A Real-time Mobile Vehicle License Plate Detection and Recognition for vehicle monitoring and management

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Abstract —In this paper we present a instant and real-time mobile vehicle license plate recognition system in an open environment. Using a nonfixed video camera installed in the car, the system tries to capture the image of the car in front and to process instant vehicle license plate detection and recognition. Relying on the instant vehicle body recognition, the system can detect and locate the vehicle license plate without the need of background image. Vehicle body detection system utilizes the color characteristics of the barking lights to carry out detection. It first detects the location of the two barking lights in the captured image. Then set license plate detection region using the probability distribution of the license plate between the two lights, thus quickly locate the license plate. This method can eliminate any environmental interference during the license plate detection. From the results of experiment, it is determined that this system can effectively and quickly capture the vehicle image, detect and recognize the license plate whether it is dark, raining or under complicated environments.

Index Terms —Wavelet, License Plate, Neural Network, Black Top-Hat.

I. INTRODUCTION

As the number of automobiles grows rapidly, the traffic problems increase as well, for example, car theft, speeding, and running the red light, etc. Due to the above mentionable traffic control problem, vehicle tracking, recognition and management has become major topics of modern traffic control system.

The current vehicle recognition system includes technique of RFID, infrared, microwave and image recognition. The first three techniques require the installation of transponders on the vehicle. But, in high speed driving, the accuracy rate of detection and recognition is low with the system using transponder. Usually the system uses a monitoring system to enhance the accuracy of the system. Meanwhile, there are still many unsolved problems. For instance, the transponder could be pirated, and the user's privacy could be violated.

In recent years, the vehicle monitoring and management system based on vehicle license plate recognition has matured. Many big parking lots and major street are using the Charge-coupled device (CCD) to carry on the vehicle monitoring and management. This system adapts the image recognition technique. In particular, it focuses on the search of cars suspected of robbery, theft, etc.

Currently most of the vehicle license plate recognition system (VLPR) already developed or proposed in academic field has been focused on motionless vehicles [1-10]. There has also been some instant VLPR installed on the road [11-12]. The above mentioned applications of VLPR are still confined to gate control management. Rarely has the problem of car theft arrest on the road been discussed.

The problem rests on that the fixed roadside recognition system having problem with distance and car speed. Hence it cannot effetely filter out the problematic cars on the road.

On the search of suspectable vehicles, the law enforcement uses video camera installed on major roads or patrol cars. This method requires the police officers to visualize the license plate (LP) and then input the LP information into the system for inquiry. This is a very inefficient method. If the VLPR system can be installed on taxies, buses or police cars, then it can quickly identify stolen cars by instantly detecting and recognizing the car in front, linking the data to the stolen car database, sounding alarm and informing the authority. It will not only increase the efficiency of search for suspectable vehicle but also increase the safety of law enforce officers. But there have been few systems capable of being installed on the car. Thus this paper proposes a VLPR system capable of implement on the car adaptable to various environments.

In order to install it on the onboard micro computers, our system adapts the feature of simple computation. We use the wavelet transformation [1-2] which requires very little computation to lower the dimension of the image and acquire the characteristics of high frequency. After wavelet transformation, based on the relationship between frequency and location, we can locate the LP through statistics on wavelet high frequency coefficients.

After accurately positioning the LP as a subimage, we filter out the noise and eliminate the shadow variation from the subimage to get a character positioning with higher separation. The multilayer neural network is used to achieve character recognition. We realize instant calculation through three procedures: automatic detection and capturing of vehicle image; providing low-intensity calculation; adaptation to complicated background and noise. The first section of this paper is the description of background, motivation and introduction. The second section illustrates the realization method of each component of the system. The third section is the system design. The forth section is experiment result. Finally the fifth section is discussion.

II. METHODOLOGIES

We start by an introduction of the the background filtering method, followed by LP detection method. Success of

background filtering that can increase the efficiency of the LP detection. Finally we introduce the character segmentation and recognition system. To facilitate illustration, we use the passenger car as model for our design, but it can be modified to other vehicles. The resolution of the video camera used is set at 320x240 pixels.

A. Filtering of background

On regular roads, various vehicle detection systems are all subject to interference form other objects, thus lose its accuracy and detection of the whole mage will be relatively ineffective. The filtering of the background with the focus of the detection on the vehicle body is the key for improving the accuracy.

