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TRIGONOMETRY-FREE BIDIRECTIONAL-SCANNING PERSPECTIVE CORRECTION FOR AUTOMATIC LICENSE PLATE RECOGNITION

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Abstract. *Automatic License Plate Recognition (ALPR) can achieve substantially better reliability and sustainability than manual license plate recognition, but its accuracy is inevitably error-prone to some horizontal and vertical perspective distortions between license plates and ALPR's cameras. Based on conventional homography-based perspective correction, this paper proposes a novel license plate perspective correction method consisting of 4 innovative techniques: 1) YCbCr-based image negative to adapt to the variation of the character/background contrast on license plates, 2) subregional histogram equalization to adapt to the variation of the border contrast between the license plate and the vehicle body, 3) bidirectional-scanning four-corner localization to adapt to the variation of the corner completeness of license plates, and 4) small-angle-approximation homography transformation to omit the trigonometric complexity and boost the processing performance. Experimental results show that the proposed license plate perspective correction method can significantly improve the accuracy of conventional ALPR and the speed of conventional perspective correction methods under various perspective distortion conditions.*

Keywords: License plate recognition, Perspective correction, Homography

1. **Introduction.** It is proven that Automatic License Plate Recognition (ALPR) based on Wiener-deconvolution vertical edge enhancement, AdaBoost plus vertical-edge license plate detection, vertical edge horizontal projection histogram segmentation stain removal, and customized Tesseract optical character recognition can detect and identify license plates anywhere, anytime, without manpower cost [1]. ALPR can be extensively applied to stolen vehicle investigation, roadside vehicle inspection, parking lot administration, shipping container logistics, and automotive factory management. Especially, ALPR can avoid the shortcomings of manual license plate recognition, such as time-consuming and poor-reliability. However, ALPR's cameras, mostly deployed aside the traffic intersection, hung over the main entrance, or installed on the robot, inevitably capture images of warping license plates because of some horizontal and vertical perspective distortions between license plates and ALPR's cameras. The slight perspective distortion threatens the plate detection accuracy of ALPR insignificantly, but degrades the character recognition accuracy of ALPR significantly. As shown in Figure 1(a), the vertical perspective distortion makes the rectangular character region of the license plate become the trapezoid one, and potentially makes the rightmost character "1" be recognized as "7". Besides, as shown in Figure 1(b), the horizontal perspective distortion makes the rectangular character region of the license plate become the wedge-shaped one, and potentially makes the rightmost character "R" be recognized as "B".

(a) (b)

Figure 1. Warping license plate images and their respective ALPR's results due to the effects of (a) vertical perspective distortion and (b) horizontal perspective distortion

2. **Conventional Perspective Correction Methods.** In the past years, most researches on perspective correction issue focus on the fields of perspective camera calibration or document character recognition [2-4], but very few focuses on the field of ALPR. So this paper's literature review takes these conventional perspective correction methods of photos or documents into account. In most conventional perspective correction methods, homography-based perspective correction is often adopted to convert out-of-plane rotated images into frontal images for comprehensive applications [5-8]. However, before performing homography transformation, how to exactly locate four corners of the quadrangular region of interest on the out-of-plane rotated image is a critical and difficult issue. In general, either diagonal-scanning scheme or quadrilateral-scanning (Houghlines-scanning) scheme is often introduced to solve four-corner localization issue for homography transformation. On the other hand, vanishing-point affine-based perspective correction is also a common and effective solution. Therefore, this paper will review the pros and cons of these 3 conventional perspective correction methods in detail as follows.

2.1. **Diagonal-scanning homography-based perspective correction.** In diagonal-scanning homography-based perspective correction method, as implied by the name, it locates four corners of the quadrangular region of interest by diagonal scanning schemes. After successfully binarizing and differentiating the quadrangular region of interest, the diagonal-scanning four-corner localization technique begins diagonal scanning schemes from four exterior corners of the out-of-plane rotated image until reaching four corners of the quadrangular region of interest, respectively. Then, homography transformation can be applied to correcting the perspective distortion of the out-of-plane rotated image [9,10]. The diagonal-scanning four-corner localization technique is effective and efficient, but it is easily degraded if some stains or reflections reside around four corners of the quadrangular region of interest. Especially, it often occurs in the automobile license plate images because of sunlight reflection or flash reflection onto four corners of white-background license plates.

