of Sensing System

Fig. 5 shows the structure of the developed sensing system. This is composed of a zoom lens, a prism beam splitter, two CCDs, a shutter control board, and a host computer installed a frame grabber board. The two CCDs are assembled precisely to make split incident rays go into the exact same position on each CCD. The shutter speed can be controlled from 1/60 s up to 1/10 000 s. The image processing for synthesizing is executed on the host computer.

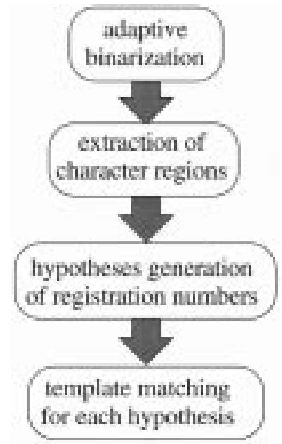


Fig. 7. Processing flow to recognize registration numbers in a license plate.

Fig. 8. Example of binarization.

The photo of the developed sensing system is presented in Fig. 6.

IV. The Algorithm to Recognize License Plates

Previous approaches to locate a license plate in an image have been generally utilizing inherent patterns in the license plate. For example, projection of edges onto vertical and horizontal axes is the important clue. However, a change of sensor placement with respect to vehicles causes perspective distortion of the plate in the image, and both vertical and horizontal axes of the image do not coincide with those of the plates. Therefore, those approaches would easily fail in recognition.

In order to make license-plate recognition more practical, a recognition algorithm robust for inclined plates has been developed. The procedure of recognition consists of four steps:

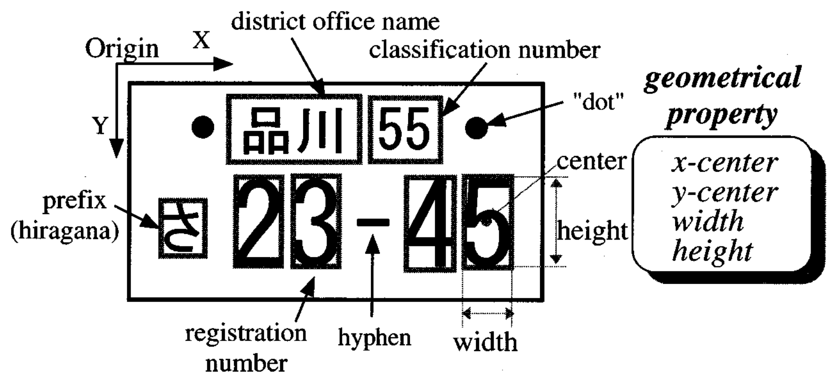


Fig. 9. Japanese license plate: a *geometrical property* for each character is defined.

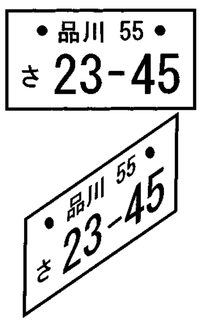


Fig. 10. Normal and inclined plates: relations between each *geometrical property* in an inclined plate would be approximately the same as those in a normal plate.

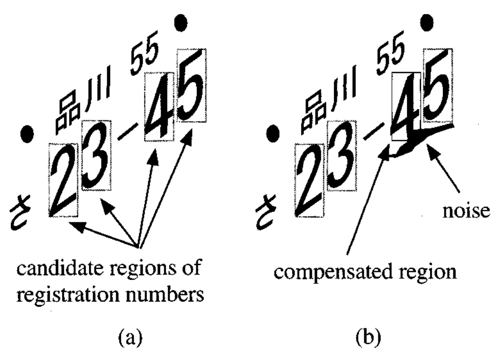


Fig. 11. Segmented regions of registration numbers. (a) All registration numbers are segmented properly. (b) Number 4 cannot be extracted as the candidate of the registration number; therefore, the region between numbers three and five is defined as a compensated region.

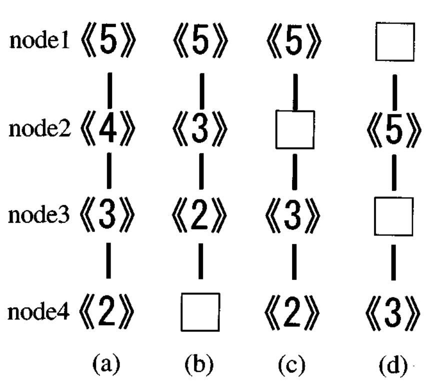


Fig. 12. Examples of hypotheses with tree representation:≪n≫ denotes the candidate segmented correctly. □ denotes the node that must be compensated.

