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SUDANESE VEHICLES LICENSE PLATE RECOGNITION

التعرف على لوحة ترخيص المركبات السودانية

A thesis submitted for the requirements for awarding the degree of Doctor of Philosophy in Computer Science

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DEDICATION

To my parents,

to my wife,

and to our daughters.

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First of all, praise be to God and thanks to God.

I would like to express my sincere gratitude to Dr. Mohamed Elhafiz Mustafa, my supervisor for the continuous support of my Ph.D. study, for his patience, motivation, and immense knowledge.

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Finally, I wish to extend my heartfelt appreciation to my family: my parents, my brothers and sisters, and my wife for their unconditional love, spiritual support and sacrifice which has enabled me to pursue my dreams.

ABSTRACT

Vehicle license plate recognition is a computer vision method that aims to automatically recognize the vehicle's identification number from the vehicle image. Therefore, it is an important component for automating many control and surveillance systems, such as: road traffic monitoring, private and public entrances, highway electronic toll collection, red light violation enforcement, and theft control. Although, considerable researches have been carried out for vehicle license plate detection and recognition in different countries, however, very few previous studies have been done for the Sudanese license plate detection and recognition. Furthermore, the vehicles in Sudan are currently being identified by traffic policemen manually. Thus, this thesis presents a novel system approach for Sudanese vehicle license plate recognition, which aims to improve the efficiency and the accuracy of the license plate detection and recognition process. A simple method is proposed for detecting and extracting the license plate, which is based on identifying the plate region by analyzing Sudanese plate features. The plate's skew angle is computed to guarantee the license plate characters were accurately segmented. The character segmentation process goes through combined techniques to improve license plate image contrast, in addition to take advantage of the prior knowledge of Sudanese license plate. The recognition is performed through two different recognizers, English character recognizer (Template Matching method) and Indian digit recognizer (a novel heuristic rules based on salient features). In order to analyze the performance and efficiency of the proposed approach a dataset for Sudanese vehicles has been created. This dataset contains 375 vehicle images. Using this new dataset, a number of experiments have been carried out. Experimental results have shown that the proposed approach is efficient with accuracy rates of 98.6% for license plate detection, 99.5 % for character segmentation, and 98.4% for recognition.

المستخلص

التعرف على لوحة ترخيص المركبة هو أحد طرق الرؤية بالحاسب الآلي (Computer Vision) ، و الهدف منه التعرف تلقائيا على الرقم التعريفي للمركبة من صورة المركبة. لذلك فأنه يعتبر مكوناً هاماً لأتمتة العديد من نظم التحكم و المراقبة ، مثل: مراقبة حركة المرور على الطرق ، والتحكم بالمداخل الخاصة و العامة ، و التحصيل الألكتروني لرسوم عبور الطرق السريعة، و تخطي الإشارة الحمراء، و السيطرة على السرقة. بالرغم من أن هنالك بحوث عديدة أجريت بدول مختلفة للكشف و التعرف على لوحة ترخيص المركبة، ومع ذلك عدد قليل جداً من الدراسات السابقة أجريت للكشف و التعرف على اللوحة الترخيص السودانية. و علاوة على ذلك، فإن التعرف حاليا على المركبات في السودان يتم يدويا بواسطة رجال شرطة المرور. لذلك تقدم هذه الرسالة منهاج لنظام جديد للتعرف على لوحة ترخيص المركبة السودانية، و هذا النظام يهدف الى تطوير كفاءة و دقة عمليتي الكشف و التعرف على لوحة الترخيص. تم اقتراح طريقة مبسطة للكشف و استخراج لوحة الترخيص ، و التي تستند على تعريف منطقة وجود اللوحة من خلال تحليل سمات اللوحة السودانية. و لضمان دقة تجزاءة حروف لوحة الترخيص تم ايجاد زاوية ميلان اللوحة. كما نفذت عملية تجزاءة حروف لوحة الترخيص من خلال تقنيات مشتركة و ذلك لتحسين تباين صورة لوحة الترخيص، بالاضافة الى الاستفادة من المعرفة المسبقة للوحة الترخيص السودانية. تم التعرف على لوحة الترخيص (The Recognition) باستخدام طريقتين للتعرف (Two Recognizers)، و هما التعرف على الحرف الإنجليزي (طريقة مطابقة القوالب) (English Character Recognizer) و التعرف على الرقم الهندي (قواعد كشف جديدة مبنية على السمات البارزة) (Indian Digit Recognizer). أُنشاءت مجموعة بيانات خاصة بالمركبات السودانية لتحليل أداء و كفاءة المنهجية المقترحة. تتكون مجموعة البيانات من ٣٧٥ صورة. أجريت العديد من التجارب باستخدام هذه المجموعة الجديدة، حيث أظهرت نتائج التجارب أن المنهجية المقترحة فعالة و بمعدلات دقة ٩٨,٦ % للكشف و تحديد لوحة الترخيص، و ٩٩,٥ % لتجزئة الحروف، و ٩٨,٤ % للتعرف على اللوحة.

TABLE OF CONTENTS

DEDICATION i
ACKNOWLEDGEMENT ii
ABSTRACT IN ENGLISH........ iii
ABSTRACT IN ARABIC........ iv
TABLE OF CONTENTS........v
LIST OF TABLES........ viii
LIST OF FIGURES ix
LIST OF ABBREVIATIONS xii
LIST OF APPENDICES xiii
CHAPTER I: INTRODUCTION........1
1.1 Overview 1
1.1.1 VLPR Applications........2
1.1.2 Sudanese Vehicle License Plate 3
1.2 Problem Statement........4
1.3 Research Hypotheses 5
1.4 Aims and Objectives 5
1.5 Research Scope........5
1.6 Contributions 6
1.7 Thesis Structure 6
CHAPTER II: LITRATURE REVIEW 8
2.1 Introduction 8
2.1.1 Typical System Structure of VLPR Systems........8
2.2 License Plate Detection and Extraction 9
2.3 License Plate Character Segmentation........15
2.3.1 License Plate Skew Correction........15
2.3.2 Character Segmentation 17
2.4 License Plate Recognition........20
2.4.1 Template Matching 20
2.4.2 Artificial Neural Network........21
2.4.3 Other Methods 22
2.5 Previous Work on Sudanese VLPR 24
2.6 Summery 24

CHAPTER III: DATASET AND METHODODLOGY **26**
3.1 Introduction 26
3.2 Dataset..26
3.3 Methodology...28
3.3.1 Image Acquisition 29
3.3.2 License Plate Detection And Extraction 29
3.3.3 License Plate Character Segmentation...30
3.3.4 License Plate Character Recognition 32
3.4 Summery 33
CHAPTER IV: LICENSE PLATE DETECTION AND EXTRACTION **34**
4.1 Introduction 34
4.2 The Proposed LP Detection and Extraction Method 34
4.2.1 The Green Channel and Edge Detection..36
4.2.2 Regions of Interest Filtration..38
4.2.3 Dilation and Candidate Regions Detection 39
4.2.4 Accurate Plate Detection/Extraction...41
4.3 Experimental Results and Discussion...43
4.4 Summery 47
CHAPTER V: LICENSE PLATE CHARACTER SEGMENTATION **48**
5.1 Introduction 48
5.2 Skew Correction 49
5.2.1 Contrast Enhancement and Binary Conversion..50
5.2.2 Filtering Unwanted Regions...51
5.2.3 Computing Skew Angle 52
5.3 Character Segmentation 53
5.3.1 Eliminating LP Upper Part and Detect LP Boundaries (Frame) 54
5.3.2 Regions of Interest Extraction Based on Bottom-hat Filtering 58
5.3.3 Indian Numbers segmentation 60
5.3.4 English Characters Segmentation 65
5.4 Experimental Results and Discussion...67
5.4.1 Skew Correction...67
5.4.2 Character Segmentation 68
5.5 Summery 70
CHAPTER VI: LICENSE PLATE CHARACTER RECOGNITION **72**
6.1 Introduction 72
6.2 Indian Numbers Recognition..73
6.2.1 Indian Numbers Features..73

6.2.2 The Recognizer 76
6.3 English characters Recognition 79
6.3.1 The Recognizer 79
6.4 Experimental Results and Discussion 80
6.4.1 Indian numbers recognition 81
6.4.2 English characters recognition...82
6.4.3 The overall number of recognized LPs 83
6.5 Summery..84
CHAPTER VII: CONCLUSION AND FUTURE WORK.................................85
7.1 Conclusion 85
7.2 Future Work..86
REFERENCES 87
APPENDIX 95
LIST OF PUPLICATIONS 99

