TECHNICAL NOTE

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A 3-D Transformation to Improve the Legibility of License Plate Numbers

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ABSTRACT: In this paper, a novel three-dimensional transformation method for vehicle license plate number recognition is proposed. This method provides an efficient solution to normalize skew distorted vehicle license plate images. The Hough transform is used to estimate the license plate position and the normalization angle. After the three-dimensional transformation and normalization processes, the vehicle license plate numbers are recognized easily. Real vehicle license plate images are used to show the capability of the proposed method. The provided method is also useful for other skewed writings, such as the text printed on a suspect's shirt.

KEYWORDS: forensic science, Hough transform, three-dimensional transformation, vehicle license plate number recognition

Recognition of vehicle license plate numbers plays an important role in solving forensic image problems. For normalized vehicle license plates (i.e., in the frontal view), we can read license numbers easily; however, for vehicle license plates with skew distortion, we have difficulty in recognizing the numbers directly. Unfortunately, in practical forensic cases, we usually need to recognize the numbers of skew distorted vehicle license plates.

In this paper, a novel three-dimensional transformation method for vehicle license plate number recognition is proposed. The method is based on the Hough transform (1–8) and three-dimensional transformation techniques (9). The Hough transform is used to estimate the plate position (and four corner intersection points) on a skew distorted vehicle license plate image and the rotation angle needed to normalize the plate image, while the three-dimensional transformation techniques are used to normalize the skew plate image with the estimated information.

The Hough transform is a well-known tool for detecting features of objects on an image. In 1962, the Hough transform was first proposed by Hough (1). A difficult image pattern detection problem is converted into a local peak detection problem by using the Hough transform (2). From previous works, we can apply the Hough transform to detecting image patterns, such as lines (3), circles (4), ellipses (5), curves (6), and polygons (7). Here, we use the Hough transform to estimate the plate position (and four corner intersection points) and the rotation angle needed to normalize the skew distorted vehicle license plate image. After the three-dimensional transformation with the estimated information, the vehicle license plate numbers are recognized easily.

Methods

In this section, we will summarize techniques used in our method, including the Hough transform, X-Y plane rotation, three-dimensional transformation, application to a skew distorted vehicle license plate image, interpolation, and minimum-filtering.

Hough Transform

In our method, we apply the Hough transform to obtaining the four edge line equations of a skew distorted vehicle license plate image. From these equations, the skew angle and position (and four corner intersection points) of the license plate are obtained.

On an image, a line can be described as (Fig. 1)

$$\rho = x \cos \phi + y \sin \phi \qquad (1)$$

where, (x, y) denote the coordinates of the points on the line, ρ is defined as the perpendicular distance (called the ρ-line) from the origin to the line, and ϕ is defined as the angle between the X-axis and the ρ-line. The ranges of ϕ and ρ are $-90°\sim90°$ and $0 \sim \sqrt{2}\,N$ (N is the image size), respectively.

One edge line of an object (such as a license plate) is defined as a set of edge points that are adjacent and belong to the same line equation. With Eq 1, the Hough transform is used to find the line equation on which these edge points lie (for a vehicle license plate image, we need to find four edge lines.). For each point interested, plug the x and y coordinates into Eq 1. Then, for each value of ϕ on the quantized Hough plane (the Hough accumulators) (Fig. 2), we can obtain a ρ value and add one to the corresponding accumulator (ρ,ϕ). This constitutes a hit for that accumulator. The scale size values of the accumulators, $\Delta\rho$ and $\Delta\phi$, are related to the accuracy of the line position and angle, i.e., a larger size value provides lower accuracy.

When the hitting process is completed, the number of hits in each accumulator means the number of points on the line defined by the values of ρ and ϕ. One accumulator (ρ,ϕ) on the quantized Hough plane corresponds to one line on the image plane. The number of hits of the accumulator means the line length. We select a threshold value and look for the accumulators (ρ,ϕ) whose hit-numbers

