Engineering and Technology Journal
Journal homepage: engtechjournal.org

License Plate Tilt Correction: A Review

Nada N. Kamal [a*], **Enas Tariq** [b]

[a] Department of Computer Science, University of Technology-Iraq, Baghdad, Iraq, 110136@uotechnology.edu.iq

[b] Department of Computer Science, University of Technology-Iraq, Baghdad, Iraq, 110038@uotechnology.edu.iq

*Corresponding author.

Submitted: 18/09/2020 Accepted: 31/12/2020 Published: 25/03/2021

K E Y W O R D

Angle, License Plate, Rotation, Skew, Survey, Tilt Correction.

A B S T R A C T

Tilt correction is an essential step in the license plate recognition system (LPR). The main goal of this article is to provide a review of the various methods that are presented in the literature and used to correct different types of tilt that appear in the digital image of the license plates (LP). This theoretical survey will enable the researchers to have an overview of the available implemented tilt detection and correction algorithms. That's how this review will simplify for the researchers the choice to determine which of the available rotation correction and detection algorithms to implement while designing their LPR system. This review also simplifies the decision for the researchers to choose whether to combine two or more of the existing algorithms or simply create a new efficient one. This review doesn't recite the described models in the literature in a hard-narrative tale, but instead, it clarifies how the tilt correction stage is divided based on its initial steps. The steps include: locating the plate corners, finding the tilting angle of the plate, then, correcting its horizontal, vertical, and sheared inclination. For the tilt correction stage, this review clarifies how state-of-the-art literature handled each step individually. As a result, it has been noticed that line fitting, Hough transform, and Randon transform are the most used methods to correct the tilt of a LP.

How to cite this article: N.N.Kamal and E.Tariq "License Plate Tilt Correction: A Review," Engineering and Technology Journal, Vol. 39, Part B, No. 01, pp. 101-116, 2021.
DOI: https://doi.org/10.30684/etj.v39i1B.1839

1. INTRODUCTION

A LP is used to identify vehicles while they are moving on the roads of transportation systems. The LP can be described as a collection of alphanumerics, that appears as a part of a metallic plate. The plate fixed onto the body of the vehicles. The LP is used by recognition systems to identify different types of vehicles. Usually, automatic recognition systems, process and store the LP in the form of a digital image. It is well known that any recognition system consists of three basic stages: pre-processing, feature extraction, and classification. The pre-processing phase of the LPR system must include a substantial phase called "Tilt Correction". Tilt correction stage embraces the steps of detecting and correcting a tilt that appears in the digital images of the LPs while they are being captured by road cameras.

One may think that documents share common factors with LPs. This similarity may be understood as both have a rectangular shape, and containing numerals and alphabets that are stand on a contrasting background color. Also, both documents and LPs have automatic recognition systems used to identify and recognize the numbers and alphabets that appear as part of them, and usually recognition systems treat the documents and LPs as digital images. In many of these recognition systems there exist a step of correcting the tilt that appears in the images of documents and LPs.

There are many pieces of literature present reviews about how the tilt of documents is corrected. The work of Verma and Malik [1], Changming Sun, and Deyi Si [2] represent two examples of document tilt correction surveys. In contrast, a researcher barely finds a complete state-of-the-art review for the methodologies used in literature to correct the tilt that appears in the images of vehicles' LPs. So, based on that, the authors of this academic article believe that this is the first of its kind review of the literature to survey the different methods that are used to detect and correct LPs tilting issues.

Many methodologies are documented in the literature and used to identify and correct the inclination angles of cars LPs. This survey reviews different methods, algorithms, transforms, steps, and models to allow the researchers to have an overview of how this problem was solved, so they can use or develop a previously proposed method, or use a combination of two methods or more, or even proposes a new one that is not stated in the surveyed literature.

The autonomy of this paper is structured as the following: Section 2 clarifies how the term "tilt" appears in different kinds of literature. Section 3 presents the types of tilting. Section 4. Clarifies how the survey was conducted. Section 5 displays how sometimes the tilt correction stage is ignored or not explained in detail in other academic articles. Section 6 shows a review of different tilting correction methodologies. Section 7 presents the summarization and result tables. The conclusions and future work appear in section 8.

2. THE TERMS RELATED TO "TILT" CORRECTION IN THE LITERATURE

The term tilt correction of LPs comes in different variations in the literature. For example, the word "Tilt" correction" or "tilt rectification" appears in many references, such as in [3]–[9]. While the term "Rotation" appears in the references [10]–[12]. "Slant" is seen in [13], [14], and "Inclination" is observed in [15]–[17]. In addition to these terms, the word "Skew" is a very popular one and used in the references [18], [19], [28], [20]–[27]. "Orientation" also referred to as another term to describe the LP tilting issue, and it appears in [29] while "Obliqueness" is seen in [30]. Table I. Summarizes the set of terms used to refer to "tilt" of a LP in the surveyed literature with its related correction terms, while Figure 1 shows examples of skewed LPs.

TABLE I: The terms used to refer to "tilt" of the LP in the literature

Tilt Terms	Correction terms
Tilt Skew Rotation Inclination Slant Orientation Obliqueness	Detection, De-skewing, Correction, or Rectification

Figure 1: Examples of tilted LP.

3. TILT TYPES

There are two types for the tilt cases for the images of the LPs: a horizontal tilt and a vertical tilt. With the horizontal tilt, the plate will have a tilt angle about its horizontal pivot. While with the vertical tilting, the rotation angle comes around the vertical pivot of that plate.

For both the horizontal and the vertical tilting, the angle may come greater or less than zero, or in other words, positive or negative. “No tilting case” means that a LP registration number comes with an angle equals to zero. The literature may denote the rotation angle by θ, α, or sometimes β.

A hybrid case means that a plate contains both horizontal and vertical tilt issues. Figure 2. depicts “no tilt case”, while Figure 3. depicts vertical, horizontal, and hybrid tilt of both positive and negative angles. The references may present similar illustrations for these figures are [3]–[5], [9], [17], [22].