2.2. **Quadrilateral-scanning homography-based perspective correction.** Quadrilateral scanning (Houghlines-scanning) four-corner localization technique is an alternative solution. On the edge image converted by Canny operator, Houghlines transform can locate four sides of the quadrangular region of interest by detecting four dominant edges. So four corners of the quadrangular region of interest can be estimated through four intersection points of its four sides. Then, in the same way, homography transformation is applied to correcting the perspective distortion of the out-of-plane rotated image [11,12]. However, Houghlines transform is time-consuming and error-prone, especially on the motorcycle license plate images whose backgrounds are often filled with strong and complex edge noise.

2.3. **Vanishing-point affine-based perspective correction.** Other than these 2 aforementioned four-corner localization and homography-based perspective correction methods, vanishing-point affine-based perspective correction method requires only three corners of the quadrangular region of interest for affine transformation, after it successfully searches two vanishing points extended from two pairs of opposite sides of the quadrangular region of interest and performs projective transformation of vanishing line function. That is, through projective transformation and affine transformation, vanishing-point affine-based perspective correction also can correct the perspective distortion of the out-of-plane rotated image in a similar way [13-17]. However, against the four-corner localization and homography-based perspective correction methods, the accuracy and reliability of vanishing-point perspective correction method are more sensitive to occlusive sides of the quadrangular region of interest due to stains or reflections. It essentially requires explicit four-side localization for both projective transformation and affine transformation.

3. **Proposed Perspective Correction Method.** As analyzed in Section 2, it is fundamental for conventional perspective correction methods to accurately localize four corners or four sides of the quadrangle region of interest. Unfortunately, for diverse license plate images and applications, it is more difficult for conventional perspective correction methods to accurately localize four corners or four sides of the license plate. This is because sunlight reflection or flash reflection often accompanies the license plate images, and occludes corners or sides of the license plate. As shown in Figure 2, this paper proposes 4 practical auxiliary techniques to improve homography-based perspective correction for ALPR: 1) YCbCr-based image negative to adapt to the variation of the character/background contrast on license plates (e.g., black/white, white/green, or white/red license plates), 2) subregional histogram equalization to adapt to the variation of the border contrast between the license plate and the vehicle body (e.g., silver-like or white-like vehicle body), 3) bidirectional-scanning four-corner localization to adapt to the variation of the corner completeness of license plates (e.g., occluded by stains or reflections), and 4) small-angle-approximation homography transformation to omit the trigonometric complexity and boost the processing performance, to overcome various perspective distortion conditions and various image interference conditions with less computational time.