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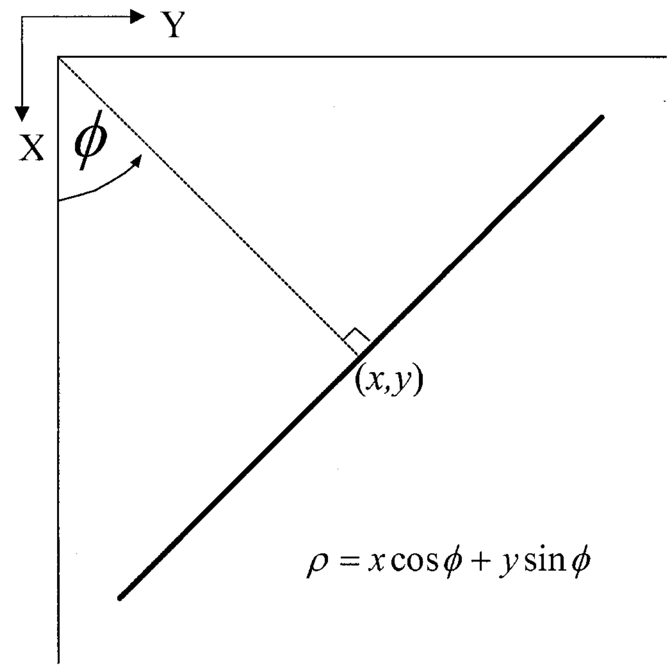


FIG. 1—*A line equation used in the Hough transform, where (x, y) denote the coordinates of the points on the line,* ρ *is defined as the perpendicular distance (called the* ρ*-line) from the origin to the line and* Φ *is defined as the angle between the X-axis and the* ρ*-line.*

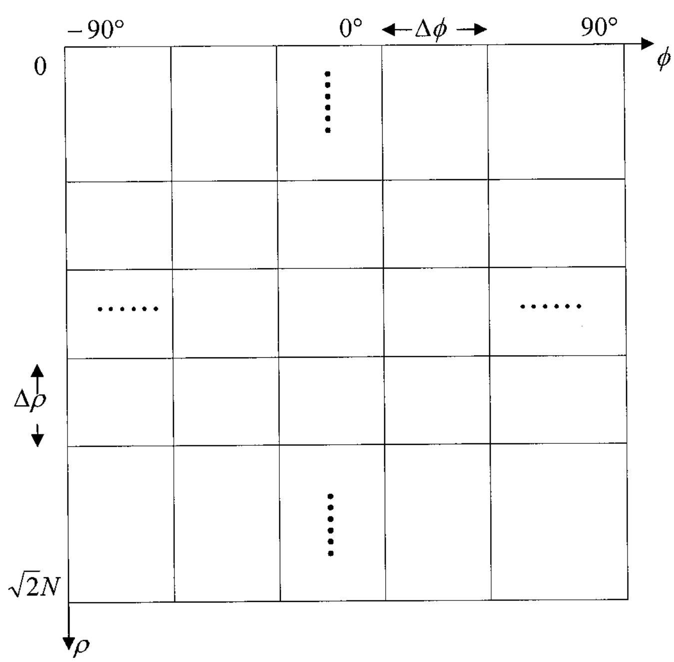


FIG. 2—*The quantized Hough plane (the Hough accumulators).* ρ *is the perpendicular distance (the* ρ*-line) defined in Fig. 1;* Φ *is defined as the angle between the X-axis and the* ρ*-line;* Δρ *and* ΔΦ *are the scale size values of* ρ *and* Φ*, respectively. Each* (ρ, Φ) *is an accumulator.*

are larger than the threshold value (i.e., the line length is long enough). In the vehicle license plate case, we choose a proper threshold value and obtain four longest lines. From Eq 1 and the chosen (ρ, ϕ) pairs, we can obtain the skew angle, position, and four corner intersection points of a vehicle license plate on an image.

X-Y Plane Rotation

Before the three-dimensional transformation operation, we need to align the "vertical" edge line of a vehicle license plate image with the Y-axis (i.e., two-dimensional rotation on the X-Y plane). Without losing the generality, we define a rotation angle β and the position (x_r, y_r) of the pivot point about which the object is to be rotated (Fig. 3). The transformation equation for rotating a point from the position (x, y) to the new position (x', y') through an angle β is described as

$$\begin{cases} x' = x_r + (x - x_r)\cos\beta - (y - y_r)\sin\beta \\ y' = y_r + (x - x_r)\sin\beta + (y - y_r)\cos\beta \end{cases}. \tag{2}$$

In order to align the "vertical" edge line of a vehicle license plate image with the Y-axis, we can rotate every point on the license plate through an angle (−β) about the pivot point (x_0, y_0) (Fig. 4).