LIST OF TABLES

Table 1.1: Sudanese Vehicles Plates Types ………………………………….. 3
Table 4.1: LP Detection and Extraction Experiments Results ………………. 43
Table 5.1 LP Skew Correction Experiments Results ………………………… 67
Table 5.2 LP Character Segmentation Experiments Results ………………… 68
Table 5.3 Several Results of Character Segmentation Step ………………….. 69
Table 5.4 Failure in Character Segmentation ………………………………... 70
Table 6.1: Indian Number Recognition Experiments Results ……………….. 81
Table 6.2: Unsuccessful results of Indian Number Images Recognition …….. 81
Table 6.3: English Character Recognition Experiments Results …………….. 82
Table 6.4: Unsuccessful results of English Character Images Recognition …. 83
Table 6.5: LPs Recognition Experiments Results …………………………… 83

LIST OF FIGURES

Figure 1.1: Sudanese LP Layout ……………………………………………….. 4

Figure 1.2: Sudanese Private Vehicle LP (a) Plate with Silver Metallic Bar. (b) Plate with Vertical Text …………………………………………………... 4

Figure 2.1: VLPR Systems Main Stages …………………………………….. 8

Figure 3.1: (a) Vehicle Image from The Front (b) Vehicle Image from The Rear. 26

Figure 3.2: Some Images Samples ……………………………………………... 27

Figure 3.3: Sudanese VLPR System…………………………………………. 28

Figure 3.4: The Input and Output to LPD Stage………………………………… 29

Figure 3.5: License Plate Character Segmentation Steps……………………… 31

Figure 3.6: Three Horizontal Lines Crossing the Plate………………………….. 31

Figure 4.1: LP Detection and Extraction Method …………………………... 35

Figure 4.2: RGB Image……………………………………………………... 35

Figure 4.3: Green Channel Extraction………………………………………. 36

Figure 4.4: (a) Edge Detection (b) Thicken Edge ……………………………... 37

Figure 4.5: License Plate Contents Selection…………………………………... 38

Figure 4.6: Remove Unwanted Regions……………………………………. 39

Figure 4.7: Visualization of How the Plate Vertically Divided………………... 40

Figure 4.8: Perform First Dilation. (a) First Dilation. (b) Removing Regions Contiguous to the Image Border. (c) Removing Small Regions……………….. 40

Figure 4.9: Perform Second and Third Dilation (a) Second Dilation. (b) Selecting Regions Bigger Than A specific Area. (c) Third Dilation……………. 41

Figure 4.10: Connected Components. (a) Connected Component Surrounded By Smallest Rectangle. (b) Corresponding Rectangle on RGB image………… 42

Figure 4.11: Extracted License Plate……………………………………….. 43

Figure 4.12: The Results of License Plate Detection and Extraction for Several Vehicles …………………………………………………………………... 45

Figure 4.13: Failure in LP Detection…………………………………………. 46

Figure 5.1: English characters and Indian numbers within Sudanese Private Vehicle License Plate……………………………………………………... 48

Figure 5.2: Skew Angle, (a) Un-skewed Image (b) Positive skewed Image (c) Negative skewed Image…………………………………………………... 49

Figure 5.3: The Middle Horizontal Line………………………………………... 50

Figure 5.4: Contrast Enhancement and Binary Conversion (a) Gray-scaled Image (b) Contrast Enhancement by CLAHE (c) Binary-scaled Image……….. 51
Figure 5.5: Filtering Unwanted Regions Step………………………………... 52
Figure 5.6: Computing Skew Angle Step……………………………………. 53
Figure 5.7: Eliminating LP Upper Part (a) Middle Line on Skew corrected Image. (b) The Result Image…………………………………………………. 55
Figure 5.8: (a) Input Gray Image. (b) Contrast Enhancement by CLAHE. (c) Binary Image. (d) Complement of the Binary Image…………………………. 56
Figure 5.9: (a) Input Gray Image (b) Result after Detecting LP Boundaries……. 58
Figure 5.10: (a) The Input Gray Image. (b) After Performing Bottom-hat. (c) The Result Image of Subtraction Operation……………………………………. 59
Figure 5.11: Binary Image Conversion (a) Enhanced Image. (b) Binary-scaled Image………………………………………………………………………. 59
Figure 5.12: (a) Complement of the Image. (b) ROI Surrounded by a Red Rectangle. (c) English Characters Image. (d) Indian Numbers Image………….. 60
Figure 5.13: Removing Regions Contiguous to the Image Border………………. 61
Figure 5.14: Eliminating screws contiguous to the Indian number ……………. 63
Figure 5.15: Removing Noise and Vertical Lines………………………………. 64
Figure 5.16: (a) Filled Image. (b) Each Indian Number in a green Rectangle…… 65
Figure 5.17: (a) Input Cropped Image (b) Result of Morphological Open (c) Result of Removing Contiguous Regions to Image Border……………………. 65
Figure 5.18: Connected Component Analysis to Detect Each Character ………. 66
Figure 5.19: Several Results of Skew Correction Method …………………….. 68
Figure 6.1: The Input to LP Character Recognition Stage (a) English Characters Image. (b) Indian Numbers Image………………………………….. 72
Figure 6.2: Indian Numbers…………………………………………………….. 73
Figure 6.3: Digit Four Features…………………………………………………. 74
Figure 6.4: Digits Six and Nine Features (a) The Six's Image. (b) The Nine's Image……………………………………………………………………………. 75
Figure 6.5: Digits Two and Three Features (a) The Two's Image. (b) The Three's Image…………………………………………………………………... 75
Figure 6.6: Digits Seven and Eight Features (a) The Seven's Image. (b) The Eight's Image…………………………………………………………………… 76
Figure 6.7: The Recognition Process of Sudanese LP Indian Number…………. 78
Figure 6.8: English Characters Image…………………………………………... 79

Figure 6.9: English Characters Templates (a) 6 Templates for Arabic Digits Image. (b) 2 Templates for English Alphabets……………………………………. 80
Figure A.1: Sudanese VLPR System Main GUI………………………………… 95
Figure A.2: Loaded Vehicle mage………………………………………………. 96
Figure A.3: Extracted License Plate…………………………………………….. 96
Figure A.4: Segmented Characters……………………………………………… 97
Figure A.5: Recognized License Plate………………………………………….. 97
Figure A.6: License Plate Extraction Failure…………………………………… 98
Figure A.7: License Plate Recognition Failure…………………………………. 98

LIST OF ABBREVIATIONS

VLPR	**V**ehicle **L**icense **P**late **R**ecognition.
LP	**L**icense **P**late.
LPD	**L**icense **P**late **D**etection.
CCA	**C**onnected **C**omponenets **A**nalysis.
CCL	**C**onnected **C**omponenets **L**abeling.
SE	**S**tructural **E**lement.
CLAHE	**C**ontrast-**L**imited **A**daptive **H**istogram **E**equalization.
ROI	**R**egion **O**f **I**nterest.
OCR	**O**ptical **C**haracter **R**ecognition.
CCF	**C**ross-**C**orrelation **F**unction.
SVM	**S**uport **V**ector **M**achine.

LIST OF APPENDICES

APPENDIX A: Simulation of the Developed System ……………………… 93

CHAPTER I

INTRODUCTION

1.1 Overview

Vehicle License Plate Recognition (VLPR) is a computer vision method used to identify vehicles by their License Plates (LP) without direct human interference. VLPR system was introduced in 1976 at the police scientific development branch at the United Kingdom [45, 58, 59]. Since the 21st century, social development and living standards improvements, the number of vehicles is continuously increased, the traffic conditions are worsening, this brought huge pressures to the society and the environment. Therefore, VLPR system is an important component for automating many control and surveillance systems, such as road traffic monitoring, parking lots, access control, highway electronic toll collection, red light violation enforcement, finding stolen cars, gathering traffic flow statistics [1, 2]. License plate recognition system can solve the various road problems generated by traffic congestion, thus receiving more and more attention. VLPR is also called in different references as [2, 3, 4, 10, 18, 37, 58]:

- Automatic License Plate Recognition (ALPR) [2, 3].
- Automated Number Plate Recognition (ANPR) [4, 18, 37, 58].
- Number Plate Recognition (NPR)[18].
- Automatic Vehicle Identification (AVI) [2].
- Car Plate Recognition (CPR) [10].
- Optical Character Recognition (OCR) for Cars [2].