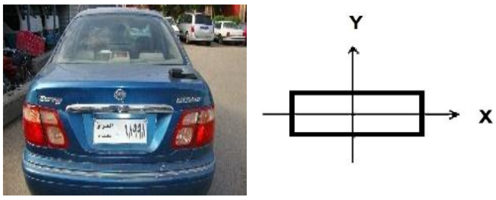


Figure 2: No tilt case this means that the rotating angle equals to zero.

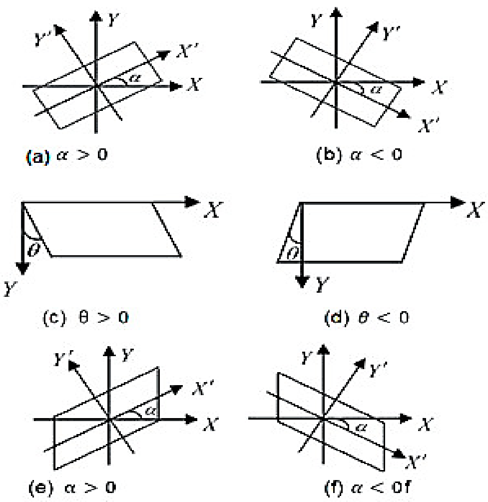


Figure 3: Types of tilt (a) positive horizontal tilting. (b) negative horizontal tilting. (c) positive vertical tilting. (d) Negative vertical tilting. (e) Positive hybrid tilting. (f) negative hybrid tilting [31].

4. HOW THE SURVEY IS CONDUCTED AND HOW THE LITERATURE IS CLASSIFIED

The researchers collect different kinds of literature that tackle the LPR system issue, where the keywords mentioned in Table I are included in their search for and within the related work. In general, LPR systems consist of three basic stages: preprocessing stage, plate detection stage, character segmentation, and character recognition stage. Actually, due to many factors, such as car movement, the LP image in LPR systems may appear in a rotated obliqueness manner, and if this obliqueness is not rectified then the character segmentation process will be affected, which leads to inaccurate character recognition result because of the distorted segmented characters, and here the importance of LP tilt correction appears, where it must be done and implemented before character segmentation process as part of preprocessing stage of any LPR system.

Since the LP title correction problem is solved through four basic steps as shown in Figure 4, then the authors of this article classify the surveyed papers according to these steps which include: detecting the corners of the plate, determining the inclination angle, then correcting the horizontal, vertical and mixed horizontal-vertical tilt cases. Before going deep with these steps, Section 5. represents another classification of the surveyed literature.

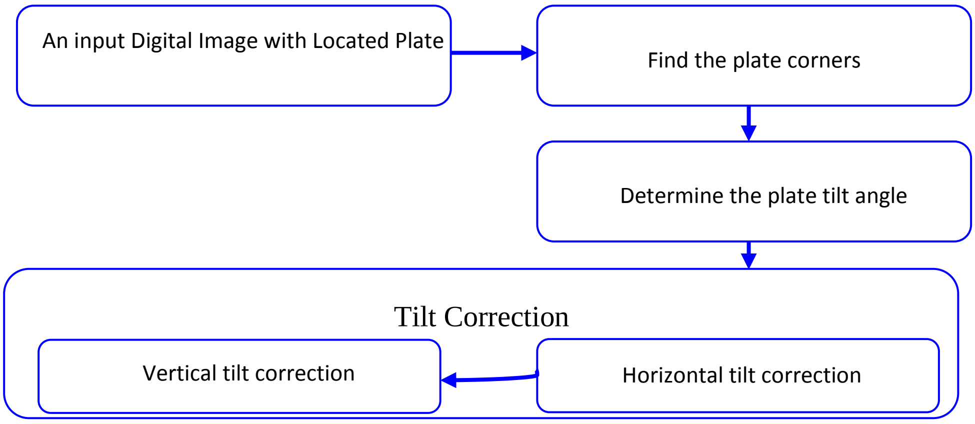


Figure 4: general layout of the tilt correction stage

5. Cases of "Failure”, “limited", or "No" inclination rectification in license plate recognition systems

This section divides the literature based on whether they give a solution for the problem of tilt correction, but in a limited manner, or whether literature presents a system that fails when it faces the case of tilt in a digital image of a LP, or even, whether these systems simply do not present any solution for the tilt correction challenges.

I. No rectification case

Despite the fact regarding the importance of tilt correction stage, there are many authors present different solutions for the problem of recognizing LPs, but many of them do not present a recognized solution for the cases of rectifying the slant of the registration number plate, such as the authors of references [33]–[37]. Those researches can be referred to as “No rectification case”.

II. Limited rectification case

Other researchers may set their systems to deal with cases of “limited” slants of angles, such as [38], where their system and deal with skewed images that come in $\mp 5°$. In [39] the rotation angle in the system is limited to $\mp 15°$. While a slight angle of $\mp 30°$ can be corrected in [40], [41] as shown in Figure 5. In [8] the researchers document that the used method is sensitive less ability for angles less 20°.

III. Failure case

However, many other authors document that their system “fails” if there is any inclination in the angle of the LP image, such as [42]–[44].
No much detail about the tilt correction operation is explained in [45]–[47]. While in [48], the authors report that their system sustains little inclinations, and authors of [49] state that their recognition method does not need tilt correction, however, regarding the opinion of the authors of this article, it considers the ignoring of finding a solution for the tilt correction is considered as not reasonable manner.

Figure 5: Slight slant angle captured by a LPR system [40]

6. TILT DETECTION AND CORRECTION METHODOLOGIES

The tilt of a plate in a digital image may appear due to many factors such as camera perspective, curvy or uneven roads. The importance of the tilt correction stage comes from the fact that it plays a crucial role in any LPR system.

This section explores how the reviewed papers solved the tilt of the registration plate challenge through classifying the presented solutions into four basic steps which include: I. Finding the corners of the plate II. Determining the slant angle of the LP, III. Correct the horizontal tilt, IV. and Correcting the vertical and shearing cases of the plates.

I. Finding the corners of the LP

The corners of the LP are utilized by many authors to catch the plate, and then, perform the required inclination correction. Many of the methodologies used to specify the location of these corners are clarified below.

A. Hough lines

The corners, or the vertexes, of the rectangular plate, are extracted as the intersection of Hough lines as in [4], [50]. As illustrated in Figure 6, such lines present the output of applying edge detectors on image pixels, then, creating the Hough lines, and intercept these lines to determine corners locations.