Three-Dimensional Transformation

While the X-Y plane rotation operation is performed on the two-dimensional (2-D) *XY* coordinate plane, the three-dimen-

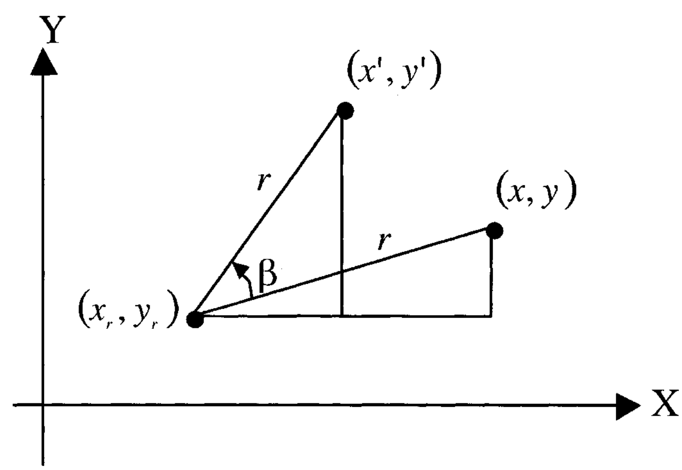


FIG. 3—*Rotate a point from x, y to x′, y′ through an angle* β *about the pivot point* x_r, y_r.

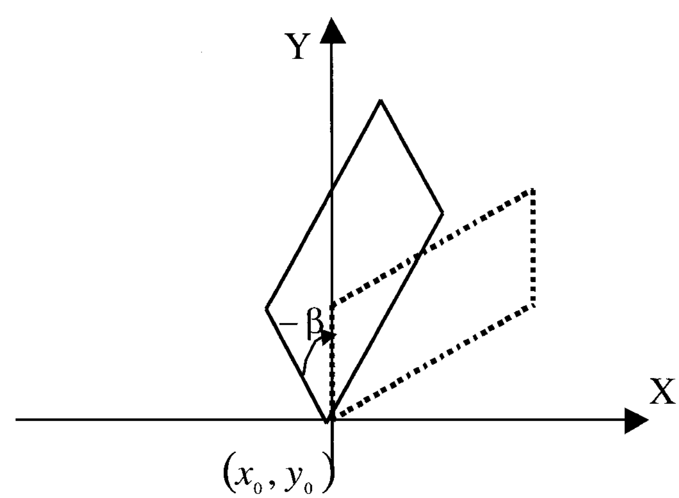


FIG. 4—*We can rotate a vehicle license plate image through an angle* −β *about the pivot pint* x_0, y_0 *with Eq 2 and align the vertical edge line of a vehicle plate image with the Y-axis.*

sional (3-D) transformation is processed in the three-dimensional *XYZ* coordinate space. Since a vehicle license plate image is a kind of 2-D data established by the X and Y-axes, the key point for our method is how to define the X, Y, and Z-axes on a 2-D image. In this section, we will explain how to establish a 3-D coordinate system on a 2-D image, and how to normalize a skew distorted vehicle license plate image with the 3-D transformation techniques.

Without losing the generality, we use Fig. 5 to explain the 3-D transformation techniques used in our method. As shown in Fig. 5*a*, the Z-axis is defined and aligned with the lower edge line of a skew distorted vehicle license plate. The Y-axis is defined and aligned with the left edge line of the vehicle plate. Since this vehicle license plate image was processed with the 2-D X-Y plane rotation operation, the Y-axis (or the left edge line) is a vertical line. The X-axis is defined as a horizontal line, and the vehicle license plate image is on the Y-Z plane. We use the orthogonal coordinate system, i.e., any two axes are perpendicular to each other. According to the definition of the coordinate system, a point *P(x, y, z)* to the origin can form a vector $\overrightarrow{OP}(x, y, z)$ and the component *x*, *y*, and *z* can be obtained from the vector projection to the three axes respectively.