Due to the difference of LP in physical characteristics and format characteristics, such as fonts, colors and size from country to country, the field of VLPR and its applications has attracted many researchers in many countries to search and develop systems in order to identify their own vehicles LP. Thus far, many methods have been proposed for VLPR depending on the country's LP characteristics. However, a handful research has been utilized in this concern, particularly in countries such as Sudan. Therefore, this research is related to the automatic detection and recognition of license plates for Sudanese's vehicles concerning security and management.

1.1.1 VLPR Applications

VLPR systems have a wide range of applications, which use the extracted plate number to create automated solutions for several problems. These include the following sample applications:

- **Parking:** The plate number is used to automatically recognize the parking permits holders and calculate parking fee for non-permit holders.
- **Access Control:** A gate automatically opens for authorized members in a secured area, this will help in replacing or assisting the security guards.
- **Tolling:** The vehicle number is used to calculate the travel fee in a toll-road.
- **Border Control:** The vehicle number is registered in the entry or exit of the Country, and used to monitor the border crossings.
- **Violation Fine Enforcement:** The plate number is used to produce a violation fine on speed or red-light systems. The manual process of preparing a violation fine is replaced by an automated process which reduces the overhead and turnaround time.
- **Traffic Control:** The vehicles can be diverted to different lanes, according to their entry permits (such as in University complex projects). The system effectively reduces traffic congestions.
- **Stolen vehicles:** A list of stolen vehicles or unpaid fines is used to alert on a passing listed vehicle. The VLPR system is deployed on the roadside, and performs a real-time match between the passing vehicles and the list.

1.1.2 Sudanese Vehicle License Plate

The Sudanese vehicles LPs are categorized in a number of types, that categorization was based on the differences of plate's background color and characters color, Table 1.1 gives some information about these types.

Table 1.1: Sudanese Vehicles Plates Types

Type	Background Color	Characters Color
Private vehicles	White	Black
Commercials (Passenger)	White	Green
Commercials (Goods)	Black	White
Police	Blue	White
Government	Yellow	Black

The size of all plate types is 32 × 16 centimeters as shown in Figure 1.1. The plate has been divided into three regions as in Figure 1.1; region 1 on the upper part of the plate, which contains the name of the country "SUDAN" written in English and Arabic. The other two regions on the lower part of the plate. They were separated by a silver metallic bar (Old Plates) as presented in Figure 1.2 (a), or a vertical text "جمهورية السودان" (New Plates) as presented in Figure 1.2 (b). Region 2 on the right lower part consists of numerals (1 to 5 numbers) written in Arabic and Indian form. Where, region 3 on the left lower part consists of characters or a character and number written in English and Arabic form, the characters are an abbreviation of Sudanese states names, and the number to keep the sequence of the numbering. This study focuses on the first type: private vehicles, as shown in Figure 1.1 (a) and (b).

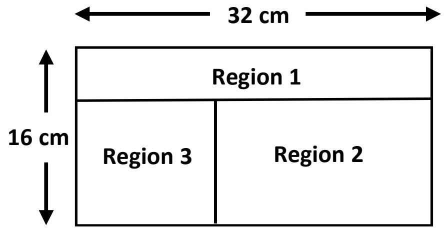
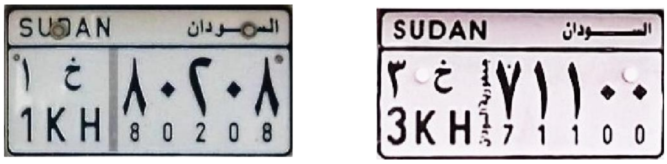


Figure 1.1**:** Sudanese LP Layout



(a) **(b)**

Figure 1.2: Sudanese Private Vehicle LP **(a)** Plate with Silver Metallic Bar. **(b)** Plate with Vertical Text

1.2 Problem Statement

Although there is a commercial software available for vehicle LP identification, but was not applied in Sudan this due to the differences in plate's style, design, and the implementation cost.

Considerable researches have been carried out in different countries, for instance, India [18 - 21], Saudi Arabia [5, 6, 34], Iran [26, 31], Jordan [37], China [22, 23], Turkey [17] and Malaysia [3] vehicle LP detection and recognition. But there are very few studies in the literature have been done for Sudanese LP detection and recognition, or almost nonexistent. Thus far, one study has been found, which reported in [61].

Moreover, according to the General Police Traffic Management, the vehicles LP in Sudan is currently being identified by traffic policemen manually. There are obvious drawbacks associated with undertaking the identification task manually, such as: lack of efficiency, record-keeping problem, unease of retrieval, etc.

This research is concerned with the detection and recognition of Sudanese LP, therefore the this research is looking at "*How to improve the efficiency and the accuracy of the detection and the recognition process of Sudanese vehicle LP*".

1.3 Research Hypotheses

The hypotheses of this research are formulated as follows:

- Vehicle LP can be detected and extracted accurately from the vehicle image, which captured at different day time and different illuminations.
- LP characters can be successfully segmented even though some difficulties, such as, variation in contrast, size, and rotated plates.
- LP Indian numbers and English characters can efficiently be recognized.

1.4 Aims and Objectives

The general objective of the research is to develop a system that is capable of detecting and extracting the LP from a vehicle image, and recognizing the characters and numbers on the LP. The specific objectives are outlined as follows:

- Review different techniques and algorithms for developing the Sudanese VLPR system.
- Develop an appropriate method for detection and extraction of plate region from the image.
- Develop an appropriate method for LP character segmentation.
- Develop an appropriate recognition method to identify vehicles.

1.5 Research Scope

The following points describe the scope of this research:

- Concentrate on the Sudanese LP.
- Deal with Private Vehicle LP.
- Captured images of parked vehicle.

- The VLPR system is detecting a single vehicle plate in an image.
- The VLPR system recognizes the Indian digits and the English characters on the LP.

1.6 Contributions

The contributions of this thesis are:

- Collecting a dataset for Sudanese private vehicle images, which has been captured manually as explained in chapter 3. The dataset can be used by researchers in the field of Sudanese vehicle license recognition.
- Developing a simple and automatic method for detecting and extracting the LP. The method is based on identifying the plate region by analyzing the Sudanese LP features, in addition to a set of other rules for detecting and extracting the accurate plate region.
- Developing a method for the LP skew correction. The method utilizes the mathematical concepts of linear function as well as morphological operations to compute the skew angle of the LP.
- Developing combined techniques of morphological operation's bottom-hat, vertical and horizontal projection profile, prior knowledge of Sudanese LPs, and connected components analysis, for screw elimination and LP character segmentation.
- Developing a novel approach for LP character recognition. The approach uses two different recognizer, where, the recognition process is performed separately based on different regions of the LPs. The approach introduces a novel heuristic rules based on salient features, and template matching as the two different recognizer.

1.7 Thesis Structure

The rest of the thesis is structured as follows:

Chapter 2 presents a theoretical background for the typical system structure of vehicle license plate recognition. In addition, a review for some related works of vehicle license plate recognition.

Chapter 3 describes the dataset that used in the experiments. In addition, introduces our methodology and the framework of Sudanese vehicle license plate recognition system.

Chapter 4 explains the license plate detection an extraction stage, and present the experiments results and discussion about these results.

Chapter 5 explores the license plate character segmentation stage, and present the experiments results and discussion about these results.

Chapter 6 lists and describes the license plate recognition stage, and present the experiments results and discussion about these results.

Chapter 7 introduces the conclusion and the future work based on the experiments results.

CHAPTER II

LITRATURE REVIEW

2.1 Introduction

VLPR systems have received a lot of attention from the research community. Research work in this area is being restricted to a specific region, city, or country due to the lack of standardization among different license plates (i.e., the dimension and the layout of the license plates). This chapter gives an overview of the research carried out so far in this area and the techniques employed in developing a VLPR system in the following three stages: license plate detection and extraction, license plate segmentation and license plate recognition phases. Section 2.1.1 introduces those stages.

2.1.1 Typical System Structure of VLPR Systems

The typical VLPR System's structure are consisting of three main stages [20, 42, 45, 46, 59] as shown in Figure 2.1: License Plate Detection (LPD) and Extraction, License Plate Character Segmentation and License Plate Recognition. An independent module performs each stage.