In the locking-in and following a targeted vehicle, the picture captured with an on board camera is very complicated. The picture may contain the sky, the buildings, road signs, street lights and non targeted vehicle, and can't use the background filtering method. We use the braking light with its particular color, which is common characteristic of every car, to position targeted vehicle.

Braking light is an active red light source. Its brightness and color is not venerable from the interference of other lights. We change the LL image transformed from wavelet into YUV color format. The Y component is used to judge the brightness and should be greater than 150.The V component is used to decide if it reaches the saturation level of light and should be greater than 60. Those values are fine parameters through experimental statistics. The search of lights uses the block of 8

8 pixels. Blocks overlap by 4 pixels. If there are at least 15 qualified Y-components and at least 12 qualified V-components, it will be an effective region. A few effective regions will be marked as a single object through connected components method.

During detection, we may find other red lights besides the target vehicles, e.g. motorcycle, other vehicles or red lighted signboard. But they can be filtered out through the following method. First, the distance between two objects with the same height must be greater than 60 pixels. Next, the top edges of the two objects must be close horizontally, no more than 8 pixels in error. The same must be to the bottom edge.

Because the LP will be too small to be recognized when the distance to the car in front is over 10 meters, the width of a vehicle will be at least 60 pixels. And the 2 rear lights of the same vehicle must be of the same level horizontally. Through matching of the objects, we select two appropriate ones. Then dissect the picture region between the two tail lights as the picture for LP detection. We consider the possible location of the LP between the two lights (see Fig.1) LP may be located slightly above the lights level or quite below. Through observation, the chosen region of dissected picture is set as:
left boundary: left edge of left red light region.
right boundary: right edge of right light region.
upper boundary: Top edge of left and right red lights region – 1/4 distance of lights.
lower boundary: Top edge of left and right red lights region +3/4 distance of lights.(distance of lights is the horizontal distance between the center of left and right red lights).

Fig. 1 The Distribution of Common Lights and LP of Current Passenger Cars.

B. Vehicle license plate detection

The proposed technique of vehicle license plate detection as follow: We use wavelet transformation and projection method. The wavelet transformation performs multi-resolution of the signal to acquire the relationship between the frequency and the location. There are two functions in the transformation. They are used to acquire the parameters of the high frequency H and the low frequency L. it will produce four combinations in the two dimensional video signal: LL, HL, LH and HH. These four frequency bands represent low-frequency, horizontal, vertical and diagonal frequency energy respectively.

In regard to the grey-level image that could contain the LP, we use one level discrete wavelet transformation to extract the high frequency content. Considering the characteristics of the letters in the LP, there are six characters in the LP. In ideal situation, there are at least 12 vertical boundary points in the horizontal projection of the LP region. Moreover, the characteristics in the vertical direction of the vehicle structure are very obvious. It will be difficult to differentiate LP if we do the projection of the high frequency energy in the vertical direction. Thus, the horizontal energy best represents the characteristics of the LP. We will only use the HL filtered frequency band.

A horizontal projection of the frequency band i.e. adding energy values at the same horizontal edge of the frequency band will produce a horizontal frequency total energy distribution graph with the same vertical direction.(see Fig.2a). We wish to find blocks with higher values. The position of the blocks represents the upper and lower edges of the LP as seen in Fig.2b.

A two-stage process is proposed in the approach, the rough location, and the accurate location. The rough location in which candidate regions of license plate are found, and the accurate location where the exact plate region is extracted from candidate regions.
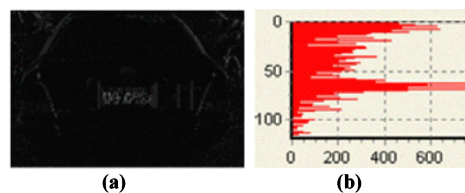

(a)   (b)

Fig.2 (a)characteristics point inside vehicle body.(HL)
(b) The histogram of the horizontal projection for the picture on the left (The vertical coordinates corresponds to the height of the left picture and the horizontal coordinates are the accumulated characteristic values.)