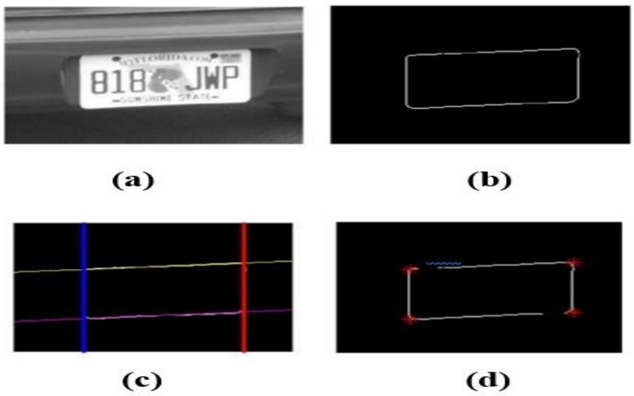


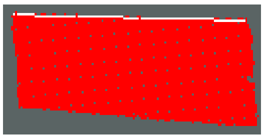
Figure 6: LP corner detection using Hough lines: (a) input image of the LP, (b) detected edges, (c) Hough line based on edges, and (d) detected plate's corners [50].

B. Line equations

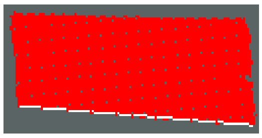
Other authors utilize vertical and horizontal line equations, i.e. equation (1) and equation (2), where the partial derivatives and linear regression are used to collect the points that represent the four edges of the rectangular plate, as shown in Figure 7., then the intersections of these lines will define the four vertexes of the car plate [10].

$$y = ax + b \qquad (1)$$
$$x = cy + d \qquad (2)$$

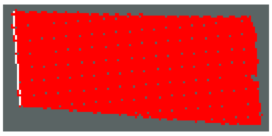
In equations (1) and (2) the x and y are the collected lines' points, c and a represent the line slop, while b and d give the interception points. More details could be found in [10]. This method is considered as easy to implement math equations, but it is considered a time-consuming algorithm.



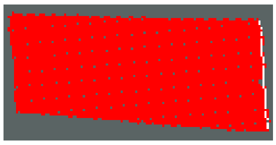
(a) The line of the top side which is gotten through the equation $\boldsymbol{y = a_{top}x + b_{top}}$



(b) The line of the bottom side which is gotten through the equation $\boldsymbol{y = a_{bottom}x + b_{bottom}}$



(c) The line of the left side which is gotten by $\boldsymbol{x = c_{left}y + d_{left}}$



(d) The line of the right side which is gotten through the equation $\boldsymbol{x = c_{right}y + d_{right}}$

Figure 7: Four lines extracted from the LP image segment: (a) the top line, (b), the bottom line, (c) the left line, and (d) the right line [10], [11].

C. Corner Detectors

Many Corners detectors are reviewed such as SUSAN which briefly represents an image edge and corner with structure and noise removing operations [9].
Another one is the Harris corner detector, which is presented as a proposed algorithm in [22], where it is considered as the Principal Component Analysis (PCA) method to detect the corners and finding the tilt angle.

D. Certain Transformation

Karhunen-Loeve Transform (K-L) is used in [31] to find plate corners. It finds the mean of the plate point, then calculates the covariance matrix, then eigenvalues are extracted to apply the orthogonal K-L Transform.

Figure 8: Centres of blob characters are used to determine the tilt angle in [7]

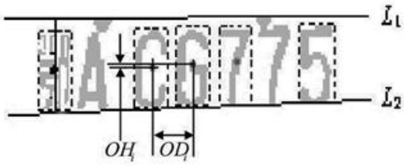


Figure 8: Centres of blob characters are used to determine the tilt angle in [7]

E. Artificial Neural Network (ANN) Model

The authors in [30] authors present five models to detect the LP corners based on deep ANN. The limitation of this method is that it needs memory to work efficiently.

II. Determining the tilt angle of the plate

Finding the tilt angle of the LP is the essential initial step in correcting the tilt of the LP in an LPR system. Usually, equations are used to determine the angle of the registration plate. Here are some of these equations.

A. Character-based angle

In [7], equation (3) is used to find the correct inclination θ^* angle between bounded characters. As shown in Figure 8. By the bounded character the researcher means locating the outer boundary of each character of the LP. In this figure finding the tilt angle in is done by locating the Hough lines L1 and L2, then the plate angle is determined after determining the successive angles of the blob characters through finding the arctan of OD which represent the horizontal distance between the center positions of two neighboring characters divided by OH which represent the distance vertically.

$$\theta^* = \frac{1}{n}\sum_{i=1}^{n}\theta_i \qquad (3)$$

Where θ_i represents a set of angles for characters bonded boxes n.
In [17] equation (4) is used to find the vertical angle of the characters of a LP

$$\theta = tan^{-1}\left(\frac{\sum_{i=1}^{N}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{N}(y_i - \bar{y})^2}\right) \qquad (4)$$

In equation (4) x and y are the image coordinates, while $\bar{x}$ and $\bar{y}$ are the mean values x and y. As the plate characters reflect the tilt angle of the LP, then, the overall plate angle θ; is determined for each extracted character from the plate. However, since some characters, like hyphens, may not reflect the correct inclination angle of the plate, the mean μ_i and the standard deviation σ_i of angles θ_i are used to find the overall skew, in addition to that, a filter rule, as shown in equation (5), is applied to determine the case of including or excluding a calculated angle θ_i for a certain plate segment

$$\left.\begin{array}{c}\theta_i \; is \; kepted \; if \\ \theta_i \; is \; removed\end{array}\right\} \begin{array}{c}|\theta_i - \mu_\theta| < \sigma_\theta \\ otherwise\end{array} \qquad (5)$$

B. Derived equation-based angle

The authors in [10] define the segment that represents a registration plate, then firstly, they determine its center point (x_c, y_c), using equations (6.a) and (6.b).