From Fig. 5*a*, we denote $(x_j, y_j)_2$ (in the following, Footnotes 2 and 3 mean the 2-D and 3-D representation, respectively) as the image points belong to the vehicle license plate (the 2-D image plane with x-axis and y-axis), $(x', y')_2$ as the left-lowest point of the vehicle license plate. After transforming the 2-D data into the 3-D data, the point $(x', y')_2$ will become the origin $(x_0, y_0, z_0)_3$, where $x_0 = y_0 = z_0 = 0$, in the new 3-D X-Y-Z space. Here, we will show how to transform 2-D point $(x_j, y_j)_2$ into a 3-D point $(x_i, y_i, z_i)_3$.

Since we define the 2-D vehicle license plate image is on the Y-Z plane of the 3-D X-Y-Z space, x_I can be simply defined as:

$$x_i = 0 \tag{3}$$

The Z-axis of the 3-D X-Y-Z space is also a line on the 2-D X-

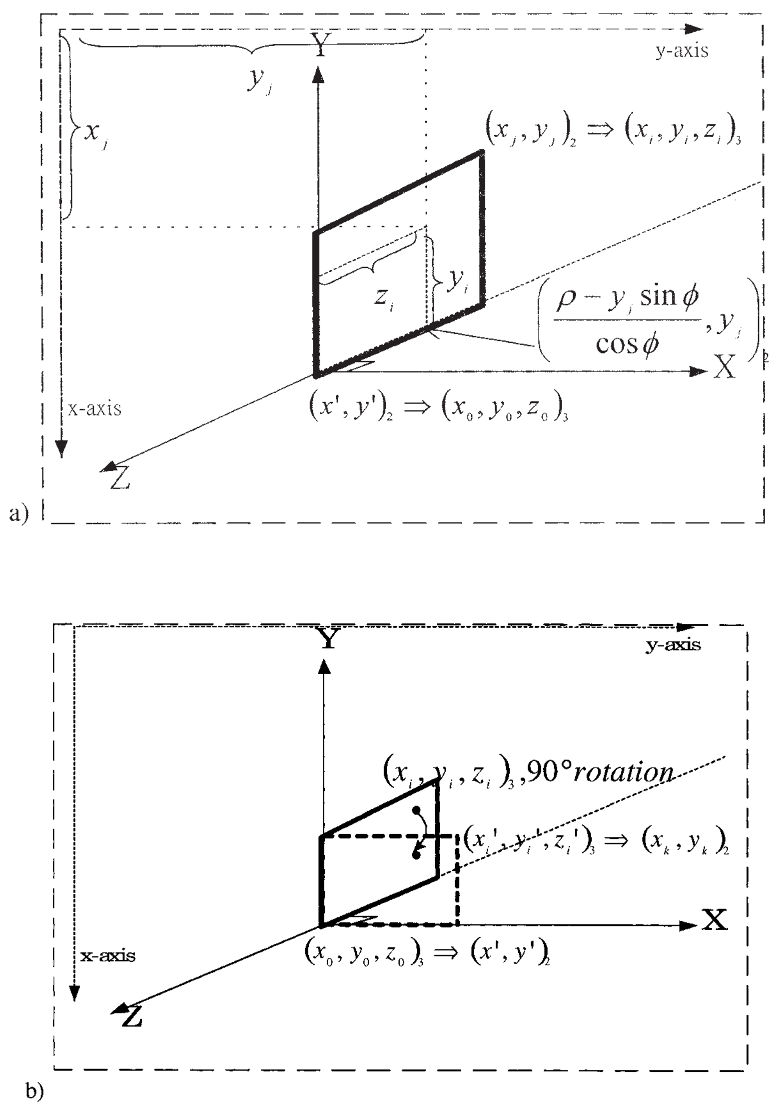


FIG. 5—*Transformation of 2-D data (x-y) plane into 3-D data (X-Y-Z space); a) $(x_j, y_j)2$ is a 2-D point, $(x_i, y_i, z_i)_3$ is the same point in the 3-D X-Y-Z; $(x_j', y_j')_2$ and $(x_0, y_0, z_0)_3$ are the origins for 2-D and 3-D, respectively; b) a license plate image is rotated from the Y-Z plane to the X-Y plane, i.e., all points $(x_i, y_i, z_i)3$ are transformed to $(x_i', y_i', z_i')_3$.*

