Morphology Based Approach To Recognize Number Plates in India

A Thesis submitted in partial fulfillment of the requirements for the award of degree of

Master of Engineering

in

Electronic Instrumentation and Control

Submitted by
PHALGUN PANDYA
(Roll No. 800951018)

Under the Guidance of

Mr. M.D. Singh
Assistant Professor

Department of Electrical and Instrumentation Engineering

Thapar University
(Established under the section 3 of UGC act, 1956)

Patiala, 147004, Punjab, India
July 2011

CERTIFICATE

I hereby certify that the work which is being presented in the thesis entitled **"Morphology Based Approach To Recognize Number Plates in India"** in partial fulfillment of award of degree of **Master of Engineering** in **Electronics Instrumentation and Control** submitted in Electrical and Instrumentation Engineering department, Thapar University, Patiala is an authentic record of my own work carried under the supervision of **Mr. M.D. Singh**, Assistant Professor, Department of Electrical and Instrumentation Engineering, Thapar University, Patiala, Punjab.

Date: 14/07/11

PHALGUN PANDYA
Roll No: 800951018

I certify that the above statement made by the student is correct to the best of my knowledge and belief.

Date: 14/07/11

Mr. M.D. Singh
Assistant Professor
Department of Electrical and Instrumentation Engineering
Thapar University, Patiala
Punjab

Countersigned By

S. Ghosh 14/7/11

Dr. Smarajit Ghosh
Head of Department
Department of Electrical and Instrumentation Engineering
Thapar University, Patiala
Punjab

Dr. S K Mohapatra
Dean of Academic Affairs
Thapar University, Patiala
Punjab

A Singh 7/10/11

I

ABSTRACT

Along with the progress of the society, the rhythm of people's life becomes quick, which makes the need of automobile inevitable. Also, the fast development of computers, communication and computer network techniques, makes the transportation management automation an inevitable goal. As an important means of automatic traffic management especially red light signal violation, license plate recognition technique plays an increasingly obvious role. Automatic License Plate Recognition is an essential stage in intelligent traffic systems. The use of vehicles has been increasing because of population growth and human needs in recent years. Therefore, control of vehicles is becoming a big problem and much more difficult to solve. The License Plate Recognition (LPR) technology applies image processing and character recognition techniques to identify vehicles by automatically reading their license plates. The automatic license plate recognition, which is an important technique to obtain traffic information, mixes computer vision, image processing techniques and pattern recognition techniques. In a vehicle license plate recognition system, plate region detection is the key step before the final recognition. This thesis introduces the whole process of plate region detection.

This thesis entitled “Morphology Based Approach to Recognize Number Plates in India” deals with a novel approach for locating the license plate. By using simple pre-processing techniques and morphology based techniques, this system locates the license plate and then recognizes the characters of the License plate. The experimental results show that this new algorithm is efficient and robust in detecting license pates of Indian vehicles.

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My greatest thanks are to all who wished me success especially my parents and brother, whose support and care makes me stay on earth.

Place: Thapar University, Patiala PHALGUN PANDYA
Date: 800951018

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LIST OF ABBREVIATIONS

LPR	License plate recognition
RTO	Regional Transport Office
MATLAB	Matrix Laboratory
2-D	Two Dimensional
CAT	Computer Aided Tomography
OCR	Optical Character Recognition
VLP	Vehicle License Plate
ROI	Region of Interest
FFT	Fast Fourier Transform
DCT	Discrete Cosine Transform
DICOM	Digital Imaging and Communications in Medicine
DCAM	Distributed Intelligent Control And Management
ODBC	Open Database Connectivity
JDBC	JAVA Database Connectivity
JPEG	Joint Photographic Experts Group
TIFF	Tagged Image File Format
PNG	Portable Network Graphics
HDF	Hierarchical Data Format
HDF-EOS	Hierarchical Data Format - Earth Observing System
FITS	Flexible Image Transport System
ASCII	American Standard Code for Information Interchange
LANDSAT	Land Satellite
NITF	National Imagery Transmission Format
MRI	Magnetic Resonance Imaging
RGB	Red Green Blue
YIQ	Luminance (Y), In-phase Quadrature (NTSC color space)
HSV	Hue, Saturation, and Value
YCrCb	Luminance (Y), Chrominance (Red-Yellow), Chrominance (Blue-Yellow)

BMP	Microsoft Windows Bitmap
CUR	Microsoft Windows Cursor resource
XWD	X Window Dump
ICO	Windows Icon resource
RAS	Sun Raster image
PPM	Portable Pixmap
PGM	Portable Graymap
PCX	Windows Paintbrush
PBM	Portable Bitmap
GIF	Graphics Interchange Format
K-L Transform	Karhunen-Loeve Transform
DTW	Dynamic Time Wrapping
CBP	Component Block Projection
MLP	Multilayer Perceptron
SVM	Support Vector Machine

CHAPTER 1 INTRODUCTION

1.1 Overview

License plate recognition (LPR) is an image-processing technology used to identify vehicles by their license plates. This technology is gaining popularity in security and traffic installations. Much research has already been done for the recognition of Korean, Chinese, European, American and other license plates and for the same reason this thesis presents a license plate recognition system for the Indian conditions.

The complexity of automatic number plate recognition varies throughout the world. In some countries such as Great Britain, number plate design is highly standardized. Standard plate design makes it easier to detect and read number plates in video images.

License plates in general are easily readable by the human beings because of very high level of intelligence but when it comes to do the same using machines, many effects such as illumination, blur, background and foreground color etc. pose a problem. Unlike other countries where things have been standardized, License plate recognition (LPR) in India is difficult in the sense that the traffic rules are hardly followed.

Indian number plate designs vary widely in all aspects providing a much more challenging environment for automatic number plate recognition. Other parameters like, size of number plate characters, location of number plate, type of font used, background (white for non commercial vehicles and yellow for commercial vehicles) and foreground color (black for commercial and non commercial vehicles), etc. makes the task of number plate localization more difficult. This has made it difficult for existing commercial systems to be deployed in India.

Main aim of this thesis is to implement a method efficient in recognizing license plates in Indian conditions. Our work is not restricted to car but is expanded to many types of vehicles like motor cycle (in which size of license plate is small), transport vehicles which carry extra stylized characters and soiled license plate. Our proposed algorithm is found to be robust to detect vehicle license plates as well as extracting the numbers from them. In India we have various kinds of number plates. Old number plates following 1939 series as well as the vehicles following new number system [29]. The new format license plates can be of lengths 8,9,10. A typical example of an Indian license plate (for car) is shown in the fig. 1.1. Another variant of an Indian license plate which is mostly used for two wheelers is also shown below it.

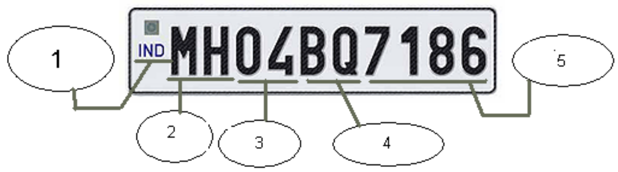


Figure 3.1 Format of Indian License plate (image courtesy of Google Images)

The latest license plate format is shown above.

1. Country Code
2. State Code
3. District Code
4. Type of Vehicle (car, two wheeler, commercial etc)
5. Actual Registration Number

Figure 1.4 Another Valid License Plate format (image courtesy of Google Images)

1.2 Applications of LPR Systems

Vehicle license plate recognition is one form of automatic vehicle identification system. LPR systems are of considerable interest, because of their potential applications to areas such as highway electronic toll collection, automatic parking attendant, petrol station forecourt surveillance, speed limit enforcement, security, customer identification enabling personalized services, etc.

License plate recognition technology has gained popularity in security and traffic applications as it is based on the fact that all vehicles have a license plate which is an important parameter to verify the legality of the vehicle and there is no need to install any additional tracking apparatus in the vehicle itself. LPR plays a major role in automatic monitoring of traffic rules and maintaining law enforcement on public roads. The plate number is used to produce a violation fine on speeding vehicles, illegal use of bus lanes, and detection of stolen or wanted vehicles

An LPR system is used to automatically store the vehicle plates to keep a track of vehicles that are entering and exiting a parking lot. Such a system is also used for automatic control of toll gates. This application is used to register entry and exit from a country, and can be used to monitor the border crossings. The vehicle information is registered into a central database and can be linked to additional information.

The LPR system's ability to read strings of alpha-numeric characters and compare them instantaneously to Hot Lists allows a Command Center to organize and strategize efforts in reaction to the information captured. Fixed LPR systems which can be mounted to bridges, gates and other high traffic areas can help keep a watch on entire cities, ports, borders and other vulnerable areas

1.3 Elements of Typical LPR System

LPR systems normally consist of a camera which takes image of a vehicle from either front or rear end. A controlled light is required to facilitate day and night operation of the system. In most cases the illumination is Infra-Red (IR) which is invisible to the driver. An interface board between the camera and the PC allows the software to read the image information. The LPR application is run and controlled by a computer that reads the images, analyzes and identifies the plate, and interfaces with other applications and systems. The application software forms the recognition package in which the defined algorithm is stored. The events are recorded on a local database or transmitted over the network. This data includes the recognition results and (optionally) the vehicle or driver-face image file.

1.4 Objective

In this thesis, for solving the problems mentioned in section 1.1, a morphology based approach (opening and closing) using MATLAB has been implemented to detect the License plates from images. The best candidate region is filtered using region based heuristics. The number plate region thus filtered is extracted and is aligned horizontally. The tilt corrected number plate image is cleaned for border effects and fixing bolt regions. The binary image is finally segmented into comprising characters and then is recognized by template matching process. Correlation score has been used as the matching parameter between the segmented character and the template sample. The assessment is made on the basis of accuracy of localization and recognition processes.

A brief overview of the proposed method has been shown below

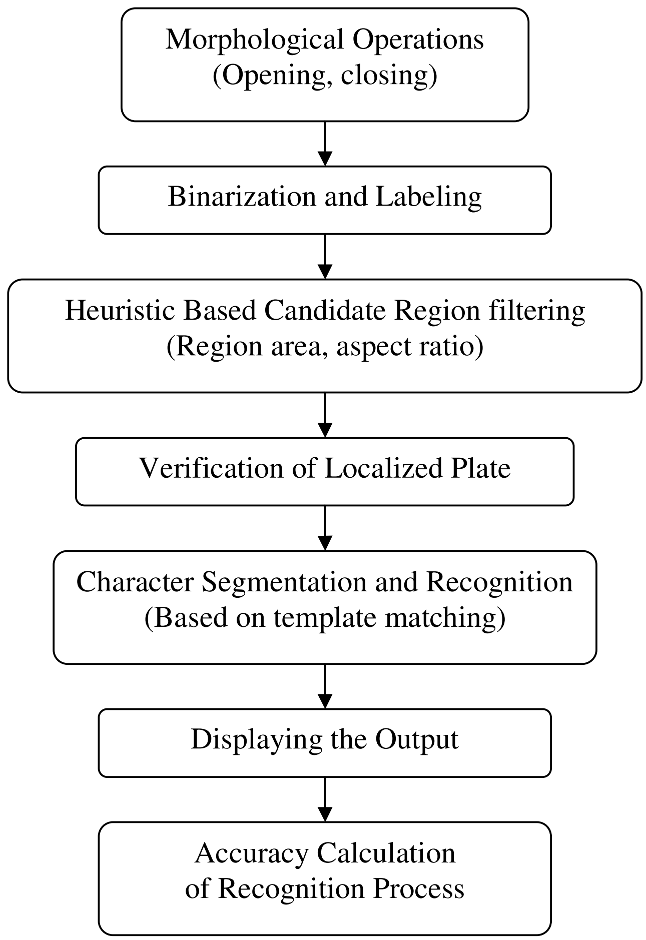


Figure 1.3 Flowchart representing overview of the proposed method

1.5 Organization of Thesis

- Chapter 1 "**INTRODUCTION**", it includes the introduction about the objective and overview of the work done in this thesis.
- Chapter 2 "**LITERATURE SURVEY**", it provides the overview of the work done in this area.

- Chapter 3 “**DIGITAL IMAGE PROCESSING**”, it gives the basics of topics which are useful in understanding complicated concepts in digital image processing and the work done.
- Chapter 4 “**MATLAB IMAGE PROCESSING TOOLBOX**” explains the potential of MATLAB IPT and its usage.
- Chapter 5 “**MORPHOLOGY**” explains all the basic concepts of mathematical morphology for both binary and gray-scale images.
- Chapter 6 “**METHODOLOGY**” gives the algorithm used for License plate Recognition.
- Chapter 7 “**RESULTS AND DISSCUSSION**”, presents output images, assessment of the output obtained after applying the proposed method on different vehicle images.
- Chapter 8 “**CONCLUSION AND FUTURE SCOPE**”, conclude thesis with future scope.

CHAPTER 2

LITERATURE SURVEY

N. Otsu, [1] (1979) proposed a threshold selection method from gray level histograms which is still the most popular and widely used method for threshold selection. An optimal threshold (or set of thresholds) is selected by maximizing the discriminant measure of seperability of the resultant classes in gray levels. The proposed method is characterized by its nonparametric and unsupervised nature of threshold selection with advantages such as simplicity, feasibility to multi thresholding problems and automatic selection of an optimal threshold (or set of thresholds). The method suggested by Otsu is still recommended as the most simple and standard one for automatic threshold selection that can be applied to various practical problems.

George Nagy, [2] (1992) studied the desirability of recognizing groups of similar characters rather than individual specimens. He concluded that in order to extract groups of similar characters, some type of document analysis is necessary. He showed that digitized document analysis forms an integral part of OCR. Character classification by itself cannot be expected to produce usable results on complex documents without a correct interpretation of the relationship between larger textual and graphic units. He analyzed the importance of the graphic content arising from the uniformity and homogeneity of pixel patterns of identical symbols within the same document.

S. Mori, [3] (1992) reviewed some OCR systems based on research and development as well as historical point of view. He focused on making the methods more precise and not a mere accumulation of empirical knowledge. The problem of making machines that would gain complete confidence of the users was also discussed. The R&D of machines using contextual knowledge such as ‘word recognition’ for various practical applications was also discussed. It was finally concluded that template matching and structural analysis techniques were most promising among all and creating a system having very high accuracy like humans would only be possible if exclusive features of other techniques are also brought together.

Da-shan Gao, et. al., [4] (2000) proposed a car license plate detection method from complex scene. In their research, a novel algorithm of extracting car license plate in a complex image is proposed. Considering the distribution of characters in a license plate and the geometrical features of a license plate comprehensively, a set of confidence values were applied to candidate regions and combined them under some rules. Their algorithm requires only prior knowledge of the range of license size, so it is robust to the deterioration of the image such as blur. The algorithm is also robust to detect the distorted license plate derived from different visual angles because of the application of a skew rectangle generated by a K-L transform to bind the license region. The algorithm can detect different size of license to some extent and offers robustness in dealing with distorted license plate.

Yassin M. Y. Hasan, et. al., [5] (2000) presented a morphology based text extraction method from images. Their method was found to be insensitive to noise, skew and text orientation. Removal of artifacts usually introduced by both fixed/optimal global thresholding and fixed-size block-based local thresholding was also presented in their research. The main feature of their research was the use of basic morphological operations such as dilation and erosion for the extraction of text from complex images. However, the system proposed could not efficiently detect the fragmented text regions.

R.P. van Heerden, et. al., [6] (1996) addressed the problem of optimizing the recognition of vehicle license plates with multiple segmentation methods. In their research, they compared different license plate search algorithms and symbol segmentation techniques. The search algorithms identify a license plate region in the image, from which the symbol segmentation techniques extract the license plate symbols. The recognition confidence score for each technique was then calculated for combining and weighing the different methods to achieve the best segmentation results. In their research they concluded that by combining the pre-segmentation techniques, the average score and the recognition rate improves.

Rangachar Kasturi, et. al., [7] (2002) summarized some of the basic building blocks that comprise a document analysis system. These blocks include OCR (Optical Character Recognition) for text, page layout analysis for skew detection, line processing for corners and curves, region and symbol processing for filled regions. It was also inferred from the analysis the need for a system which on application produces computer readable description from the pixel data.

Toni M. Rath, et. al., [8] (2002) proposed a word image matching using dynamic time warping and concluded that their proposed method produces much better results than a number of other techniques, including shape context matching. The average precision was around 65% for the technique based on dynamic time warping. The technique found out to be much faster than the other methods. However their technique has much poorer accuracy.

Hanchuan Peng, et. al [9] 2003 proposed a document image recognition technique based on template matching of CBP(Component Block Projections) for office automation and digital library applications to find the most similar template for any input document image in a pre-stored template document image data set. CBP-based template-matching method was found to possess advantages such as high matching accuracy even for a large template set and distorted input images and reduction in computational cost.

Datong Chen, et. al., [10] (2004) found a localization/verification scheme for finding text in images and video frames based on contrast independent features and machine learning methods. A vertical/horizontal edge based method was proposed combined with a baseline detection technique, to perform fast localization with a very low rejection rate and a proper false alarm rate. In the verification task, background independent features are proposed for training MLP (Multilayer Perceptrons) and SVM (Support Vector Machine) to remove the false alarms. Application of constant gradient variance feature provided good performance in characterizing text textures of unknown grayscale values.