$$x_c = \frac{1}{N}\sum_{i=1}^{N} seg.x_i \qquad (6.a)$$

$$y_c = \frac{1}{N}\sum_{i=1}^{N} seg.y_i \qquad (6.b)$$

Where N represents the number of points in a certain registration plate segment seg, and i represents a counter of a loop of pixels. After that equation (7) is applied as the second step to get the inclination angle θ of the plate.

$$\theta = \frac{1}{2}tan^{-1}\left(\frac{2\sum_{x,y}(x - x_c)(y - y_c)}{\sum_{x,y}((x - x_c)^2 + (y - y_c)^2)}\right) \qquad (7)$$

In [29] equation (8) used to correct the inclination angle of the LP

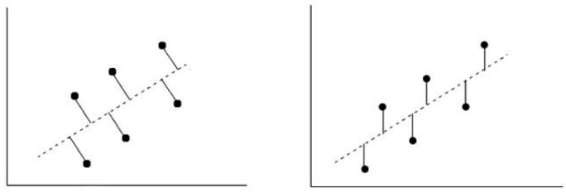
$$tan(2\theta_i) = \frac{\sum_{i=0}^{n-1}\sum_{i=0}^{n-1} rcI(r,c)}{\sum_{i=0}^{n-1}\sum_{i=0}^{n-1} r^2cI_i(r,c) - \sum_{i=0}^{n-1}\sum_{i=0}^{n-1} c^2I_i(r,c)} \qquad (8)$$

Where r and c stand for the rows and the columns of the digital image I respectively. This is considered an easy to implement math model but is considered time-consuming especially with large images.

C. Line fitting based angle

In the references [3], [4], [17] least square fitting with perpendicular offset is used to determine the inclination angle α estimated as shown in equations (9.a) and (9.b).

$$A = \frac{1}{2}\frac{\sum_{i=1}^{n} y_i^2 - n\bar{y}^2 - \sum_{i=1}^{n} x_i^2 - nx^2}{n\bar{x}\bar{y} - \sum_{i=1}^{n} x_i y_i} \qquad (9.a)$$



$$\alpha = -A \mp \sqrt{A^2 + 1} \qquad (9.b)$$

Figure 9: Figure 9: Lease square fitting for a straight line: (a) Perpendicular offsets, and (b) vertical offsets [17]

Where x and y represent the coordinates of the image pixels of the LP, while n refer to the number of processed pixels. Equation (10) shows how the tilt angle α of the LP is determined using least square fitting with a vertical offset

$$\alpha = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2} \qquad (10)$$

Similar to equations (9.a) and (9.b), the equation (10), the x, y presents image coordinates with related n that refer to the number of pixels being processed. The researchers state that finding the tilt angle using line fitting with the least square fitting with vertical offset is better than finding the tilt angle using the least square fitting with perpendicular offset. Figure 9. Shows the two methods of least square fitting of straight lines.

The linear fitting is used in [12], where the angle of a straight line with the level of the X-axis is calculated using equation (11)

$$a = acrctan(p1) * \frac{360}{2\pi} \qquad (11)$$

Where $p1$ represents the slope of a line equation. While edge detection operators are adopted in [51]. Where the slope of the max length edges is calculated using equation (12), then, the tilt angle is determined through the use of equation (13).

$$slope = \frac{lineEnd(y) - lineStrat(y)}{lineEnd(x) - lineStrat(x)} \qquad (12)$$

$$\alpha = slope\frac{180}{\pi} \qquad (13)$$

In equation (12), the x and the y represent coordinates of the edge line, while equation (13) α denotes the angle of the plate.

D. Different image factors

Choosing different factors extracted from the digital image is used to find the slant angle in [3], such as the center of area filtered as LP, and the axis of the least second moment. The authors in [50] and [51] searching a bound box area that surrounds the LP segment, then, testing if one of the top corners represents a foreground pixel, then if so, the other corner is searched down until the foreground pixel is found. The angle is found when Tan $^{-1}$ is calculated for the ratio between the two points. This method is considered a very simple method with a short time of execution because it does not navigate all of the segments' pixels.

A horizontal tilt correction for the plate, made through finding the center of the plate segment, followed by 2D rotation in [6], such rotation may lead to issues of adhesion between numerals and characters of the plate, that's why finding the minimum projection to determine the vertical slant is adopted. The overall width of the horizontal projection for the rotated large segments is found. A repeated pixel rotation processes are made for the pixels with angles ranges from 45° to -45°, while a comparison is constantly made between the first large horizontal projection with the obtained current one, until finding the minimum projection which represents the vertical slant angle. This process is clarified in Figure 10.

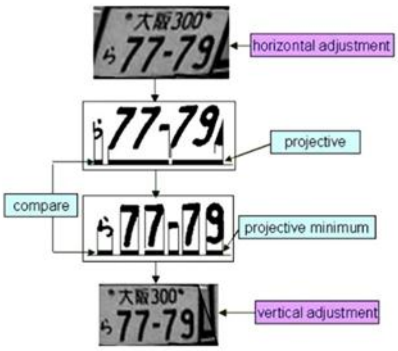


Figure 10: 2D Horizontal tilt correction, and vertical tilt correction using minimum projections [6]

In [54] the grey-scaled image is subdivided into $n \times n$ of non overlapped areas. The researchers found that the best values for n is set to 5. The domestic orientation of each area is counted using the gradients $[G_x, G_y]$ for the corresponding areas. After that, the histogram with values ranges from 0 to 179 are found, in which these values represent probable angle directions. The inclination angle is determined through the extraction of the highest accumulated local value.

E. ANN-based angle

An Artificial Neural Network model can be used to get the tilt angle. For example, [13] used what so-called Self Organizing map (SOM). This model involves: creating the map, initializing the weight array, train it, then; finding the desired angle θ. As documented the number of tested images is 200 and the researcher reports that the SOM model is a robust one.

III. Correcting the tilt horizontally

There are many methods mentioned in the literature and used to correct the horizontal tilt of the LP. Below is an exploration for a wide part of them:

A. Hough Transform

Hough Transform is used by many authors to correct the horizontal tilt of the LP, such as [20], [24], [27], [55]–[59]. Since the Hough Transform has the well-known characteristic to create connected straight lines, this transform was adopted in [15]. To correct the horizontal inclination of the LPs, as illustrated in Figure 11. Instead of using edge detection techniques and despite its computation and implantation complexity, the Hough Transform, usually used, to find the horizontal tilt, because it generates straight clear lines.

