Robust Car License Plate Recognition System Verified with 163,574 Images Captured in Fields

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Abstract

We have been manufacturing our own License Plate Recognition (LPR) systems since 1999 for parking lots in Japan. We have implemented a number of enhancements for our latest LPR system and one of the most important enhancements is for ranges of acceptable license-plate attitude angles. We collected 163,574 actual images so far and we selected 6,648 images randomly from this image database to verify our latest design. The histograms of plate attitude angles are estimated for these 2,836 images by measuring the license-plate shapes in the images and analyzed statistically. The analysis results for these actual 2,836 images prove that our latest LPR system accepts the attitude angles within its product specifications with enough margins.

1. Introduction

License Plate Recognition (LPR) is one of embodied commercial fields derived from Optical Character Recognition (OCR) technology. We have been manufacturing our own LPR system since 1999 for parking lots in Japan.

The word robust is often used in descriptions or papers about LPR systems [1], [3], [4], [5], [6], [7], [9]. There are some pieces in robustness, such as, image contrast and brightness, quality of license-plate itself or license-plate attitude angles. The robustness regarding contrast and brightness should be solved with cameras and illumination primarily. About the quality of license-plate, it is difficult to evaluate robustness for dirty plates or bended plates quantitatively [2], [8]. On the contrary, the robustness for license-plate attitude angles can be resolved by image processing in closed circumstances. In addition, from the standpoint of practical applications, attitude angles of license-plates are very important. In other words, LPR systems have to accept wide ranges of attitude angles with the following reasons: (1) plate positions vary with the types of cars, (2) car approach angles toward cameras vary according to drivers, (3) car approach angles toward cameras are not constant even if the same drivers and (4) there is no strict rule for mounting angles of license-plates on car bodies.

This paper describes widening acceptable attitude angles of license-plates which is one of major improvements for our latest system. This paper also reports distributions of attitude angles in actually captured plate images in fields. We could verify validity of our latest LPR system with these actual data. Attitude angles were discussed in [2] and [3] without any actual distributions of the angles. These angle distributions are important to evaluate LPR system robustness because they influence recognition rates.

We describe Japan car license-plates and an example configuration of our LPR system briefly as prerequisite information. Japan plate consists of four fields as shown in Figure 1. Figure 2 shows an example of our LPR system configuration. Yaw, pitch and roll angles are normally used as definition of attitude angles for aircrafts and we also use these words for attitude angles of license-plates for convenience in this paper. Figure 2 illustrates these three angles. Note that zero yaw angle means 23 degrees against camera’s center line shown as in the figure.

![Figure 1. Japan car license plate.](image_url)
2. Description of Image Processing

2.1. Overview

There are three steps in our license-plate recognition. The first one is a process to locate plate positions in captured images. We employed the method of template matching for edge images in this step. Sizes of license-plates in captured images vary because the distances between cameras and license-plates are not constant. In addition, there are two different sizes of license-plates in Japan. We prepared six different sizes of templates to overcome this difficulty. The detailed process is described in Subsection 2.2 later.

In the second step, we extract partial images from original full images based on the first step result. These partial images are expected to contain license-plates. They are called “plate images” hereafter. These plate images are always transformed because a camera does not face license-plates straight (Figure 2). We normalize these transformed plate images as if a camera faces license-plates straight and its distance is constant virtually. This process is necessary to use a pattern matching method to recognize each character in plate images. The detailed process is described in Subsection 2.3 later.

Each character is extracted in the final third step and compared with the patterns registered in the corresponding character dictionaries. The character which has the highest degree of coincidence is selected as a result. We composed these character dictionaries from 50 extracted actual character images from our image database. We made an experiment about how many images should be used to compose characters for the dictionaries. We tried 10, 25, 50 and 100 images and found 25 is the best one in terms of recognition rate.

2.2. Separated Templates

Our LPR system accepts wide ranges of attitude angles of license-plates. In other words, our LPR system gets more robust against shape transformation in converting real three-dimensional objects into two-dimensional still images. To accomplish this improvement, we use two separated templates; right half and left half templates. These two separated templates are coupled with each other weakly to absorb large transformation and exclude incorrect relative positions of left and right templates. Figure 3 shows the actual template shapes. A fundamental method using a single template does not work for larger transformation because of a low degree of similarity between an actual image and a template.