P. V. Suryanarayana, et. al., [11] (2005) worked on a morphology based technique for car license plate extraction. Their algorithm uses morphological operations on the preprocessed, edge images of the vehicles. The edge images are generated by performing Sobel edge detection operation on the grayscale image. Characteristic features such as license plate width and height, character height and spacing are considered for defining structural elements for morphological operations. Connected component analysis is used to select the band containing license plate from the candidate segmented. Their research also shows the dependency of structuring element on the accuracy of the system.

Leonard G. C. Hamey, et. al., [12] (2005) discussed the complexity of automatic number plate recognition throughout the world. An algorithm was proposed for the recognition of license plates in Australian conditions. In their system consistency of background and foreground colors in Australian plates were analyzed. Edge-based (color adaptation of canny edge detector) texture analysis was used to locate candidate plate regions in the image. Fixed size rectangular regions of the edge image were considered and the ones having low edge density were discarded since number plates contain a high density of edges. The algorithm would read the number plate from the best candidate plate region. If the best candidate would not contain a number plate, the algorithm would use an alternative candidate plate region. This heuristic resulted in improving processing speed by rapidly rejecting unlikely plate regions as well as accuracy of the system.

M.L.M Karunanayaka, et. al., [13] (2005) discussed thresholding, noise reduction and skew correction technique of Sinhala (Sri Lankan language script) handwritten words. In their work they introduced a skew detection method based on least square method and also robust indirect skew correction method of unconstrained cursive Sinhala words. Threshold selection in combination with three methods such as QIR, NIR, and analyzing gray level intensity distribution was proposed. Median filtering algorithm and connected component analysis method were used to reduce the noise in Sinhala handwritten word images along with a vertical projection profile histogram validation technique to improve the noise reduction of the image.

Feng Tang, et. al., [14] (2007) presented an accelerated multi scale template matching method using binary features. It was analyzed that traditional methods are usually slow because the template needs to be matched to every location in the image and the matching involves element-by element floating point multiplications. The process is even slower when multi-scale matching is needed which make them unsuitable for time-critical applications. Representing the template as a linear combination of a small number of Haar-like binary features saves the computation time. This representation replaces the element-by-element floating point multiplications with several additions thus significantly improves the speed. It was found that such simple features can easily adapt to template scale changes with negligible extra computation cost.

C. Nelson Kennedy Babu, et. al., [15] (2008) proposed a license plate localization using morphology and recognition technique. It is based on combining morphological operation sensitive to specific shapes in the input image with a good threshold value by which the license plate is located. The technique uses the edge features of the license plates and characters to detect vertical edges in the input image. The resultant binary image is then followed by counting the number of ON pixels in each row which are stored in an array. The row corresponding to the highest values is treated as the license plate region. The morphological operations such as dilation and erosion are used to remove the unwanted regions and enhance the candidate region. The enhanced region is then extracted.

Zhenhui Zhang, et. al., [16] (2008) discussed Hough Transform and Its Application in Vehicle License Plate Tilt Correction. Vehicle license plate recognition system is greatly affected by vehicle license plate tilt. Tilt has a bad effect on character segmentation and recognition of VLP. They presented effectiveness of Hough Transformation to obtain vertical or horizontal angle. Tilt vehicle license were rectified using interpolation a rotation method.

Jui-Chen Wu, et. al., [17] (2008) presented a morphology based text line extraction algorithm for extracting text regions from cluttered images. The method depends on set of morphological operations for extracting important contrast regions as possible text line candidates. A moment-based method is then used for estimating text region orientations. For text verification, an x-projection based technique is used. They discussed a recovery algorithm for fragmented text regions due to noise to form a complete text line from different pieces of segments. Application of a verification scheme for verifying all extracted potential text lines according to their text geometries results in improved detection rate.

Velappa Ganpathy, et. al., [18] (2008) designed a GUI for Malaysian vehicle license plate localization and recognition system. In their proposed method, the pros and cons of Hough transform were analyzed for the skew correction and it was found that although the computation requirement of this transform puts a burden on the overall system but is highly reliable than any other method. The problem of separation of very close characters is also discussed posing problem in the overall accuracy of the system. The basis of the whole system is vertical and horizontal edge detection.

Shishir Kumar, et. al [19] (2008) in their license plate recognition system assumed the plate to be already localized and then proposed a system for correction of skew of the license plate based on homography. They also described the features of the Indian license plate registration system followed by recognition of the segmented characters of the plate region. In their research it, they found the importance of adjusting the contrast and intensity variations for proper segmentation.

Prathamesh Kulkarni, et. al., [20] (2009) proposed a feature based approach for localization of Indian number plates. In their work, the features of characters are used to find the probable characters locations and the features of number plates are used to find the probable number plate locations. The process of localization involves steps based on general features of characters as well as number plate. The probable character locations were found by rolling an inverted 'L' shaped mask over the entire image. From these, the false character locations are eliminated by performing dimension thresholding and white pixel thresholding at each location. The remnant locations are then checked for certain characteristic features of the license plate. The character locations in the group of rows are eliminated if the density is found to be below a certain value. This process is then done column-wise. Syntax of the retained locations is then checked to finally locate the true license plate.

Mei-Sen Pan, et. al., [21] (2009) proposed a method for correcting vehicle License Plate tilt by analyzing K-L trans-formation feature. In the horizontal tilt correction they used K-L transformation to carry on tilt correction. In the vertical tilt correction, they proposed three correction methods to get the vertical tilt angle. Their experimental results showed that their proposed method was more effective and also showed that K-L transformation, LFMBKC, and LFMBLS are good vertical tilt correction methods, among which the correction effect difference is not obvious. The results also showed that K-L transformation is superior to LFMBKC and LFMBKC when time factor is also considered. However, their method produces final corrected image the characters having some burrs and the smoothing operation needs to be carried out for the same.

Rodolfo P. dos Santos, et. al., [22] (2009) proposed a morphology based algorithm to segment handwritten text lines. The text line algorithm uses a morphological operator to obtain the features of the images. A Y- histogram projection is performed to find the text lines positions followed by consecutive application of threshold to divide the lines in different regions and to eliminate false lines. Recovery of lost text area was based on X-histogram projection method. In order to optimize the area of the manuscript text line, a text selection was carried out. The new approach was found to be robust, fast and produced very good score rates.

M.I.Khalil, et. al., [23] (2010) studied application of template matching technique for car plate recognition. He found that this template matching based approach can be applied equally to Egyptian and Saudi Arabian cases and can be extended to cover more countries. It is based on keeping the names of these countries along with a list of Arabic characters as entries in a table and then matching these entries one by one with the car plate. In his research he analyzed some of the techniques that are applied for recognizing the segmented characters and numbers. He found that template matching method has shown high accuracy but requires efficient searching method and needs a large storage to save all the numbers and character templates. Fuzzy logic based technique also performs well along with high accuracy and short processing time but is sensitive to the noise and distortion.

Kumar Parasuraman, et. al., [24] (2010) proposed another method for Indian vehicle license plate extraction and character segmentation. It consists of three steps, extraction of plate region, segmentation and recognition of plate characters. Extraction of plate region is done by edge detection algorithm along with vertical projection method. Segmentation is done by filtering, thinning and vertical and horizontal projection technique. Chain code concept with different parameter is applied on the segmented region for recognition of the characters.

Kaushik Deb, et. al., [25] (2010) introduced a vehicle license plate tilt correction method based on the straight line fitting and minimizing variance of coordinates of projection points for Korean vehicles. Three correction methods were implemented for comparing with the tilt performance results. They concluded that LSFPO and principal axis method tilt correction are more precise than LSFVO. Moreover, LSFPO outperforms principal axis because of faster computational time, more precise and easily implementable tilt correction. They emphasized on the implementation of a new method to detect candidate regions when vehicle bodies and License Plates (LP) have similar color and improve the traditional threshold selection in color based LP detection method, by using HSI color model as these candidate regions may include LP regions. The proposed method is capable to locate differences in size of LP region and more than one LP in the same vehicle image. Vehicle License plate (VLP) regions containing predetermined alphanumeric character were verified and detected by using position in the histogram. Color arrangement and predetermined alphanumeric character of the Korean license plate were also considered as important features for verification and detection of license plate regions. However, their method is found to be sensitive with motion blur in the input image.

Chirag N. Paunwala, et. al., [26] (2010) proposed a multiple license plate extraction technique for complex background in Indian traffic conditions. The algorithm uses edge analysis and morphological operations, which easily highlights the number of probable candidate regions in an image. In their method, exact location of license plate is determined with the help of connected component analysis and using different filtering conditions along with plate companionable filter. Contrast enhancement is employed using sigmoid function to extract the license plates from the images taken in dark conditions as well as images with complex backgrounds. However the work has been restricted to plate localization only.

Weihua Huang, et. al., [27] (2010) proposed a video text detection method through classification of low and high contrast images. it was inferred that relying on fixed threshold for the segmentation of text is the main cause of failure to achieve good detection rate and low false alarm rate . Fixed threshold-based methods fail to detect text in low contrast images where text has dim intensity values. It was found that determining a good threshold value for low contrast video images is very difficult as compared to high contrast ones and setting a low threshold in order to capture low contrast text will result in merger of multiple text lines, leading to more false positives. On the other hand, if the threshold is set too high, then low contrast text may be missing. The algorithm proposed yielded good results but was limited to horizontal text lines only.

Krishna Kant Singh, et. al., [28] (2010 studied various image segmentation algorithms for different types of images. In the research it was analyzed that some specific segmentation algorithms also take the type of image inputted like color, gray scale and text into consideration. In their study, some segmentation algorithms used for text detection based on difference and similarity features were also discussed. These algorithms have pros and cons of their own. Some cannot be used on samples having similar background and foreground while the others cannot be used being unstable. Finally, it was concluded that based on the image that is inputted the algorithm should be chosen to get the best results.

CHAPTER 3 DIGITAL IMAGE PROCESSING

3.1 Introduction

Image processing - a moving horizon! Walking towards a horizon is open ended. The horizon never gets any closer to you, but continually recedes from you. Thus it has been with the growth of image processing, as a technical discipline. Constant progress is being made - but the potential is far from exhausted. In the early years of image processing the concern was of basic phenomena, for example, making models for image data compression, image restoration and image enhancement. Currently there is a great interest in moving beyond physical phenomena and into the realms that are wrapped with psychology, perception and cognition. The research in this branch of image processing is often called as 'Image Understanding'.

The field of a digital-image processing has experienced dramatic growth and increasingly widespread applicability in recent years. Fortunately, advances in computer technology have kept pace with the rapid growth in volume of image data in these and other applications. Digital-image processing has become economical in many fields of research and in industrial and military applications. While each application has requirements unique from the others, all are concerned with faster, cheaper, more accurate, and more extensive computation. The trend is toward real-time and interactive operations, where the user of the system obtains preliminary results within a short enough time that the next decision can be made by the human processor without loss of concentration on the task at hand. An example of this is the obtaining of two dimensional (2-D) computer-aided tomography (CAT) images. The ability to place earth oriented sensors into orbit, because of its large economic potential has received considerable research emphasis, and many operational systems have been evolved. Land remote sensing has been evolving since 1960s and its various applications in urban land utilization, forestry and food commodity production forecasting has been producing remarkable results. An off shoot of remote sensing by satellites has been the use of this data for military purposes.

The processing of two-dimensional data, or images, using a digital computer or other special digital hardware typically involves several steps. First, the image to be processed must be put in a format appropriate for digital computing. This image acquisition step can be accomplished in a number of ways, depending on the application. Then the processing must be performed in order to extract the information of interest from the image(s). Finally, the imagery must be reformatted for human or machine viewing, storage, or hardcopy documentation.

3.2 Definition of Digital Image

An image is a 2D array of values representing light intensity. For the purposes of image processing, the term image refers to a digital image. An image is a function of the light intensity.

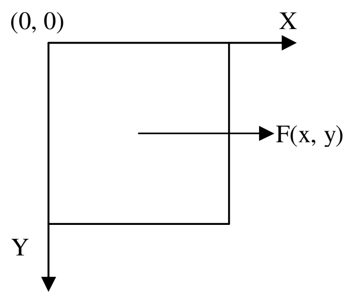


Figure 3.1 2-D Image Representation

where f is the brightness of the point (x, y), and x and y represent the spatial coordinates of a picture element, or pixel. By convention, the spatial reference of the pixel with the coordinates (0, 0) is located at the top, left corner of the image. Notice in Figure 3.1 that the value of x increases moving from left to right, and the value of y increases from top to bottom. While performing operations (especially looping) related to dimensions of the image, special care has to be taken. When we perform an operation in x-direction, then the output will show a change in the columns and when an operation is performed in y-direction then the resulting output will show a change in the rows.

3.3 Defining Image Processing

The traditional view of image processing tends to embrace one or more of picture processing, pattern recognition, image interpretation and even graphics. 'Graphics' deals with the generation of images from non-pictorial information and covers diverse applications. In the order of increasing complexity, production of plots of functions, composition of displays for the computer games and scenes used in flight simulators are some of the examples of displays. Image processing deal with problems in which inputs and outputs are pictures.

'Pattern Recognition' deals with methods for producing either a description of the input picture or an assignment of the picture to a particular class. In a sense, it is the inverse problem of computer graphics. It starts with a picture and transforms it into an abstract description, a set of numbers, a string of symbols, etc. Further processing of these forms results in assigning the original picture to one of several classes. An automatic mail sorter that examines the postal code written on an envelope and identifies the digits is a typical example of the application. However, the term 'Image Processing' should be used as a catch all for all these activities and in a much broader context with the implicit understanding that the fundamental underlying activity is that of 'Information Processing'.

It is clearly evident that in coming days, much information is going to be represented, and subsequently processed, as digital images, be it X-ray scans, satellite images, video films or whatever. This is no more than a reflection of the fact that our information processing channel with the highest band width, by a long way, is the visual one. It is this primacy of images in information representations that renders a digression into the possible social impact of information processing.

3.4 Aspects of Image Processing

It is convenient to subdivide different image processing algorithms into broad subclasses. There are different for different tasks and problems. The aspects of image processing are image enhancement, image restoration and image segmentation.

- **Image Enhancement:** It is among the simplest and most appealing areas of digital image processing. Basically, the idea behind enhancement techniques is to bring out detail that is obscured, or simply to highlight certain features of interest in an image. A familiar example of enhancement is when we increase the contrast of an image because "it looks better." It is important to keep in mind that enhancement is a very subjective area of image processing.
- **Image Restoration**: It is an area that also deals with improving the appearance of an image. However, unlike enhancement, which is subjective, image restoration is objective, in the sense that restoration techniques tend to be based on mathematical or probabilistic models of image degradation. Enhancement, on the

other hand, is based on human subjective preferences regarding what constitutes a "good" enhancement result.

- **Image Segmentation**: Segmentation procedures partition an image into its constituent parts or objects. In general, autonomous segmentation is one of the most difficult tasks in digital image processing. A rugged segmentation procedure brings the process a long way toward successful solution of imaging problems that requires objects to be identified individually. On the other hand, weak or erratic segmentation algorithms almost always guarantee eventual failure[28]. In general, the more accurate the segmentation, the more likely recognition is to succeed.

3.5 Applications

3.5.1 Automatic Visual Inspection System

Automated visual inspection systems are essential to improve the productivity and the quality of the product in manufacturing and allied industries.

- **Automatic inspection of incandescent lamp filaments:** An interesting application of automatic visual inspection involves inspection of the bulb manufacturing process. Often the filaments of the bulbs get fused after short duration due to erroneous geometry of the filament, e.g., non-uniformity in the pitch of the wiring in the lamp. Manual inspection is not efficient to detect such aberrations. In an automated vision-based inspection system, a binary image slice of the filament is generated, from which the silhouette of the filament is produced. This silhouette is analyzed to identify the non-uniformities in the pitch of the filament geometry inside the bulb. Such a system has been designed and installed by the General Electric Corporation.
- **Faulty component identification:** Automated visual inspection may also be used to identify faulty components in an electronic or electromechanical system. The faulty components usually generate more thermal energy. The infra-red (IR) images can be generated from the distribution of thermal energies in the assembly. By analyzing these IR images, we can identify the faulty components in the assembly.
- **Automatic surface inspection systems:** Detection of flaws on the surfaces is important requirement in many metal industries. For example, in the hot or cold

rolling mills in a steel plant, it is required to detect any aberration on the rolled metal surface. This can be accomplished by using image processing techniques like edge detection, texture identification, fractal analysis, and so on.

3.5.2 Remotely Sensed Scene Interpretation

Information regarding the natural resources, such as agricultural, hydrological, and mineral, forest, geological resources, etc., can be extracted based on remotely sensed image analysis. For remotely sensed scene analysis, images of the earth's surface are captured by sensors in remote sensing satellites or by a multi-spectral scanner housed in an aircraft and then transmitted to the Earth Station for further processing. Techniques of interpreting the regions and objects in satellite images are used in city planning, resource mobilization, flood control, agricultural production monitoring, etc. The timely forecasting of information thus extracted can be helpful in preventing loss of life and property caused by natural calamities such as tornados, floods, tsunamis etc.