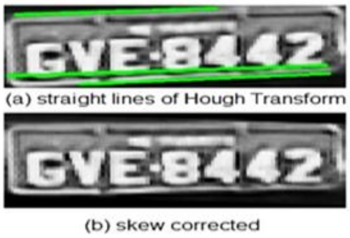


Figure 11: Inclination correction based on the Hough Transform [15].

The straight lines of the Hough Transform can be generated using equation (14):

$$\rho = x \cos\theta + y \sin\theta \qquad (14)$$

Where a point can be represented as (ρ, θ) in polar coordinate instead of (x, y) of cartesian coordinate.

B. Randon Transform

Randon Transform used to find the projection of a digital image in a certain direction in the references [14], [25], [26], [60], [61]. To find the total of absolute differences, the application of Randon transform for two times is adopted in [62] in which a wide range of values, the rotation angle of the two directions, horizontal and vertical, is determined through finding the two highest total values of the projection points.

C. Line fitting methods

To compare among them, line fitting methods were two of the three methods that are implemented in [4], [17] for the sake of correcting the horizontal tilt of LP registration number. The first method, is the least square fitting with perpendicular offset, while the second method is the least square fitting with vertical offsets. After a set of derivatives, the researchers used equations (10.a), (10.b), and (11) to obtain the inclination angle. Line fitting is also used in [12], [23], [63] to perform such correction.

D. General rotation mapping

The well-known rotation equation (15), or the 2D-rotation equation [6] adopted by many authors in many references, such as in [13], [23], [54].

$$\begin{bmatrix} x_{new} \\ y_{new} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \qquad (15)$$

To get new points x_{new} and y_{new}. As shown in equations (17.a) and (17.b), the authors of [10] used the variety of equation (16) to perform the horizontal tilt correction about the center point of the plate (x_c, y_c). Figure 12 shows a set of original images of LPs with their horizontal tilt correction.

$$x_{new=}(x - x_c)\cos\theta + (y - y_c)\sin\theta + x_c \qquad (16.a)$$

$$yx_{new=} -(x - x_c)\sin\theta + (y - y_c)\cos\theta + y_c \qquad (16.b)$$

Figure 12: Examples of horizontal skew correction of LPs [54]

E. Other different models

The Matchstick model is proposed and presented in [5], where the characters of the registration plate are abstracted through many operations. The operations include morphological erosion to create equal length sticks, in which these sticks intercept equidistant horizontal lines which strike these sticks, as depicted in Figure 13. For this model the researcher report that 500 images are examined, also the researcher document that this method gives better results than Hough Transform in about 10%.

Figure 13: The characters of the LP abstracted to "Matchsticks" and stroked with equidistant horizontal lines [5]

For horizontal rectification, the reordering of adjacent binary pixels is utilized in [16]. These pixels are satisfying the condition of being connected in a single route in a plate from one corner to another.

IV. Correcting the vertical shearing of the registration plate

Many transformations are applied to correct the tilt LP vertically. This section presents a bunch of these techniques.

A. shearing factors correction

The vertical shear γ^* is used in [7] as shown in equation (17).

$$SH(\gamma^*) = \begin{bmatrix} 1 & 0 & 0 \\ tan\,\gamma^* & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad (17)$$

B. Affine transform

Affine transform, which combines the basic transformations of translation, scaling, and shearing in a single transform, used by [4] to correct the vertical inclination of the registration plate, as shown in Figure 14.

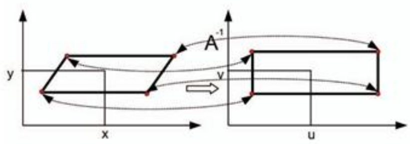


Figure 14: Affine Transform [10]

This transform was also used by [10] to correct the shearing of the plates. Where, the new position of points $(\grave{x}_i, \dot{y}_i)$ is obtained through the mapping of original points position (x_i, y_i) by using bilinear interpolation. In which the equations (18.a) and (18.b) are solved with partial derivative concerning each of the six unknown variables a_0, a_1, a_2, b_0, b_1, b_2. Figure 15. present the effect of Affine transform.

$$\grave{x}_i = a_0 + a_1\, x_i + a_2\, y_i \qquad (18.a)$$

$$\dot{\mathrm{y}}_\mathrm{i} = \mathrm{b}_0 + \mathrm{b}_1\, \mathrm{x}_\mathrm{i} + \mathrm{b}_2\, \mathrm{y}_\mathrm{i} \qquad (18.\mathrm{b})$$

C. Line fitting

A Line-fitting method based on least square and K-mean used in [31] to correct the vertical slant of the LP. The authors compare their work with other works that use Hough Transform and Radon Transform, and they conclude that their proposed method a better correction method.

Figure 15: The application of affine transform to correct plate shearing issues: (a) original image, and (b) obtained image after applying an affine transform.

D. Other methods

To correct the image in a vertical direction, the movement of pixels in horizontal directions are utilized in [6] by using equation (19).

$$d_x = \left(y - \tfrac{1}{2}H\right) / \tan\beta \qquad (19)$$

Where d_x is the quantity of horizontal movement for a pixel in x, y location, with an image of H height, in which this digital image has a vertical slant angle of β.

The Homographic Transformation, adopted in [64] to correct the inclination in the image of the vehicle registration plate. The Homographic Transformation is known as mapping one pint to another; in a certain space; in correlation with leas square minimization. The Homography Transformation is used in also for the same purpose of vertical correction.

A Mapping process is used in [50] to rectify the image where equations (20.a) and (20.b) are solved to obtain 2D points of a LP from the real 3D coordinates.

$$x = \frac{X}{z} \qquad (20.a)$$

$$y = \frac{Y}{z} \qquad (20.a)$$

Where the point $P(X, Y, Z)$ is mapped to $P_i(x, y, z)$ with z equal to 1. The documented success rate for de-skewing process reached 25%.1.

7. Scope of results and Summarization Tables

Tables II explores a summary of the used methods to detect LPs corners, finding the tilt angle, and the methods and algorithms used to rectify horizontal and vertical tilts. While Table III Displays some obtained results.