Y plane, and its 2-D equation can be denoted as Eq 1, obtained from the Hough transform. From Fig. 5*a*, is the distance between

$$(x_j, y_j)_2 \quad \text{and} \quad \left(\frac{\rho - y_j \sin\phi}{\cos\phi}, y_j\right)_2 : y_i = \left|\frac{\rho - y_j \sin\phi}{\cos\phi} - x_j\right| \tag{4}$$

Since the vehicle license plate image is defined on the positive Y-axis portion, the absolute symbol "| |"is used to keep $y_i > 0$. Similarly, z_i is the distance between $\left(\frac{\rho - y_j \sin\phi}{\cos\phi}, y_j\right)_2$ and $(x', y')_2$:

$$z_i = -\sqrt{(y_j - y')^2 + \left(\frac{\rho - y_j \sin\phi}{\cos\phi} - x'\right)^2} \tag{5}$$

Since the plate image is defined in the negative Z-axis direction, we keep z_i negative. From Eqs 3–5, we can obtain the three-dimensional coordinate representation $(x_i, y_i, z_i)_3$ of a 2-D point $(x_j, y_j)_2$, and point by point, we can transform all points of a 2-D vehicle license plate image into three-dimensional coordinate representation.

From Fig. 5*b*, in order to normalize the vehicle license plate image, the process we need to deal with is to transform all plate points $(x_i, y_i, z_i)_3$ from the Y-Z plane to the X-Y plane, i.e., the points $(x_i, y_i, z_i)_3$ are rotated to $(x_i', y_i', z_i')_3$ about the Y-axis by 90°. The transformation can be described as:

$$\begin{bmatrix} x_i' \\ y_i' \\ z_i' \\ 1 \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 & \sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x_i \\ y_i \\ z_i \\ 1 \end{bmatrix} \tag{6}$$

In the case of Fig. 5, we define the $\theta = -90°$, and Eq 6 becomes

$$x_i' = -z_i = \sqrt{(y_j - y')^2 + \left(\frac{\rho - y_j \sin\phi}{\cos\phi} - x'\right)^2} \tag{7}$$

$$y_i' = y_i = \left|\frac{\rho - y_j \sin\phi}{\cos\phi} - x_j\right| \tag{8}$$

$$z_i' = y_i = 0. \tag{9}$$

In order to show the normalized plate image, we need to transform the 3-D coordinate representation $(x_i', y_i', z_i')_3$ back into the new 2-D coordinate representation $(x_k, y_k)_2$ (Fig. 5*b*). Since the normalized points are on the X-Y plane, it is convenient for us to ignore the z_i' coordinate and let

$$x_k = x_i' + x' \tag{10}$$

$$y_k = y_i' + y' \tag{11}$$

where $(x', y')_2$ is still the left-lowest point of the plate, with the same 2-D coordinates in Fig. 5*a*.

Application to a Skew Distorted Vehicle License Plate Image

We use the flowchart (Fig. 6) and a real skew distorted vehicle license plate image (Fig. 7) to explain our method. In order to make our method understood easily, we use an image with minor skew distortion. Before applying the Hough Transform, we must transform the original image (with gray-level values) into the binary format image (only with black or white color) first and eliminate all pixels except the boundaries of the vehicle plate (Fig. 8). In this stage, we may obtain the approximate boundaries of the vehicle plate; however, the approximation error will not affect the result of