3.5.3 Biomedical Imaging Techniques

Some of the biomedical imaging applications are presented below.

- **Lung disease identification:** In chest X-rays, the structures containing air appear as dark, while the solid tissues appear lighter. Bones are more radio opaque than soft tissue. The anatomical structures clearly visible on a normal chest X-ray film are the ribs, the thoracic spine, the heart, and the diaphragm separating the chest cavity from the abdominal cavity. These regions in the chest radiographs are examined for abnormality by analyzing the corresponding segment.
- **Heart disease identification:** Quantitative measurements such as heart size and shape are important diagnostic features to classify heart diseases. Image analysis techniques may be employed to radiographic images for improved diagnosis of heart diseases.
- **Digital mammograms:** Digital mammograms are very useful in detecting features (such as micro-calcification) in order to diagnose breast tumor. Image processing techniques such as contrast enhancement, segmentation, feature extraction, shape analysis, etc. are used to analyze mammograms. The regularity of the shape of the tumor determines whether the tumor is benign or malignant.

3.6 Template Matching and its Significance in Digital Image Processing

The history of science and technology does not flow like a straight canal, but is usually tangled like a meander. The OCR research like that of speech recognition is comparatively old. Since its debut in 1955, OCR technology has shown spectacular progress due to advances in processor and digitizer technology. It was due to these advancements that during 1960s and 1970s tens of thousands of high performance systems with fast document transports and hard wired recognition logic were sold in United States. George Nagy [2] and S.Mori [3] in 1992 studied the capabilities of the OCR systems and the need for developing machines that could have high fidelity. According to their study, the techniques based on template matching and structural analysis showed promising results and hence in the following section we have discussed significance of the same in Digital Image Processing for VLP recognition.

In the template matching approach, we have to create a library of possible visual patterns of vehicles (objects) to seek similarity between a segment of the actual image (or video frame) and a library image, or template. Once such similarity is found, the frame part is classified as that of vehicles (objects) image. Although this approach can be useful in some circumstances, it is not very efficient because it requires the creation of a huge library of templates [7]. Template matching is one of the ways for performing operations like: object recognition, identification or classification, and detection.

Template matching is conceptually a simple process. We need to match a template to an image where the template is a sub-image that contains the shape we are trying to find. Accordingly, we centre the template on an image point and count up how many points in the template matched those in the image. The procedure is repeated for the entire image, and the point that led to best match, the maximum count, is defined to be the point where the shape (given by the template) lie within the image. If standard deviation of the template image compared to the source image is small enough, template matching may be used.

Templates are most often used to identify printed characters, numbers, and other small, simple objects. Template matching is performed on either bi-level image (black and white) or grey level image depends on the application. For example, for character recognition and number plate of vehicle bi-level image are used while for vehicle or object recognition grey level image is used.

Template matching uses a similarity criterion for locating an object, where one common method calculates a correlation coefficient using the following equation:

$$\beta = \frac{\sum_x \sum_y (A_{xy} - \bar{A})(B_{xy} - \bar{B})}{\sqrt{\sum_x \sum_y (A_{xy} - \bar{A})^2 \sum_x \sum_y (B_{xy} - \bar{B})^2}}$$

where A and B are image matrices, and $\bar{A}$, $\bar{B}$ are the 2-dimensional means of the respective image matrices, and (x, y) are the spatial coordinates within A and B. This correlation coefficient closely resembles a traditional statistical correlation, with the difference being that the traditional method is calculated in one dimension instead of two dimensions. A high correlation coefficient in a pixel-by-pixel comparison between the template and the region of interest (ROI) indicates a good match.

3.7 Template based vehicle (object) detection

If a template describing a specific object is available, object detection becomes a process of matching features between the template and the image sequence under analysis. Object detection with an exact match is generally computationally expensive and the quality of matching depends on the details and the degree of precision provided by the object template. There are two types of object template matching, fixed and deformable template matching.

3.7.1. Fixed template matching

Fixed templates are useful when object shapes do not change with respect to the viewing angle of the camera. Two major techniques have been used in fix template matching.

- **Image subtraction: -** In this technique, the template position is determined from minimizing the distance function between the template and various positions in the image. Although image subtraction techniques require less computation time than the following correlation techniques, they perform well in restricted environments where imaging conditions, such as image intensity and viewing angles between the template and images containing this template are the same.
- **Correlation: -** Matching by correlation utilizes the position of the normalized cross-correlation peak between a template and an image to locate the best match. This technique is generally immune to noise and illumination effects in the images, but suffers from high computational complexity caused by summations

over the entire template. Point correlation can reduce the computational complexity to a small set of carefully chosen points for the summations.

- **Normalized Correlation: - I**n unipolar images (with only positive intensity values) this correlation formula can give high response in a region even though the region does not fit the template at all. This is due to the fact that regions with high intensity yield higher response since no normalization is performed. Vehicle tracking by template matching calculating the normalized cross correlation is performed on consecutive image pairs and is based on the vehicle detection in the first image of an image sequence. For each vehicle detected in the first image, a template image is produced. Then, a search area for each detected vehicle is defined in the second image of the exposure sequence. Within this search area the normalized cross correlation between the template image and the second image is calculated for all 3 channels of the RGB images. The calculated correlation value gives a score for a possible hit.

3.7.2. Deformable template matching

Deformable template matching approaches are more suitable for cases where objects vary due to rigid and non-rigid deformations. These variations can be caused by either the deformation of the object or just by different object pose relative to the camera. Because of the deformable nature of objects in most video, deformable models are more appealing in tracking tasks.

CHAPTER 4

MATLAB IMAGE PROCESSING TOOLBOX

4.1 Introduction

Image Processing Toolbox provides a comprehensive set of reference-standard algorithms and graphical tools for image processing, analysis, visualization, and algorithm development. It can restore noisy or degraded images, enhance images for improved intelligibility, extract features, analyze shapes and textures, and register two images. Most toolbox functions are written in the open MATLAB language, giving us the ability to inspect the algorithms, modify the source code, and create our own custom functions.

Image Processing Toolbox supports engineers and scientists in areas such as biometrics, remote sensing, surveillance, gene expression, microscopy, semiconductor testing, image sensor design, color science, and materials science. It also facilitates the learning and teaching of image processing techniques.

4.2 Key Features

- Image enhancement, including filtering, filters design, de-blurring, and contrast enhancement.
- Image analysis, including feature detection, morphology, segmentation, and measurement.
- Spatial transformations and image registration.
- Image transforms, including FFT, DCT, Radon, and fan-beam projection.
- Support for multidimensional image processing.
- Support for ICC version 4 color management system.
- Modular interactive tools, including ROI selections, histograms, and distance measurements.
- Interactive image and video display
- DICOM import and export.

4.3 Importing and Exporting Images

Image Processing Toolbox supports images generated by a wide range of devices, including digital cameras, frame grabbers, satellite and airborne sensors, medical imaging devices, microscopes, telescopes, and other scientific instruments. It can visualize, analyze, and process these images in many data types, including single and double precision floating-point and signed or unsigned 8-, 16-, and 32-bit integers. There are several ways to import or export images into and out of the MATLAB environment for processing. It can use Image Acquisition Toolbox (available separately) to acquire live images from Web cameras, frame grabbers, DCAM-compatible cameras, and other devices. Using Database Toolbox (also available separately), it can access images stored in ODBC/JDBC-compliant databases. MATLAB supports standard data and image formats, including JPEG, TIFF, PNG, HDF, HDF-EOS, FITS, Microsoft Excel, ASCII, and binary files.

It also supports multi-band image formats, such as LANDSAT. Low-level I/O functions enables to develop custom routines for working with any data format. Image Processing Toolbox supports a number of specialized image file formats. For medical images, it supports the DICOM file format, including associated metadata, as well as the Analyze 7.5 and Interfile formats. The toolbox can also read geospatial images in the NITF format and high dynamic range images in the HDR format.

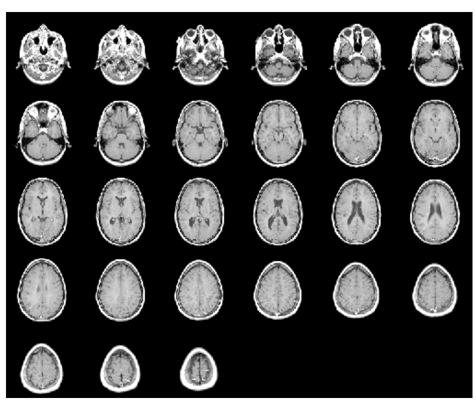


Figure 4.1: A Display of MRI Slices from a Series of DICOM files
(Image courtesy of MATLAB help manual)

4.4 Pre and Post-Processing Images

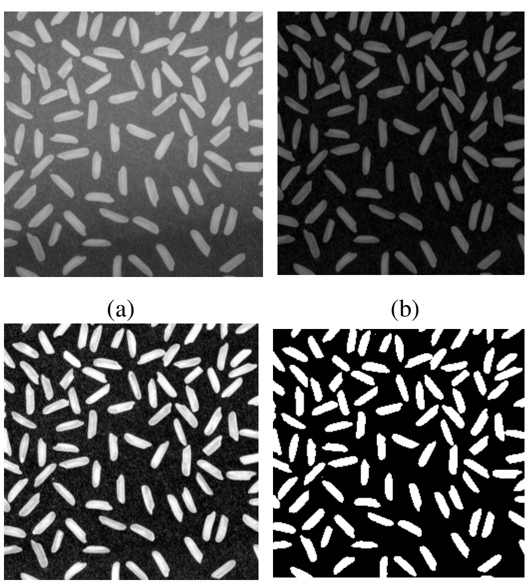
Image Processing Toolbox provides reference-standard algorithms for pre and post-processing tasks that solve frequent system problems, such as interfering noise, low dynamic range, out-of-focus optics, and the difference in color representation between input and output devices.

4.4.1 Enhancing Images

Image enhancement techniques in Image Processing Toolbox enable to increase the signal-to-noise ratio and accentuate image features by modifying the colors or intensities of an image. It can:

- Perform histogram equalization
- Perform de-correlation stretching
- Remap the dynamic range
- Adjust the gamma value
- Perform linear, median, or adaptive filtering

The toolbox includes specialized filtering routines and a generalized multidimensional filtering function that handles integer image types, multiple boundary padding options, and convolution and correlation. Predefined filters and functions for designing and implementing its own linear filters are also provided.



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

Figure 4.2
(a) Original Image of a Rice Grain with Non uniformity Background Intensity
(b) Result of subtraction of Non uniformity from Original
(c) Image After Intensity Adjustment
(d) Binary Version of the Image

4.4.2 De-blurring Images

Image Processing Toolbox supports several fundamental de-blurring algorithms, including blind, Lucy-Richardson, Wiener, and regularized filter de-convolution, as well as conversions between point spread and optical transfer functions. These functions help correct blurring caused by out-of-focus optics, movement by the camera or the subject during image capture, atmospheric conditions, short exposure time, and other factors. All de-blurring functions work with multidimensional images.

4.4.3 Managing Device-Independent Color

Image Processing Toolbox enables us to accurately represent color independently from input and output devices. This is useful when analyzing the characteristics of a device, quantitatively measuring color accuracy, or developing algorithms for several different devices. With specialized functions in the toolbox, it can convert images between device independent color spaces, such as RGB, XYZ, having more flexibility and control. The toolbox supports profile-based color space conversions using a color management system based on ICC version 4. For example, it can import n-dimensional ICC color profiles, create new or modify existing ICC color profiles for specific input and output devices, specify the rendering intent, and find all compliant profiles on our machine.

4.4.4 Image Transforms

Transforms such as FFT and DCT play a critical role in many image processing tasks, including image enhancement, analysis, restoration, and compression. Image Processing Toolbox provides several image transform functions that includes DCT, Radon, and fan-beam projection. It can reconstruct images from parallel-beam and fan-beam projection data (common in tomography applications). Image transforms are also available in MATLAB and in Wavelet Toolbox (available separately).

4.4.5 Image Conversions

Imaging applications often require conversion between data classes and image types. Image Processing Toolbox provides a variety of utilities for conversion between data classes, including single- and double-precision floating-point and signed or unsigned 8-, 16-, and 32-bit integers. The toolbox includes algorithms for conversion between image types, including binary, gray scale, indexed color, and true color. Specifically for color images, the toolbox supports a variety of color spaces such as YIQ, HSV, and YCrCb, Bayer pattern encoded, and high dynamic range images.

4.5 Analyzing Images

Image Processing Toolbox provides a comprehensive suite of reference-standard algorithms and graphical tools for image analysis tasks such as statistical analysis, feature extraction, and property measurement. Statistical functions analyze the general characteristics of an image by:

- Computing the mean or standard deviation
- Determining the intensity values along a line segment
- Displaying an image histogram
- Plotting a profile of intensity values

4.5.1 Edge-detection algorithms

Edge detection algorithms identify object boundaries in an image. These algorithms include the Sobel, Prewitt, Roberts, Canny, and Laplacian of Gaussian methods. The powerful Canny method can detect true weak edges without being "fooled" by noise.

4.5.2 Image segmentation algorithms

Segmentation which is a separation of structures having similar attributes from the background and from each other is an essential analysis function in image processing for which numerous algorithms have been developed. Typically, segmentation of an object is achieved either by identifying all pixels or voxels that belong to the object or by locating those that form its boundary. The former is based primarily on the intensity of pixels, but other attributes, such as texture, that can be associated with each pixel, can also be used for segmentation. The principle objective of the segmentation process is to divide an image into portions that are homogeneous with respect to one or more characteristics or features.

4.5.3 Morphological operators

These operations enable detection of edges, enhance contrast, remove noise, segment an image into regions, thin regions, or perform skeletonization on regions. Morphological functions in Image Processing Toolbox include:

- Erosion and dilation

- Opening and closing
- Labeling connected components
- Watershed segmentation
- Reconstruction
- Distance transform

The above mentioned morphological operations are explained in detail in chapter 5.

Image Processing Toolbox also contains advanced image analysis functions that help to:

- Measure the properties of a specified image region, such as the area, center of mass, and bounding box
- Detect lines and extract lines segments from an image using the Hough transform
- Measure properties, such as surface roughness or color variation, using texture analysis functions

4.6 Displaying and Exploring Images

Image Processing Toolbox provides a suite of tools for interactive image display and exploration. It can load an image from a file or from the MATLAB workspace, view image information, adjust the contrast, closely examine a region of pixels, and zoom and pan around the image. It can interactively place and manipulate ROIs, including points, lines, rectangles, polygons, ellipses, and freehand shapes. It can also interactively crop, create histograms and contours, and measure distances. The toolbox includes tools for displaying video and sequences in either a time-lapsed video viewer or image montage. Volume visualization tools in MATLAB let us create isosurface displays of multidimensional image data sets.

4.7 Spatial Transformations and Image Registration

Spatial transformations alter the spatial relationships between pixels in an image by mapping locations in an input image to new locations in an output image. Image Processing Toolbox supports common transformational operations, such as resizing, rotating, and interactive cropping of images, as well as geometric transformations with arbitrary-dimensional arrays. Image registration is important in remote sensing, medical imaging, and other applications where images must be aligned to enable quantitative analysis. Using Image Processing Toolbox, it can interactively select points in a pair of images and align the two images by performing a spatial transformation, such as linear conformal, affine, projective, polynomial, piecewise linear or local weighted mean. We can also perform image registration using normalized 2-D cross-correlation.

4.8. Use of Image Processing in MATLAB

After knowing the potential of the MATLAB IPT, a question arises that how to handle images in MATLAB? When working with images in MATLAB, there are many things to keep in mind such as loading an image, using the right format, saving the data as different data types, how to display an image, conversion between different image formats, etc. There are some commands designed for these operations. Most of these commands require having the Image processing tool box installed with MATLAB. To find out if it is installed or not, type "ver" at the MATLAB prompt. This gives a list of the toolboxes that are installed on the system. To understand how commands work in MATLAB is to carefully work with the examples.

A digital image is composed of pixels which can be thought of as small dots on the screen. A digital image is an instruction of how to color each pixel. We will see in detail later on how this is done in practice. A typical size of an image is 512-by-512 pixels. It is convenient to let the dimensions of the image to be a power of 2. For example, 2^9=512. In the general case it can be said that an image is of size *m*-by-*n* if it is composed of *m* pixels in the vertical direction and *n* pixels in the horizontal direction.

Let us say that we have an image of supported format of size 512-by-1024 pixels. This means that the data for the image must contain information about 524288 pixels, which requires a lot of memory! Hence, compressing images is essential for efficient image processing. Fourier analysis and Wavelet analysis can help us to compress an image significantly.