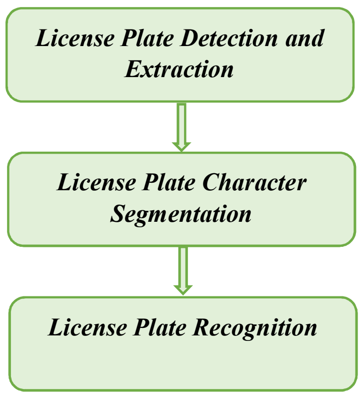


Figure 2.1: VLPR Systems Main Stages

A. License Plate Detection and Extraction

License Plate (LP) Detection and Extraction is an integral and inseparable part of the system, as it locates the plate that encloses the LP characters. This stage involves image processing techniques combined with some decision making based on deterministic threshold. The input to this stage is a vehicle image, and the output is a portion of the image containing the potential LP without any prior knowledge on where it is located.

B. License Plate Character Segmentation

The LP segmentation process is also called as the Character Separation [45] or Character Isolation [18]. The input of this stage is the LP image resulting from the previous stage. The LP image would be divided into single character images without losing features of the characters for recognition stage.

C. License Plate Recognition

LP Recognition is the last stage of the VLPR system, which is also known as Optical Character Recognition (OCR) [20, 33, 37, 57]. This stage is the main part of the recognition process which decides the accuracy and recognition rate of the system. In this stage, the plate character images that are taken out from the LP image have to be recognized and identified in some way.

2.2 License Plate Detection and Extraction

Many efforts have been reported for solving the problem of detecting potential LP area from an image or a video. Different state-of-the-art methods apply different image processing approaches, techniques and algorithms to build their LP detection methods. To detect an LP area from an image, different features such as geometric feature, texture feature and color feature of the LP are utilized individually or jointly [2].

According to Sarfraz et al., the LP extracted from the gray-scaled image by detecting vertical edges using the Sobel edge detector, which uses a 3x3 mask, then filtering out unwanted regions by applying seed-filling algorithm. The LP region is extracted by comparing the size ratio of the rectangular area between two vertical regions with the actual standard size ratio of the LP [5].

Alginahi used the method reported in [5] without filtering step, in order to locate different LP types in shapes and size [6]. Shidore and Narote introduced similar technique to detect Indian LP by using Sobel filter, morphological operations and connected component analysis [18].

Kasaei et al. applied vertical and horizontal Sobel operator on the gray image. Then closing morphological operation with a rectangular structural element is performed in the horizontal direction. To find the correct region among candidate regions, some features such as shape, aspect ratio, and size of the plate are tested for all regions [26].

Basalamah introduced a method for LPD based on detecting a black cross that centers the plate, so an edge detector is applied to find the horizontal and vertical maps, and then before median filter performed the binary image is obtained by using the average value of pixels in each map as a threshold [34].

Abulgasem et al. proposed Radial Basis Function Neural Network (RBF NN) to detect the Libyan LP. First Sobel edge detector applied, and then some morphological methods are used to thicken edges and remove unwanted edges. The remaining regions are detected and categorized into plate and not plate manually to train the RBF NN, which afterwards is used to detect the LP automatically in other images during the testing phase [8].

Mousa presented an algorithm for Palestine LPD based on Canny edge detector. This edge detection method is used to find image's edges based on local maxima of the gradient, which calculated by the derivative of a Gaussian filter [9]. Kocer and Cevik used canny edge detection operator to locate the LP in the image [35].

The method proposed by Mohammad et al. for LPD based on identifying the location of the screws that hold the plate in place using pattern matching, plate aspect ratio (width to height ratio), and intensity levels. Then by applying a coordinate system, the plate area is masked with respect to each screw position [11].

Shapiro et al. used pre-processing, segmentation and verification for LPD. In the pre-processing the global thresholding is used to map the color intensity into gray scale. In vertical segmentation stage the authors assumed two points: plates are oriented horizontally and there is a significant intensity difference between the character foreground and plate's background. Therefore, Roberts' edge operator is used in order to emphasize the vertical edges. Then the image is convolved with horizontally oriented rank-filter of size $M \times N$ pixels. Where $M = 20\%$ of the image width and $N = 3$. Then vertical projection is used to detect plate's vertical boundaries. Sometimes the plate is skewed, so Randon Transform (RT) function is used in conjunction with Dirac's delta function to eliminate the skew position in a LP. The original image clipped and deskewed then passed to the horizontal segmentation stage. Horizontal boundaries are detected by using Roberts' operator and series of morphological erosions with horizontally oriented structured elements. Finally, the verification procedure consists of two steps. In the first step, the global binarization is done via Otsu's algorithm to separate the plate into dark and light areas. The authors assumed dark characters and bright background for this purpose. In the second step, the binarization threshold is compared to the plate intensity median. The probability of detecting the LP is higher when the intensity median of the plate zone is greater than the threshold. After passing all the test number plate is approved successfully. If any of the tests fails, then the current plate region is rejected and the system goes back to the segmentation stage to search for another plate region. If the maximum number of iterations is reached and no plate is found, the search stops and a failure message is issued [12].

Dashtban et al. applied Gaussian filter on colored image to lessen the effect of noises and adjust image intensity followed by gray space conversion. The conventional histogram equalization is utilized to increase the intensity level range. Then the vertical Sobel operator is used for edge detection. Candidate LP region is selected using connected components analysis. The authors found that if the regions have been sorted and if the LP has been among the extracted regions, then the region containing LP is within the four biggest regions. The appropriate LP region is selected among the four candidate regions by investigating four issues: area, the ratio of length to width, range of length and width and region intensity [13].

Davis et al. developed a mechanism for Indian LPD. First, the gray-scaled image is converted to binary image by using adaptive thresholding. Then applied unwanted line elimination algorithm based on 3x3 mask, which is moved throughout the image to identify the central pixel and testing the remaining 8 neighbor pixels. After that the vertical edges are extracted followed by highlighting the required regions technique. Once again unwanted line elimination algorithm is used. As a last step, the image is scanned for continuous black pixel in order to obtain the two diagonal corners of the LP [19].

Ozturk and Ozen used Bottom-Hat filtering to enhance the potential plate regions. In binarization process, Otsu's Thresholding technique is used. Then each segment of the binary image is labelled according to the color of each segment to enable classification. If more than one candidate plate regions are obtained, then the selection is based on the plate features [32].

Ozbay and Ercelebi proposed smearing algorithm. Smearing is a method for the extraction of text areas on a mixed image. The binarized image is scanned along vertical and horizontal directions (scan-lines). If the number of white pixels is less than a desired threshold or greater than any other desired threshold, white pixels are converted to black. After that, a morphological dilation operation is applied to the image for specifying the plate location. However, there may be more than one candidate region for plate location. To find the exact region and eliminate the other regions, some criteria tests are applied to the image [17].

Zhang and Wang proposed a weighted statistical method. Before processing further, the color image is converted into the grayscale image, and then Image enhancement is achieved by the gray histogram balanced method in order to improve the definition of contour lines of LP number. The authors used weighted statistical to make the plate position more prominent in the image. So a 2D image matrix of N rows and M columns is prepared. Then the modified image matrix is formed after adding weights [23].

Patel et al. developed plate detection method based on overlapping windows and region clustering. First, two scanning windows W1 and W2 are sliding and overlapping each other from first row to nth row and based on four-neighbor connectivity. The authors are observed that number plate with only white color characters or only black color characters does not exist. So rows and columns having contiguous black or white color are eliminated. Region clustering is performed row and column wise on a binary image and in each cluster, the percentage of pixels having white color and black color are calculated separately. The process of clustering is repeated until the entire image is scanned. During that, the clusters satisfying specific criteria are stored in an array as candidate region and counted. Depending on a cluster regions counter, the plate region is selected [21].

Kaushik Deb et al. used sliding concentric window (SCW) based on a novel adaptive image segmentation technique for detecting candidate region. After applying SCW on vehicle image, HSI color model is used for candidate region color verification witch based on hue and intensity in HSI color model verifying green and yellow LP and white LP, respectively [27, 28].

Shan presented a method LPD. Author proposes a two stage binarization mechanism. First stage, using Otsu method to detect LP candidates. Character filtering and text-line construction were operated to verify the candidate regions due to LP candidates may contain noises which could be considered as plate by mistakes. After the text-line construction, the incorrect candidates will be removed, only the LP region is preserved. Second stage of binarization, the preserved LP region is divided into several regions according to the features of the LP, and each region is binarized by locally optimal adaptive binarization [22].