TABLE I
EXPERIMENTAL CONDITIONS

shutter speed	1/1000 sec.
brightness	about $1.0 \times 10^4 cd/m^2$ (under direct sunshine)
camera placement	pan ±20, tilt 10 degrees
colors of vehicles	white, navy blue, silver
speed of vehicles	$30km/h$ approx.

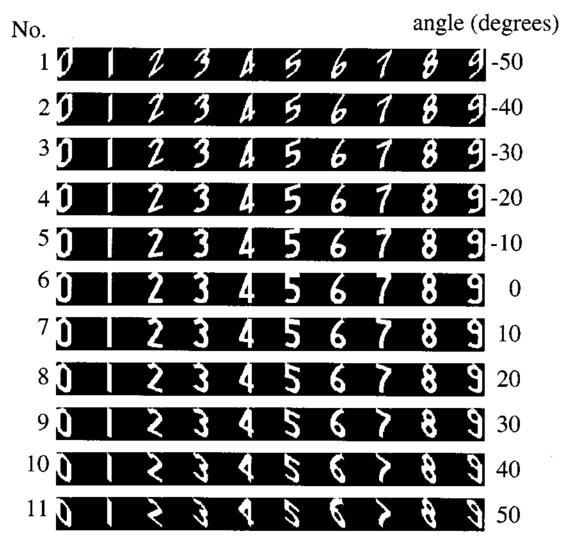
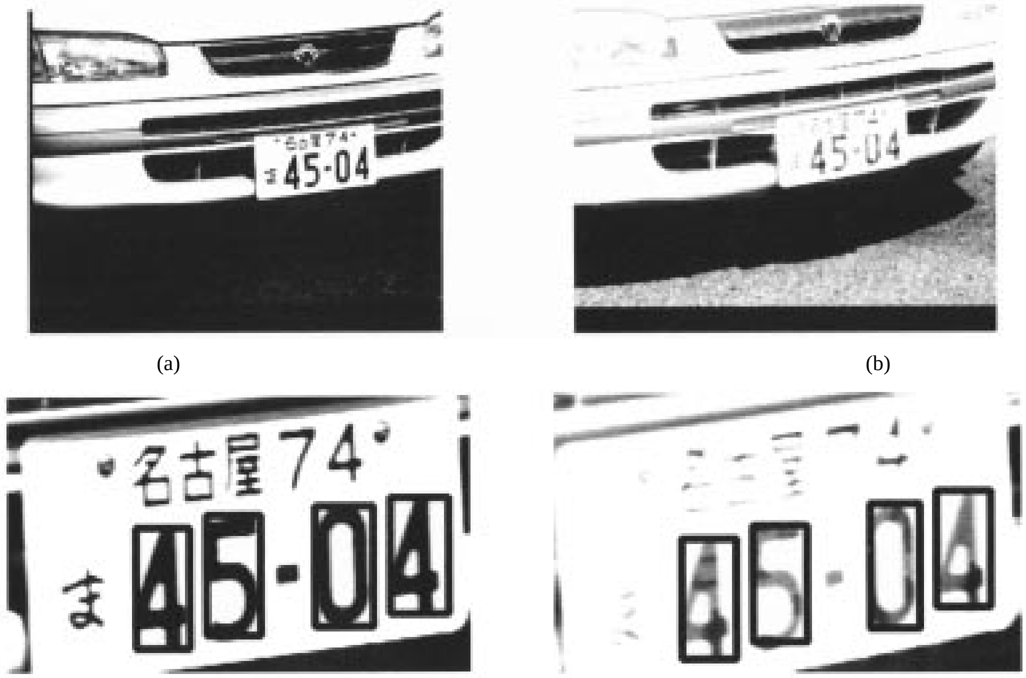


Fig. 13. Inclined templates.

1) binarization of a whole image;
2) extraction of character regions from the binarized image;
3) hypotheses generation of registration numbers;
4) template matching to recognize registration numbers.