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(1) Rough location

Step1: Horizontal projection of HL

As Fig.2a shown, the vertical gradient values of license plate are significant, and texture of the license plate in the HL sub-band is more complicated. The horizontal projection of the wavelet coefficients in the HL sub-image is calculated by (1). Fig.2b shows the horizontal projection of Fig.2a.

$$T_H(i) = \sum_{j=1}^{n} g_v(i,j) \qquad (1)$$

From Fig.2b, the horizontal position of license plate must be a wave crest of the projection. We should search the crest to get the possible horizontal position of license plate. However, there are many burrs in the horizontal projection in Figure 2b. In order to get rid of these burrs, we introduce Gauss filter. The Gauss filter is shown in (2).

$$G(x, \sigma) = e^{-x^2/2\sigma^2} \qquad (2)$$

But in practice, because the curve is discrete, we often use Eq.3 to filter the image.

$$T'_H(i) = \frac{1}{k}\left\{ T_H(i) + \sum_{j=1}^{w}\left[\begin{matrix} T_H(i-j)h(j,\sigma) + \\ T_H(i+j)h(j,\sigma) \end{matrix} \right] \right\} \qquad (3)$$

Where $h(j,\sigma) = e^{-(j\sigma)^2/2} \qquad k = 2\sum_{j=1}^{w} h(j,\sigma) + 1$

In (3), $T_H(i)$ represents the original projection value, $T'_H(i)$ shows the filtered projection value, and i changes from 1 to m. w is the width of the smoothness region; $h(j,\sigma)$ is the Gauss filter and σ represents the parameter of Gauss filter. After many experiments, the practicable values of Gauss filter parameters have been concluded. In our algorithm after many experiments, w= 4 and σ =0.05. The result of horizontal projection smoothing by Gauss Filter is shown in Fig. 3. As shown in Fig. 3, one of wave crests must represent the horizontal position of license plate. So the apices and vales should be checked and chosen. The regions can be gotten from the position of apices and vales in the next step.

Step 2: Candidates extraction.

In order to obtain the position of license plate, we make use of two known features of license plate: firstly, the license plate usually lies on the bottom of the image; secondly, the several integrals of all apices denote the possible horizontal position of license plate. Therefore, with the purpose of finding the real apices and vales of the curve, we examine those apices and vales carefully in order to get rid of the false ones. We calculate the integral around the remained apexes and compare them to get the most possible horizontal position of license plate. If there are still several positions, some more strict inspections will be applied to ensure the horizontal position of license plate. If there are not any candidates in this region, we will adjust the parameters and repeat step 1 to step 2 orderly until we can get some candidates. The result of above algorithm is shown in Fig. 4. For extracting the candidate region, we use the proper mask to search the HL sub-image in the initial candidates. We calculate the value of total pixels for each mask and find the maximum. Then, the corresponding mask with maxima value is the possible license plate region. The result of above algorithm is shown in Fig. 5.
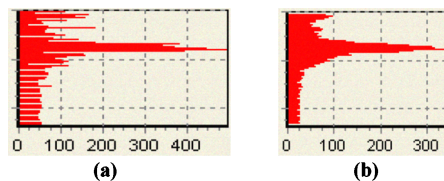

Fig.3 (a) The histogram of the horizontal projection for the image. (b) The result of smoothing by Gauss Filter from Fig.3(a)
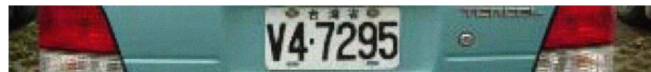

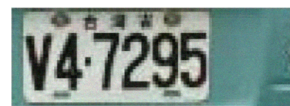Fig.4 The initial candidates of the input image.

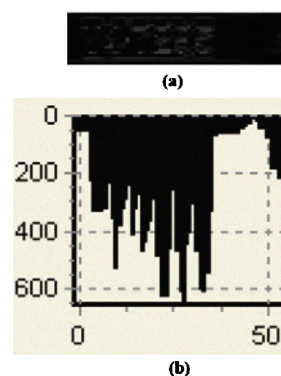Fig. 5 The rough location of the input image.

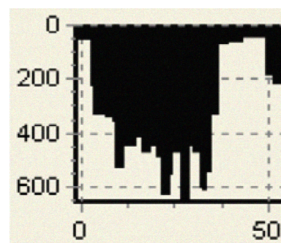Fig.6 (a)The rough location from HL sub-image (b)The vertical projection of Fig. 6(a).
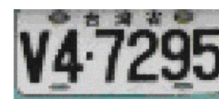

Fig.7 The vertical projection after close operation.

Fig.8 The detected license plate image.

(2) Accurate location

From rough detection, one or more candidates have been taken from HL. We transfer the relative location to HL sub-image and processed it one by one using mathematical morphology.

Step 1: Vertical projection of HL.

Get Vertical projection of HL, the results are shown in Fig.6b.

