Vehicle License Plate Tilt Correction based on the Weighted Least Square Method

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Abstract—Tilt correction is a very crucial part of the Vehicle License Plate (VLP) automatic recognition. In this paper, according to the Weighted Least Square Method (WLSM), the VLP region is fitted to a straight line and then the line slope \( a_i \) is obtained, by which the rotation angle \( \alpha \) is calculated. Finally the whole image is rotated by \(-\alpha\) and the image tilt correction is performed. The experimental results definitely show that, this paper method can quickly and accurately get the tilt angle and has great robustness and adaptability. Compared with the Least Square Method (LSM), in this paper method the tilt angle is more precise and the value of objection function is smaller; Compared with Hough Transformation (HT) and Radom Transformation (RT), this paper method is featured in faster processing time and more precise tilt angle, which is particularly well adapted to the real-time tilt correction in Intelligent Transportation System (ITS).

Keywords- Vehicle license plate; image; least square method; Hough transformation

I. INTRODUCTION

In the procession of taking the VLP images, because of the weather, the illumination, the road condition and so on, the VLP in the image frequently has some clear and serious tilt so that the touching and broken characters are created, which, as we know too well, is a tremendous and serious obstacle to the character segmentation and recognition [1-4]. In order to approach the above problem, experts at home and abroad have undertaken colossal and in-depth research and exploration over many years and have conceived many ingenious and practical solutions, among which Hough Transformation Method (HTM), Projection Profile Method (PPM), and Component Nearest Neighbor Clustering Method (CNNCM) are the most typical ones. HTM[2-4], as the most extensively-employed and prevalent one, uses HT to calculate the possible track in parameter space according to target pixel coordinates in the image space. It is very well adapted to linear graphic, but with a lot of computational load and lack of robustness for a tilt VLP image. PPM [1], which is built on the analysis for the projection shape, has an extremely heavy computational load because it needs to calculate the projection shape of each angle. CNNCM [5], by discovering \( K \) nearest neighbors of the central point of all connected components, computes the vector direction of each couple nearest neighbor and gets the statistical histogram where the peak value denotes the entire image tilt angle. Since there exist some connected components in the image, its processing time is also a quite prodigious load [6-8].

On the basis of a comprehensive and thorough investigation into WLSM, we propose vehicle license plate tilt correction based on the weighted least square method. In this paper, through fitting the straight line using WLSM, the line slope \( a_i \) is obtained, by which the rotation angle \( \alpha \) is calculated. Finally the whole image is rotated by \(-\alpha\) and image tilt correction is finished. The rest of this paper is organized as follows. Section 2 describes the implementation of this method in detail. Section 3 gives experimental results and comparisons to test our method. The conclusions are given in Section 4.

II. VEHICLE LICENSE PLATE TILT CORRECTION BASED ON THE WEIGHTED LEAST SQUARE METHOD

When there exists some tilt in the VLP image (see Fig.1), there is a tilt angle \( \alpha \) between the principal axis \( X' \) and the horizontal axis \( X \) of the tilt VLP region. In view of this, we think that once \( \alpha \) is got, the entire image can be rotated by \(-\alpha\) and the tilt correction is completed. In Fig.1a, \( \alpha > 0 \) denotes that the correction angle is \(-\alpha\), contrarily, the correction angle is \( \alpha \).

![Figure 1. Image tilt](image)

(a) \( \alpha > 0 \)
(b) \( \alpha < 0 \)

A. Fitting the straight line based on LSM

In the course of engineering design and experimental statistics, upon analysis and procession to a batch of data, the data are often fitted to a curve. LSM is a widely-used fitting method. If we use a smooth curve \( y = f(x) \) to fit a set of data \((x_i, y_i) (i = 1, 2, \cdots, n)\), then in principle, the deviation between the data and the curve should be minimized. The deviation \( \varepsilon_i = f(x_i) - y_i \) is usually called residue. LSM enables the sum of \( \varepsilon^2 \) to achieve the minimum, namely, the objective function \( Q = \sum_{i=1}^{n} \varepsilon_i^2 \) is the minimum. In this paper...
we use a straight line to fit the data. Let the linear equation be expressed as \( y = a_1 x + a_0 \), and then the objective function \( Q \) is:

\[
Q = \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} (a_1 x_i + a_0 - y_i)^2
\]  

(1)

The matrix form of Equation (1) is shown as follows:

\[
Q = (AX - Y)^T (AX - Y)
\]  

(2)

where \( Y = [y_1 \ y_2 \ \cdots \ y_n]^T \), \( A = [a_0 \ a_1]^T \), and \( X = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ x_1 & x_2 & \cdots & x_n \end{bmatrix} \).