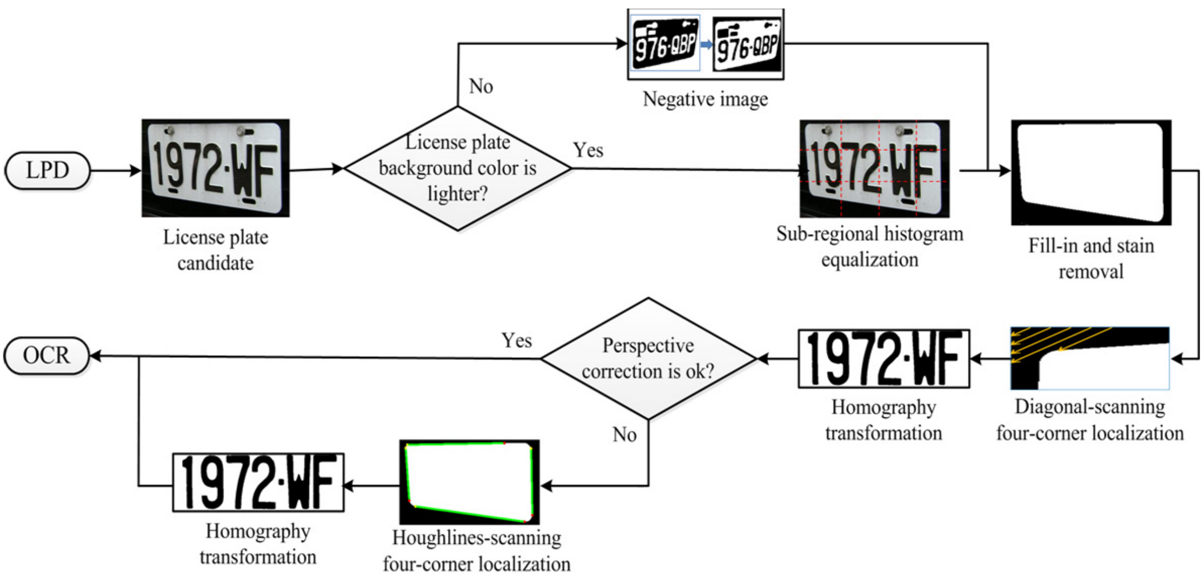


FIGURE 2. Flowchart of the proposed perspective correction method for ALPR

3.1. **YCbCr-based image negative.** Different countries around the world offer different types of license plates, and even each country in itself offers a variety of types of license plates. In Taiwan, there are also a lot of combinations of character/background colors on the license plates, like black/white, white/green, or white/red, for diverse sorts of vehicles or specialties. In ALPR system, after our own unique self-developed AdaBoost-classifier License Plate Detection (LPD) successfully detects the candidates of license plate regions and binarization processing, the license plates composed of darker character and lighter background must not be transformed to negative images, but the ones composed of lighter character and darker background must be. Then, ALPR can perform original Optical Character Recognition (OCR) on these license plate images composed of darker character and lighter background as well as usual.

Specifically, in most countries, like Taiwan, China, Japan, Korea, or United States, green-background or red-background license plates embedding white characters are often offered. These two types of license plate images must be negatively transformed for original OCR of ALPR after binarization processing. Thus, in this paper, YCbCr-based image negative technique is proposed to pick out green-background or red-background license plates from extracted Cr component or Cr composition of license plate images, respectively, for image negative processing. The detailed procedure of the proposed YCbCr-based image negative technique is illustrated as Figure 3.

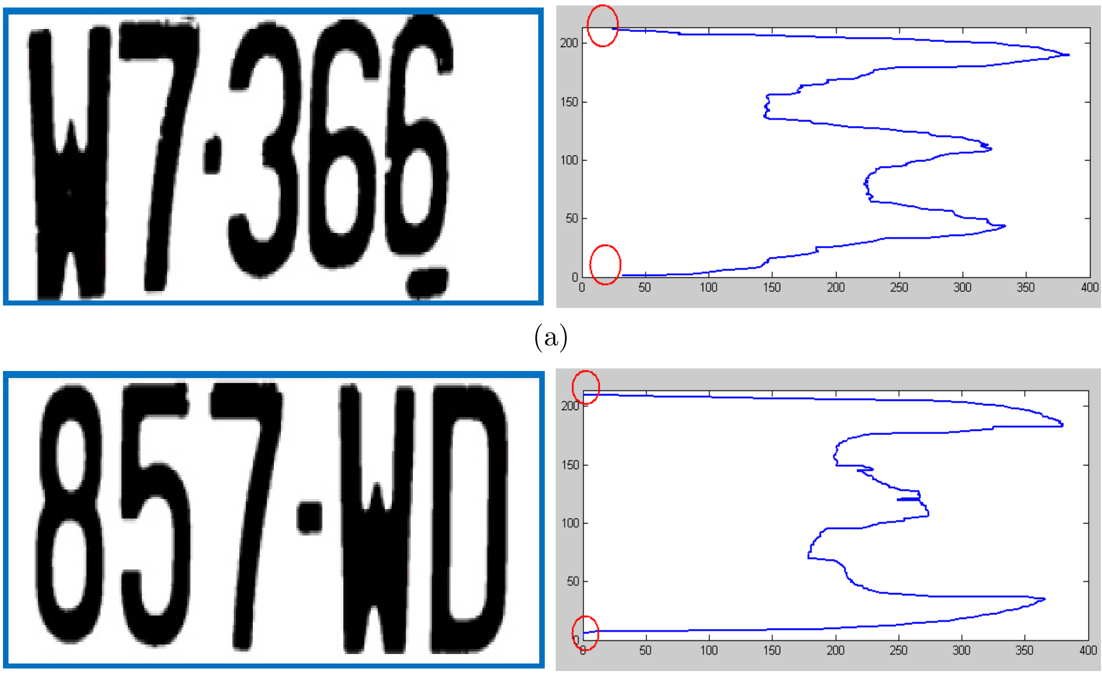
(a) (b) (c) (d)