Step 2: Process with Mathematical morphology

Mathematical morphology [13-15] is a non-linear filter, with the function of restraining noises, to extract features and segment images etc.

We use close arithmetic to deal with the vertical projection. The maximum space between characters is important feature for designing structure element. The result after close operation is shown in Fig.7.

If the projection value is smaller than the threshold, we consider the column may not be the part of license plate region, and exclude the checking region. Now we can define the new right and left boundary of license plate from rough location. We wipe off the regions with too small or too big width-to-height ratio. Finally the accurate both left side and right side of the license plate are detected. The extracted license plate image is shown in Fig.8.

C. Character recognition

To carry out character recognition, we first calibrate the LP tilt, and then use the projection method to do the character segmentation. Finally, we use back-propagation neural network to recognize each character.

In addition, we add an excellent preprocessing. The LP boundary is usually not obvious due to the unevenness of lights, especially during night or dusk. For example, the top of the LP may be darker while the bottom of the LP brighter. This will affect the efficiency of the segmentation. We tried to use the grey level value around the edge as the threshold for binary process. We also tried to use the median of the LP's shading value as the threshold. But the character separation and integrality are not good. Finally we use the Black top-hat [16-17] technology to eliminate the shadow and get an optimal manifestation.

Black top-hat is a derived application of the closing operation in morphology. It subtracts the result after closing operation from the original picture. The difference is the dark object of the image. Fig.9 shows the calculation process.

It needs a design of a proper structural element in morphology operation. In accordance with the characteristics of the LP characters, this structural element should be able to fill the black characters in the LP. Hence the width of the element needs to be larger than the width of the stroke of the character. It is observed that the width of the stroke of the character is no greater than 1/6 of the height of the LP. We design the size of the structural element as 1/6 of the height of the LP. For example, if the height of the LP is 24 pixels, then the size of the structural element is 4x4 pixels. Using this structural element to perform closing calculation, the gaps between the characters in the LP can be filled. Then we subtract the LP background from the original picture to get a background brightness evenly distributed LP. During the final binary process, the choice of threshold becomes easy. Just take the value close to the brightest grey level in the picture.
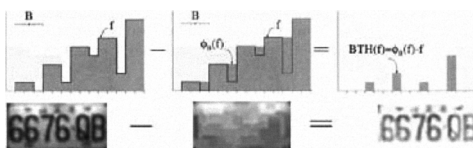
(a)The top left figure is the original picture.(b)The top middle figure is the original picture after the calculation of closing. (c)The top right figure is the dark object after elimination of background shadow.(d)The bottom figures are the corresponding actual cases of the tip figures.

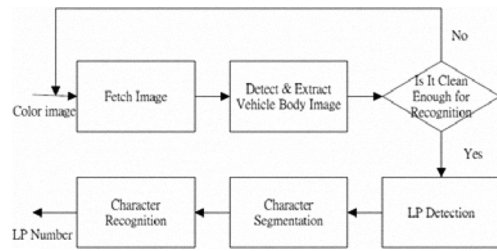Fig. 9 Illustration of Black top-hat process.

Fig.10 The Flowchart of proposed system

III. SYSTEM DESIGN AND EXPERIMENTATION

While driving on the road, the car in front will not disappear within a second. The chasing car will no pass constantly. The LP will stay in front of the on board video camera for a while. According to the camera's picture taking speed, if 10 pictures can be taken in 1 second, and if the car in front stayed in front of the camera for 10 seconds, we will get 100 pictures for processing. In theory, it shouldn't be a problem even if the operation of the system is slow. But the condition of the shooting might be raining, cloudy, under the tree shadow of bright days or at night. The vehicle body where the camera is installed might rock due to the road condition during shooting. It is also common to lose focus of the camera. Thus, many of the 100 pictures taken within 10 seconds might be useless due to negative factors. With nonideal pictures, the probability of recognition mistake of LP is large. Sometimes it can't even locate the LP. The objective of proposed system is to overcome those difficulties.

The system is composed of 3 parts introduced in section 2. Fig.10 shows the flowchart of proposed system. In practice, in order not to output the wrong LP, we add a determinant for the image quality. We filter out the fuzzy image according to the above mentioned characteristics. We perform statistics on the information of the wavelet high frequency HH within the vehicle body boundary. Through experimentation, if the ratio of the total sum of HH values to the area of vehicle body is less than 3, then it is a fuzzy image that the LP is visually unrecognizable. Only when the vehicle body is not a fuzzy image, the system will proceed with LP detection and recognition.