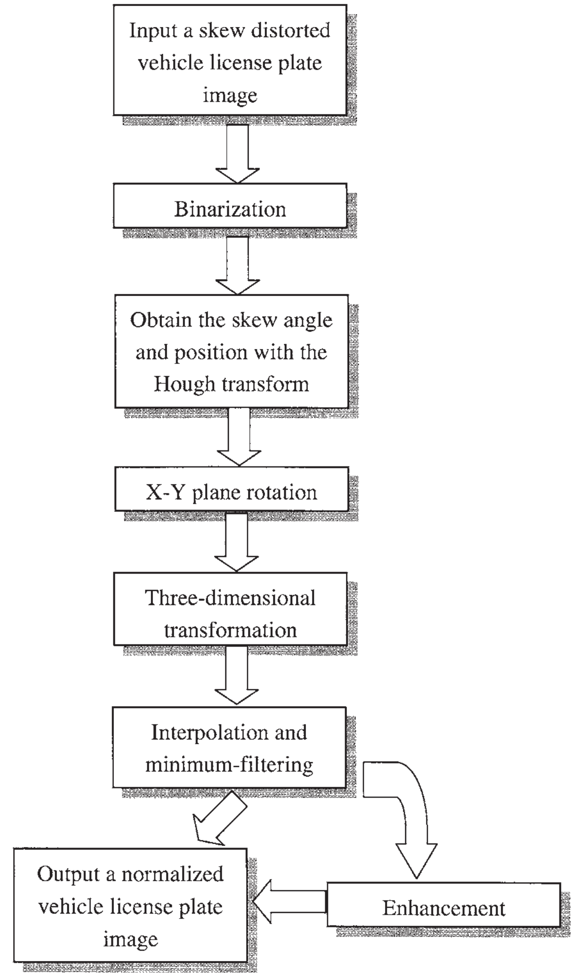


FIG. 6—*The flowchart of vehicle license plate number recognition with the three-dimensional transformational method.*

FIG. 7—*A skew distorted vehicle plate image (8M-4097); the image size = 330*330.*

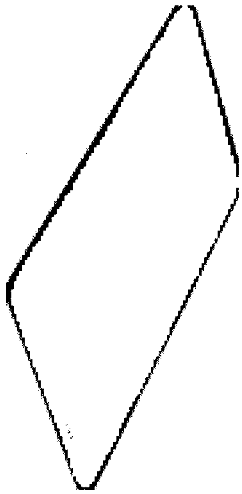


FIG. 8—*The boundaries of the vehicle plate obtained from Fig. 7; the image size = 330*330.*

FIG. 9—*The position of Fig. 7's vehicle license plate image is processed by X-Y plane rotation.*

number recognition. With Fig. 8 and the Hough Transform, we can obtain the skew angle, position and four corner intersection points of the plate (Fig. 9).

After the X-Y plane rotation, we can align the left edge line of the plate with the Y-axis. In this example, we rotate the image with 20° (Fig. 10).

After the three-dimensional transformation (in this example, $\theta = -90°$), we can obtain the 3-D rotated image (Fig. 11*a*). From the result, we can read the numbers in the front view, however, we still need to improve the quality of the result, and that is why we add the interpolation and minimum-filtering processes.

Interpolation and Minimum-Filtering

In practice, the edge contour of the vehicle license plate image is not a parallelogram, as shown in Fig. 5*a*. This fact makes the normalized vehicle plate image fail to form a rectangle as we expected. In addition, there are many white stripes on the normalized image (Fig. 11*a*).

In order to expand the normalized image into a rectangle, we apply the polynomial regression method to interpolating points into each column (8). This process produces an enlarged effect in every column and makes every one have the same point number (Fig. 11*b*).

In order to reduce the white-strip effect, we process the whole image with a 3*3 minimum-filter (8). We consider each point $(x,y,)$ and its eight neighboring points:

$$\begin{aligned}&(x+1, y), (x-1, y), (x, y+1), (x, y-1)\\ &\qquad (x+1, y+1), (x+1, y-1),\\ &\qquad\qquad (x-1, y+1) \quad \textit{and} \quad (x-1, y-1)\end{aligned} \tag{12}$$

If the gray-level value of the point (x,y) is 255 (white), we replace its gray-level value with the minimum one around its neighboring points. The filtered result is shown as Fig. 11*c*.

After above interpolation and minimum-filtering processes, we obtain the better result (Fig. 11*d*). If it is needed, we can also process the result with the enhancement techniques (8), and obtain the final result (Fig. 11*e*).

Results

In order to show the capability of the proposed method, we use more sample images with different skew distortion angles to redo the experiments.