4.9 Image Formats Supported By MATLAB

The following image formats are supported by MATLAB:

- BMP (Microsoft Windows Bitmap)

- CUR (Microsoft Windows Cursor resource)
- GIF (Graphics Interchange Format)
- HDF (Hierarchical Data Format)
- ICO (Windows Icon resource
- JPEG (Joint Photographic Experts Group)
- PBM (Portable Bitmap)
- PCX (Windows Paintbrush)
- PGM (Portable Graymap)
- PNG (Portable Network Graphics)
- PPM (Portable Pixmap)
- RAS (Sun Raster image)
- TIFF (Tagged Image File Format)
- XWD (X Window Dump)

Most images found on the Internet are JPEG-images which is the name for one of the most widely used compression standards for images. If it has stored an image it can usually see from the suffix what format it is stored in. For example, an image named testimage.jpg is stored in the JPEG format.

4.10 Image Types

If an image is stored as a JPEG-image on the disk, first it will have to be read into MATLAB. However, in order to start working with an image, for example perform a wavelet transform on the image, it must be converted to a supported data type. This section explains four common image types.

4.10.1 Intensity image (gray scale image)

This is equivalent to a "gray scale image". It represents an image as a matrix where every element has a value corresponding to how bright/dark the pixel at the corresponding position should be colored. There are two ways to represent the number that represents the brightness of the pixel: The double class (or data type). This assigns a floating number (a number with decimals) between 0 and 1 to each pixel. The value 0 corresponds to black and the value 1 corresponds to white. The other class is called uint8 which assigns an integer between 0 and 255 to represent the brightness of a pixel. The value 0 corresponds to black and 255 to white. The class uint8 only requires roughly 1/8 of the storage compared to the class double. On the other hand, many mathematical functions can only be applied to the double class.

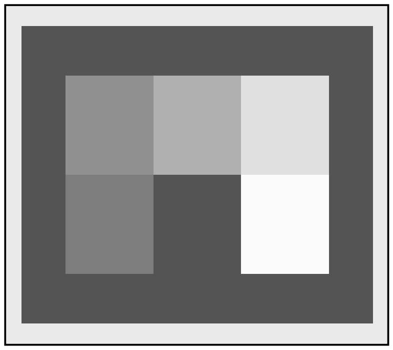


Figure 4.3 (a)A grayscale image

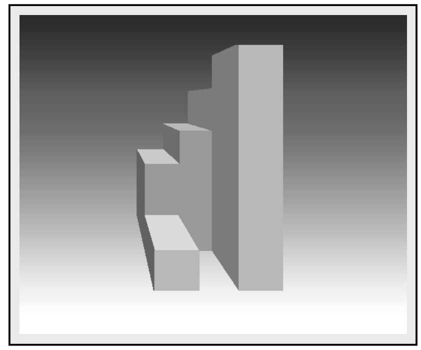


Figure 4.3(b) 3D representation of figure 4.3(a)

4.10.2 Binary Image

A binary image is a logical array of 0s and 1s. Pixels with the value 0 are displayed as black pixels with the value 1 are displayed as white. In MATLAB, a binary image must be of class logical that is why the intensity images that happen to contain only 0's and 1's are not taken as binary images**.**

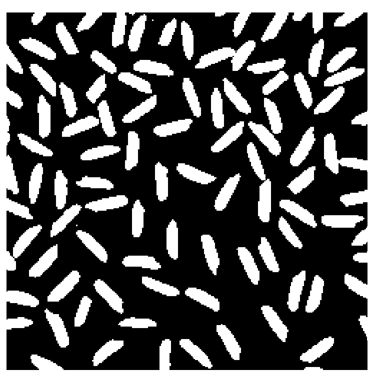


Figure 4.4 A binary image

4.10.3 Indexed Image

An indexed image consists of a data matrix, X, and a colormap matrix termed as "map". The "map" is an m-by-3 array of class double containing floating-point values in the range [0, 1]. Its every row specifies the red, green, and blue components of a single color. For these images pixel values are directly mapped to their corresponding colormap values. The color of each image pixel is determined by using the corresponding values of X as an index into map. The value 1 points to the first row in map, the value 2 points to the second row, and so on.

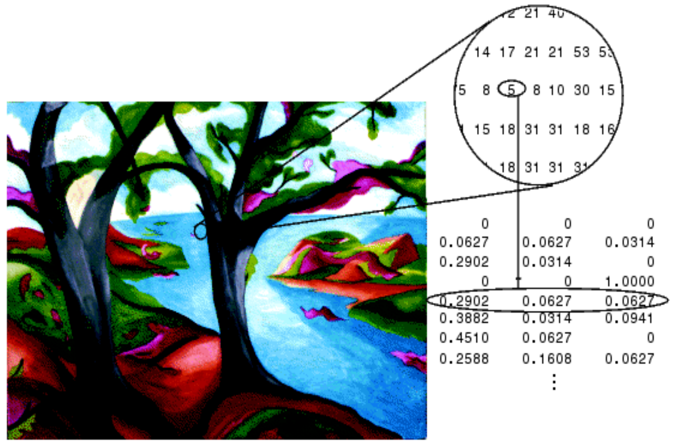


Figure 4.5 An indexed image with data and colormap matrix
(image courtesy of MATLAB help manual)

4.10.4 RGB Image

An RGB image is also referred as a true- color image. In MATLAB these images are stored in the form of an m-by-n-by-3 data array that defines red, green, and blue components for each individual pixel. The color of each pixel is determined by the combination of the red, green and blue intensities stored in each color plane at the pixel's location. Graphics file formats store RGB images as 24-bit images, where the red, green and blue components are 8 bits each. An RGB array can be of class double, uint8, or uint16. In an RGB array of class double, each color component is a value between 0 and 1. A pixel whose color components are (0,0,0) is displayed as black, and a pixel whose color components are (1,1,1) is displayed as white. The three color components for each pixel are stored along the third dimension of the data array. In this work we are mainly dealing with intensity images that are also known as gray scale images.

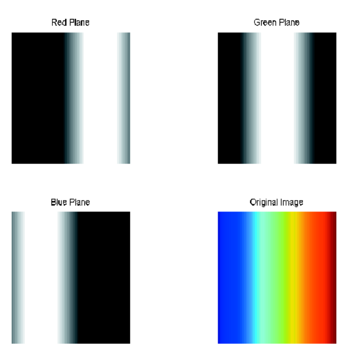


Figure 4.6 Separate bands of an RGB image

4.10.5 Multi-frame image

In some applications we want to study a sequence of images. This is very common in biological and medical imaging where we might study a sequence of slices of a cell. For these cases, the multi-frame format is a convenient way of working with a sequence of image. The table below summarizes the way MATLAB interprets data matrix elements as pixel colors, depending on the image type and storage class.

Table 4.1 Summary of Image Types and Numeric Classes

Image Type	Storage Class	Interpretation
Binary	logical	An array of zeros (0) and ones (1)
Indexed	double	An array of integers in the range [1, *p*]
	uint8 or uint16	An array of integers in the range [0, *p*-1]
Intensity	double	An array of floating-point values. The typical range of values is [0, 1].
	uint8 or uint16	An array of integers. The typical range of values is [0, 255] or [0, 65535].
RGB(Truecolor)	double	An m-by-n-by-3 array of floating-point values in the range [0, 1].
	uint8 or uint16	An m-by-n-by-3 array of integers in the range [0, 255] or [0, 65535].

CHAPTER 5 MORPHOLOGY

5.1 Mathematical Morphology

For the purposes of image analysis and pattern recognition there is always a need to transform an image into another better represented form. During the past five decades image-processing techniques have been developed tremendously and mathematical morphology in particular has been continuously developing because it is receiving a great deal of attention because it provides a quantitative description of geometric structure and shape and also a mathematical description of algebra, topology, probability, and integral geometry. Mathematical morphology is extremely useful in many image processing and analysis applications.

Mathematical morphology denotes a branch of biology that deals with the forms and structures of animals and plants. It analyzes the shapes and forms of objects. In computer vision, it is used as a tool to extract image components that are useful in the representation and description of object shape. It is mathematical in the sense that the analysis is based on set theory, topology, lattice algebra, function, and so on.

5.2 Basic Concepts from Set Theory

Let Z be a set of integers. The sampling process used to produce the digital image may be viewed as a partitioning in the x y -plane in to a grid, with coordinates of the centre of each grid being a pair of elements from the Cartesian product Z^2. In the terminology of set theory the function f (x, y) is said to be a digital image if (x, y) are integers from Z^2 and f is a mapping that assigns an intensity value in the set of real numbers, R, to each distinct pair of coordinates (x ,y). If the elements of R also are integers, a digital image then becomes a two-dimensional function, whose coordinates and the amplitude values are integers.

Let A be a set in Z^2, the elements of which are pixel coordinates (x, y). If w = (x, y) is an element of A, then it is written

$$w \in A$$

Similarly, if w is not an element of A, it is written

$$w \notin A$$

A set of B pixels satisfying a particular condition is written as

$$B = \{w \mid condition\}$$

For example, the set of all pixel coordinates that do not belong to A, denoted by Ac, is given by **complement** of A

$$Ac = \{w|w / A\}$$

The **union** of two sets, denoted by

$$C = A \cup B$$

is the set of all elements that belong to either A or B, or both.

Similarly, the **intersection** of two sets A and B is the set of elements that belong to both sets, denoted by

$$C = A \cap B$$

The **difference** of sets A and B, denoted by A – B, is the set of all elements that belong to A but not to B:

$$A - B = \{w \mid w \in A, w / B\}$$

Fig 5.1 illustrating these set operations.

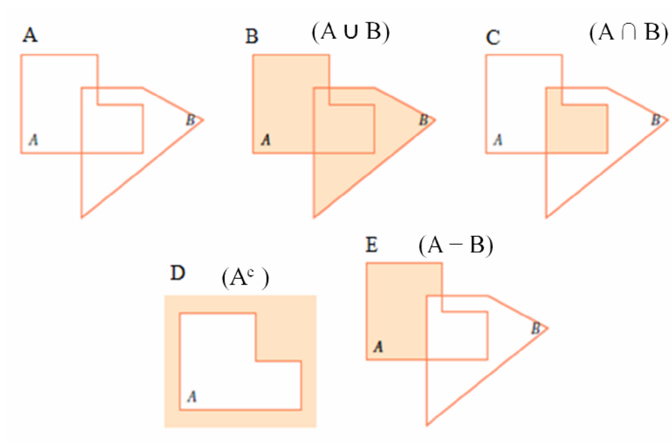


Figure 5.1 Basic concepts from set theory

In addition to the basic operations, morphological operations often require two operations that are specific to sets whose elements are pixel coordinates. The **reflection** of set B, denoted by Bˆ, is defined as

$$\hat{B} = \{w|w = -b, \text{ for } b \in B\}$$

The **translation** of set A by z = (z x, z y), denoted by (A)z, is defined as

$$A_z = \{c \mid c = a + z, \text{ for } a \in A\}$$

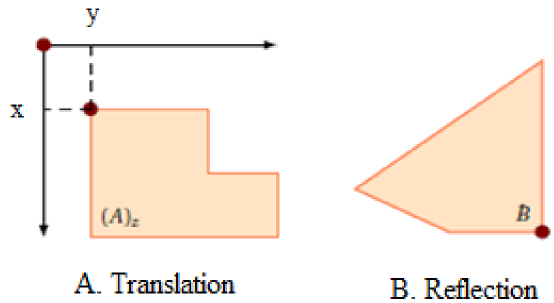


Figure 5.2 Translation and reflection

The union and intersection can be exchanged by logical duality (De-Morgan's Law) as

$$(A \cup B)^C = A^C \cup B^C$$

And

$$(A \cup B)^C = A^C \cap B^C$$

5.3 Structuring Element

The basic idea in morphology is to probe a binary image with a simple, pre-defined shape, drawing conclusions on how this shape fits or misses the shapes in the image. This simple "probe" is called structuring element, which is also a binary image (i.e., a subset of the space or grid). Mathematical morphology involves geometric analysis of shapes and textures in images. An image can be represented by a set of pixels.

Morphological operators work with two images. The image being processed is referred to as the active image, and the other image, being a kernel, is referred to as the structuring element. Each structuring element has a designed shape, which can be thought of as a probe or a filter of the active image. The active image can be modified by probing it with the structuring elements of different sizes and shapes.

Mathematical morphology use morphological structuring elements in order to measure and distill corresponding shape of an image to attain objective of analysis, to reduce image data and to keep basic shape character.

5.4 Morphological Operators

There are 4 morphological operators listed below.

5.4.1 Dilation

Dilation is an operation that grows or thickens objects in a binary image. The specific manner and the extent of this thickening are controlled by structuring element.

Dilation is a process that translates the origin of the structuring element throughout the domain of the image and checks to see whether it overlaps with 1-valued pixels.

The output image is 1 at each location of the origin of the structuring element if the structuring element overlaps at least one 1-valued pixel in the input image.

Mathematically, dilation is defined in terms of set operations. The dilation of A by B, denoted by $A \oplus B$, is defined as

$$A \oplus B = \{z | \hat{B}_z \cap A \neq \Phi\}$$

where Φ is the empty set and B is the structuring element. In words, the dilation of A by B is the set consisting of all the structuring element origin locations where the reflected B overlaps at least some portion of A.

Dilation is commutative, i.e., $A \oplus B = B \oplus A$. It is a convention in image processing to let the first operand of $A \oplus B$ be the image and the second operand is the structuring element, which is usually much smaller than the image. It is typically applied to binary images, but there are versions that work on gray scale images. The basic effect of the operator on a binary image is to gradually enlarge the boundaries of regions of foreground pixels (i.e. white pixels, typically). Thus areas of foreground pixels grow in size while holes within those regions become smaller.

- **Working of dilation**

The dilation operator takes two pieces of data as inputs. The first is the image which is to be dilated. The second is a (usually small) set of coordinate points known as a structuring element (also known as a kernel). It is this structuring element that determines the precise effect of the dilation on the input image.

As an example of binary dilation, suppose that the structuring element is a 3×3 square, with the origin at its centre, as shown in matrix. In this matrix, foreground pixels are represented by 1's.

$$\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

Set of coordinate points-{(-1,-1) (0,-1) (1,-1) (-1,0) (0,0) (1,0) (-1,1) (0,1) (1,1)}.

To compute the dilation of a binary input image by this structuring element, the structuring element is superimposed on top of the input image for each foreground pixel so that the origin of the structuring element coincides with the input pixel position. If at least one pixel in the structuring element coincides with a foreground pixel in the image underneath, then the input pixel is set to the foreground value. If all the corresponding pixels in the image are background, however, the input pixel is left at the background value.

Most implementations of this operator expect the input image to be binary, usually with foreground pixels at pixel value 255, and background pixels at pixel value 0. Such an image can often be produced from a gray scale image using thresholding. The structuring element may have to be supplied as a small binary image, or in a special matrix format, or it may simply be hardwired into the implementation, and not require specifying at all.

The effect of a dilation using this structuring element on a binary image is shown in fig.5.3 below.

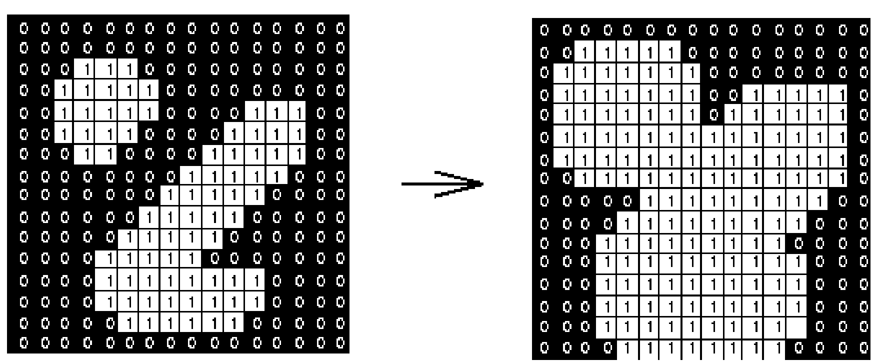


Figure 5.3 Process of dilation

The 3×3 square is probably the most common structuring element used in dilation operations, but others can be used. A larger structuring element produces a more extreme dilation effect, although usually very similar effects can be achieved by repeated dilations using a smaller but similarly shaped structuring element. With larger structuring elements, it is quite common to use an approximately disk shaped structuring element, as opposed to a square one. Gray scale dilation with a flat disk shaped structuring element will generally brighten the image. Bright regions surrounded by dark regions grow in size, and dark regions surrounded by bright regions shrink in size. Small dark spots in images will disappear as they are `filled in' to the surrounding intensity value. Small bright spots will become larger spots. The effect is most marked at places in the image where the intensity changes rapidly and regions of fairly uniform intensity will be largely unchanged except at their edges.

5.4.2 Erosion

Erosion is the morphological dual to dilation. Erosion shrinks or thins in a binary image. As in dilation, the manner and extent of shrinking is controlled by the structuring element. The output of erosion has a value 1 at each location of the origin of the structuring element, such that the structuring element overlaps only 1-valued pixels of the input image.

The mathematical definition of erosion is similar to that of dilation. The erosion of A by B, denoted by A Θ B, is defined as

$$A \ominus B = \{z | B_z \cap A^c \neq \Phi\}.$$

In other words, erosion of A by B is the set of structuring element origin locations where the translated B has no overlap with the background of A.

It is typically applied to binary images, but there are versions that work on gray scale images. The basic effect of the operator on a binary image is to erode away the boundaries of regions of foreground pixels (i.e. white pixels, typically). Thus areas of foreground pixels shrink in size, and holes within those areas become larger.