Fig. 7 shows the processing flow. The key of this algorithm to recognize distorted plates is the way to generate hypotheses that represent combination of segmented regions of registration numbers, in consideration of geometrical constraints on the inclined license plates.

The details in each step are described as follows.



(a) (b) (c) (d)

Fig. 14. Examples of images captured by the developed sensing system and the conventional camera: rectangles depicted in (c) and (d) were defined manually to evaluate saturated pixels.

A. Binarization

As preprocessing to extract character regions inscribed on the license plate, a synthesized image with a wide dynamic range is binarized. A static threshold for a whole image causes miss-binarization when the image includes local variances of brightness. Thus, small window regions are defined over the image. Then the dynamic threshold method proposed in [24] is applied to each region. This method is fairly robust for a local change of brightness in images. Fig. 8 shows an example of binarization.

B. Extraction of Character Regions

At the beginning of this step, the binarized image is labeled and segmented. From the configurations of the sensor (e.g., a focal length) and the range of the distance between the sensor and vehicles, the size of characters observed in the images can be estimated in advance. Fig. 9 shows an example of a Japanese license plate. It consists of a district office name, a classification number, a prefix (Hiragana), and registration numbers. According to the regulations, the heights of registration numbers are twice as large as the other characters in the plate despite the degree of inclination of the plates. Utilizing the range of the size of each character (including registration numbers), both the candidate regions of registration numbers and other characters are extracted. Additionally, a hyphen and a couple of "dots" that are screws to fix a plate on a vehicle are also extracted from the images because those are helpful to specify the position of the registration numbers. In this paper, only registration numbers are the targets to recognize.

C. Hypotheses Generation of Combination of Registration Numbers

As shown in Fig. 9, a *geometrical property* composed of the center position, width, and height is defined for each region. Despite the degree of inclination of the plates, relations between each *geometrical feature* in an inclined plate would be approximately as same as those in a normal plate, as shown in Fig. 10. Therefore, from all candidate regions of registration numbers, hypotheses compounded from those candidates are generated in consideration of the following geometrical constraints.

1) All candidate regions in one hypothesis must align.
2) Geometrical relations between each candidate region must be proportional to those of the actual license plate. These geometrical relations can be derived from each *geometrical property*.
3) Around candidate regions of registration numbers included in one hypothesis, several candidates of other characters, which are assigned to a district office name, a classification number, or a prefix, must exist. In addition, a hyphen and a couple of dots must also exist in the right places.

Furthermore, each hypothesis must be composed from two, three, or four candidates. For practical applications, a few registration numbers could not be segmented properly. In particular, this failure frequently arises from an inclined plate. To cope with unsegmented registration numbers, the hypotheses generator compensates for lack of regions of unsegmented registration numbers. Also, to deal with all possible combinations of candidates of registration numbers efficiently, hypotheses are represented with tree interpretation [25].

Examples illustrating compensation of the unsegmented region and tree representation are shown in Figs. 11 and 12.

First, hypothesis generation is described while focusing on the number five. For the simplest case that all registration numbers are segmented successfully, as shown in Fig. 11(a), the hypothesis depicted in Fig. 12(a) is generated. However, for example, in the case where the number four is not segmented, as shown in Fig. 11(b), several hypotheses must be generated carefully. If the numbers five, three, and two satisfy the geometrical constraints as node-1 (root), node-2, and node-3, respectively, the hypothesis shown in Fig. 12(b) is generated. In this case, node-4 is not specified currently. Thus, although this hypothesis is incorrect, the region whose position and size are estimated from the defined nodes is compensated, and then this region is assigned to node-4 in this hypothesis. Additionally if the numbers five, three, and two satisfy the constraints as node-1, node-3, and node-4, respectively, a compensated region between the numbers five and three is defined by the same manner. Then another hypothesis shown in Fig. 12(c), which is assumed to be correct, is generated.

In these examples, the number five is always marked as node-1 (root). However, it should not necessarily be root. For instance, it is possible that another candidate of registration numbers to the right of the number five may exist. Therefore, after generating all possible hypotheses whose node-1 is the number five, hypotheses in which the number five is assigned to node-2 (and/or node-3) are generated, as shown in Fig. 12(d).