Figure 12*a* is a seriously skew distorted vehicle license plate im-

FIG. 10—*Figure 7's vehicle license plate image is processed by X-Y plane rotation.*

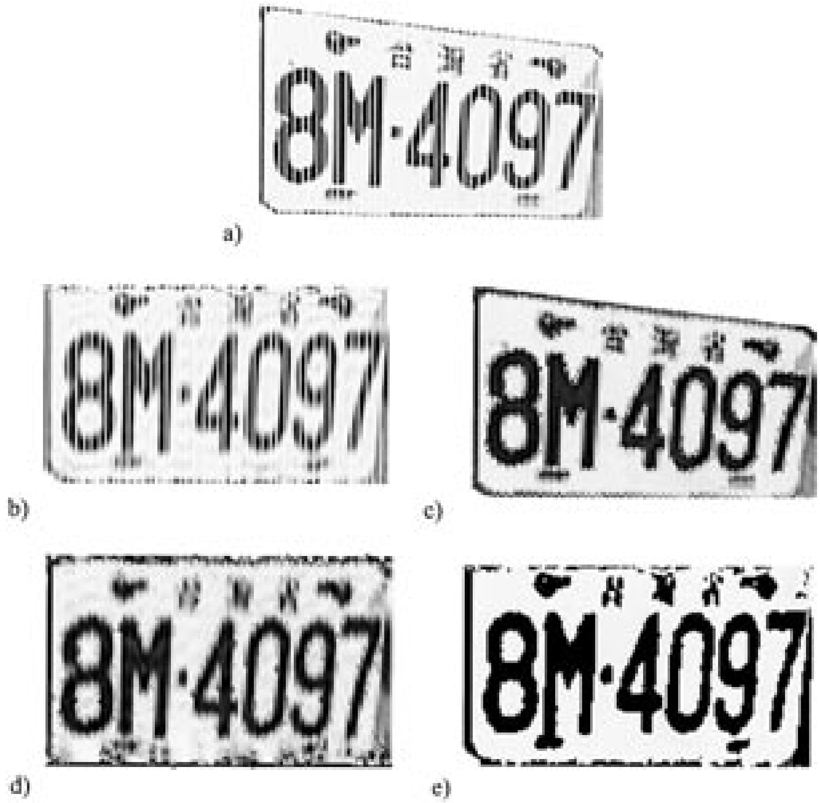


FIG. 11—*The normalized results of Fig. 7: a) without interpolation and minimum filtering; b) with interpolation but without minimum filtering; c) without interpolation but with minimum filtering; d) with interpolation and minimum filtering; e) processing; d) with enhancement.*

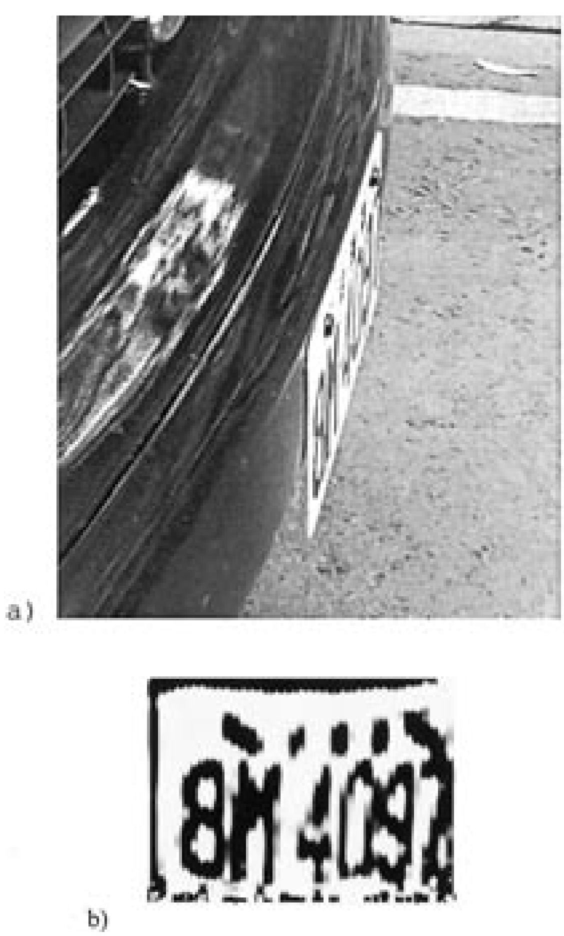


FIG. 12—*a) A seriously skew distorted vehicle license plate image (8M-4097); the image size = 330*330; b) the normalized result.*