- **Working of erosion**

The erosion operator takes two pieces of data as inputs. The first is the image which is to be eroded. The second is a set of coordinate points known as a structuring element. It is this structuring element that determines the precise effect of the erosion on the input image.

As an example of binary erosion, suppose that the structuring element is a 3×3 square, with the origin at its center as shown below. 1’s represent foreground pixels here.

$$\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

Set of coordinate points-{(-1,-1) (0,-1) (1,-1) (-1,0) (0,0) (1,0) (-1,1) (0,1) (1,1)}.

To compute the erosion of a binary input image by this structuring element, the structuring element superimposed on top of the input image for each foreground pixel so that the origin of the structuring element coincides with the input pixel coordinates.

If for every pixel in the structuring element, the corresponding pixel in the image underneath is a foreground pixel, then the input pixel is left as it is. If any of the corresponding pixels in the image are background, however, the input pixel is also set to background value. Erosion is the dual of dilation, i.e. eroding foreground pixels is equivalent to dilating the background pixels.

Most implementations of this operator will expect the input image to be binary, usually with foreground pixels at intensity value 255, and background pixels at intensity value 0. Such an image can often be produced from a gray scale image using thresholding.

The effect of erosion using this type of structuring element on a binary image is shown in fig. 5.4 below.

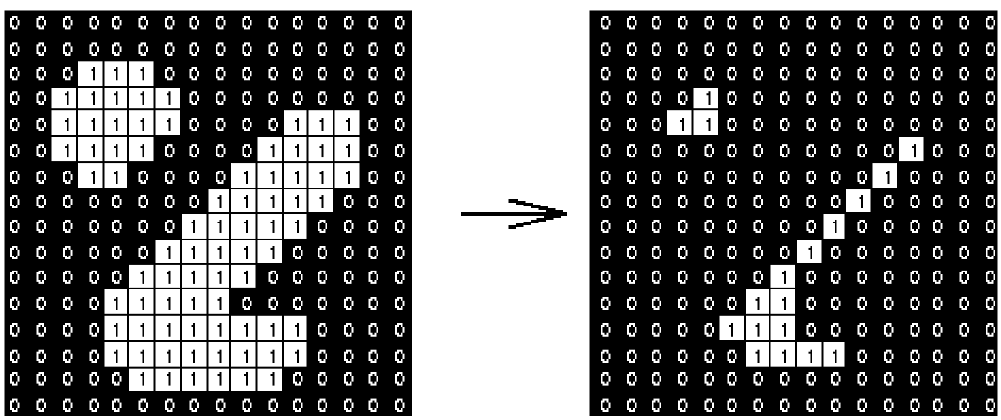


Figure 5.4 Process of erosion

The 3×3 square is probably the most common structuring element used in erosion operations, but others can be used. A larger structuring element produces a more extreme erosion effect, although usually very similar effects can be achieved by repeated erosions using a smaller similarly shaped structuring element. With larger structuring elements, it is quite common to use an approximately disk shaped structuring element, as opposed to a square one.

Erosions can be made directional by using less symmetrical structuring elements. For example, a structuring element that is 10 pixels wide and 1 pixel high will erode in a horizontal direction only. Similarly, a 3×3 square structuring element with the origin in the middle of the top row rather than the center will erode the bottom of a region more severely than the top.

Grayscale erosion with a flat disk shaped structuring element will generally darken the image. Bright regions surrounded by dark regions shrink in size, and dark regions surrounded by bright regions grow in size. Small bright spots in images will disappear as they are eroded away down to the surrounding intensity value, and small dark spots will become larger spots. The effect is most marked at places in the image where the intensity changes rapidly, and regions of fairly uniform intensity will be left more or less unchanged except at their edges.

5.4.3 Opening

The morphological opening of A by B, denoted by A o B, is simply erosion of A by B followed by the dilation of the result by B.

$$A \circ B = (A \ominus B) \oplus B.$$

An alternative mathematical formulation of opening is

$$A \circ B = \cup \{(Bz) | (Bz) \text{ is a subset of } A\}.$$

Where $\cup\{.\}$ denotes the union of all sets inside braces, and the notation ($C \subseteq D$) means that C is a subset of D. This formulation has a simple geometric interpretation:

A o B is the union of all translations of B that fit entirely within A.

Morphological opening removes completely regions of an object that cannot contain the structuring element, smoothes the object contours, breaks thin connections, and removes the protrusions.

Opening and closing are two important operators from mathematical morphology. They are both derived from the fundamental operations of erosion and dilation. Like those operators they are normally applied to binary images, although there are also gray level versions. The basic effect of an opening is somewhat like erosion in that it tends to remove some of the foreground (bright) pixels from the edges of regions of foreground pixels. However it is less destructive than erosion in general. As with other morphological operators, the exact operation is determined by a structuring element. The effect of the operator is to preserve foreground regions that have a similar shape to this structuring element, or that can completely contain the structuring element, while eliminating all other regions of foreground pixels.

- **Working of opening**

An opening is defined as erosion followed by a dilation using the same structuring element for both operations. The opening operator requires two inputs: an image to be opened, and a structuring element.

Opening is the dual of closing, i.e. opening the foreground pixels with a particular structuring element is equivalent to closing the background pixels with the same element.

While erosion can be used to eliminate small clumps of undesirable foreground pixels, quite effectively, it has the big disadvantage that it will affect all regions of foreground pixels indiscriminately. Opening gets around this by performing both erosion and a dilation on the image. The effect of opening can be quite easily visualized. Imagine taking the structuring element and sliding it around inside each foreground region, without changing its orientation. All pixels which can be covered by the structuring element with the structuring element being entirely within the foreground region will be preserved. However, all foreground pixels which cannot be reached by the structuring element without parts of it moving out of the foreground region will be eroded away. After the opening has been carried out, the new boundaries of foreground regions will all be such that the structuring element fits inside them, and so further openings with the same element have no effect. The property is known as idempotence. The effect of an opening on a binary image using a 3×3 square structuring element is illustrated in Fig5.5 below.

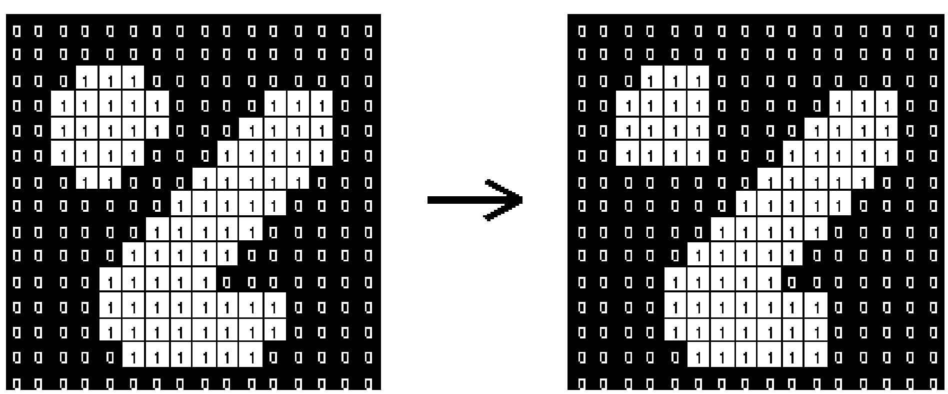


Figure 5.5Process of opening

As with erosion and dilation, it is very common to use this 3×3 structuring element. The effect in the above figure is rather subtle since the structuring element is quite compact and so it fits into the foreground boundaries quite well even before the opening operation. To increase the effect, multiple erosions are often performed with this element followed by the same number of dilations. This effectively performs an opening with a larger square structuring element.

5.4.4 Closing

The morphological closing of A by B, denoted by $A \bullet B$, is a dilation followed by erosion:

$$A \bullet B = (A \oplus B) \ominus B.$$

Geometrically, $A \bullet B$ is the complement of the union of all translations of B they do not overlap A.

Like opening, morphological closing smoothes the contours of the objects. Unlike opening, however, it generally joins narrow breaks, filling long thin gulfs, and fills holes smaller than the structuring element.

Closing is an important operator in the field of mathematical morphology. Like its dual operator opening, it can be derived from the fundamental operations of erosion and dilation. Like those operators it is normally applied to binary images, although there are gray level versions. Closing is similar in some ways to dilation in that it tends to enlarge the boundaries of foreground (bright) regions in an image (and shrink background color holes in such regions), but it is less destructive of the original boundary shape. As with other morphological operators, the exact operation is determined by a structuring element. The effect of the operator is to preserve background regions that have a similar shape to this structuring element, or that can completely contain the structuring element, while eliminating all other regions of background pixels.

- **Working of closing**

Closing is opening performed in reverse. It is defined simply as dilation followed by erosion using the same structuring element for both operations. The closing operator requires two inputs: an image to be closed and a structuring element.

Gray level closing consists straightforwardly of a gray level dilation followed by gray level erosion.

Closing is the dual of opening, i.e. closing the foreground pixels with a particular structuring element, is equivalent to closing the background with the same element.

One of the uses of dilation is to fill in small background color holes in images. One of the problems with doing this, however, is that the dilation will also distort all regions of pixels indiscriminately. By performing erosion on the image after the dilation, i.e. a closing, some of this effect is reduced.

The effect of closing can be quite easily visualized. Imagine taking the structuring element and sliding it around outside each foreground region, without changing its orientation. For any background boundary point, if the structuring element can be made to touch that point, without any part of the element being inside a foreground region, then that point remains background. If this is not possible, then the pixel is set to foreground. After the closing has been carried out the background region will be such that the structuring element can be made to cover any point in the background without any part of it also covering foreground point, and so further closings will have no effect. This property is known as idempotence. The effect of a closing on a binary image using a 3×3 square structuring element is illustrated in Fig5.6.

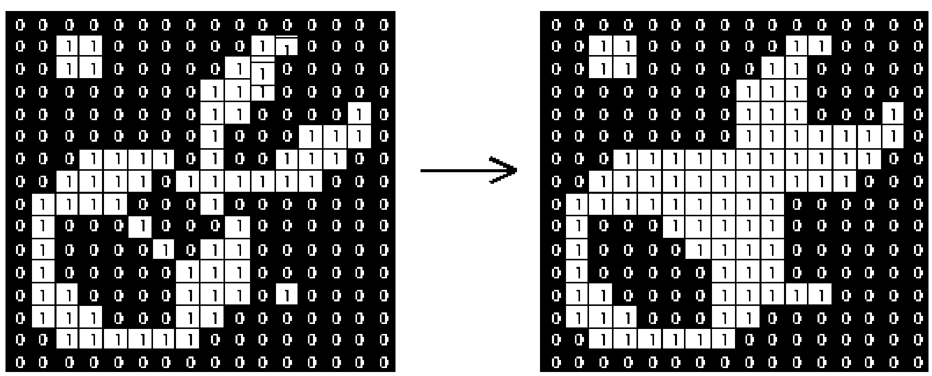


Figure 5.6 Process of closing

As with erosion and dilation, this particular 3×3 structuring element is the most commonly used, and in fact many implementations will have it hardwired into their code, in which case it is obviously not necessary to specify a separate structuring element. To achieve the effect of a closing with a larger structuring element, it is possible to perform multiple dilations followed by the same number of erosions. Closing can sometimes be used to selectively fill in particular background regions of n image. Whether or not this can be done depends upon whether a suitable structuring element can be found that fits well inside regions that are to be preserved, but doesn't fit inside regions that are to be removed.

5.5 Gray scale Morphology

Grayscale morphology is a multidimensional generalization of the binary operations. Binary morphology is defined in terms of set-inclusion of pixel sets. So is the grayscale case, but the pixel sets are of higher dimension. In particular, standard R×C, 1-band intensity images and the associated structuring elements are defined as 3-D solids wherein the 3rd axis is intensity and set-inclusion is volumetric.

5.5.1 Morphological operations on gray scale images

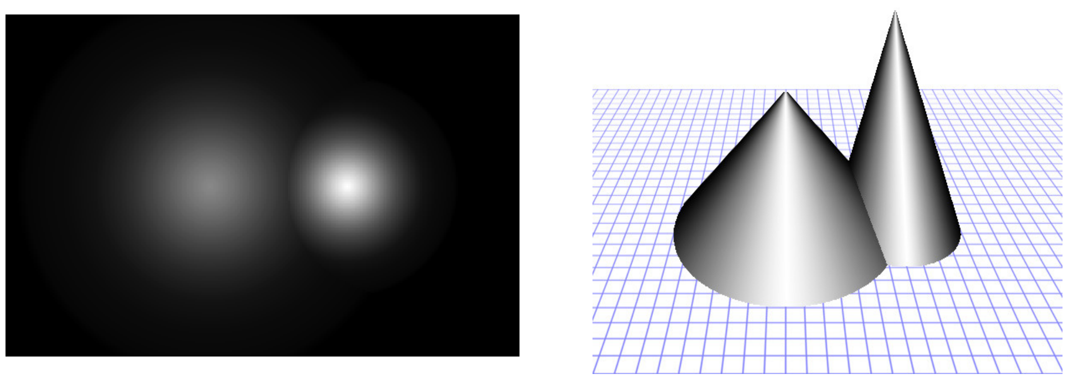


Figure 5.7 Gray scale image and its surface

Grayscale dilation is defined by the following function

$$[I \oplus Z](\vec{p}) = \max_{\vec{q}\in \mathrm{supp}(\breve{Z}+\vec{p})} \left\{ I(\vec{q}) - \breve{Z}(\vec{q}-\vec{p}) \right\} = \max_{\vec{q}\in \mathrm{supp}(\breve{Z}+\vec{p})} \left\{ I(\vec{q}) - Z(\vec{p}-\vec{q}) \right\}$$

This equation implements a process similar to the concept of spatial convolution.
The dilated image is computed by rotating the structuring element about its origin and translating it to all locations in the image, just as the convolution kernel is rotated and then translated about the image. At each translates location, the rotated structuring element values are added to the image pixel values and the maximum is computed

Grayscale erosion is defined by the following function

$$D = \{ I(\vec{q}) - \breve{Z}(\vec{q}) \} \mid \vec{q} \in \mathrm{supp}\{\breve{Z}\} \} = \{ I(\vec{q}) + z(-\vec{q}) \} \mid \vec{q} \in \mathrm{supp}\{\breve{Z}\}$$

As in dilation where we use maximum value at each translated location after addition, in erosion, the structuring element values are subtracted from the image pixel values and the minimum is taken.

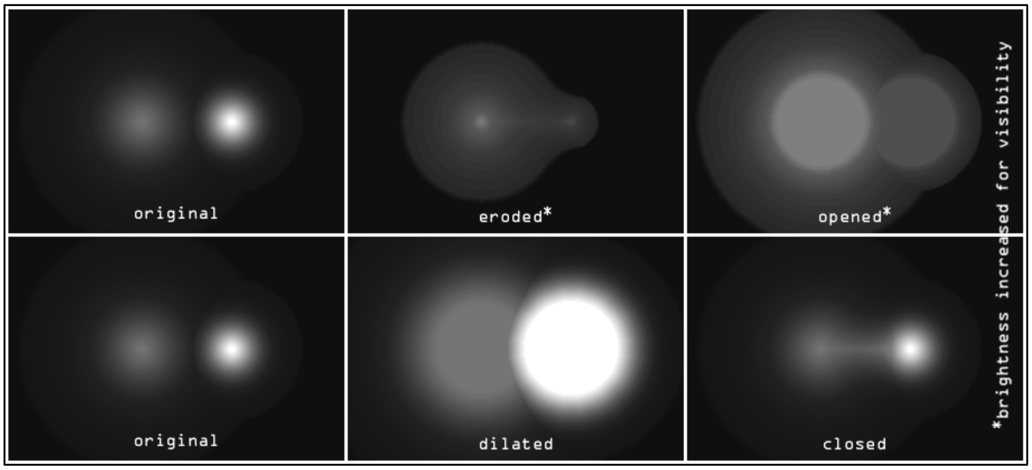


Fig 5.8 Different morphological operations on grayscale images with the structuring element

5.6 Morphological Reconstruction

Reconstruction is a morphological transformation involving two images and a structuring element (instead of single image and structuring element). One image, the marker, is the starting point of the transformation. The other image the mask, constrains the transformation. The structuring element used defines connectivity. 4- connected, 8- connected, hexagonal connectivity etc. are the common examples.

For example 8- connectivity implies that the structuring element is a 3 X 3 matrix of 1s, with its center defined at co-ordinates (2, 2).

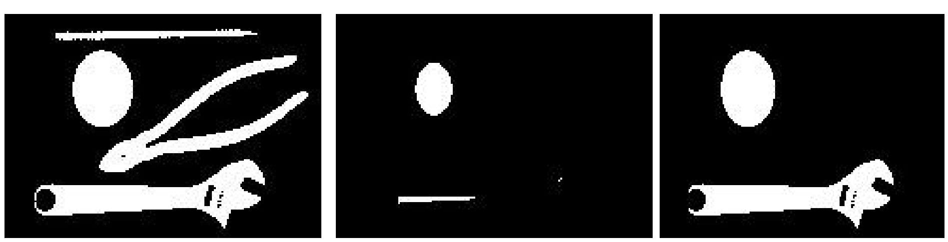


Figure 5.9 Process of Reconstruction with the help of mask and a marker image

Although it can easily be defined in itself, it is often presented as part as a set of operators known as geodesic ones.