So far, the number five is focused; thus all hypotheses include the number five. But it might be possible that the number five cannot be segmented properly or that this candidate does not actually correspond to the registration number of the license plate. So hypotheses generation focusing on other candidates (numbers four, three, and two) must be executed.

As a result of combination of both segmented candidates and compensated regions, a number of hypotheses would be generated. For recognizing registration numbers efficiently at the final step, each hypothesis is ranked according to the confidence value calculated from the following criteria:

1) a hypothesis composed of more segmented candidates is given a larger value;
2) a hypothesis around which there exist more candidates of other characters (e.g., a distinct office name) is given a larger value.

In our experiments, the confidence value C was calculated from the following equation:

$$C = N_{\mathrm{RN}} + N_{\mathrm{OC}} + N_{\mathrm{HD}}$$

where N_{RN} represents the number of registration numbers included in a hypothesis. Also N_{OC} and N_{HD} represent the number of other characters and a hyphen/dots extracted around a hypothesis.

TABLE II
PERCENTAGE OF SATURATED PIXELS FOR REGISTRATION NUMBERS

sensor	percentage of saturated pixels		
	each color		total
developed system	white	39%	42%
	navy blue	44%	
	silver	44%	
conventional camera	white	45%	49%
	navy blue	51%	
	silver	51%	

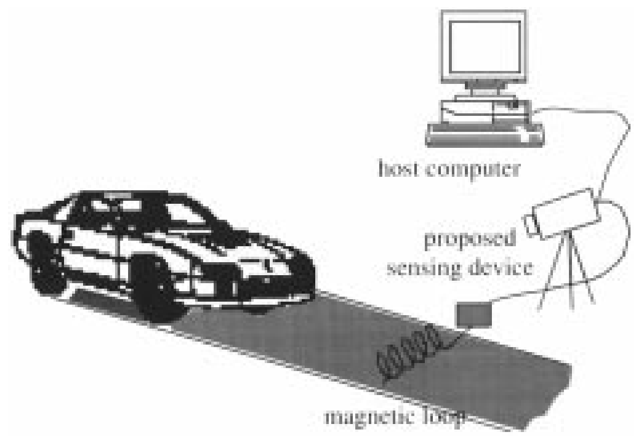


Fig. 15. Prototype system for recognizing license plates.

TABLE III
EXPERIMENTAL CONDITIONS

shutter speed	1/125 sec.
focal length	50mm
image size	640(H)×480(V) (pix)
size of license plate in images	160(H)×80(V) (pix) on average
total number of plates	949
environment	outside, taken from 8am to 5pm including sunny and rainy days
brightness	$10^1 \sim 10^4 cd/m^2$ approx.
camera placement	pan -15,tilt 10 degrees

D. *Template Matching for Recognition*

To recognize registration numbers, the technique of template matching is utilized for each hypothesis in order of the confidence values. For example, a hypothesis shown in Fig. 12(a), which was generated from the plate shown in Fig. 11(a), is matched with a set of templates composed of ten numerals, zero to nine. If all four candidates in one hypothesis can be matched and recognized successfully, this recognition step is terminated. Contrarily, in the case that matching is failed even for one candidate, template matching is applied to a hypothesis having the following confidence value.

For inclined plates, characters extracted from plates are also distorted. Therefore, according to the alignment of the candidates forming a hypothesis, the appropriate templates are uti-