From Equation (2), the partial derivative of \( A \) is obtained:

\[
\frac{\partial Q}{\partial A} = 2X^T(AX - Y) = 0
\]  

(3)

The above equation is solved and \( A \) is obtained:

\[
A = (X^T X)^{-1} X^T Y
\]  

(4)

Namely:

\[
\begin{align*}
 a_0 &= \frac{\sum_{i=1}^{n} y_i \sum_{i=1}^{n} x_i^2 - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} x_i y_i}{\sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2} \\
 a_1 &= \frac{\sum_{i=1}^{n} y_i x_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2}
\end{align*}
\]  

(5)

\( x_i \) and \( y_i \) are inserted into equation (5) and the slope \( a_1 \) is obtained.

**B. Fitting the straight line based on WLSM**

According to Equation (1), in the case of homoscedastic errors, it is reasonably assumed that \( \varepsilon_i \), produced by each \( (x_i, y_i) \) is equally treated, which denotes that each \( \varepsilon_i \) provides coequally important information. In the case of heteroskedastic errors, however, in the fitting line the position \( f(x_i) \) which corresponds to \( \varepsilon_i \) has dispersion degree being high is not precise. Therefore, fitting a straight line is made little account of the information provided by \( \varepsilon_i \). In other words, the higher the deviation \( \varepsilon_i \) corresponding to \( x_i \), the smaller the contribution to the information, conversely, the smaller the deviation \( \varepsilon_i \) corresponding to \( x_i \), the higher the contribution to the information. To improve the correction precision, the importance of information producing by the residue \( \varepsilon_i \) is adjusted by the weight, which is the basic thought of WLSM.

According to the above analysis, we assign a higher weight to the smaller residue square \( \varepsilon_i^2 \), but a smaller weight to the higher residue square \( \varepsilon_i^2 \). Let \( w_i \) be the weight and Equation (1) is rewritten:

\[
Q_w = \sum_{i=1}^{n} w_i \varepsilon_i^2 = \sum_{i=1}^{n} w_i (a_1 x_i + a_0 - y_i)^2
\]  

(6)

The matrix form of Equation (6) is shown as follows:

\[
Q_w = (AX - Y)^T W (AX - Y)
\]  

(7)

where \( W = diag(w_1, w_2, \cdots, w_n) \), \( A = [a_0 \ a_1]^T \), \( Y = [y_1 \ y_2 \ \cdots \ y_n]^T \), and

\[
X = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ x_1 & x_2 & \cdots & x_n \end{bmatrix}
\]

From Equation (7), the partial derivative of \( A \) is obtained:

\[
\frac{\partial Q_w}{\partial A} = 2X^T W (AX - Y) = 0
\]  

(8)

The above equation is solved and \( A \) is obtained:

\[
A = (X^T WX)^{-1} X^T WY
\]  

(9)

We suppose that

\[
w_i = \frac{1}{\sigma^2} = \frac{1}{\sigma_i^2 y_i}
\]  

(10)

According to Equations (8)-(10), \( a_0 \) and \( a_1 \) are expressed:

\[
\begin{align*}
 a_0 &= \frac{\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2} \\
 a_1 &= \frac{\sum_{i=1}^{n} x_i^2 - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2}
\end{align*}
\]  

(11)

\( x_i \) and \( y_i \) are inserted into equation (11) and the slope \( a_1 \) is obtained.

**C. Tilt correction based on WLSM**

Suppose the original image is a binarization image with the left-top pixel being \((1,1)\), in which the background is black (gray value is 0) and the characters are white (gray value is 1). \( \mathbf{P} \) is the set of coordinates \((x, y)\) representing all the white pixels in the image, \( I \) is the number of elements in \( \mathbf{P} \), namely \( \mathbf{P} \in \mathbb{R}^{2 \times I} \), where \( \mathbb{R} \) is a real domain. \( \mathbf{P} \) is inserted into Equation (11) and the slope \( a_1 \) of the fitting line is worked out. Let \( \tan \alpha = a_1 \) and compute the tilt angle \( \alpha \). Then this paper method is described as follows:

Step1. Get the set \( \mathbf{P} \) of coordinates \((x, y)\) representing all the white pixels in the image;
Step 2. Put $P$ into Equation (11) and calculate $a_i$:

$$\alpha = \arctan a_i \times \frac{180}{\pi} \quad (10)$$

Step 3. Let $\tan \alpha = a_i$ and get the tilt angle $\alpha$:

$$\begin{bmatrix} X' \ Y' \ 1 \end{bmatrix} = \begin{bmatrix} \cos \alpha & -\sin \alpha & 0 \\ \sin \alpha & \cos \alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \ Y \ 1 \end{bmatrix} \quad (11)$$

Where $X$ and $Y$ respectively represent the $x$ and $y$ coordinate matrices in the image. By comparison, $X'$ and $Y'$ respectively represent the $x$ and $y$ coordinate matrices in the final correction image.

III. EXPERIMENTAL RESULTS AND COMPARISONS

In this section, we take the VLP images in Fig.2 as the experimental ones, which have been binarized to black background and white characters. It is our experimental environment that working software is MATLAB 7.0 and CPU is Celeron(R) with 2.13GHz.

In tilt correction experiments, we compare the results of this paper method with those of LSM, HT and RT. The results are shown in Figs.3-5 and correlation performance indexes are shown in Table 1. In HT, the angle varying range is $[-90^\circ, 90^\circ]$ and the varying size is $1^\circ$. In RT, the angle varying range is $[0^\circ, 180^\circ]$ and the varying size is also $1^\circ$. In Figs.3-5 this paper method has already performed more precise correction, and the top line is basically horizontal. But LSM, HT and RT are some slight tilt, and the rotation angles are either small or large. The correlation indexes in Table 1 are accordance with the results in Figs.3-5.

From Table 1 and Figs.3-8, the paper method and LSM both can well reflect the tilt trends of the VLP in experimental images, so they have good correction effects. But the slope of the line fitted by LSM is slightly small and the rotation angle is not enough, which is accordance with the results in Figs.6-8. This paper method is the same with LSM in the processing time. Both methods, however, have considerable difference in the objective functions, which further shows that this paper method is superior to LSM.

Fig.9 is the coefficient figure of HT, in which the brighter the color, the higher the coefficient. In Fig.9a the highest Hough coefficient is about $-3^\circ$, so $\alpha = -3^\circ$, which is slightly small; In Fig.9b the highest Hough coefficient is about $8^\circ$, so $\alpha = 8^\circ$, which is slightly large; In Fig.9c the highest Hough coefficient is about $-10^\circ$, so $\alpha = -10^\circ$, which is relatively precise. Fig.10 is the coefficient figure of RT, in which the brighter the color, the higher the coefficient. In Fig.10a the biggest Radon coefficient is about $87^\circ$, so $\alpha = -(90-87)^\circ = -3^\circ$, which is slightly small; In Fig.10b the highest Radon coefficient is about $96^\circ$, so $\alpha = -(90 - 96)^\circ = 6^\circ$, which is relatively precise; In Fig.10c the highest Radon coefficient is about $78^\circ$, so $\alpha = -(90 - 78)^\circ = -12^\circ$, which is obviously excessive.

According to the data in Table 1, this paper method is distinctly superior to HT and RT in the processing time, which is 17.1-29.0 times faster than HT and 11.6-17.6 times faster than RT. The less processing time in real-time tilt correction of ITS is very important and competitive.

![Figure 2. Experimental images](image1)

![Figure 3. Tilt correction of No.1 image](image2)

![Figure 4. Tilt correction of No.2 image](image3)

![Figure 5. Tilt correction of No.3 image](image4)
<table>
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<tr>
<th>Correction Method</th>
<th>Index</th>
<th>Experimental Images</th>
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</table>
In the final corrected image, the characters appear some burrs and need to be carried on the smooth operation, but this paper doesn’t cover the topic.

IV. CONCLUSIONS

After thoroughly and deliberately analyzing the features of LSM and WSLM, we propose vehicle license plate tilt correction based on the weighted least square method. The experimental results show that, compared with LSM, this paper method is featured in more precise tilt angle and less objective function; and compared with HT and RT, the shorter processing time and the more precise tilt angle are characteristic of this paper method, which is better adapted to the real-time tilt correction in ITS.

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