Reconstruction can be defined for grayscale images as well. In this framework, it turns out to be particularly interesting for several filtering, segmentation and feature extraction.

Morphological reconstruction can be thought of conceptually as repeated dilations of an image, called the marker image, until the contour of the marker image fits under a second image, called the mask image. In morphological reconstruction, the peaks in the marker image "spread out," or dilate.

The figure 5.10 illustrates this processing in 1-D. Successive dilation is constrained to lie underneath the mask. When further dilation ceases to change the image, processing stops. The final dilation is the reconstructed image. (Note: the actual implementation of this operation in the toolbox is done much more efficiently. The figure shows the successive dilations of the marker.

Repeated Dilations of Marker Image, Constrained by Mask

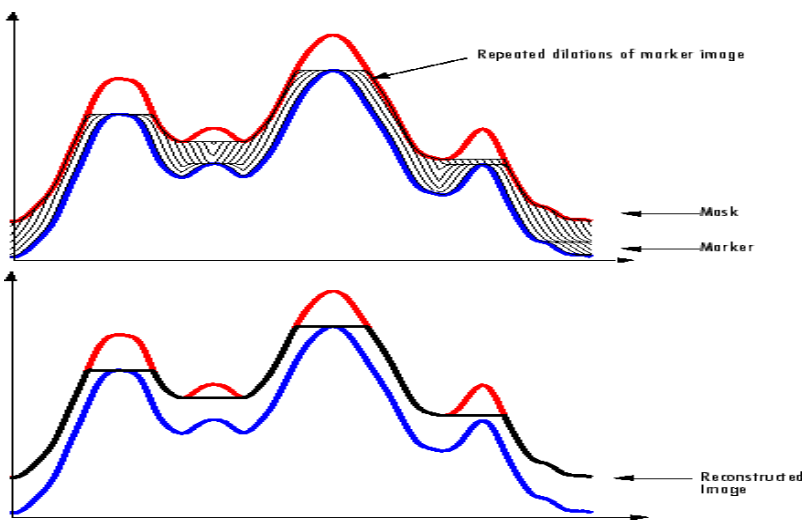


Figure 5.10 Reconstruction process in 1-D
(Image courtesy of Mathworks.com)

Morphological reconstruction is based on morphological dilation, has the following unique properties:

- Processing is based on two images, a marker and a mask, rather than one image and a structuring element.
- Processing is based on the concept of connectivity, rather than a structuring element.
- Processing repeats until stability; i.e., the image no longer changes.

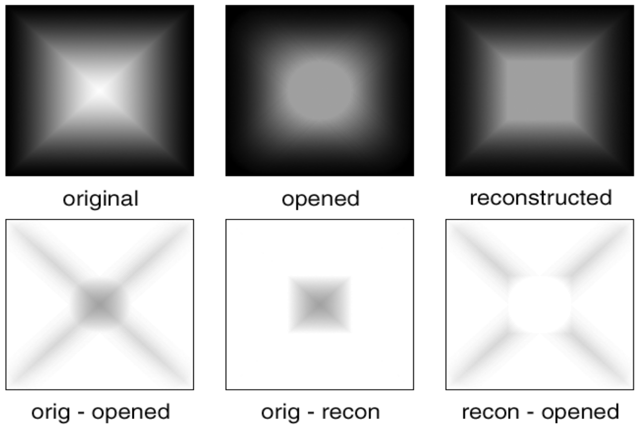


Figure 5.11 Reconstruction processes on Gray scale Images

5.7 Applications of Mathematical Morphology

Mathematical morphology is used in various applications. Some applications of morphology are described as following.

- image enhancement
- image segmentation
- image restoration
- edge detection
- texture analysis
- particle analysis
- feature generation
- skeletonization
- shape analysis
- image compression
- component analysis
- curve filling
- general thinning
- feature detection
- noise reduction
- space-time filtering

CHAPTER 6 METHODOLOGY

6.1 Problem Definition

Traffic problems are significant in a developing or developed country. Massive integration of information technologies into all aspects of modern life caused demand for processing vehicles as conceptual resources in information systems. Because a standalone information system without any data has no sense, there is also a need to transform information about vehicles between the reality and information systems. This can be achieved by a human agent, or by special intelligent equipment which is able to recognize vehicles by their number plates in a real environment and reflect it into conceptual resources. Because of this, various recognition techniques have been developed and number plate recognition systems are today used in various traffic and security applications, such as parking, access and border control, or tracking of stolen cars.

The problems associated with application of these systems in Indian conditions have been discussed in Chapter 1 section 1.1. As the number of vehicles entering the Indian highways is increasing many folds, the problem becomes more and more complex. This chapter takes us through the steps involved in the proposed algorithm.

6.2 Methodology

Generally the text written on the number plates has high contrast as compared to the background and based on this property of text, a localization technique has been proposed.

The work is divided into four parts:-

- Binarization
- Filtering Candidate Regions
- Verification of the Localizes candidate
- Number extraction and verification

This work aims on gray intensity based license plate extraction and hence begins with color to gray conversion. The flowchart shown in figure 6.1 below indicates the workflow of the proposed method.

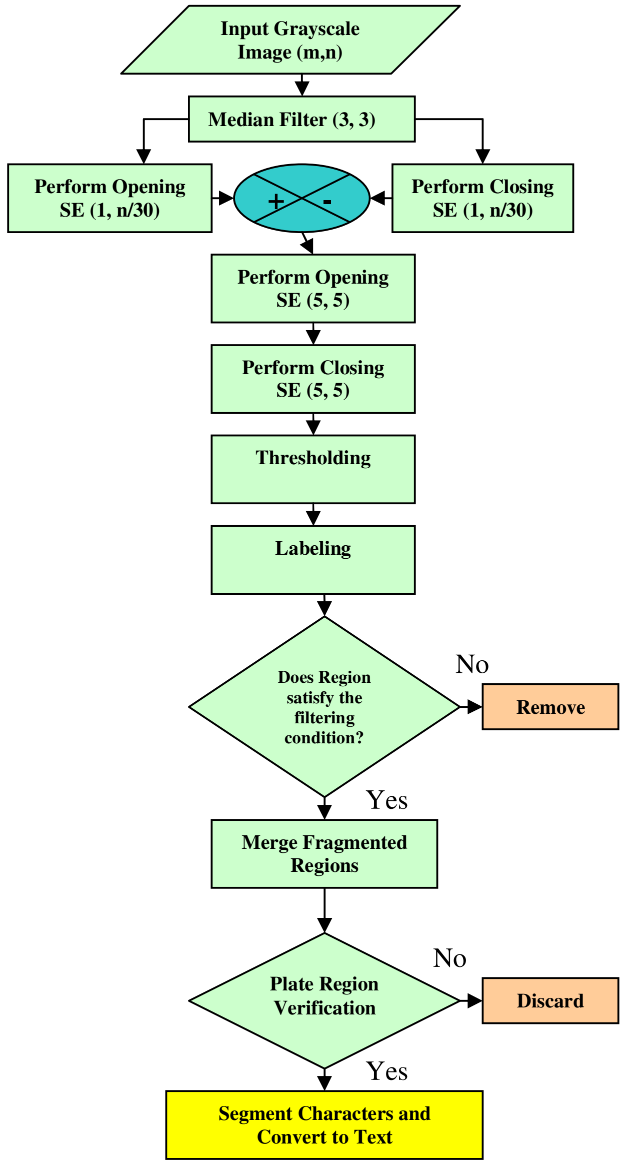


Figure 6.1 Flowchart of the Proposed Algorithm

6.2.1 Binarization

The first part of the algorithm deals with the conversion of the input grayscale image into a binary image.

- **Increase contrast: -** During image acquisition, the lighting conditions may vary and hence the image taken may not be suitable for direct implementation. Hence the first processing step is increasing the contrast of the input grayscale image.
- **Application of morphological operations: -** The image is then filtered using median filter to create a blurred image (to prevent over segmentation) [5] and the

difference image[17] is obtained by subtraction of opened grayscale image from a closed grayscale image using equations 1 and 2 below.

$$F \circ B = (F \ominus B) \oplus B \quad (1)$$

$$F \bullet B = (F \oplus B) \ominus B \quad (2)$$

The difference image is then closed and opened using 5*5 size structuring element.

- **Thresholding: -** The resulting image is then binarized using global threshold value [1]. The threshold is computed using *graythresh()* function which uses Otsu's method. This completes the Binarization process.

6.2.2 Candidate Region Filtering

Since a number plate can be assumed to have larger lengths as compared to their width and also they are mostly horizontally aligned as compared to other regions a region based filtration technique can be applied to remove non-candidate regions.

- **Labeling: -** Connected component analysis requires labeling of the binarized image. Labeling of the binarized image is done using function *bwlabel()*.
- **Filtration:** - Since all the binarized regions cannot be considered as the license plate regions, some heuristics must be applied to filter out the unwanted regions. The filtration constraints used in the method are stated below.
  - Area(R)> Total Image area/400 [25]
  - Aspect Ratio(R) > 2
  - den(R)>0.1

  Aspect Ratio=width/height; den(R) =Area of R/ (w(R) * h(R));

  R defines the region of interest; w(R) and h(R) are the bounding box width and height respectively;
- **Candidate merging: -** It is possible that the number plate regions thus extracted can be fragmented in parts and hence these parts should be merged in order to correctly localize the plate. The basis for merging fragments is that if the number plate is recognized but in fragments then both the fragments should have similar heights and orientations just like fragmented text lines [17]**.** The merging of the ith and jth regions is based on the following equations.

$$d\theta(R_i, R_j) = min(|\theta_{Ri} - \theta_{Rj}|, |\theta_{Ri} - \theta_{Rj} + 360^\circ|, |\theta_{Ri} - \theta_{Rj} - 360^\circ|) < 10^\circ \quad (3)$$

$|Cen_{Ri} - Cen_{Rj}| < 2(h_{Ri}^{R\theta I} + h_{Rj}^{R\theta j})$ (4)

Let *LR* be the longest axis of *R* denoted by this equation:

$y = m_R x + b_R$

Then, the distance between the major axes *LRi* and *LRj* of *Ri* and *Rj* can be defined as follows

$dL(Ri, Rj) = |yCen_{Rj} - m_{Ri}\, xCen_{Rj} - bRi|/2*sqrt(1 + m^2_{Ri})$

$-|yCenRi - mRj\, xCen_{Ri} - b_{Rj}|/2*sqrt(1 + m^2_{Rj})$ (5)

Such that dL<5;

Since the font size in a number plate is quite large, the value of dL may have to be increased.

6.2.3 Verification of localized candidate

Even after filtration, if false number plate location is present, it is discarded by using character count. The number of characters in finalized number plate areas is calculated. If number of characters is less than four, then it is discarded. After applying these steps on an input image, all other unwanted data except number plate is removed. Number plate co-ordinates are applied on an input gray-scale image and number plate is extracted. Extracted number plate is binarized using Otsu's method [1] to enhance its quality.

6.2.4 Number extraction and verification

After the number plate has been extracted, the extracted sub-image is then passed through character recognition module.

- **Skew correction: -** Since the license plate region may be inclined at some angle, it needs to be corrected for increasing the accuracy of character extraction. This was done by rotating the extracted binary image by an angle equal to orientation angle of the region but in opposite direction [13].
- **Character filtering**: - The unwanted areas such as the regions belonging to plate fixing bolts and boundary areas pose a problem for accuracy of the system and hence must be removed. The remaining significant characters are then segmented from the binarized image [12].
- **Character Recognition**: - For the purpose of recognition of segmented characters, they are passed through template matching process [9]-[19]-[23].

Each segment is matched with a pre-loaded collection of templates (Arial Black and Times New Roman fonts have been used) and the segment having highest correlation coefficient is considered to be the best match. The process continues until all the segments have been identified.

- **Verification**: - Since the accuracy of template matching is highly dependent on the contrast and illumination conditions, some similar characters can be misinterpreted. The characters such as 'B' '0' '1' 'G' can be misinterpreted as '8' 'O' 'I' 'C or 6' having similar characters which leads to lowering of Recognition efficiency[2]. The number thus extracted can stored in an array and can be verified on the basis of rules [24] followed in India (figure 1.1). In the case of Indian number plates, the length can be 8, 9 or 10. rules corresponding to the number plate lengths are as follows
    - If the number of segmented characters counts to 7, the number plate follows 1939 series having first three characters as alphabets and rest as numbers.
    - If the number of character counts to 8, the first two characters should be alphabets and rest should be numbers.
    - If the number of character counts to 9, the first, second and fifth characters should be alphabets and rest should be numbers.
    - If the number of segments counts to 10, the first, second, fifth and sixth characters will be alphabets and rest will be numbers.
    - Exceptions- The foreign vehicle number plates contain third and fourth characters as alphabets and rest as numbers. Also for the case of Delhi not following 1939 series the fourth character is an alphabet containing information about the type of vehicle.
- **Displaying the output: -** At last when all the characters are verified, the number stored in an array is displayed.
- **Quantitative Analysis:**- The analysis of the system is based on the localization and character recognition accuracy. Accuracy of the recognized plate is calculated by finding the ratio of the characters recognized (correct) to total characters.

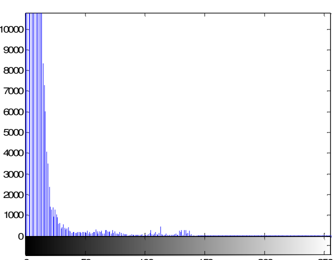
CHAPTER 7	EXPERIMENTS AND RESULTS

7.1 Results

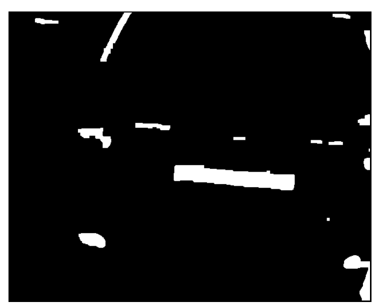
The tests were made on images taken with the help of a digital camera. This chapter takes us through the results of the steps involved in the proposed method. The results reveal that method is efficient in localization as well as recognition of license plates in Indian conditions. The following images show step by step results of the proposed method.

(a)

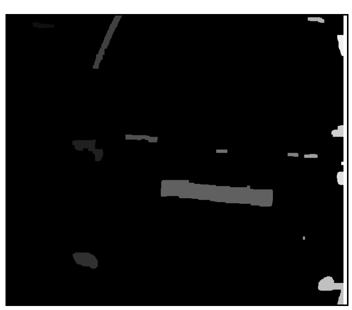
(b)



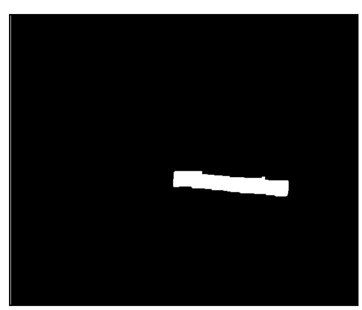
(c)



(d)



(e)



(f)

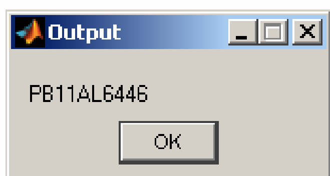
(g)

(h)

(i)

(j)

(k)



(l)

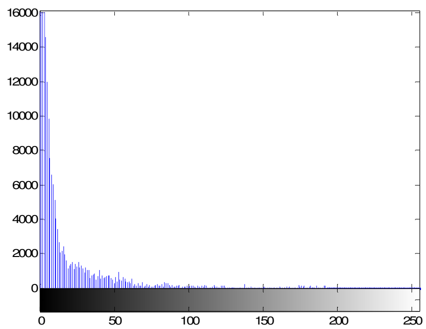
Figure 7.1 (a) to (l) Results of test image 1

The step by step results of the proposed method have been shown in the fig.7.1 (a) to (k).

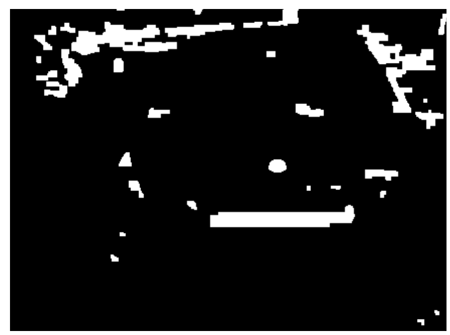
The fig. 7.1 (b) is the results of morphological operations (opening and closing) on the input grayscale image fig. 7.1(a) followed by differencing. The fig. 7.1(d) shows that after binarization of the difference image, some unwanted regions along with the number plate regions also appear and they must be removed [26]. So after labeling this binary image as shown in fig. 7.1 (e), some heuristics as discussed in chapter 6 have been applied to it. From fig. 7.1 (f), it is clearly visible that the unwanted regions have been eliminated, except the required license plate region. This region has been highlighted on the input image in fig. 7.1 (g) and then extracted from the original input image as shown in fig. 7.1 (h). From fig 7.1(h) it is visible that the extracted number plate region is not aligned to the horizontal. Tilt has a bad effect on character segmentation and recognition of VLP and hence it must be aligned for achieving better accuracy of character recognition system. The extracted number plate is horizontally aligned by calculating the orientation angle of the number plate region in fig. 7.1 (f). The effective segmentation of characters requires that all the unwanted area on the boundary along with the fixing bolt regions should be eliminated. Fig7.1 (j) shows the cleaned image. Finally the segmented characters and the final output message box are shown in fig 7.1 (k) and fig 7.1 (l).

