3.1 Introduction

License plate is a unique identifier of any vehicle and it is attached to vehicle for official identification purpose. Recent license plates in India have many high security features added in that. Many techniques are investigated by different researchers on license plate segmentation and registration. LPR is a challenging area of research because of its variety of applications. It can be used for automatic toll collection, in the parking lot for automatic ticketing, for vehicle tracking during violation of traffic signal and for security control.

3.1.1 Features of Recent High Security License Plates

High Security Registration Plate (HSRP) was introduced by Ministry of Road Transport and Highway. It is made with 1 mm special grade aluminum and with white/yellow laminated reflective sheets. It has

Figure 3.1 High Security Registration License Plate

High Security Registration Plate (HSRP) was introduced by Ministry of Road Transport and Highway. It is made with 1 mm special grade aluminum and with white/yellow laminated reflective sheets. It has
security features like hot stamped chromium based hologram, Ingressed IND legend, Laser etched 9 digit code (non erasable), snap lock, embossed characters upon which black foil with security inscription are hot stamped. Figure 3.1 shows feature of high security license plate.

### 3.1.2 Steps Involved in the Registration for the License Plates

There are several methods used for license plate detection such as edge extraction, morphological operations, saliency features, Hough transform, Histogram analysis, fuzzy based or neural network based for color or grayscale classification. Edge extraction methods are faster than other methods but it is very sensitive to unwanted edges which are generated from the region around licenses plate.

Hough transform method is used for line detection, so it is applicable where the image is having large plate area where we can get the shape of license plate defined by lines. But still it requires large memory space for the coordinates and also requires high computation time. Histogram analysis cannot be applicable where the license plate is having tilt or pan. Morphological operations are not applicable where image is noisy and will require large time. There are many challenges in license plate detection such as poor illumination, diverse location of license plate.

Kranthi et al. [2] suggested another method for contrast enhancement of license plate region. Firstly, all the gray levels are scaled down into the range of 0 to 100 from 0 to 255 so character pixels and background pixel becomes weak. Then sorting all pixels in descending order and multiply top 20 % pixels gray level of by 2.55, so most of the character pixels are enhanced while background pixels become weak.

In multi view image registration, two images (Reference and Sensed) are captured at different angles. So first detection of license plates from the two images, then apply transformation to sensed image such
that it align with the reference image and then segment the characters from the registered image. Figure 3.2 shows pan and tilt angles while capturing the images of a vehicle.

![Web camera tilt / pan placement (courtesy: Abbas et al. [5])](image)

For license plate segmentation, first it should be localized, then if it is having pan or tilt angle then registration is required and finally segmentation of character is done. If the characters are properly segmented then only license plate recognition accuracy will improve. So segmentation is very important step of license plate recognition system.

License plate localization is very important step which provides only LP region from the input image. For that one can used vertical edge detection followed by horizontal and vertical projection or for robust detection stroke width transform algorithm can be used. Detected sensed image is transformed and various quality assessment parameters like Root Mean Square Error (RMSE), Peak Signal to Noise Ratio (PSNR), Cross Correlation (CC) and Structural Similarity Index Matrix (SSIM) are determined. Then if small objects are left then it can be removed by using morphological operator called opening and connected component analysis and labeling can be carried out for segmentation of license plate. Figure 3.3 enlists these steps involved in license plate segmentation.
Figure 3. 3 Steps involved in License Plate Detection, Registration and Segmentation

3.1.3 Geometric Spatial Transformation

The sensed image can be transformed by using rotation, scaling, translation and/or shearing transform. Basically in all transformation, coordinate values are changing (coordinate mapping) by applying suitable formula. Table 3.1 shows various transformation matrixes where black and orange color represents original and transformed shapes respectively.

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<thead>
<tr>
<th>Type</th>
<th>Example</th>
<th>Transformation Matrix</th>
<th>Function</th>
</tr>
</thead>
</table>
| Translation   | ![Translation Example](image) | \[
\begin{bmatrix}
1 & 0 & 0 \\
0 & 1 & 0 \\
dx & dy & 1
\end{bmatrix}
\] | $dx$ specifies translation along the X axis. $dy$ specifies translation along the Y axis. |
| Rotation      | ![Rotation Example](image) | \[
\begin{bmatrix}
\cos \theta & \sin \theta & 0 \\
-\sin \theta & \cos \theta & 0 \\
0 & 0 & 1
\end{bmatrix}
\] | $\theta$ Specifies the angle of rotation. |
Table 3.1 Geometric Spatial Transformation

### 3.1.4 License Plate Detection using Edge Density and Integral Image

Tarabek [14] proposed a method of license plate detection using edge density and integral image. He had used a sliding window approach to detect multiple license plates of varying size. Edge density should be calculated for the rectangle sliding window.