TABLE II: Summary of title correction methods with pros and cons

	References	Method	Pros	Cones
Finding the plate corners methods	[4], [50]	Hough lines	A well-known method to find straight lines	Affected by LP edges deformation
	[10]	Line fitting	Easy to implement	Cost time because it depends because it searches all image segment
	[9]	SUSAN	No noise reduction is needed Better than line fitting	7x7 mask may costs time
	[22]	Harris	Need less time	The complexity of eigenvalues implementation
	[31]	K-L Transform	Better than line fitting	Burrs characters need smoothing
	[30]	Deep ANN	The ability to learn	Needs enough memory to work efficiently
determinin g the tilt angle	[7], [17]	Bounder characters or vertical angle of characters	Accurate method	Sensitive with motion blur
	[10], [29]	Derived	Easy to implement	Needs time with large images

		equations		
	[3], [4], [12], [17], [51]	Least square fitting with perpendicular or vertical offsets or line fitting	Easy to implement	Consumes time
	[3], [54]	Different image factors	Fast and simple	Fails with a poor focused image
	[6]	Minimum projections	Present satisfactory results	Needs illumination correction
	[13]	ANN	Unsupervised learning	More implementations' iterations mean more time
Horizontal tilt correction methods	[15], [20], [24], [27], [55], [56], [57], [58], [59]	Hough Transform	Good when speed is highly recommended	Computation complexity
	[14], [25], [26], [27], [60], [61],	Randon Transform	Simple	Need fixed size step
	[4], [12], [17], [23], [63]	Line fitting	Easy to implement	Consumes time
	[13], [23], [54]	General rotation	Well known	Consumes time
	[5]	Matchstick model	Better than the Hough method	Not documented
	[16]	Adjacent binary pixels	Not documented	Not documented
Vertical tilt correction methods	[7]	Shearing factor	Not documented	Not documented
	[4], [10]	Affine Transform	Well known and easy to implement	Cannot rectify distorted images
	[31]	Line fitting	Easy to implement	Consumes time
	[6]	Pixel movement	Present satisfactory results	Requires high computations
	[64][65]	Homographic Transform	Better than Affine Transform	Computation complexity
	[50]	Mapping	Robust method	Consumes time

TABLE III: State-of-the-art documented success rates of tilt correction methods

References	Method	Success Rate%
[5]	Matchstick model	10% better than Hough transform
[50]	Mapping	25.1%
[26]	Randon Transform	85.71%
[25]	Randon Transform	97.22%
[65]	Homography	97.61%

8. Conclusions and Future work

This article presents a brief, first of its kind, theoretical review for more than 55 papers from the past 25 years. The paper handled the issue of correcting the tilt of LP vehicles in LPR systems.
Since the literature poorly documents the success rates of the de-skewing stage in LPR systems, then, the evaluation process for the different algorithms to determine which method is considered as the best tilt correction technique is considered to be a difficult task. Because, to obtain considerable reasonable results, a time-consuming implementation for each of the reviewed methods should be made, in companion with ideal conditions, such as the using of a unified dataset of tilted LPs.

For future work, a researcher may program and implement a set of methods and algorithms that are used in a certain single aspect of rectifying LP tilting, such as implementing the algorithms that are utilized to find plate corners, or the methods used to find the angle of the plate, or the transforms and equations used to rectify the tilt of the plate horizontally or vertically, by using the same dataset, to determine which algorithm gives the best results.