(a)

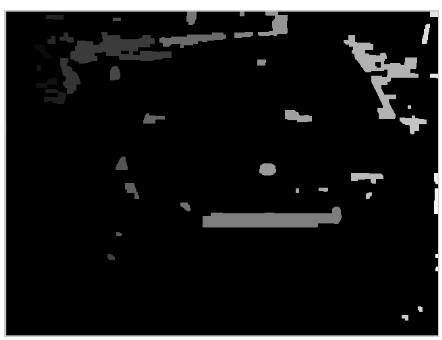
(b)



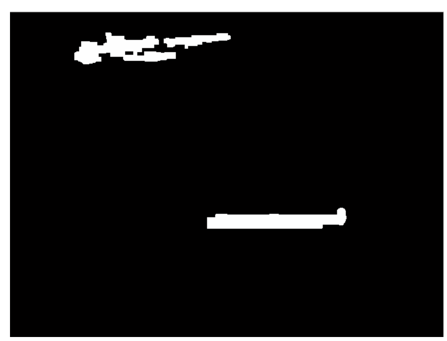
(c)



(d)



(e)



(f)

It is evident from the fig 7.2 (a) that the background is very complex and the binarization of difference image verifies this. Even in the fig 7.2(f) some unwanted regions are present but the region satisfying the heuristics for license plate clears the process resulting in successful extraction of LP region.

(g)

(h)

(i)

(j)

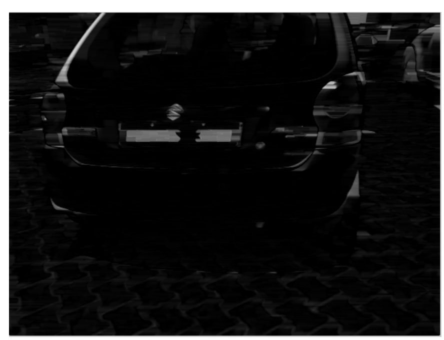
(k)

(l)

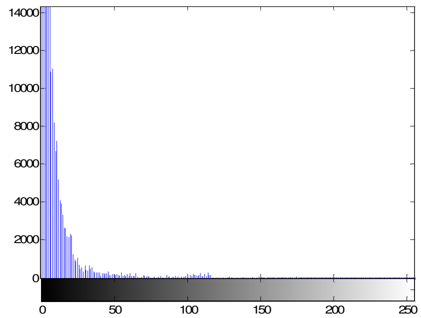
Figure 7.2 (a) to (l) Results of test image 2

The output of test image 2 reveals that proposed method is efficient in detecting license plate from complex background and is robust to change in the font type, however the font type is still simple and not much stylized that could pose a problem to accuracy.

(a)

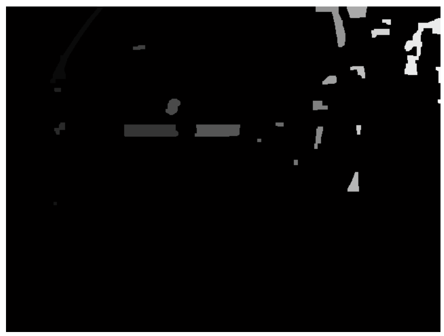


(b)

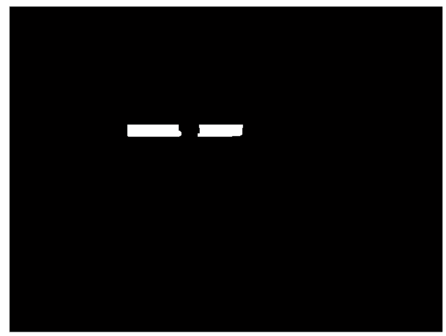

14000
12000
10000
8000
6000
4000
2000
0
0
50
100
150
200
250

(c)

(d)



(e)



(f)

(g)

(g)


PB 11AS 3761

(h)


PB 11AS 3761

(i)


PB 11AS 3761

(i)

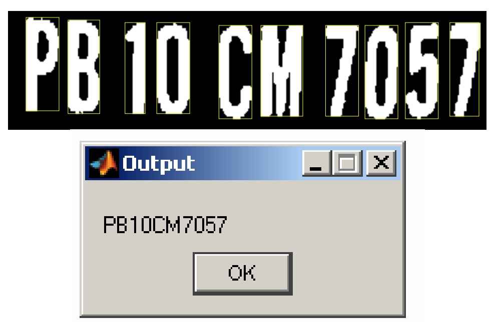

PB 11AS 3761

(k)

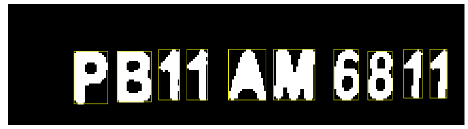
(l)
Figure 7.3 (a) to (l) Results of test image 3

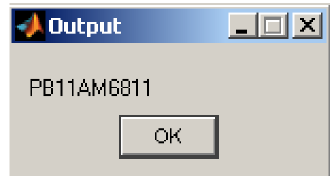
The fig 7.3 (b) shows the difference image produced by morphological operations. The morphological operations followed by binarization produced potential LP regions prior to region filtration process. Fig. 7.3 (d) and 7.3 (f) reveal that the license plate is detected in fragments and shows the effect of merging function. The merging of fragmented license plates extracts complete license plate regions and improves the accuracy of the method in this case. The final output is shown in fig 7.3(l).

The proposed method has been tested on 100 images taken from nearby places. The data set comprise of the images of vehicles from different states, front as well as rear view images of vehicles and special numbers. Out of 100 images, input and output of 40 images has been shown below in fig 7.4, the intermediate steps being the same as of fig 7.1, 7.2 and 7.3.

Input Image	**Extracted Number/License Plate and Output displayed**
	
	

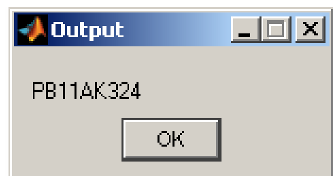

PB11 AM 6811


PB11 AM 6811


Output
PB11AM6811
OK


PB11AK 324


PB11AK 324

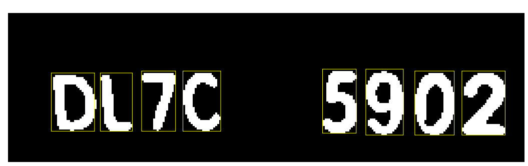

Output
PB11AK324
OK


PB 29 J 8606


PB 29 J 8606

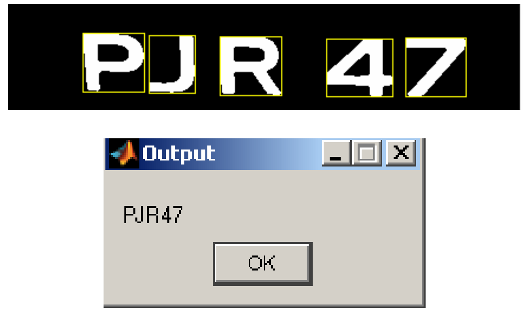

Output
PB29J8606
OK


DL7C 5902

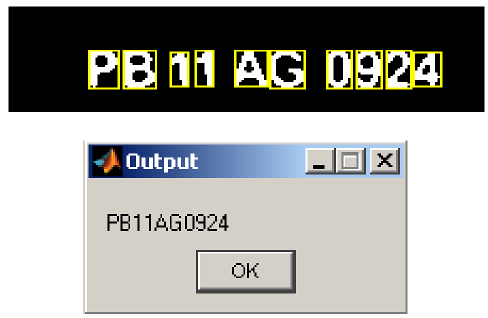

DL7C 5902


Output
DL7C5902
OK


PJR 47


PJR 47
Output
PJR47
OK

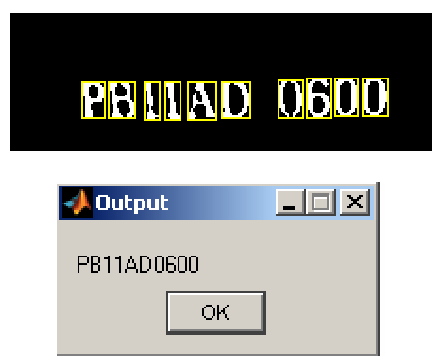

PB 11 AG 0924

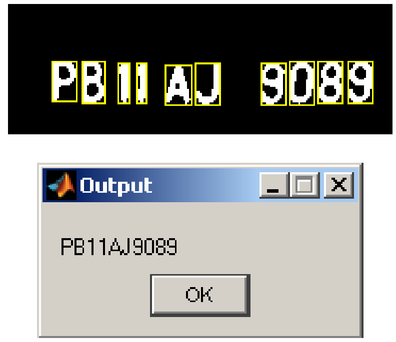
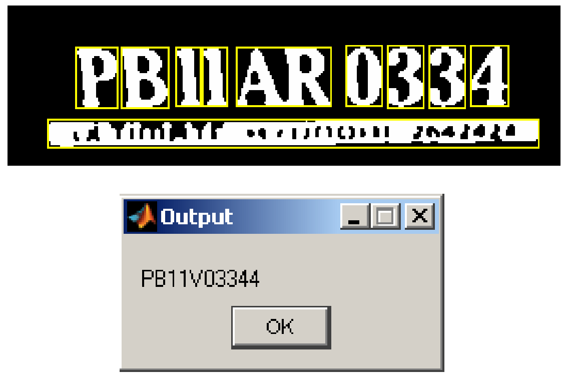
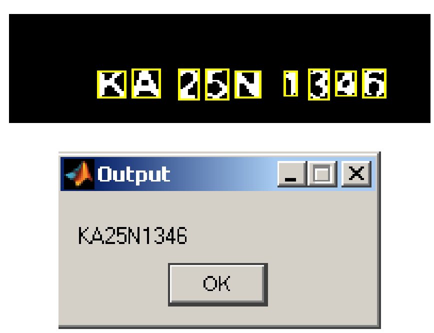