#### 3.1.4.1 Integral image

It is the image of summed area table which generates sum of row and column values in a specific manner of a rectangular subset of a grid. Applications are in texture mapping, fact detection and stereo correspondence. The sum can be calculated by calculating the value of a function for each pixel individually without an integral image. But when we need to calculate sum of multiple overlapping rectangular
window then by using integral image it become very easy using linear preprocessing.

First step is to compute integral image is finding sum of each pixel from the addition of the pixel present left side of that.

\[
\text{sum}(j) = \sum_{y=1}^{j} f(x,y) \quad \text{for all rows } x = 1 \text{ to } M
\]  

(3.1)

Where \( f(x, y) \) is the original image and \( M \times N \) is the size of that image and \( \text{sum}(j) \) represents all cumulative gray values column addition.

Integral image can then be determined by the following equation. Figure 3.4 shows an example of Integral image by taking random intensity values.

\[
\text{intimg}(i,j) = \begin{cases} 
\text{sum}(j) & \text{if } i = 1 \\
\text{intimg}(i,j) + \text{sum}(j) & \text{otherwise}
\end{cases}
\]  

(3.2)

![Figure 3.4 (a) Original matrix (b) Integral Image](image)

![Figure 3.5 Finding the sum of a rectangular area](image)
Figure 3.5 depicts how one can find the sum of a rectangular region (indicated with red color) using integral image.

\[
\text{window}_{\text{sum}} = I(C) + I(A) - I(B) - I(D)
\]  

(3.3)

To speed up the process, the concept of integral image was used which rapidly compute the addition of edge pixel within the window. Integral image is the matrix having sum of previous rows and columns in single pass.

### 3.1.4.2 Edge Density

Edge density is the ratio of total count of edges for the rectangular window to the product of height and width of that rectangle. In first step, vertical edges are calculated using Sobel mask. Secondly integral image is computed and then sliding window of size 15 X 75 is traverse along with the image from left to right and top to bottom. Next step is to find edge density using the following equation.

\[
ed = \frac{1}{W \times H} \sum_{x=1}^{W} \sum_{y=1}^{H} e(x, y)
\]  

(3.4)

Where \( W \) and \( H \) are the width and height of the rectangle which is taken 75 and 15 respectively and \( e(x, y) \) is the rectangle matrix. If \( ed \) is less than some predefined threshold then that rectangle will be rejected otherwise save that particular region rectangle values from the original matrix/image. So various high density regions can be found and highlighted with green color which also include license plate region. Results are shown in figure 3.6 and figure 3.7.
Case 1: Single License Plate Detection

Figure 3. 6 (a) Input Image (b) Edge Detection using Sobel Vertical Mask (c) High Density Region (d) Probable License Plate Region

Case 2: Multiple License Plate Detection

Figure 3. 7 (a) Input Image (b) Edge Detection using Sobel Vertical Mask (c) High Density Region (d) Probable License Plate Region
Chirag Paunwala and Suprava Patnaik [25] suggested adaptive integrated rule based license plate localization that is based on edge density and it is suitable for complex background. They are using adaptive edge mapping, fuzzy rule based saliency with confidence level estimation and finally reassessment of decision by color attributes filtering.

In [22], they have detected license plate of car, motor cycles (which size is very small and double line) and transport vehicles (which carry popular sayings, extra text and may be dirty soiled LP) during day and night time. If the image is taken during night time then proper preprocessing is required. For those images, authors have computed variance which gives information regarding visual characteristics of the image. If variance is less than threshold then is considered as a low contrast image and for preprocessing un-sharp masking and Sigmoid function should be applied. Then they have applied edge detection and morphological deal for noise removal and extraction of region, horizontal projection and Gaussian analysis, connected component analysis, rectangularity and aspect ratio, plate companion filter (where scanning lines at three positions and edge count have been calculated) and finally they got license plates.

3.2 Vertical Edge based License Plate Registration

Abbas et al. [5] proposed a method of vertical edge based car license plate detection method. Their algorithm is based on the contrast between the gray scale values. They have used adaptive thresholding for binarization, an unwanted line elimination algorithm followed by vertical edge detection using 2 * 4 mask and finally candidate region extraction for license plate detection.