Some work reported in the literature involves the detection of LPs by locating their colors in the image. Wang et al. proposed a fuzzy logic based method. First, obtaining the valid LP regions as rough localization. Eliminating noise from the input image. Find the rectangular area of the candidate region by applying edge detection. Based on size, histogram distribution and other information, filter invalid rectangle regions. Geometric correction is used to obtain LP candidate region. Second, Color space of the image is converted into HSV space. The three components of the HSV (Hue, Saturation, and Value) are mapped to fuzzy sets according to different membership functions. The fuzzy classification function is then described by the fusion of three weighted membership degrees [30].

Abolghasemi and Ahmadyfard proposed an edge-based color-aided method for LPD. The proposed method is consisted of two parts. In the first part, developing an enhancement algorithm to increase the image contrast at locations where might be a LP by using two features: local intensity variance and local vertical edge density. In the second part, plate detection, which involves several steps. Vertical edge density estimation is used to avoid missing plate edges, especially in bad lighting condition. In the next step a Gaussian mixture is used to emphasize the constancy of intensity values within plate region, along the horizontal direction. Then the threshold value equal to 80% of maximum intensity value in the result image is used to detect candidate region. Next step, morphological operation (close and open) and geometrical features such as shape, aspect ratio and size of the region is used to detect LP. The final step, color analysis of candidate regions are used in order to increase the accuracy of LPD. The authors considered Iranian national flag, which is a part of LPs as multimodal color neighborhoods with unique modes. Therefore, the Multimodal Neighborhood Signature method is used [31].

Chen et al. proposed a feature salient method to extract LP by using salient features like shape, texture and color. Hough transform (HT) is used to detect vertical and horizontal lines from rectangular LP and then processed it by converting red, green, blue (RGB) to hue, intensity and saturation (HIS). Based on probability density function of the shape feature (length to width ratio), texture feature and color feature the LP is extracted [33].

Yousef et al. developed Scale Invariant Feature Transform (SIFT) based template matching technique to detect the LP. SIFT-based template matching is used to match SIFT keypoints extracted from the vehicle input image, and the keypoints of the templates stored in the memory of the computer. Once there is a successful match, the matches used as a seed for segmenting out the LP from the input image. We use the successfully matched keypoints from the template matching stage as a seed for extracting the LP. A windowed Hough Transform is used to detect a rectangle around the selected seed on the binarized image. The ratio between the width and length is used to make sure that the detected rectangle is corresponds to the LP [37].

Dewan et al. presented a LPD method based on an image edge detection by using Ant colony optimization (ACO) technique. This technique processed by pheromone matrix, which is generated by the movement of the ant species [38].

Azam et al. proposed a method to detect LP area from an image in the hazardous conditions. Hazardous condition means an image can have rainy or foggy weather effects, low contrast environments, objects similar to the LP, and horizontally tilted LP area. Discrete Fourier Transformation is used to remove rain effect, which is applied to the grayscale image. Removing non-periodic noises based on applying the Local Wiener noise filter. To enhance the image contrast the Tamura contrast value and the Contrast-Limited Adaptive Histogram Equalization (CLAHE) jointly is performed. In binary conversion process Standard Deviation and Mean is used. Then morphological opening operation is utilized in order to remove small thin white regions, extended outer regions of an LP, and thin connectivity between large white objects. The candidate regions are extracted using Connected Components. Then candidate regions tilt is corrected. Finally, Filtering Non LP regions among tilt corrected candidate regions based on size ratio and orientation, entropy and the average horizontal counting [40].

2.3 License Plate Character Segmentation

To recognize the vehicle LP, a single character must be extracted from vehicle plates. Some issues make the character segmentation task complicated, such as image noise, plate frame, plate's rotation and light variance. The segmentation stage should overcome all of these problems in a pre-processing step. Therefore, the next section discusses previous work done for LP Skew Correction:

2.3.1 License Plate Skew Correction

Skew Correction is a pre-process before LP Character Segmentation. Proper skew correction after LP detection enables perfect character segmentation and recognition in VLPR process. There are several techniques available to correct the skew of the extracted LP including Least Square, Connected Component analysis, Centroid method, principal component analysis, Hough Transform method and Radon Transform method as explained below:

Chen et al. proposed the least square skew detection method, which starts with finding all the connected regions in the LP and calculating the centered of each region. Afterwards, skew angle detects by least square [33]. Mansour performed the skew correction by least squares based on the centroid [7]. Moghassemi applied similar technique based on connected component analysis to compute the centroids of all characters in LP, then with coordination of left and right characters the skew angle Θ is computed [50].

Dashtban et al. used Canny line detection algorithm and Hough Transform to find the longest line in the plate image. Then the slope of the line is used to rotate the plate [13]. Arulmozhi K et al. proposed polar Hough Transform [42].

Shapiro et al. utilized Randon Transform (RT) function in conjunction with Dirac's delta function to eliminate the skew position in a LP [12]. Azam et al. used Radon Transform to detect the skew angle. Before that, Bernsen binarization method with a local window of 15×15 is applied to the grayscale candidate LP images, then generating the perimeter image from the binarized image [40].

Kaushik Deb et al. proposed least square fitting with perpendicular offsets (LSFPO) for skew correction in horizontal direction and estimating the rotation angle of the LP region. Then the whole image is rotated for skew correction in the horizontal direction by this angle. Skew correction in vertical direction is implemented by reorientation of the titled LP candidate through inverse affine transformation [27].

Cheng and Bai introduced an approach based on of self-organizing map (SOM) to find the skew angle of the LP. Regarding the aim of correcting the skew plate and segmenting 7 characters subsequently, authors choose a SOM network with 7 output points and take the coordinates of white pixels as the input vectors. Then initializing the weight matrix. After training the SOM, white pixels are classified and new weight vectors are got. Finally, the skew angle is calculated [36].

Renlong Pan et al. proposed an approach for LP skew correction. First, the plate image is divided into a set of 5×5 non-overlapping blocks. The local orientation of each block is estimated by gradients of pixels in the block. The horizontal incline angle of license plate is detected by the local maximum of the direction angle histogram. The plate image is rotated according to this angle. Then, the vertical distortion of the LP image is corrected by the single character projection method [41].

Modi et al. developed a combined method for skew correction of plate's image based on the Harris corner detector and principal component analysis (PCA). First, corner points are extracted as features using the Harris corner detector. PCA is applied onto these features to find out the principal component in the direction of maximum eigen value. This principal component reflects the skew angle of the plate, which is used to rotate the plate image. Paunwala et al. [44] proposed a combined method based on wavelet transform and PCA. Extraction of Feature points, which are considered as the edge of characters on the LP are extracted by using the two level wavelet transform. The PCA gives the information about skewed angle of the plate, with the help of feature points [43].

2.3.2 Character Segmentation

There is a number of published studies describing solutions for the problem of character segmentation through different image processing approaches, techniques and algorithms.

Sarfraz et al. alcropped the upper part of the extracted LP (about 30%) to remove the word "السعودية". Next, the binary-scaled LP is segmented using vertical projections into six regions, one region for each character or numeral [5].

Alginahi removed the upper part contains the word "السعودية" by using horizontal projection. Afterwards, the 8-connected components is used to segment all numerals and characters in the image [6].

C. Patel et al. used vertical and horizontal projection profile technique to isolate each character or numeral [4]. Ozturk and Ozen performed character segmentation by calculating the Column Sum Vector chart (CSV) and its local minima of extracted LP [32].

Abulgasem et al. [8] and Yousef et al. [37] performed character segmentation by using thresholding and Connected Component Analysis. Shapiro et al. proposed the character segmentation algorithm based on adaptive iterative thresholding and connected component analysis [12].

Shidore and Narote introduced character segmentation through a sequence of operations as, character region enhancement, connected component analysis and projection analysis. In enhancement, histogram equalization on gray image is used. Connected Component Analysis is used to remove the unwanted regions on the plate.

Finally, vertical projection analysis is used to find the gaps between the characters [18].

Mohammad et al., the process of segmentation is achieved through applying edge detection on binary-scaled image, dilation operation, filling, and blob analysis, which implies another filling and generates groups based on labels. The LP image splits into three images: one holds country name, one for city name and one for numbers [11].