References

[1] R. N. Verma and L. G. Malik, "Review of Illumination and Skew Correction techniques for scanned documents," *Procedia Computer Science, ELSEVIER*, vol. 45, no. C, pp. 322–327, 2015.
[2] C. Sun and D. Si, "Skew and slant correction for document images using gradient direction," in *4th International Conference on Document Analysis and Recognition, IEEE, Germany*, 2002, vol. 2, pp. 142–146.
[3] K. Deb, I. Khan, A. Saha, and K.-H. Jo, "An efficient method of vehicle license plate recognition based on sliding concentric windows and artificial neural network," *Procedia Technology, ELSEVIER*, vol. 4, pp. 812–819, 2012.
[4] K. Deb, A. Vavilin, and K. H. Jo, "An efficient method for correcting vehicle license plate tilt," in *International Conference on Granular Computing Proceedings, IEEE*, 2010, pp. 127–132.
[5] Y. Du, "An approach to horizontal tilt correction of vehicle license plate based on matchstick model," *1st International Conference on Information Science and Engineering, IEEE, China*, pp. 1124–1128, 2009.
[6] Y. Wen, Y. Lu, J. Yan, Z. Zhou, K. M. Von Deneen, and P. Shi, "An algorithm for license plate recognition applied to intelligent transportation system," *IEEE Transactions on Intelligent Transportation Systems*, vol. 12, no. 3, pp. 830–845, 2011.
[7] H. Deng, Q. Zhu, J. Tao, and H. Feng, "Rectification of license plate images based on Hough Transform and projection," *TELKOMNIKA Indonesian Journal of Electrical Engineering*, vol. 12, no. 1, 2013.
[8] H.-P. Ren and Z.-F. Ma, "License plate recognition using complex network feature," *The 11th World Congress on Intelligent Control and Automation, IEEE, China*, no. July, pp. 5426–5431, 2015.
[9] M. Hossen, "Ve*art Computing Review*, vol. 4, no. 5, pp. 371–388, 2014.
[10] N. N. Kamal and L. E. George, "A localization system for car license plate," *International Journal of Scientific & Engineering Research*, vol. 4, no. 6, pp. 831–839, 2013.
[11] N. N. Kamal, "Iraqi license plate recognition system," University of Baghdad, 2013.
[12] F. Lv, S. Y. hicle license plate detection and tilt correction based on HSI color model and SUSAN corner detector," *The Sm*Zhang, and L. J. Hu, "Image extraction and segment arithmetic of license plate recognition," *PEITS - 2nd Conference on Power Electronics and Intelligent Transportation System, IEEE, China*, vol. 3, pp. 378–381, 2009.
[13] R. Cheng and Y. Bai, "A novel approach for license plate slant correction, character segmentation and Chinese character recognition," *International Journal of Signal Processing, Image Processing and Pattern Recognition*, vol. 7, no. 1, pp. 353–364, 2015.
[14] A. Y. Bai, B. H. Hu, C. F. Li, D. W. Shuang, and E. L. Gong, "A recognition system of China-style license plates based on mathematical morphology and neural network," *International Journal of Mathematical Models and Methods in Applied Sciences*, vol. 4, no. 1, pp. 66–73, 2010.
[15] L. Araújo, S. Pio, and D. Menotti, "Segmenting and recognizing license plate characters," in *SIBGRAPI Conf. on Workshop of Undergraduate Works-Graphics, Patterns and Images*, 2013, pp. 251–270, [Online]. Available: http://www.ucsp.edu.pe/sibgrapi2013/eproceedings/wuw/115776_1.pdf.
[16] R. Azad, B. Azad, H. Reza, and S. Brojeeni, "Real-time and efficient method for accuracy enhancement of edge based license plate recognition system," in *First International Conference on computer, Information Technology and Digital Media*, 2013, pp. 146–155.
[17] K. Deb, A. Vavilin, J. W. Kim, and K. H. Jo, "Vehicle license plate tilt correction based on the straight line fitting method and minimizing variance of coordinates of projection points," *International Journal of Control, Automation and Systems, Springer*, vol. 8, no. 5, pp. 975–984, 2010.
[18] Z. Shaaban, "An intelligent license plate recognition system," *IJCSNS International Journal of Computer Science and Network Security*, vol. 11, no. 7, pp. 55–61, 2011, [Online]. Available: http://paper.ijcsns.org/07_book/201107/20110709.pdf.
[19] A. K. Ghosh, S. K. D. Sharma, M. N. Islam, S. Biswas, and S. Akter, "Automatic license plate recognition (ALPR) for Bangladeshi vehicles," *Global Journal of Computer Science and Technology*, vol. 11, no. 21, pp. 68–73, 2011.
[20] A. Raseena, A. Prof, and M. Sajeer, "Automatic skew detection and localisation of vehicle license plate using Hough Transform," *International Journal of Scientific & Engineering Research*, vol. 4, no. 8, 2013.
[21] V. Manchikalapudi, "Skew correction and localisation of number plate using Hough Rectangular Transform," *International Journal of Computer Science and Technology*, vol. 2, no. 3, pp. 472–476, 2011.
[22] N. D. Modi, C. K. Modi, C. N. Paunwala, and S. Patnaik, "Skew correction for vehicle license plates using principal component of Harris corner feature," *International Conference on Communication Systems and Network Technologies, IEEE, India*, no. 2016, pp. 339–343, 2011.
[23] P. Xiang, Y. Xiuzi, and Z. Sanyuan, "A hybrid method for robust car plate character recognition," *International Conference on Systems, Man and Cybernetics, IEEE, Netherlands*, pp. 4733–4737, 2004.
[24] V. Ganapathy and W. L. D. Lui, "A malaysian vehicle license plate localization and recognition system," *Journal of Systemics, Cybernetics and Informatics*, vol. 6, no. 1, pp. 13–20, 2008.
[25] M. N. Veena, S. J. Shruthi, and T. Vasudev, "Detection of skew and mirror images in vehicle number plates using Radon Transform and geometric moments," *International Journal of New Innovations in Engineering and Technology Detection*, vol. 3, no. 2, pp. 6–11, 2015.