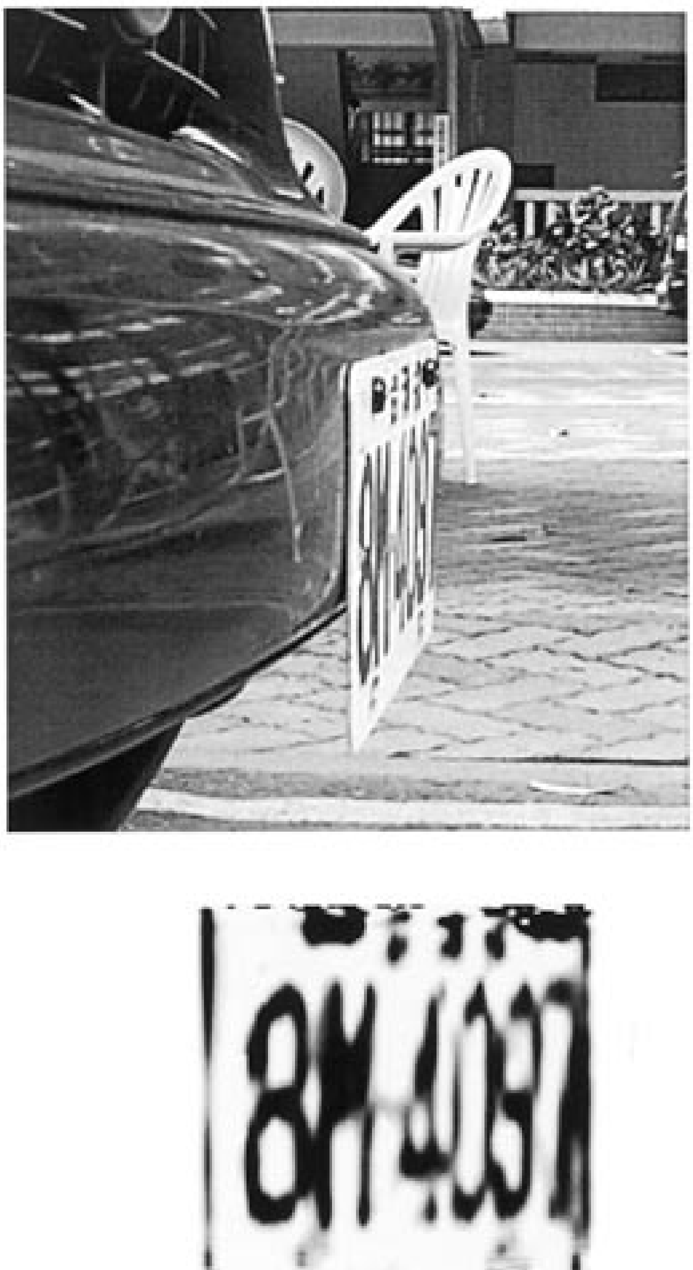
age. After the 3-D transformation process, the numbers can be recognized easily (Fig. 12*b*). The images in Figs. 12*a* and 13*a* are the same vehicle license plate, but taken by cameras with different height position. From Fig. 13*b*, we can see the camera position does not affect the normalized result. Figure 14*a* shows a vehicle license plate image with the other site view. In this example, all procedures are still the same, except the rotating angle θ in Eq 6 is changed to $\theta = 90°$. The transformed result is shown in Fig. 14*b*.

Discussion

In this paper, we proposed a novel three-dimensional transformation method for vehicle license plate number recognition. After the three-dimensional transformation and normalization, the vehicle license plate numbers are recognized easily. From the experimental results, this method is flexible for different skew angles, and it provides an efficient solution to normalize skew distorted vehicle license plate images. In fact, the provided method is also useful for other skewed writings, such as the text printed on a suspect's shirt.

Although this method provides a good solution for skew distortion problems, there are still unanswered questions, such as what are the limitations (angles and positions of the method)? How can we combine this method with image processing techniques (enhancement and restoration)? We will work on them in the future work.

a)



b)

FIG. 13—*a) A seriously skew distorted vehicle license plate image (8M-4097); the image size = 330*330; b) the normalized result.*

FIG. 14—*a) A vehicle license plate image with a different skew distortion angle; b) the normalized result.*

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