Figure 3. (a) Original white-character and green-background license plate image, (b) Cr component of (a), (c) Cr composition of (a) after binarization, and (d) negative image of (c)

3.2. **Subregional histogram equalization.** To overcome the border contrast variation between the license plate and the vehicle body, especially on the silver-like and white-like vehicle body, this paper proposes subregional histogram equalization technique to segment the license plate image into 12 subregions, and to enhance the border contrast of the surrounding 10 subregions by histogram equalization, as shown in Figure 2. Finally, the border, including four sides and four corners, of the white-background license plate encompassed by the silver-like or white-like vehicle body can be easily differentiated.

3.3. **Bidirectional-scanning four-corner localization.** In order to overcome some stains or reflections existing around four corners of license plates, this paper proposes bidirectional-scanning four-corner localization technique to double scan four corners or four sides of license plates. That is, this paper not only adopts diagonal-scanning four-corner localization technique to locate four corners of the quadrangular region of interest, but also adopts quadrilateral-scanning (Houghlines-scanning) four-corner localization technique to relocate four intersection points of scanned four sides of the quadrangular region of interest, as shown in Figure 2, for homography-based perspective correction.

Because Houghlines transform is actually time-consuming and error-prone to strong and complex edge noise, this paper further proposes a perspective correction verification scheme to determine if the corrected outcome of diagonal-scanning homography-based perspective correction is proper and if quadrilateral-scanning (Houghlines-scanning)



(a)

(b)

FIGURE 4. (a) Failed perspective corrected image and its respective horizontal projection histogram, and (b) passed one

homography-based perspective correction can be bypassed, as shown in Figure 2. The perspective correction verification scheme determines the corrected outcome by evaluating the blank margin at the top and bottom of horizontal projection histograms of license plate images, as shown in Figure 4.

3.4. **Small-angle-approximation homography transformation.** It is well known that the rotation matrix is the critical computational complexity of homography transformation, rather than the translation matrix or the scaled matrix. Thus, this paper makes good use of small angle approximation to reform the rotation matrix as (1) into the trigonometry-free matrix as (2) by precisely approximating $\sin(\theta) = \theta$ and $\cos(\theta) = 1 - \theta * \theta * 0.5$, when the perspective angle ranges from 0 degree to 45 degree.

$$\begin{aligned} R_{zyx} &= R_z(\varphi) \cdot R_y(\theta) \cdot R_x(\emptyset) \\ &= \begin{bmatrix} \cos\varphi & -\sin\varphi & 0 \\ \sin\varphi & \cos\varphi & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\emptyset & -\sin\emptyset \\ 0 & \sin\emptyset & \cos\emptyset \end{bmatrix} \\ &= \begin{bmatrix} \cos\theta\cos\varphi & \sin\emptyset\sin\theta\cos\varphi - \cos\emptyset\sin\varphi & \cos\emptyset\sin\theta\cos\varphi + \sin\emptyset\sin\varphi \\ \cos\theta\sin\varphi & \sin\emptyset\sin\theta\sin\varphi + \cos\emptyset\cos\varphi & \cos\emptyset\sin\theta\sin\varphi - \sin\emptyset\cos\varphi \\ -\sin\theta & \sin\emptyset\cos\theta & \cos\emptyset\cos\theta \end{bmatrix} \end{aligned} \quad (1)$$