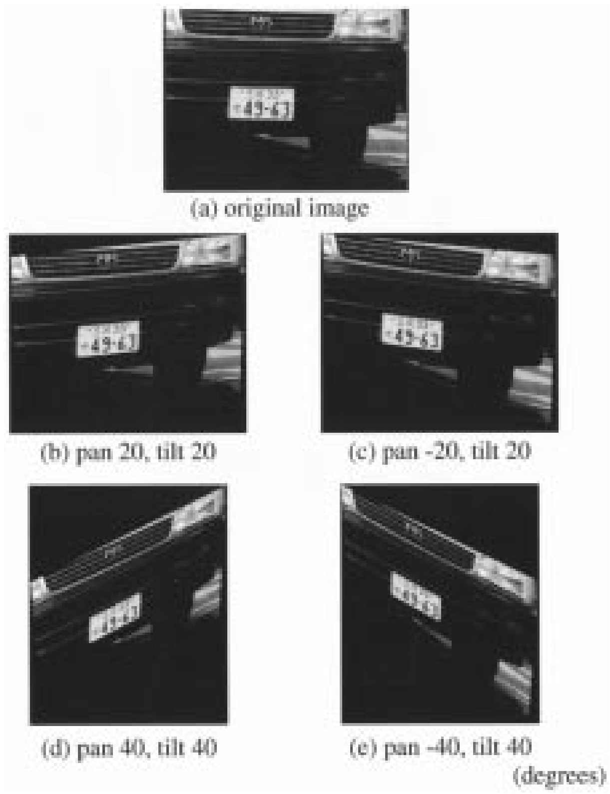


Fig. 16. Examples of transformed images. (a) is the original image. (b)–(e) are the transformed images according to each camera placement.

lized for template matching. To reduce computational time, in our experiments described in the next section, those templates were prepared in advance. As a result of preliminary experiments, typically 11 sets of templates whose horizontal inclined angles are distributed from -50 to 50° are sufficient practically. Fig. 13 shows the templates used in our experiments.

V. Experiments

A. Evaluation of the Developed Sensing System

To evaluate the effectiveness of the developed sensing system, the percentage of saturated pixels in the regions of registration numbers has been investigated for passing vehicles in comparison with a conventional CCD camera.

Table I shows the experimental conditions. Under the direct sunshine at noon, brightness was approximately 1.0 $\times$ 10^4 cd/m^2. In consideration of the influence of colors of vehicles, three types of vehicles were utilized in this experiment. The TV camera was located at a couple of locations.

Fig. 14 shows examples of whole and zoomed images captured by the developed system and the conventional camera. In Fig. 14(d), some characters on the license plate are saturated and indistinct. On the other hand, the images captured by the developed sensing system are fairly clear without blurring, and all characters are easily readable.

For all images, saturated pixels in the regions of registration numbers, which were defined manually as shown in Fig. 14(c) and (d), were counted. Table II shows the results. The percentage of saturated pixels for the developed sensing system is always about $6 \sim 7$ points lower than those for the conventional camera.

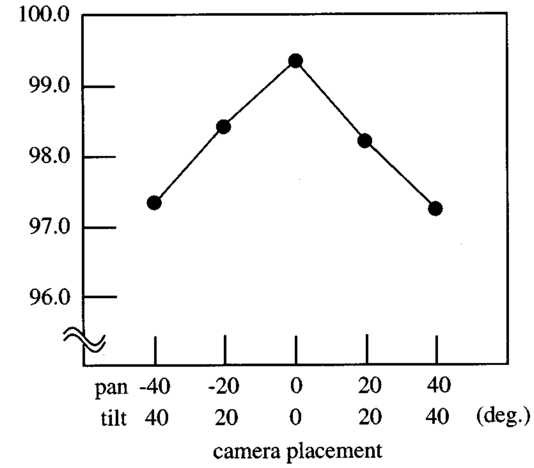


Fig. 17. Recognition rates for the original and the transformed images of the vehicles.

TABLE IV
Recognition of the Registration Numbers for the Original and the Transformed Images

camera placement[degrees]	percentage (success/total)	average
original	99.3%(942/949)	——
pan:20,tilt:20	98.1%(931/949)	98.3% (1866/1898)
pan:-20,tilt:20	98.5%(935/949)	
pan:40,tilt:40	97.2%(922/949)	97.3% (1846/1898)
pan:-40,tilt:40	97.4%(924/949)	

These results prove that the developed system is competent for capturing scenes with a wide dynamic range, including direct sunshine. Furthermore, it is confirmed that this system can be utilized for quickly passing vehicles.

B. Performance of License-Plate Recognition System

Fig. 15 shows the experimental system for license-plate recognition utilizing the developed sensing system. The magnetic loop was laid underground to detect vehicles. The signal from this magnetic sensor triggered the sensing system to frame a pair of images including the front of vehicles. Captured images were synthesized on the host computer to expand a dynamic range, and then recognized. This system was set up at the gate of the parking area.

Experiments were conducted for three days, including sunny and rainy days, from 8 am to 5 pm. The distribution of brightness on license plates through the experiments was approximately estimated from 10^1 up to 1×10^4 cd/m^2. The number of vehicles to be recognized was 949. The pan angle of the camera was -15°, and tilt was 10°.The details of the experimental conditions are summarized in Table III.