3.2.1 Adaptive Thresholding

The basic thresholding technique will choose fixed threshold and compare each pixel with that. Fixed thresholding method often fails when illumination varies spatially in the image, so adaptive thresholding technique can be used.

Adaptive thresholding (AT) is an adaptive binarization technique which produces black and white image. It will convert gray scale variation of illumination changes into binary. Bradley [11] suggested this method using the integral image. The main difference between this two methods is different threshold is computed for each neighborhood rather than fixed threshold. AT is more robust to illumination changes.

In adaptive thresholding, single pass of scanning is required and each pixel is compared with an average of the neighboring pixels and approximate moving average is calculated by traveling from left to right and top to bottom. If the current pixel value is T percent lower than the average then it is set to black, otherwise it is set to white. This method will preserve hard contrast lines and reject short gradient changes.

The rectangular window size can be calculated from the width of the input image. It can be one eighths of the image width.

\[
s = \frac{N}{8}
\]

(3.5)

Where N is the width of the image and s is the local window rectangle size s X s.

\[
s_1 = \frac{s}{2}
\]

(3.6)

So for any center pixel location \((i, j)\), the rectangle corner coordinates are \((i-s_1, j+s_1), (i+s_1, j+s_1), (i+s_1, j-s_1)\) and \((i-s_1, j-s_1)\).
Threshold \( t(i, j) \) for each pixel can be computed by using the following equation.

\[
t(x, y) = (1 - T) \ast window_{sum}
\] (3.7)

Where \( T \) is a constant \((T = 0.15)\) which is the best value for the all types of images after testing on many images.

\[
out(i, j) = \begin{cases} 0 & \text{if } f(x, y) \ast s^2 < t(x, y) \\ 255 & \text{otherwise} \end{cases}
\] (3.8)

Where \( out(i, j) \) represents the adaptive threshold image, \( s^2 \) represents rectangular local window area for the selected region.

### 3.2.2 Vertical Edge Detection

After binarization, next step is to calculate vertical edges which can be computed by using spatial filtering between a predefined mask and the binary image. A proposed mask of size 2 X 4 can be defined as follows which

\[
\begin{array}{cccc}
1 & -2 & 0 & 1 \\
1 & -2 & 0 & 1 \\
\end{array}
\]

![Figure 3. 8 A 2 X 4 mask for vertical edge detection](image)

The advantage of this edge detection is to distinguish the plate detail region, especially the beginning and end of each character. The first edge can have a white pixel width of 2 and the second edge have a white pixel width of 1.

### 3.2.3 Highlight License Plate Region

After applying vertical edge detection, the next step is to highlight the desired detail that is license plate region. In this step, all the edge pixels are scanned from left to right and top to bottom. If there are two white pixel followed by one white pixel, then highlight that part by drawing white horizontal lines connecting two white and one white
edge pixels. So after implementing this step, there are more white pixels in license plate region and can be found using horizontal and vertical projection.

3.2.4 Horizontal Histogram Processing

In this processing, number of ones are computed for each row so one array \(array1(i)\) is produced of size same as number of rows. Apply filtering which required some value, so average value is considered for filtering. Average value is computed from the array which is total sum of array value divided by number of rows. If \(array1(i)\) is less than average value then make it zero, otherwise keep it as it is. Find out maximum value in \(array1\) and save the maximum value and row number. From that row number, go in the upward and downward direction until we get the value zero and save the lower and upper row numbers. Lower row and upper row is used for horizontal projection which consists of license plate region.

3.2.5 Vertical Histogram Processing

Horizontal candidate region detected from the previous step is now processed in vertical direction which is column-wise. Number of ones in each column is computed and then smoothing is applied. Smoothing is required because there is a gap between two consecutive characters which results zero in vertical histogram so to remove those zeros, neighboring average is required. Then from maximum projection, traverse left and right side until count becomes zero and storing those columns. So finally we get complete license plate detected area. Results are shown in following figures (3.9 to 3.16).
Figure 3.9 (a) Reference Image (b) Binary image using Adaptive Thresholding (c) Complemented image (d) Vertical edge detection using 2 X 4 mask

Figure 3.10 (a) Highlight desired details (b) Occurrence of ones in each row (c) Filtering Histogram (d) Horizontal Projection
Figure 3.11 (a) Occurrence of ones in each column (b) Smoothing (c) Vertical Projection (d) License Plate Detection