While driving on the road, under consideration for safety, a proper distance must be maintained with the car in front. A safety distance of at least 5 meters will usually be maintained by a regular driver in the instance of urban streets with a speed limit of 50 kilometers per hour. Thus it is set that the object for detection is a vehicle 2-10 meters in front. When the resolution of an input image is 320x240 pixels, and the detector needs the height of the the character of the LP to be more than 10 pixels, the focus of the camera lens should be 120 mm, about 2.5 times of the focus of regular camera.

A. Acquiring of Samples

The video camera in the system is installed under the windshield of the vehicle. It constantly shoots pictures of the vehicle in front on the road. The shooting location of the system is chosen to be the urban streets with a speed limit below 60. The environment includes clear day, raining day,

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daytime (8:00-18:00), evening(18:00-24:00). The image is captured through the video capture card in the computer. The size of the captured 24-bit color picture is 320x240 pixels. The total number of samples is 257 vehicles within a searching range above 3 seconds.

B. The Test of the system Recognition Speed

The CPU of the testing platform has a clock speed of 3.0 GHz, a memory of 512 MB. The resolution of the input image is 320x240 pixels. From reading of single image, locating of LP, character segmentation to correct output of the LP number, the average required time is approximately 0.07 seconds.

IV. Research Result

In this section, we introduce how the samples were acquire, display the success rate of this system, and exam the cause of failure of some sample.

A. Experiment Result

We define processing success as being able to output two or more sets correctly. In the acquired 257 sample images, the samples deemed success are 228, and 29 are deemed failure. The rate of successful recognition is 88.71%. Table I shows the result.

From Table II, we see that the recognition success rate in the evening is rather poor. There are two reasons for its very arability for failure:

1. Over exposure and under exposure.

If it is over exposed at night, the vehicle body and LP might easily have reflection. If it is under exposed, the image might be dark. It will cause weak contrast between the LP characters and the background. And, this causes the misjudgment of the LP location and the failure of character segmentation.

2. Fuzziness of input image.

When shooting picture at night, due to the inadequacy of background lights, it is easy to lose focus, causing the blur of the input image. The system will consider the image of the vehicle body to be blurred and to be eliminated. Or the boundary characteristics of the characters and LP background is not intense, the LP region will be treated as noise and be filtered out.

From table III, the recognition success rate is low for the raining day. The reason is that the action of the windshield wiper will leave water drop on the windshield. The LP's characters will be fuzzy and cause the failure of character segmentation and recognition.

Table IV is the experimental result under different car speed. The result shows that the recognition success rate is approximately between 89% and 91% when the car speed is between 0 and 40. When the car speed reaches above 40, the recognition rate will be much lower. This is because the driving safety distance is longer when the car speed is over 40. The target vehicle is harder to get into the detection range of the system. Fathomer, the size of the LP is much smaller in far distance. It might be treated as noise and be filtered out. Or, because the characters in the LP are rather small, the characters can not be clearly segmented causing the failure of character recognition.

B. The Successful Cases of the System Testing

The image in Fig.11a contains complicated texture objects like side street trees, overpass, etc. Since the system will first extract the image of the vehicle without background of street, it will be able to effectively filter out noises outside of the vehicle body and to enhance the accuracy of the LP positioning.

The color of the vehicle body and its tail lights are very similar in Fig.11b. Since the research considers color and brightness information, the system can still effectively catch the tail light and accurately extract the tail end image. Moreover, on the shooting environment, the uneven road surface can cause the slight tilting of the vehicle body. The system is able to effectively calibrate the tilting and successfully recognize the license number.

The picture of Fig.12a is taken at an overpass in the evening with driving speed of approximately 60 kilometers per hour. Because of the further distance of the detection, the height of the output LP is only 10 pixels. The system can still output a few LP images in a short period of time. It allows the system to carry out multiple recognition process to enhance the recognition rate for the evening driving.

The picture in Fig.12b is taken in raining condition. If the wiper can clear water mark on the windshield and keep the clearness of the LP characters, the system can still have a high recognition rate.

C. The Incorrect Cases of the System Tests

The sample in Fig.13a is collected in a very dark condition. Moreover, the target vehicle does not have a LP lighting device. It was illuminated by the head light of the car behind. If the light of head light of the car behind is not bright enough, it will result in weak edge characteristics of the character and LP background. That will cause the LP region to be treated as noise and being filtered out, and effect the positioning of the LP. In Fig.13b, the left side of the vehicle body has a flagrantly contrasting and inseparable reflecting area while the contrast of the LP itself is not strong enough. It causes a misjudgment of the LP region by the system.