PB 11 AG 0924
Output
PB11AG0924
OK


HR09L 2071

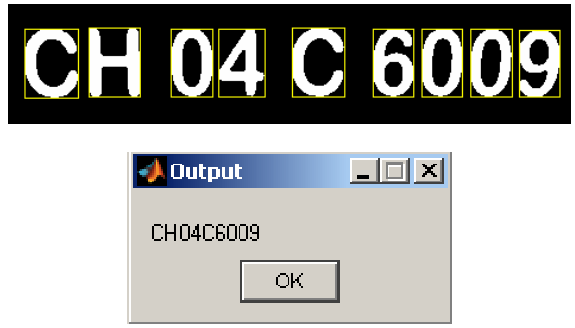

HR09L 2071
Output
HR09L2071
OK


PB11AD 0600

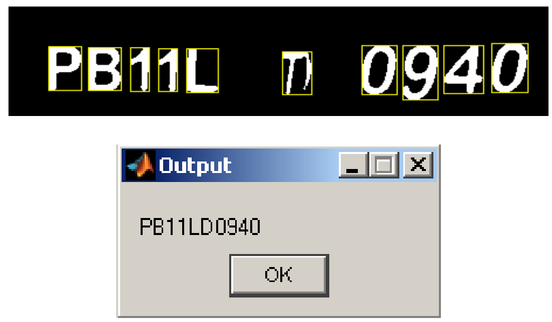

PB11AD 0600
Output
PB11AD0600
OK

	
	 Partially Successful Result
	 Partially Successful Result
	

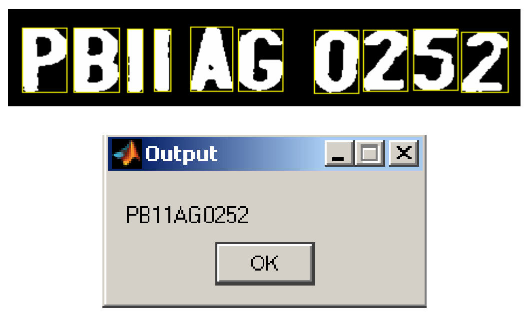

CH 04 C 6009


CH 04 C 6009
Output
CH04C6009
OK

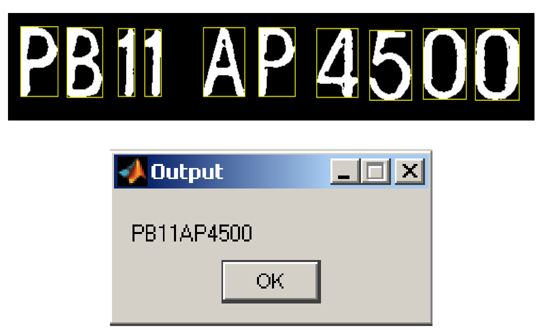

PB11L 0940


PB11L 0940
Output
PB11LD0940
OK


PBII AG 0252


PBII AG 0252
Output
PB11AG0252
OK


PB11 AP 4500


PB11 AP 4500
Output
PB11AP4500
OK

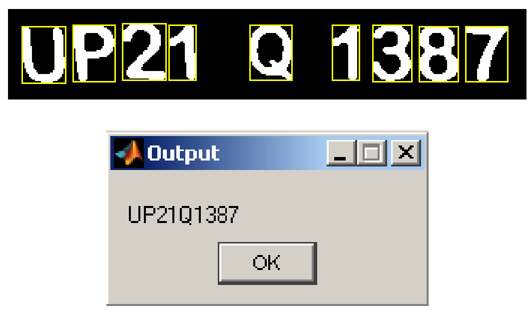

UK08M0075


UK08 M 0075
Output
UK08M0075
OK


UK08N7329


UK08N7329
Output
UK08N7329
OK

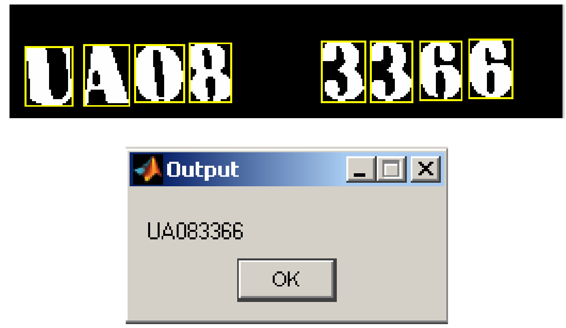

UP21 Q 1387


UP21 Q 1387
Output
UP21Q1387
OK

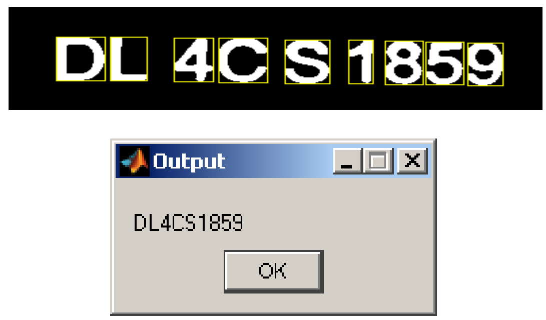

UK08M0075


UK08 M 0075
Output
UK08M0075
OK

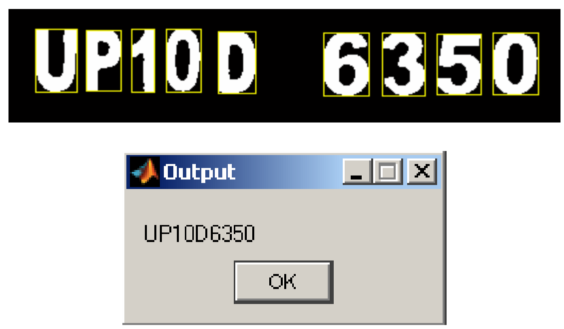

UA08 3366


UA08 3366
Output
UA083366
OK

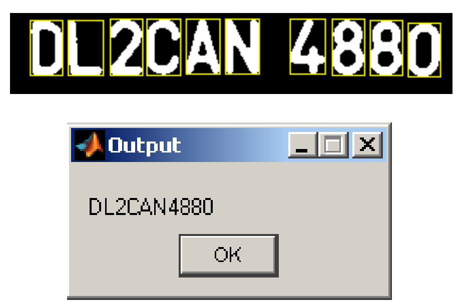

DL 4C S 1859


DL 4C S 1859
Output
DL4CS1859
OK

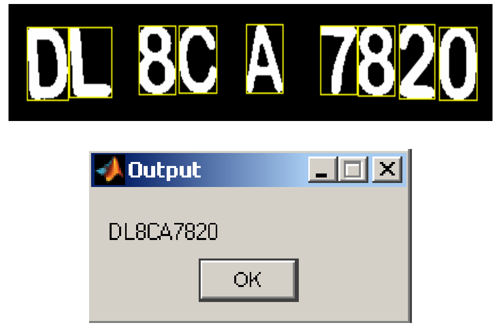

UP10D 6350

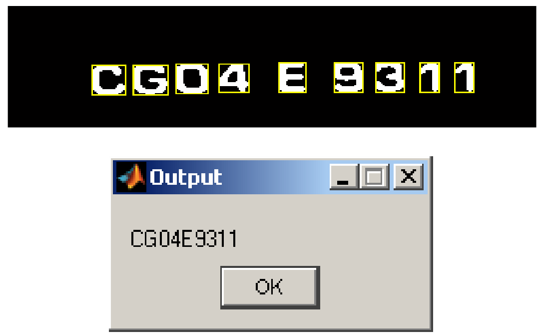

UP10 D 6350
Output
UP10D6350
OK


DL2CAN 4880

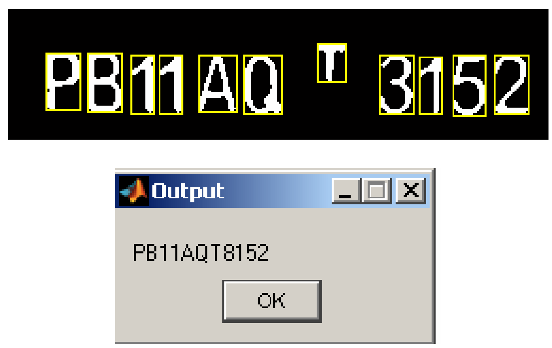

DL2CAN 4880
Output
DL2CAN4880
OK

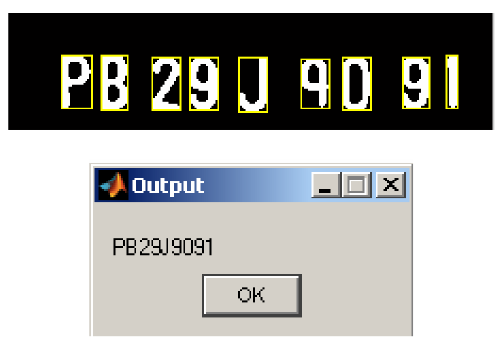

DL 8C·A·7820

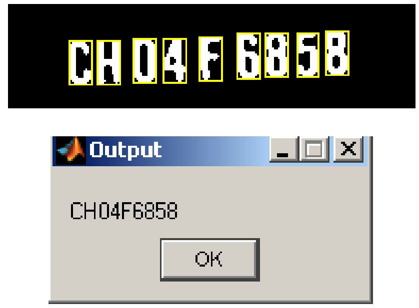

DL 8C A 7820
Output
DL8CA7820
OK

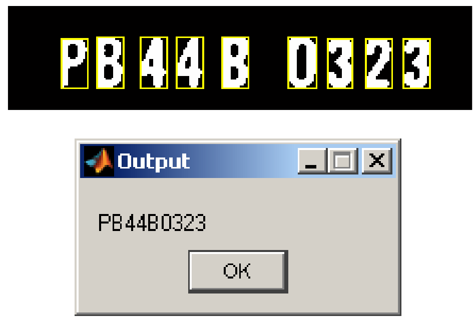

CG04 E 9311
Output
CG04E9311
OK

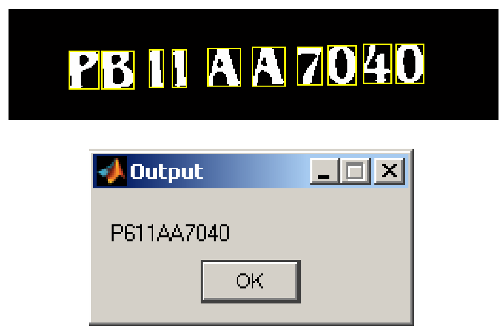

PB11AQ T 3152


PB11AQ T 3152
Output
PB11AQT8152
OK

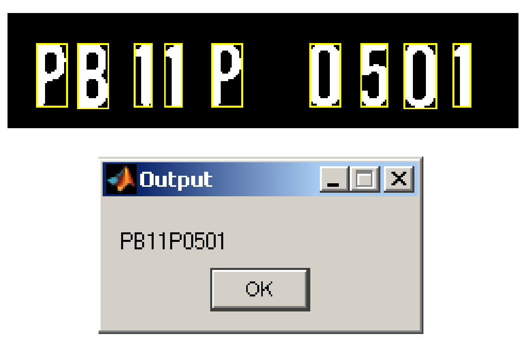

PB 29 J 90 91
Output
PB29J9091
OK







Partially Successful Result



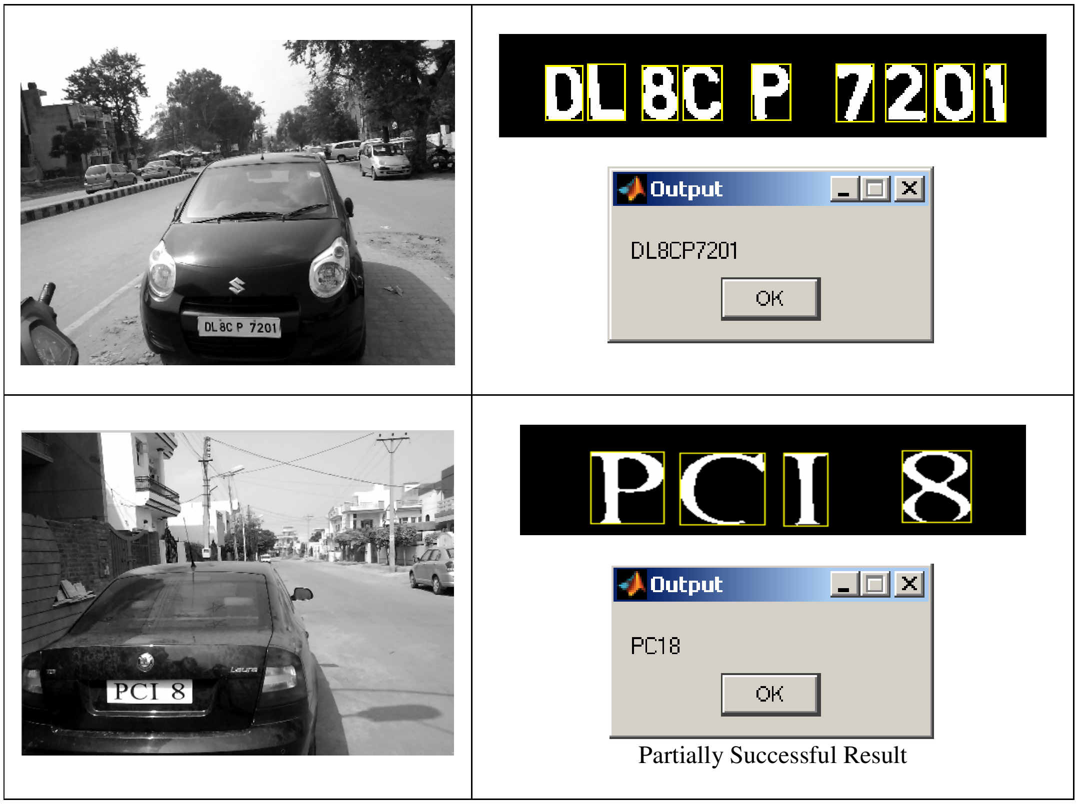


Figure 7.4 Results of the proposed method (40 out of 100 images)

Recognition Accuracy (%) =100*(1-E/T)

E=total error in character recognition; T=total number of characters in the number plate;

TABLE 7.1 Assessment of results

Results						
Number plate image	Localization status	Segmented characters	Character recognition results	Character Recognition accuracy		
				Error in alphabet	Error in number	Accuracy (1-E/T)*100
PB11AL6446	SUCCESS	PB11AL6446	PB11-AL-6446	NIL	NIL	100%
PB10CM7057	SUCCESS	PB10CM7057	PB10-CM-7057	NIL	NIL	100%
PB11AM6811	SUCCESS	PB11AM6811	PB11-AM-6811	NIL	NIL	100%
DL7C5902	SUCCESS	DL7C5902	DL7C-5902	NIL	NIL	100%
HR03E9707	SUCCESS	HR03E9707	HR03-E-9707	NIL	NIL	100%
CH04C6009	SUCCESS	CH04C6009	CH04-C-6009	NIL	NIL	100%
PB11AK3244	SUCCESS	PB11AK324	PB11-AK-324	NIL	1	((9/10)*100 = 90%
PB11AS3761	SUCCESS	PB11AS3761	PB11-AS-3761	NIL	NIL	100%
HR09L2071	SUCCESS	HR09L2071	HR09-L-2071	NIL	NIL	100%
PB11R0566	SUCCESS	PB11R0566	PB11-R-0566	NIL	NIL	100%
PB29J8606	SUCCESS	PB29J8606	PB29-J-8606	NIL	NIL	100%
PJR47	SUCCESS	PJR47	PJR-47	NIL	NIL	100%

PB11AG0924	SUCCESS	PB11AG0924	PB-11-AG-0924	NIL	NIL	100%
HR09L2071	SUCCESS	HR09L2701	HR09-L-2701	NIL	NIL	100%
PB11AD0600	SUCCESS	PB11AD0600	PB11-AD-0600	NIL	NIL	100%
PB11AJ9089	SUCCESS	PB11AJ9089	PB11-AJ-9089	NIL	NIL	100%
PB11AR0334	SUCCESS	PB11AR0344	PB11-V-03344	1	1	((8/10)*100 = 80%
DL2FDR0064	SUCCESS	L2FDR006	L2F-DR-006	1	1	((8/10)*100 = 80%
KA25N1346	SUCCESS	KA25N1346	KA25-N-1346	NIL	NIL	100%
PB11L(T)0940	SUCCESS	PB11LT)0940	PB11-L-D-0940	1	0	((10/12)*100 = 83.3%
PB11AG0252	SUCCESS	PB11AG0252	PB11-AG-0252	NIL	NIL	100%
PB11AP4500	SUCCESS	PB11AP4500	PB11-AP-4500	NIL	NIL	100%
UK08M0075	SUCCESS	UK08M0075	UK08-M-0075	NIL	NIL	100%
UK08N7329	SUCCESS	UK08N7329	UK08-N-7329	NIL	NIL	100%
UP21Q1387	SUCCESS	UP21Q1387	UP21-Q-1387	NIL	NIL	100%
UK08M0075	SUCCESS	UK08M0075	UK08-M-0075	NIL	NIL	100%
UA083366	SUCCESS	UA083366	UA08-3366	NIL	NIL	100%
DL4CS1859	SUCCESS	DL4CS1859	DL4C-S-1859	NIL	NIL	100%
UP10D6350	SUCCESS	UP10D6350	UP10-D-6350	NIL	NIL	100%
DL2CAN4880	SUCCESS	DL2CAN4880	DL2C-AN-4880	NIL	NIL	100%
DL8CA7820	SUCCESS	DL8CA7820	DL8C-A-7820	NIL	NIL	100%
CG04E9311	SUCCESS	CG04E9311	CG04-E-9311	NIL	NIL	100%
PB23F0192	SUCCESS	PB23F0192	PB23-F-0192	NIL	NIL	100%
PB11AQ2323	SUCCESS	PB11AQ2323	PB11-AQ-2323	NIL	NIL	100%
HR26AE9084	SUCCESS	HR26AE9084	HR26-AE-9084	NIL	NIL	100%
HP152733	SUCCESS	HP152733	HP15-2733	NIL	NIL	100%
PB11AQT8152	SUCCESS	PB11AQT8152	PB11-AQ-T-3152	NIL	1	((10/11)*100 = 99%
PB29J9091	SUCCESS	PB29J9091	PB29-J-9091	NIL	NIL	100%
CH04F6858	SUCCESS	CH04F6858	CH04F6858	NIL	NIL	100%
PB44B0323	SUCCESS	PB44B0323	PB44-B-0323	NIL	NIL	100%
PB11AA7040	SUCCESS	PB11AA7040	P611AA7040	1	NIL	((9/10)*100 = 90%
PB11P0501	SUCCESS	PB11P0501	PB11-P-0501	NIL	NIL	100%
DL8CP7201	SUCCESS	DL8CP7201	DL8C-P-7201	NIL	NIL	100%
PCI8	SUCCESS	PCI8	PC1-8	1	NIL	((3/4)*100 = 75%

The assessment of results in table 7.1 and 7.2 clearly shows that the system is very efficient in recognizing the number plates and its characters.

Out of 100 images, license plates in 98 images were localized correctly. The remaining 98 correctly localized images when passed through template matching function produced 91 correct results. Hence the accuracy of the overall system comes out to be 91%.

Accuracy (%) =100*(no. of correct output sample/total samples);

7.2 Problems Encountered

The major problems that we faced during our project are discussed below.

1. There is no standard size of Indian number plates, no standard of font style or size either which makes it quiet difficult for the software to recognize the alphanumeric characters. Using a larger template set would require more time to find the best match and thus it may not be used for real time applications. Standardization of font can help rectify this problem which would result in requirement of smaller template set and hence reduction in computation time.
2. In image processing, the systems are greatly affected by lightening conditions, our system is also sensitive to lightening conditions which are hard to keep constant while working in the middle of a busy road.
3. The threshold calculation is also a major parameter that affects the segmentation of characters since very high threshold can break characters while very low threshold may join the characters [27], thus affecting the accuracy of the matching process. Adaptive threshold calculation can be helpful in removing the threshold related problems.
4. An attempt has been made to make the proposed system insensitive to the angle at which images are being taken but in cases of already tilted characters the system provides false results. This problem can be solved by extending the template set and achieving the accuracy at the cost of computation time or by the use of a trained Artificial Neural Network.
5. The results are also affected by ambiguity in similar characters such as ‘0’, ‘O’, ‘B’, ‘8’ etc. The use of different syntaxes for different states along with the use of VIP numbers also affects the accuracy. The solution to this problem is to fix the syntax for country as a whole instead of individual states.

7.3 Discussion

A morphology based approach to recognize license plates in Indian conditions has been proposed in this thesis and it is evident from the results shown in fig 7.4 and the assessment table 7.1 that the method proposed is very effective not only in localizing the license plates from images but also in segmenting and recognizing the respective characters of the extracted plate. Previously, some License plate tilt correction methods based on K-L transform [4]-[21] and hough transform have been proposed. Edge based segmentation [11]-[15]-[20] methods for localization of License plate have also been proposed. But these were either restricted to localization or tilt correction only

In our thesis, keeping in mind the fact that recognizing the actual number is as important and difficult as localizing a license plate is [5]. Hence, a method efficient in performing both these tasks equally well has been developed. Unlike hough transform based tilt correction methods [16], the tilt correction is based on the region orientation and hence significant saving of computation time has been achieved. Testing results revealed that the time taken for extracting the plate region takes less than a second (.5 to .8 sec) and the matching process takes about 2-3 seconds. This shows that the method is well suited for locations where vehicle speeds are low or at parking places.

CHAPTER 8 — CONCLUSION AND FUTURE SCOPE

8.1 Conclusion

The process of vehicle number plate recognition requires a very high degree of accuracy when we are working on a very busy road or parking which may not be possible manually as a human being tends to get fatigued due to monotonous nature of the job and they cannot keep track of the vehicles when there are multiple vehicles are passing in a very short time. An effort has been made in this work to develop an accurate and automatic number plate recognition system of Indian license plates.

Our approach for localization is based on morphology while the number recognition is based on template matching. A difference image is created by subtracting the ‘opened’ and ‘closed’ input image followed by ‘opening’ and ‘closing’ again. The resulting image is then binarized and the plate region is filtered out. The segmented characters are then compared to 72 templates created artificially and their correlation scores are stored. The best score between the segment and template is treated as the best match.

In this approach, number plate located at any corner of image can be recognized. Number plates having variations in background as well as font can be easily localized. Unwanted conditions such as screws and unwanted text on number plate which create problem for localization are treated suitably and taken into consideration. We have used MATLAB 7.6 (R2008a) with Image Processing Toolbox to obtain the desired results.

The setup has been tested for 100 vehicles containing different number plates from different states out of which 91 were recognized correctly. Thus, we get an overall accuracy of 91% for this system. Accuracy has been calculated on the basis of character recognition. The output has been considered as wrong even if a single character is wrongly matched, no matter if the License plate is correctly extracted.

The advantages of the system include very high localization accuracy (98 out of 100), automatic skew correction without much computation and syntax independent recognition. The proposed method faced problems in recognition of stylized fonts, broken characters and soiled license plates. Finally, it can be concluded that the project has been by and far successful.

8.2 Future Scope

Though we have achieved an accuracy of 91% by optimizing various parameters, it is required that for the task as sensitive as tracking stolen vehicles and monitoring vehicles for homeland security an accuracy of 100% cannot be compromised with. Therefore to achieve this, further optimization is required. Also, the issues like stains, smudges, blurred regions & different font style (especially in trucks) and sizes need to be taken care of. This work can be further extended to video frames for real time applications as well as minimizing the errors using adaptive threshold methods and faster matching techniques such as Haar like binary features (used in face detection) and Artificial Neural Networks.

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