Yoon et al. proposed an algorithm for character segmentation based on blob extraction. The algorithm consists of three steps. First, adjusting the input image and generating a binary image by using Niblack's method, which shows better result and performance. Second, analyzing blobs, which is a connected set of pixels in the binary image, and removing the noisy blobs and also merging and splitting the blobs. This step starts with connected components analysis and excluding the non-character blobs, plate boundaries, small dirties, and unrelated marks or bars. In the final step, correcting the rotated plate images and selecting final seven character blobs. Seven blobs with higher matching scores are selected [15].

Kocer and Cevik applied histogram equalization and median filtering techniques to enhance the gray level plate images. Then used the blob-coloring algorithm to segment each character within the LP image [35].

Hongyao and Xiuli combined the projection and template matching to segment plate's characters, in order to overcome the problems of different light strength in a different time and partial light shadow. Projection is done in the horizontal direction to detect the edge of a single LP in the vertical direction. The segmentation process is refined by using template matching. Templates are designed based on prior knowledge about the LP, and take similarity measures to match the image segmented by projection. Then to improve the accuracy of image segmentation minimum distance classifier is used [16].

Dashtban et al. proposed multistage model for character segmentation. First, median filter is used to remove noises followed by histogram equalization. Second, the LP image is rotated to correct the skew. Third, to convert the image into binary adaptive local thresholding along with Otsu's method is used. Finally, eliminating the main plate boundary by the horizontal projected histogram, then morphological erode operation is used for enhancing the extracted plate. Vertical projected histogram based technique in regard with the valleys is used to find space between characters [13].

Guo et al. developed a projection based character segmentation algorithm. Where, horizontal and vertical projection are used. The algorithm considers the relationships among characters to improve the segmentation rate [14].

Chen et al. used horizontal and vertical projection for character segmentation. The threshold segmentation method is in binary conversion process. The threshold value is calculated by maximum entropy criterion. Sliding neighbor region is used to eliminate the noise from binary image. Then, performing LP skew correction. Finally, Horizontal and vertical projection are implemented on the corrected image [33].

Ozbay and Ercelebi proposed smearing algorithms, filtering and some morphological operations. The segmentation process starts with filtering the image for enhancement and removing noise and unrelated parts. Then separating the characters that are close to each other by morphological dilation operation. Finally, finding the character regions by horizontal and vertical smearing. The last step is to cut the plate characters, which is done by finding starting and end points of characters in horizontal direction [17]. Renuka and KanagapushpavaUi also applied horizontal and vertical smearing algorithm to identify the region of each character within the LP [25].

Kasaei et al. used morphological process for character segmentation. It removes all small connected elements. Then dilation operator is applied to separate the character from each other. Finally, partition scanning is done for character segmentation [26].

Nagare performed the segmentation by using line-scanning technique. Usually scanning done from left to right of the LP. The process involves several steps, first the grayscale image is converted into a binary image. In order to partition the text on the LP into lines ‘Lines’ function which uses “clip” function is used. Usually this “Clip” function crops black letter with white background. Then, resizing is done. At the end same procedure is repeated on the cropped image till all the characters are segmented [20].

Shan developed segment method of vertical projection with prior knowledge. Prior knowledge, such as the size of the LP, the size of a character, size of the interval between the characters and the number of characters within a Chinese LP are used [22].

Abo Smara and Khalefah introduced a design of a Genetic Algorithm (GA) to detect the locations of the LP characters. An adaptive threshold method is applied to convert the image into binary. Connected component analysis technique is used to detect candidate objects inside the image. A scale-invariant Geometric Relationship Matrix has been introduced to model the characters layout in any LP [39].

2.4 License Plate Recognition

The recognition process helps in identifying and converting all digit and character images into editable text. There are several different solutions for character recognition problems, Template Matching and Artificial Neural Network are the most popular methods used for LP recognition among other methods [4]. An explanation of each method in various literature as follows:

2.4.1 Template Matching

This subsection discusses previous researches in the literature that used the Template Matching Technique in the LP recognition stage. Some of them are as follows:

Sarfraz et al. each segmented character is normalized to an image of size 40 x 40, then template matching based on the Hamming distance approach is used to match all the normalized characters to the characters in the database [5].

C. Patel et al. [4] and Khalil [10] proposed moving window with template matching method in order to recognize each character. This recognition method based on distance measures (Squared Euclidean Distance) technique for matching the moving window and the plate image.

Mansour proposed chain code before applying the moving window. The chain code is used to bind the shapes of character and distinguishing similar characters by local structural features [7].

Ozbay and Ercelebi proposed template matching based on statistical cross-correlation. Each segmented character is normalized to an image of size 36 × 18 [17]. Kasaei et al. [26], Kaushik Deb et al. [27] and Yousef et al. [37] applied a similar technique as in [17] for the recognition process.

Cheng and Bai proposed a hybrid algorithm cascading two steps of template matching to recognize Chinese characters segmented from the LPs, which is based on the connected region feature and standard deviation feature respectively. The templates used are a sequence of 32 matrices of size 32 × 16, which represent 32 Chinese characters that appear in civilian vehicle plates [36].

2.4.2 Artificial Neural Network

Artificial Neural Network (ANN) sometimes known as Neural Network (NN) is a mathematical term, which contains interconnected artificial neurons. This subsection discusses research in the literature are based on ANN as follows:

Abulgasem et al. used the Radial Basis Function Neural Network (RBF NN) with a feature extraction process for recognition. Two features ratio of size and ratio of foreground and background pixels are extracted to determine non-number image, as well as a matrix of size 4 x 2 contains a number feature, which is obtained by dividing a character image into a sequence of horizontal "scan lines" by using the raster scanning. Those features are fed into RBF NN to recognize the number [8].

Shan applied similar NN as reported in [8]. The features vector is composed of 360 feature points, which are extracted by the coarse grid method. The multilevel classification RBF NN is then used as a classifier with feature vectors as input. The first level RBF NN, which contains Chinese character sub-network, capital letter sub-network, mixing sub-network and number sub-network, is designed to rough classification. The second level network is designed for improving the recognition accuracy. It contains several sub-networks classifying the confusable characters, such as 2, 3 and 7 [22].

Dashtban et al. utilized a Multi-Layer Perceptron (MLP) with a feed forward neural network for recognizing characters. Two independent MLPs are used, one for letters and one for numbers with the same internal structure, and each one processed its inputs singly and independently. Third MLP has been trained and used as an intelligent control error unit in order to control the empty segments [13].

Kocer and Cevik encoded the feature vector of a character image by using Average Absolute Deviation algorithm. An MLP model is used as a classifier, in addition to, the numbers and the letters were classified by using two separate ANN to prevent the complexity of recognition of similar numbers and letters such as [0 and O], [2 and Z] and [8 and B]. For training the ANN, feed-forward back-propagation algorithm was chosen and mean square error (MSE) function for measuring the training performance [35]. Ozturk and Ozen used Probabilistic Neural Network (PNN) [32].

Nagare proposed two feature extraction techniques for training and simulating Neural Network. One is Fan-beam Transform and other technique is based on Character Geometry. Fan-beam Transform is used for computing an alternative mathematical representation of an image using Fan-beam projections, which computes projections of an image matrix along specified directions. Character Geometry based on the basic line types that form the character skeleton. In recognition step, Two learning based neural network techniques BP ANN (Back Propagation Artificial Neural Network) and LVQ NN (Learning Vector Quantization Neural Network) are used. The Author used two techniques in order to find out the best recognition technique based upon the time taken and accuracy [20]. Zhang and Wang also proposed BP ANN [23].

Yilmaz combined correlation and LVQ NN in recognition process. The character first passed to the image correlation if its value is greater or equal to the 0.5 then characters is recognized correctly. If it's less than 0.5 then the character is wrong. Finally, it passes to the NN for recognition and accepted the character as the right one [24].

2.4.3 Other Methods

This subsection presents the other methods that were also used to recognize the individual characters. Many different methods have been reported in the literature as follows:

Alginahi proposed the horizontal projection profiles and zoning as features extractor for each character or numeral and Mahalanobis distance and Multilayer perceptron Neural Network (MLP-NN) as classifiers. The Mahalanobis Distance to measure the similarity between the characters tested and the prototype ones and the MLP-NN verifies or rejects the results [6].