Figure 3.12 Results of Adaptive Thresholding and Vertical Edge Detection of Sensed image
Chapter 3: License Plate Registration

Zoomed part

Figure 3. 13 Zooming some part of vertical edge detection

Figure 3. 14 Results of Horizontal Projection
My contribution in this application area is license plate registration using Stroke Width Transform (SWT). SWT is a novel image operator that will find a stroke width for each pixel. This operator is local and data dependent which makes it fast and robust. It is able to detect text regardless of its scale, direction, font and language.
3.3.1 Stroke Width Transform

Figure 3.17 The algorithm of License Plate Detection using Stroke Width Transform

3.3.1.1 Stroke Width

The SWT is a local operator which computes width of the stroke. The output of the SWT is an image of size same as input image where each element contains the width of the stroke associated with the pixel.

Figure 3.18 (a) A typical Stroke (b) Canny edge detection (c) Stroke width (courtesy: Epshtein et al. [23])

Figure 3.18 shows a typical stroke. The pixels of the stroke in this are darker than the background pixels. After edge detection, for any ‘p’ pixel on the boundary of the stroke, searching in the direction of the gradient at ‘p’, directs to find ‘q’ which is the corresponding pixel on the other side of the stroke and storing the width. Each pixel will assign by the minimum width of the stroke.
The image gradient is a directional change of intensity in an image. It is a measure of image changes and provides magnitude and direction.

For a image \( f(x,y) \) the gradient of \( f \) at coordinates \((x,y)\) is defined as the two dimensional column vector as mentioned in equation 3.9.

\[
\nabla f = \text{grad}(f) = \begin{bmatrix} g_x \\ g_y \end{bmatrix} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix}
\]

Magnitude \( M(x, y) \) and angle \( \theta(x, y) \) is described by equation 3.10 and 3.11 respectively. Magnitude tells us how quickly image is changing while direction tells us the direction in which the image is changing most rapidly.

\[
M(x, y) = \text{mag}(\nabla f) = \sqrt{g_x^2 + g_y^2}
\]

\[
\theta(x, y) = \tan^{-1} \frac{g_y}{g_x}
\]

The initial value of each element of the SWT is set to \( \infty \). First compute edges and then find out gradient direction of each pixel ‘p’ as shown in 3.18 (b). If ‘p’ lies on a stroke boundary then traverse in the gradient direction until another edge pixel \( q \) is found.

### 3.3.1.2 Finding Letter Candidates

The output of the previous step is an image where each pixel contains the width of the most likely stroke. The next step is to identify letter candidates from the stroke width image. Two neighboring pixels may be grouped together if they have similar stroke width. Connected component labeling can be used for binary image but here input is not binary so modified method should be used. Group two neighboring pixels if their SWT ratio is lower than 3. This rule guarantees that strokes with smoothly varying widths can be grouped together.
3.3.1.3 Word Detection

The next step is to group letters. Generally, license plate consists of 8 to 10 characters which can be grouped together and it is very significant filtering mechanism which will remove randomly scattered noise. For this step, height ratio, the distance between letters and average colors parameters are optimized based on the performance of training data set.

3.3.2 Image Quality Assessment

Visual quality measurement is a fundamental step for image analysis. A simple and widely used fidelity measure is the Peak Signal to Noise Ratio (PSNR) and corresponding distortion measure is the Root Mean Square Error (RMSE). It is an attractive measure for the image analysis because of its mathematical convenience. Conversely, this parameters and human judgment of quality is not always useful for most applications.

3.3.2.1 Root Mean Square Error

\[
RMSE = \sqrt{\frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} (x(i,j) - y(i,j))^2}
\]  

(3.12)

It is measure of estimator which suggests the accuracy of registration with respect to reference image. It should be near to zero for best match.

3.3.2.2 Peak Signal to Noise Ratio

\[
PSNR = 10 \log_{10} \left( \frac{(2^n - 1)^2}{MSE} \right)
\]  

(3.13)

It is a ratio of maximum possible power of signal to power of corrupting noise that affects the fidelity of representation. Its range is wide so it is expressed as logarithmic scale. Maximum value of PSNR indicates good match between the two images.
3.3.2.3 Cross Correlation

\[
Cross\ Correlation = \frac{\sum_{i=1}^{M} \sum_{j=1}^{N} (x(i,j) - \bar{x})(y(i,j) - \bar{y})}{\sqrt{\sum_{i=1}^{M} \sum_{j=1}^{N} (x(i,j) - \bar{x})^2 \sum_{i=1}^{M} \sum_{j=1}^{N} (x(i,j) - \bar{y})^2}}
\]  

(3.14)

Range of cross correlation is between -1 to +1. Minimum value indicates the dissimilarity between the images. For maximum matching, its value is 1.