[26] V. M.N, S. S.J, and V. T, "Detection of oriented and skewed number plate in vehicle using hybrid approach," *The International journal of Multimedia & Its Applications*, vol. 7, no. 4/5, pp. 21–30, 2015.
[27] Z. Ji-Yin, Z. Rui-Rui, L. Min, and L. Yin, "License plate recognition based on genetic algorithm," in *International Conference on Computer Science and Software Engineering, IEEE, China*, 2008, pp. 965–968.
[28] L. Jin, H. Xian, J. Bie, Y. Sun, H. Hou, and Q. Niu, "License plate recognition algorithm for passenger cars in chinese residential areas," *Sensors, Switzerland*, vol. 12, no. 6, pp. 8355–8370, 2012.
[29] C. N. E. Anagnostopoulos, I. E. Anagnostopoulos, V. Loumos, and E. Kayafas, "A license plate recognition algorithm for intelligent transportation system applications," *Transactions on Intelligent Transportation Systems, IEEE*, vol. 7, no. 3, pp. 377–391, 2006.
[30] H. Yoo and K. Jun, "Deep corner prediction to rectify tilted license plate images," *Multimedia Systems*, no. 0123456789, 2020.
[31] M. Sen Pan, Q. Xiong, and J. B. Yan, "A new method for correcting vehicle license plate tilt," *International Journal of Automation and Computing, Springer*, vol. 6, no. 2, pp. 210–216, 2009.
[32] S. Norul and H. Sheikh, "License plate recognition using multilayer neural networks," in *International Conference on Computing & Informatics Proceedings, IEEE, Malaysia*, 2006, pp. 4–10.
[33] F. N. Tawfeeq and Y. M. Tabra, "Gate control system for new Iraqi license plate," *Iraqi Commission For Computer & Informatics*, vol. 1, no. 1, pp. 2–4, 2014.
[34] F. M. Oliveira-Neto, L. D. Han, and M. K. Jeong, "Online license plate matching procedures using license-plate recognition machines and new weighted edit distance," *Transportation Research Part C: Emerging Technologies, ELSEVIER*, vol. 21, no. 1, pp. 306–320, 2012.
[35] X. Chi, J. Dong, A. Liu, and H. Zhou, "A simple method for chinese license plate recognition based on Support Vector Machine," in *International Conference on Communications, Circuits and Systems Proceedings, IEEE, China*, 2006, vol. 3, pp. 2141–2145.
[36] M. Mitchell, M. Hudnall, D. Brown, D. Cordes, R. Smith, and A. Parrish, "A host architecture for automobile license plate recognition," *Intelligence and Security Informatics, IEEE, USA*, pp. 87–94, 2007.
[37] M. M. Aziz, "Ishik University Gate Control based on Kurdistan License Plate," *International Journal of Enhanced Research in Science, Technology & Engineering*, vol. 5, no. 1, pp. 34–38, 2016.
[38] L. V. L. and S. K. Kopparapu, "Mobile Phone Based Vehicle License Plate Recognition for Road Policing," pp. 1–7, 2015, [Online]. Available: http://arxiv.org/abs/1504.01476.
[39] A. Król and T. Pamuła, "Localization of vehicle license plates in images using fuzzy logic and morphological operations," *Transport Problems : an International Scientific Journal*, vol. 4, no. 1, pp. 95–101, 2009.
[40] S. Goel, P. Singh, S. Batra, and A. Jain, "Vehicle license plate identification & recognition," in *International Conference on Image Processing, Computer Vision, and Pattern Recognition, India*, 2009, vol. 2, pp. 718–721, [Online]. Available: http://www.scopus.com/inward/record.url?eid=2-s2.0-84864913672&partnerID=40&md5=e0283e213b90975016902ee72e3290b3.
[41] Z. Song, K. L. Moore, Y. Chen, and V. Bahl, "Two-dimensional laser servoing for precision motion control of an ODV robotic license plate recognition system," *Proceedings of the SPIE*, vol. 5083, no. 435, p. 396, 2003.
[42] Z. Zhao, S. Yang, and X. Ma, "Chinese license plate recognition using a convolutional neural network," *Pacific-Asia Workshop on Computational Intelligence and Industrial Application Proceeding, IEEE, China*, vol. 1, pp. 27–30, 2008.
[43] C. C. Han, C. T. Hsieh, Y. N. Chen, G. F. Ho, K. C. Fan, and C. L. Tsai, "License plate detection and recognition using a dual-camera module in a large space," in *41st International Carnahan Conference on Security Technology, IEEE, Canada*, 2007, pp. 307–312.
[44] J. I. Tech, S. Eng, and G. Sharma, "Information technology & software engineering performance analysis of vehicle number plate recognition system using template matching techniques," *Information Technology & Software Engineering*, vol. 8, no. 2, 2018.
[45] F. Trobro, "Real time automatic license plate recognition in video streams," *A Maters Degree at Lund University*, pp. 1–28, 2007.
[46] C. Chen and J. Hsieh, "License plate recognition from low-quality videos," in *Conference on Machine Vision Applications, Japan*, 2007, pp. 122–125.
[47] J. Guo and J. Sun, "License plate recognition system based on orthometric Hopfield network," in *International Conference on MultiMedia and Information Technology, IEEE, China*, 2008, vol. 5, pp. 594–597.
[48] S. Basalamah, "Saudi license plate recognition," *International Journal of Computer and Electrical Engineering*, vol. 5, no. 1, pp. 1–4, 2013.
[49] G. Francisco, P. Negri, M. Mejail, and J. Jacobo, "A multi-style license plate recognition system based on tree of shapes for character segmentation," *Lecture Notes in Computer Science, Springer*, pp. 443–450, 2011.
[50] R. Li, F. Musa, and A. Georgios, "Multistage automatic license plate location & recognition," *Advances of Machine Learning in Theory, Florida Institute of Technology*, 2008.
[51] T. Chen, "A scheme of improved training in license plate character recognition," in *International Conference on Communication Technology Proceedings, IEEE, China*, 2008, pp. 704–707.

[52] P. Dhar, Z. Abedin, R. Karim, and M. S. Hossain, "Bangladeshi License Plate Recognition Using Adaboost Classifier," *2019 Joint 8th International Conference on Informatics, Electronics & Vision (ICIEV) and 2019 3rd International Conference on Imaging, Vision & Pattern Recognition (icIVPR)*, pp. 342–347, 2019.

[53] B. U. Chowdhury and P. Dhar, "License Plate Detection Based on Fuzzy Rule," vol. 29, no. 4, pp. 8583–8590, 2020.

[54] X. Mal, R. Panl, and L. Wang, "A Method based on orientation field for skew correction of license plate," in *Asia-Pacific Conference on Computational Intelligence and Industrial Applications*, 2009, pp. 308–311.

[55] C.-H. Lai, "A tripartite edge histogram scheme for a license plate recognition system," *The Smart Computing Review*, vol. 2, no. 1, pp. 28–41, 2012.

[56] X. F. Hermida, F. M. Rodriguez, J. L. F. Lijó, F. P. Sonde, and M. P. Iglesias, "A system for the automatic and real time recognition of V.L.P.'s (vehicle license plate).," *Lecture Notes in Computer Science, Springer*, vol. 1311, pp. 552–559, 1997.

[57] O. O. Khalifa and S. Khan, "Malaysian vehicle license plate recognition," *The International Arab Journal of Information Technology*, no. January, 2007.

[58] Y. Liu and N. Li, "Design of license plate recognition system based on the adaptive algorithm," in *International Conference on Automation and Logistics, IEEE, China*, 2008, no. September, pp. 2818–2821.

[59] P. Li, "Rotation correction for license plate recognition," Auckland University of Technology, 2017.

[60] M. Huo and L. JingYi, "The license plate recognition system based on improved algorithm," in *IOP Conf. Series: Materials Science and Engineering*, 2017.

[61] G. T. Sutar and A. V Shah, "number plate recognition using an improved segmentation," *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 3297, no. 5, pp. 12360–12368, 2007, [Online]. Available: www.ijirset.com.

[62] X. Jia and X. Wang, "A novel algorithm for character segmentation of degraded license plate based on prior knowledge," in *International Conference on Automation and Logistics, IEEE, China*, 2007, pp. 249–253.

[63] D. Yang, H. Zhou, L. Tang, S. Chen, and S. Liu, "A License Plate Tilt Correction Algorithm Based on the Character Median Line," *Canadian Journal of Electrical and Computer Engineering, IEEE*, vol. 41, no. 3, pp. 145–150, 2018.

[64] S. Kumar, S. Agarwal, and K. Saurabh, "License plate recognition system for Indian vehicles," *International Journal of Information Technology and Knowledge Management*, vol. 1, no. 2, pp. 311–325, 2008.

[65] M. Alhussein, K. Aurangzeb, S. I. Haider, S. Arabia, and S. Arabia, "Vehicle License Plate Detection and Perspective Rectification," pp. 47–56, 2019.