Mohammad et al. propose the Support Vector Machine (SVM) as a classifier in addition to four levels of the Haar transform for features extraction process [11]. Shidore and Narote used SVM as a classifier. First, each character image is normalized to a size of 32 X 32, then feature are extracted by the centroid of the character image. With respect to the centroid, the number of transitions along the axes, 0 to 1 and 1 to 0, up to the boundary of character are counted. Transitions are specified for axes with predetermined angles. By observing strokes of each character, 13 different angles are decided to count the transitions. Finally, recognition is achieved using the SVM [18].

Jing-Ming Guo et al. proposed a recognition algorithm. 13 features are employed for each character, and these features are extracted from binarized characters and the corresponding skeleton result. Afterward, Bayesian-based recognition method is adopted for predicting the probabilities and then determining a recognized character associated to which character class [14].

Gao et al. introduced a method for recognition based on an improved hierarchical classification algorithm based on wavelet packet decomposition and SVM. In feature extraction, find an optimal wavelet packet basis in the process of wavelet packet decomposition to obtain eigenvectors. Then the wavelet coefficients of the optimal wavelet packet basis are reduced in dimension (Dimension of eigenvectors) by K-L transform to optimize the performance. In recognition, the characters are identified by SVM. Harris corner detection is used to correct confusing characters such as {2, Z}, {0, D, Q, C, U}, {8, B, R}, {5, 8, S}, {4, A} and {C, G}. Finally, the method is optimized in recognition speed by the algorithm of digital classification decision [29].

Chen et al. propose a multistage classifier that uses the feature-salience algorithm to implement character recognition. A feature such as the zoning density, vertical projection, the left–right contour feature and the line segment features of the input character in each row and column are used [33].

2.5 Previous Work on Sudanese VLPR

Up to now, a considerable amount of literature has been published on VLPR systems in different countries. However, up to the author survey only one work had been found, which introduced by undergraduate students in 2014. Mohamed and Ahmed Almustafa introduced in their graduation project a VLPR system for Sudanese plates. The system receives a color image and convert it into a grayscale image. Prewitt edge detection operator is applied after the gray-scaled image is enhanced. Afterwards, The Convergent edges were linked by using morphological operation in order to form regions, then each region is analysed to extract the LP. In character segmentation phase, the Indian numbers and English characters had been chosen, each part was cropped using the coordinates of its location. Then, each character is segmented by applying histogram equalizer and morphological operations. Finally, Template Matching is performed in character recognition phase. The system was tested over 40 images and the recognition accuracy is 85% [61].

In spite of the undergraduate students have made a great effort in establishing this system, but their system has some limitations, which are described in the following points:

- Small dataset (40 Images).
- Liking edges: Produces errors since it is too sensitive to unwanted edges.
- Using Indian numbers and English characters coordinates: Fails to segment the accurate region when the plate is rotated, or there is a distance between plate frame and plate image borders.
- Screws connected to characters could affect the segmentation accuracy as well as the recognition accuracy.

2.6 Summery

This chapter has presented the theoretical background for the typical system structure of vehicle license plate recognition (VLPR) and review of the state-of-the-art techniques for VLPR system. Firstly, the chapter explored the stages of the typical

VLPR system. These stages are: license plate detection and extraction, license plate character segmentation and license plate recognition. A categorization has been made to the review according to the involved techniques at each stage.

A common license plate detection and extraction methods are explained, such as: edge detection (Vertical edge, horizontal edge, or both), connected component analysis, neural networks, smearing algorithm, fuzzy logic, and sliding concentric window (SCW). In LP character segmentation, a number of methods have been used, for instance, morphological operations, vertical and horizontal projection profile, blob analysis, smearing algorithm, and connected components analysis. While, template matching and artificial neural network are the most popular methods used for LP recognition among other methods.

Moreover, the review explores the most methods used in preprocessing, LP skew correction, and feature extraction.

CHAPTER III

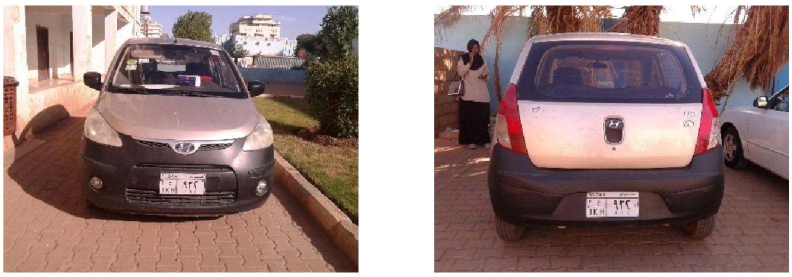
DATASET AND METHODOLOGY

3.1 Introduction

This Chapter gives a description of the data set that can be used in the experiments to evaluate the efficiency of the proposed VLPR system. Besides, it gives an overview of the proposed methodology for the VLPR system framework that achieves an accurate results in all framework stages, which are include license plate detection and extraction stage, license plate character segmentation stage, and license plate character recognition stage.

3.2 Dataset

A Dataset of 375 color images for different Sudanese private vehicle is prepared for the evaluation of the Sudanese VLPR system. The images were captured in a complex outdoor environment by a two handheld digital camera with different resolution, one had 5 megapixel resolution (size of 2576 × 1932), and the second had 3.1 megapixel resolution (size of 2048 × 1536). The images have been acquired from the front as well as from the rear of vehicles as illustrated in Figure 3.1.



(a) **(b)**

Figure 3.1: (a) Vehicle Image from the Front

(b) Vehicle Image from the Rear

Furthermore, the images of the vehicles have been captured on city streets or on parking lots at various times of the day, and under various illumination and such as sunny, daytime, nigh time... etc. The distance between the camera and the vehicle is varying from 2 to 3 meters. Some images samples taken from the Dataset are shown in Figure 3.2.

Figure 3.2: Some Images Samples

Figure 3.2 (a), (b), (g) and (h) illustrate images of typical Sudanese private vehicles, which were captured at different daytime with different illumination. Some images were captured under sun reflection either on vehicle as shown in Figure 3.2 (g) or on camera as shown in Figure 3.2 (c) and (d). In addition, Figure 3.2 (e) and (f) illustrate an example for vehicles in complex backgrounds.

All the images were stored in .jpeg format. Moreover, the images were saved on the hard drive and the processing is performed on them, so that means, they are used off-line., therefor, the overall system is not said to be real-time.

3.3 Methodology

Recently, researchers have shown an increased interest in the field of Vehicle License Plate Recognition [2, 4, 40, 45]. This interest motivates us to develop this system for Sudanese Private Vehicles Identification. According to a number of researchers reports such as in [20, 42, 45, 46], our research in VLPR system for Sudanese private vehicles consists of four main stages, which are image acquisition, License Plate detection and extraction, license plate character segmentation, license plate character recognition. The proposed Sudanese license plate recognition system is shown in Figure 3.3. An overview of each stage is presented in the following subsections.

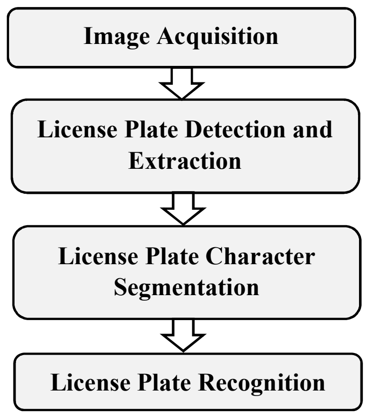


Figure 3.3: Sudanese VLPR System

3.3.1 Image Acquisition

This is the first stage of the Sudanese VLPR system, which provides an input image to the system. Image can be acquired either by using an analog camera with a scanner or by using a digital camera. Image acquisition through analog camera is impractical. The reliable and practical approach is acquiring images through digital camera [8]. Moreover, the video camera can be also used, but in real time applications with a frame grabber, which grabs a single frame in order to handle each frame as an image.

As mentioned in the previous section, images of various parked vehicles have been acquired manually from about 3 meters away using two different digital cameras. In addition, the image shows the front or rear of the vehicle. Thus, the size of the image is 2576 × 1932 pixels or 2048 × 1536 pixels.

3.3.2 License Plate Detection and Extraction

The second stage of VLPR system is LP detection and extraction that attempt to extract the License Plate (LP) from an input image. As per of [2, 4, 48], this stage is an important in the VLPR system, and plays a key role in LP recognition efficiency. Therefore, the research provides more importance to this stage. The colored vehicle image is fed into this stage, which shown in Figure 3.4 (a). The expected output is a LP image without any prior knowledge on where it is located as presented in Figure 3.4 (b).