To evaluate the robustness for camera placement, competence for recognizing the inclined plates was investigated. For reasons of the difficulty of placing the TV camera at many positions, simulated images were generated by transforming orig-

(a) (b) (c) (d)

Fig. 18. Examples recognized successfully: although in (a) both number “4”s and in (b) number “9” were not segmented properly, they were recognized correctly.

inal images. Fig. 16 shows examples of transformed images as if they had been captured from camera placement whose positions (pan, tilt) were (b) (20, 20), (c) (−20, 20), (d) (40, 40). and (e) (−40, 40)°.

The results of recognition for both original and transformed images are depicted in Fig. 17 and enumerated in Table IV. For the original images (nontransformed images), 99.3% of license plates were recognized successfully. On the other hand, for slightly inclined plates (pan $= \pm 20$, tilt $= 20°$), recognition rate was about 98%. Furthermore, for highly inclined plates pan $= \pm 40$, tilt $= 40°$, the developed system achieved a recognition rate of over 97%.

As plates inclined greatly, there were many cases where a few regions of registration numbers could not be segmented because of distortion of license plates. Fig. 18 illustrates the cases in which some registration numbers were not segmented properly. However, by compensating the regions of the unsegmented registration numbers, those plates were recognized successfully. These results prove that the function to estimate and compensate unsegmented regions is very helpful to recognize inclined plates.

The reduction of the recognition rate for the inclined plates resulted from the cases that all registration numbers could not be segmented appropriately due to the distortion of the images, as shown in Fig. 19.

For practical reasons in this experiment, the speed of vehicles had to be less than 10 km/h. Our separate experiment confirmed that for vehicles at a speed of more than 100 km/h, images captured by the developed sensing system with a shutter speed of 1/1000 s were of the same quality as those for vehicles at a low speed.

VI. Conclusion

In this paper, a novel sensing system, which utilizes two CCDs and the prism to split an incident ray into two lights with different intensities, has been presented. One of the main features of this sensing system is that it covers wide illumination conditions from twilight to noon under sunshine. The dynamic range of the developed sensing system is 1.5×10^4, which is about 30 times as wide as those of the conventional cameras. Simultaneously, this system is capable of capturing images of quickly passing vehicles without blurring.

In our previous work, the sensing system with a wide dynamic range was developed [21]. However, it captured a pair of images having different intensities sequentially during 1/30 s, so that image blurring was unavoidable against quickly moving objects. Furthermore, the vertical resolution of the previous sensing system was 242 pixels, which is approximately half of the resolution of this sensing system. Therefore, the

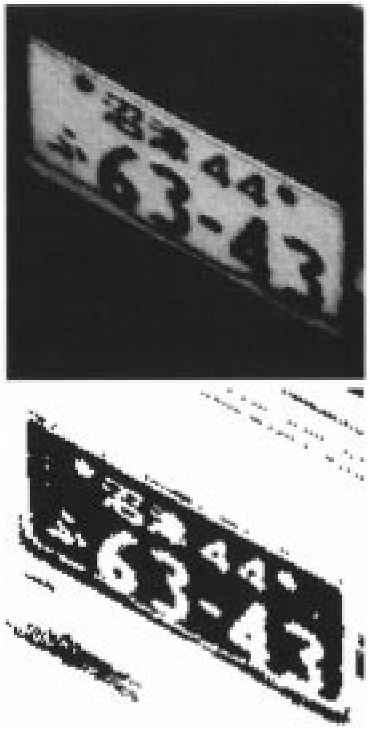


Fig. 19. Examples recognized unsuccessfully: all of the registration numbers were segmented as the same region.

sensing system described in this paper is more competent for applications of license-plate recognition.

An algorithm suitable for recognizing inclined plates has been proposed. The camera placement (pan/tilt) can be enlarged up to 40°. This characteristic makes the system flexible for camera placement in practical use.

The obtained results for the recognition system are sufficient. At the conventional camera placement, recognition rate of more than 99% could be achieved under outside environment. Even if the position of TV camera varied widely, over 97% of the license plates could be recognized successfully. Thus, this system is much qualified for many fields of license plate recognition, especially for small-scale facilities. Work remains to improve the recognition algorithm to make it more robust for dirty and damaged plates.

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