3.3.2.4 Structural Similarity Index Matrix

\[
SSIM = \frac{(2 \bar{x} \bar{y} + C1)(2 \sigma xy + C2)}{(\sigma x^2 + \sigma y^2 + C2)((\bar{x})^2 + (\bar{y})^2 + C1)}
\]  

(3.15)

It is a method for comparing the two images using similarity criterion. It is a quality measure of one of the image being compared with another image having perfect quality. It is an improved version of the universal image quality index (UIQI). The mean SSIM is one when two images are same. The difference with RMSE and PSNR is that these approaches estimate perceived errors. Conversely, SSIM considers image degradation as perceived change in structural data which is having strong inter-dependencies (important information about the structure of the object) specifically when they are spatially close.

To compute above quality parameters, the size of two images must be same. \(x(i,j)\) is the reference image, \(y(i,j)\) is the sensed image, \(n\) is the number of bits per pixel, so \((2^n - 1)\) represents maximum gray value, \(\bar{x}\) and \(\bar{y}\) are the mean values for reference and sensed image respectively, \(\sigma x^2\) and \(\sigma y^2\) are the variance of \(x\) and \(y\) images, \(\sigma xy\) is the covariance of \(x\) and \(y\), \(M\) and \(N\) are the height and width of the image. \(C_1\) and \(C_2\) are the constants.

\[
C_1 = (k_1 \cdot L)^2 \quad \text{and} \quad C_1 = (k_1 \cdot L)^2
\]  

(3.16)

Where \(k1 = 0.01\) and \(k2 = 0.03\) (default) and \(L = (2^n - 1)\)
3.3.3 Results and Discussion

Case I: When Reference and Sensed Images are differed by only Pan angle

Figure 3. 19 Set 3.3.1 (a) Original Reference Image (b) Edge Detection using Canny Operator (c) Stroke Width (d) Labeling (e) Letter Candidate (f) LP Detection

Figure 3. 20 Set 3.3.1 (a) Original Sensed Image (b) Edge Detection using Canny Operator (c) Stroke Width (d) Labeling (e) Letter Candidate (f) LP Detection
Figure 3.21 Set 3.3.1 (a) Detected Reference Image (b) Detected Sensed Image (c) Scaling (d) Translation (e) Rotation (Registered Image) (f) Segmentation

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<th>Scaling (Sx=Sy)</th>
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Table 3.2 Quality Assessment Parameters of Set 3.3.1
Case II: When Reference and Sensed Images are differed by Pan Angle and Tilt angle

Figure 3. 22 Set 3.3.2 (a) Original Reference Image (b) Edge Detection using Canny Operator (c) Stroke Width (d) Labeling (e) Letter Candidate (f) LP Detection

Figure 3. 23 Set 3.3.2 (a) Original Sensed Image (b) Edge Detection using Canny Operator (c) Stroke Width (d) Labeling (e) Letter Candidate (f) LP Detection
Figure 3.24  Set 3.3.2 (a) Detected Reference Image (b) Detected Sensed Image (c) Rotation (d) Shearing (e) Translation (Registered Image) (f) Segmentation

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</table>

Elapsed time is 10.376549 seconds

Table 3.3 Quality Assessment Parameters of Set 3.3.2
Some Additional Results:

Figure 3. 25 First Row: Reference Image, Second Row: Detected Reference Image, Third Row: Sensed Image, Fourth Row: Detected Sensed Image, Fifth Row: Registered Image, Sixth Row: Segmentation of Characters.
3.4 Comparative Discussion

Using vertical edge detection, horizontal and vertical projection, detection of license plate area and register the license plate has been done. The advantage of this method is that it is able to process complex background and low resolution images. Conversely, due to license plate border, it becomes difficult to segment characters when license plate is tilted. So another method using stroke width transform is used for accurate segmentation. By observing the result of figure 3.24, conclusion is that if the sensed image is having pan and tilt both the angles, still the SWT based algorithm can generate accurate segmentation with higher speed. When only pan angle is present in the original image then only RST transformation will provide accurate registration but when pan and tilt both are present then shearing is also required. The SWT is reliable and flexible method for license plate detection.