V. CONCLUSION

The purpose of this paper is to establish a low-cost, highly efficient dynamic vehicle LP recognition system. Instead of fixed point installation, the video camera is installed in a car to capture the LP of a random vehicle in front. Because the car is moving constantly, we cannot use fixed background to filter out non-vehicle area, a real-time vehicle body detection method is used to locate the LP.

The system uses a detection method based on the color of the tail lights of a car to instantly detect the location of the two tail lights. Using the probability distribution of the LP between the two tail lights to set the detection boundary, we can quickly acquire the position of the LP, eliminate the environmental interference that hinders LP detection. Moreover, this system will perform multiple LP detection during a time period. This will increase the accuracy rate of the LP detection and recognition under inferior environment.

In previous researches, information comes from static

recording of the camera. This system uses camera with low resolution (320×240,24fps). Even though the condition is poor, it still has an effective detection range of 5-10 meters. Meanwhile, the simplicity of calculation will achieve the effect of real time processing.
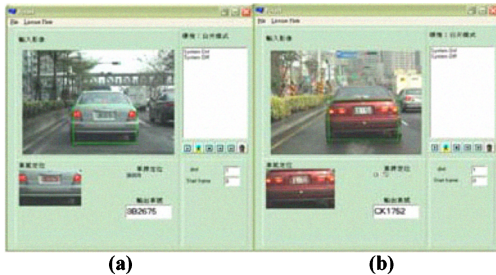

(a)   **(b)**
Fig.11 (a) The recognition result for complicated background
(b)The recognition result for red and titled vehicle body
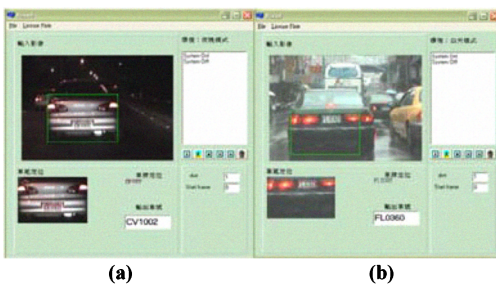

(a)   **(b)**
Fig.12 (a)The recognition result for evening high speed driving.
(b)The recognition result for raining day.
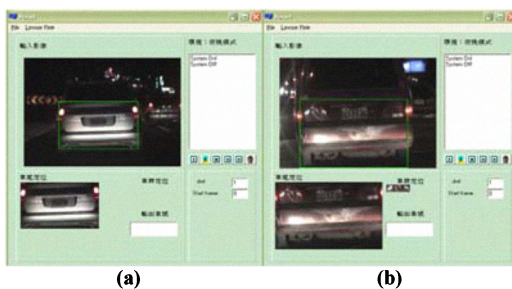

(a)   **(b)**
Fig.13 (a) Positioning Error Caused by the Low Contrast of the Input Image
(b) Positioning Error Caused by the Vehicle Body Reflection

Table I phase successful rate of the system

Steps	Phase/ Entirety	Number of Vehicles	Number of Success	Number of Failure	Recognition Rate
VehicleTail EndExtraction	Entirety	257	257	0	100%
LP	Phase	257	245	12	95.33%
Positing	Entirety	257	245	12	95.33%
Character	Phase	245	234	11	95.31%
Segmentation	Entirety	257	234	23	91.05%
LP	Phase	234	228	6	97.43%
Recognition	Entirety	257	228	29	88.71%

Table II The Recognition Success Rate on Samples in Time Intervals

Time Interval	Number of Vehicles	Number of Success	Number of Failure	LP Recognition Rate
Day Time	169	155	14	91.71%
Night Time	88	73	15	82.95%
Sum	257	228	29	88.71%

Table III The Recognition Success Rate on Samples in Weather

Weather	Number of Vehicles	Number of Success	Number of Failure	LP Recognition Rate
Clear Day	212	192	20	92.9%
Raining Day	45	36	9	80%
Sum	257	228	29	88.71%

Table IV The Recognition Success Rate on Samples in Car Speeds

Car Speed (kilometer/hour)	Number of Vehicles	Number of Success	Number of Failure	LP Recognition Rate
0-20	92	84	8	91.3%
20-40	114	102	12	89.47%
40-60	51	42	9	82.35%

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