$$\begin{bmatrix} (1-\theta*\theta*0.5)(1-\varphi*\varphi*0.5) & \emptyset*\theta(1-\varphi*\varphi*0.5) - (1-\theta*\theta*0.5)\varphi & \emptyset*\varphi + \theta(1-\varphi*\varphi*0.5)(1-\emptyset*\emptyset*0.5) \\ (1-\theta*\theta*0.5)\varphi & \emptyset*\theta*\varphi - (1-\theta*\theta*0.5)(1-\varphi*\varphi*0.5) & (1-\emptyset*\emptyset*0.5)\theta*\varphi - \emptyset(1-\varphi*\varphi*0.5) \\ -\theta & \emptyset(1-\theta*\theta*0.5) & (1-\emptyset*\emptyset*0.5)(1-\theta*\theta*0.5) \end{bmatrix} \quad (2)$$

4. **Experimental Results.** Experimental database samples 787 images of automobile license plates (Resolution: 490×260) and 400 images of motorcycle license plates (Resolution: 323×214) in Taiwan for comparison. All license plate images in the experimental database contain a great number of variations, like perspective directions and angles, license plate's character/background contrast, license plate's border contrast, and license

Table 1. Comparison on ALPR's recognition rate and ALPR's execution time

Perspective correction methods	Recognition rate on automobiles	Recognition rate on motorcycles	Execution time per frame
Trigonometry-free bidirectional-scanning perspective correction	**97%**	**89%**	**0.75 (sec)**
Diagonal-scanning homography-based perspective correction	75%	84%	0.82 (sec)
Quadrilateral-scanning homography-based perspective correction	62%	75%	0.91 (sec)
Vanishing-point affine-based perspective correction	50%	72%	0.98 (sec)

plate's occlusive corners. The experiment in Table 1 takes 4 license plate perspective correction methods into comparison: 1) the proposed trigonometry-free bidirectional-scanning perspective correction, 2) conventional diagonal-scanning homography-based perspective correction, 3) conventional quadrilateral-scanning homography-based perspective correction, and 4) conventional vanishing-point affine-based perspective correction, in view of ALPR's recognition rate and execution time per frame.

From Table 1, it is evident that the proposed perspective correction method is better at raising the recognition rate of ALPR with less processing time, for both automobile and motorcycle license plate database. This is because the proposed license plate perspective correction method consisting of: 1) YCbCr-based image negative to adapt to the variation of the character/background contrast on license plates (e.g., black/white, white/green, or white/red license plates), 2) subregional histogram equalization to adapt to the variation of the border contrast between the license plate and the vehicle body (e.g., silver-like or white-like vehicle body), 3) bidirectional-scanning four-corner localization to adapt to the variation of the corner completeness of license plates (e.g., occluded by stains or reflections), and 4) small-angle-approximation homography transformation to omit the trigonometric complexity and boost the processing performance, can improve conventional homography-based or affine-based perspective correction of ALPR to overcome more perspective distortion conditions and more image interference conditions with less computational time.

5. **Conclusions.** Trigonometry-free bidirectional-scanning perspective correction method comprised of 4 innovative auxiliary techniques is an effective and efficient solution to lighten perspective distortion issue of ALPR. However, quadrilateral-scanning (Houghlines-scanning) scheme of the proposed bidirectional-scanning four-corner localization technique is still a computational bottleneck to the overall perspective correction method. In addition to the bypass scheme of the proposed perspective correction verification, how to optimize the quadrilateral-scanning (Houghlines-scanning) scheme itself is a worthwhile research goal.

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