The formulas are shown in Equation 1, 2 and 3 to detect a candidate plate using these separated templates.

\[
P_R = \{(x_R, y_R)|SAD_R(x_R, y_R) < T_R\}
\]

\[
P_L = \{(x_L, y_L)|(SAD_L(x_L, y_L) < T_L) and(|x_L - x_R| < M) and(|y_L - y_R| < N)\}
\]

where \((x, y)\) is coordinates of pixels and \(T_R\) and \(T_L\) are threshold values for the right and left templates respectively. \(M\) and \(N\) are constant horizontal and vertical distances of neighborhood from \((x_R, y_R)\). SAD is Sum of Absolute Difference of a search image and a template. A combined score of two separated templates is defined as shown in Equation 3.

\[
S = SAD_R(x_R, y_R) \cdot SAD_L(x_L, y_L)
\]

A minimum value of \(S\) gives the most likely location of a license-plate.

2.3. Transformation Correction

We implemented another additional countermeasure for wider acceptable ranges of attitude angles, which is

![Figure 2. An example of our LPR system configuration and definitions of attitude angles. (a) Yaw angle, (b) Pitch angle, (c) Roll angle.](image-url)
an enhanced transformation correction. Though projective transformation gives precise inverse-transformed images, precise feature-point coordinates are required and it is difficult to get them. Hence, we use an approximate transformation instead of projective transformation under the condition that the distance between cameras and license-plates are much longer than sizes of plates and attitude angles are small. This approximate transformation is a conjunction of rotational and shear correction.

This method gives us the most robust capability. The detailed steps of this method are described below and illustrated in Figure 4.

(a) An example of original images.
(b) Execute a labeling process for a plate image and extract connected regions.
(c) For each region, draw a bounding rectangle. Select the candidate characters of Sequential Number by using bounding rectangles’ shapes.
(d) Determine combination of the candidates as Sequential Numbers. Assume which one of candidates is the lowest digit and verify the next higher digit. When multiple candidates exist, examine them and pick up the most probable one.
(e) Draw a line by connecting the centers of candidate shapes and measure its angle. This angle is a rotational correction angle.
(f) A rotational-corrected image. Try shear correction with some shear coefficients and select one which has the smallest horizontal sizes of characters.
(g) A final corrected image.

3. Verification with Field Data

3.1. Recognition Rate of Separated Templates

We have been gathering 163,574 actual images captured in fields along with actual operations and selected 3,812 images for verification of recognition rate. The reason why we do not use all of the images is that it is much time-consuming for persons to check true characters in the images with their eyes. The 3,812 images are randomly selected without any bias. We get the least necessary number of samples with Equation 4 statistically by assuming a population is a normally distributed one.

\[ n = \frac{N}{((\epsilon/\mu(\alpha))^2 \cdot ((N - 1)/\rho(1 - \rho)) + 1} \] (4)

where \( n \) is the least necessary number of samples, \( N \) is the size of a population, \( \epsilon \) is a degree of accuracy, \( \mu \) is a value of a normal distribution, \( \alpha \) is a confidence level, \( \rho \) is a population rate. We use \( N=163,574, \epsilon=3\%, \alpha=99\% \) and \( \rho=0.5 \) and get the number 1,829 from the equation and 3,812 is larger enough than 1,829. The 3,812 samples have enough confidence level. Table 1 shows the recognition rate comparison of single-template and separated-template methods. The separated-template method is better than the single-template by 1.2 percentage points.

<table>
<thead>
<tr>
<th>Template</th>
<th>Recognition Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single</td>
<td>95.9</td>
</tr>
<tr>
<td>Separated</td>
<td>97.1</td>
</tr>
</tbody>
</table>

3.2. Histograms of Attitude Angles

We selected another 2,836 images to estimate histograms of attitude angles. We do not use all of the 163,574 images with the same reason described in the previous subsection. Though it is impossible to get precise attitude angles of license-plates from these images, we can estimate these angles from projective transformation of plates.

The histograms of each angle are shown in Figure 5. Our LPR system can recognize all of the images counted in these graphs and its capability for attitude angles satisfies functional specifications. About yaw angle, our LPR system can recognize the plates which has larger yaw angles than the required specification.
About pitch angle, a few license-plates has larger pitch angle than the required specification and our LPR system can recognize these license-plates. About roll angle, the values of roll angles are relatively smaller than yaw and pitch angles. Some actual sample images are shown in Figure 6 to demonstrate our LPR system capability. These images were recognized correctly and the attitude angles of these images were close to the limits of specification ranges shown in 5.

Figure 6. Sample images around the limits of license-plate attitude angles. (a) Yaw angle = -30 degrees, (b) Pitch angle = 15 degrees.

4. Conclusions

We designed our latest LPR system as our company’s product and improved the capability of license-plate attitude angles. We have been collecting 163,574 actual images so far and we selected and used 6,648 images from this image database to verify our latest design. We implemented the method of two separated templates to locate plate positions and confirmed the effectiveness of this method by measuring its recognition rate of 3,812 images. We estimated actual attitude angles of 2,836 image and made their distribution histograms. These histograms prove that our LPR system accepts the attitude angles within its product specifications with enough margins.

References