(a) **(b)**

Figure 3.4: The Input and Output to LPD Stage

At the beginning of the stage, some of the input images, which have the size of 2576 × 1932 pixels, are normalized to the size 2048 × 1536 pixels. As the gray scale decreases the computational time, so the RGB image is converted into a gray scale, which, it carries only intensity information for each pixel [60].

The gray scale image is converted into a binary image using segmentation techniques, such as thresholding and edge detection. In image processing, segmentation is the process of partitioning an image into several segments or partitions. Segmentation is used for locating objects and boundaries in an image. It is also useful to change the representation of an image for easy analysis and manipulation. Afterward, a morphological operation such as dilation, erosion, open, and close are used to eliminate unwanted regions.

The resultant binary image is labeled in order to identify regions in the image (each region of connected pixels is called connected component). Then Connected Components Analysis (CCA) is used to analyze the regions independently and measure the property of each region. Since the Sudanese LP has unique features such as the following: rectangular shape, the ratio of the width to height of the rectangle is fixed and the area of the rectangle, those features are useful to identify the plate region.

3.3.3 License Plate Character Segmentation

LP character segmentation is the third stage of the VLPR system. The main goal of this stage is to find the individual characters (digits and alphabets) and extracting those characters from the plate image. Therefore, the input to this stage is the extracted LP image, while, the output is the individual character images as illustrated in Figure 3.5.

There are many problems can be facing this stage, for instance, the influence of image noise, plate frame, plate screw, plate skew and illumination variance. Therefore, as shown in Figure 3.5 this stage is constructed in two main steps, which are, skew correction and character segmentation in order to overcome these problems.

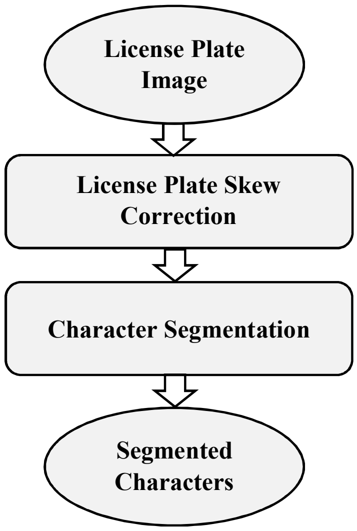


Figure 3.5: License Plate Character Segmentation Steps

The skew LP can influence the accuracy of character segmentation and indeed the recognition as well [41, 43, 44]. Therefore, it is important to implement a method, which is able to correct skewed LP, where, the LP can be rotated and skewed due to the positioning the vehicle towards the camera. According to the state of the art of VLPR system, various methods have been developed and introduced to compute the skew angle. For this study and according to Sudanese LP layout and type, the skew correction method is based on detecting the starting and ending points of the middle horizontal line as shown in Figure 3.6. The two points are distinct which forming a straight line, then the mathematical concept of the linear function is used to compute the slope angle of a straight line, which handled as a LP skew angle.

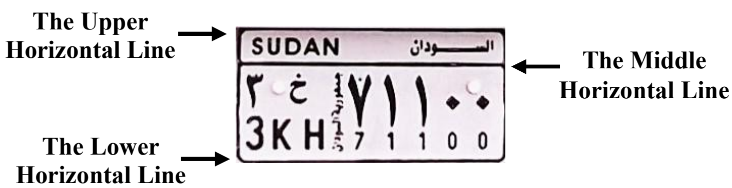


Figure 3.6: Three Horizontal Lines Crossing the Plate

The skew corrected grayscale image is passed to the next step, which is the character segmentation step. Image noise, plate frame and screw problems are handled by using techniques such as morphological operation such as bottom-hat and opening, vertical and horizontal projection profile, prior knowledge of the LP and CCA are used in order to isolate individual characters.

As mentioned beforehand, the Sudanese vehicle LP consists of digits and alphabets, digits have been written in Arabic and Indian forms, alphabet have been written in English and Arabic forms. In this study, the Indian numbers and English characters are cropped from the LP image. The cropping process produces two images, Arabic numbers and English characters images. Each of two image proceeds with the subsequent steps, which are concerned about screw elimination and segment the components of each image.

3.3.4 License Plate Character Recognition

The fourth and last stage of the VLPR system is the LP character recognition, which aim to convert a character image into an editable text, where each segmented character is recognized individually [37]. For this study, the recognition process performed by using two different recognizer to recognize the Indian numbers and English characters separately. Since, the recognition process is performed separately based on different regions of the LPs; speeds up the processing due to the limited number of comparisons [6].

In Indian number recognition, a novel approach based on salient features is used to recognize each digit separately. On the other side, English character is recognized using template matching techniques.

According to the state of the art, template matching based on binary images is simple, straightforward and effective method used in the Optical Character Recognition (OCR) [17, 37], in which the input character image is compared with a set of stored templates from each character class and the best similarity is measured. As noted by Yousef et al [37] template matching is useful for recognizing single- font, non-related, non-broken, and fixed-size characters, and therefore it used in English character recognition.

3.4 Summery

This chapter has introduced the dataset that is used in the experiments and the methodology that is followed in order to conduct the experiments. The dataset consists of 375 color images of different Sudanese private vehicles, which are captured manually on city streets or on parking lots at various times of the day, where the distance between the camera and the vehicle is varying from 2 to 3 meters.

The research methodology of the Sudanese VLPR system composed of four stages, image acquisition, License Plate detection and extraction, license plate character segmentation, license plate character recognition. Each stage is performed by using the proposed techniques in order to achieve it is task.

CHAPTER IV

LICENSE PLATE DETECTION AND EXTRACTION

4.1 Introduction

This chapter presents the construction of License Plate Detection and Extraction method as the second stage of Sudanese Vehicle License Plate Recognition (VPLR) System. The results of this method have been published in [47].

License Plate Detection (LPD) has been considered as the most important and essential stage of VLPR systems, which is directly, influences the success and the accuracy of VLPR systems [2, 4, 48]. For that, LPD requires more attention; moreover detecting a License Plate (LP) on a complex background is a difficult task. Thus, there are many factors should be considered in order to successfully detect and extract the LP, for example [2, 4, 48]:

1. LPs normally, occupy a small portion of the whole image.
2. The difference of LPs in formats, styles and colors from country to others.
3. In most cases, the detecting is performed without prior knowledge of the license plate's location in the image.
4. The probability of facing some common drawbacks which could influence the efficiency of the extraction, such as, blurry image, uneven or low illumination, vehicle motion, low resolution of the image, distorted characters, dirty plate, shadows or reflection… etc.

4.2 The Proposed LP Detection and Extraction Method

The proposed method designed for Sudanese vehicle LPD. It is composed of four steps, including green channel and edge detecting, regions of interest filtration, dilation and candidate regions detection, and accurate plate detection and extraction, as shown in Figure 4.1.

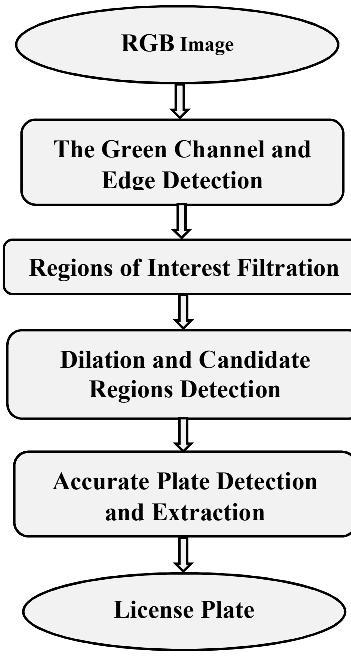


Figure 4.1**:** LP Detection and Extraction

The input of the method as illustrated in Figure 4.2 is the original image of the vehicle on the RGB scale of size 2576 × 1932 pixels or 2048 × 1536 pixels taken from real scene.

Figure 4.2: RGB Image

First, if needed the input image is resized to size 2048 × 1536 pixels. The details of other steps are presented in the following subsections.

4.2.1 The Green Channel and Edge Detection

The RGB image consists of three channels red, green and blue, the value of each channel in the range 0- 256, whereas the gray scale image contains just one channel [49]. Thus, extraction of one channel decreases the computational time, as well as the storage space. Experiments showed that the green channel provides sufficient contrast for the image, which in turn directly increases the efficiency of the proposed method than other channels or gray conversion. Thus, green channel extracted as in Figure 4.3.

Figure 4.3: Green Channel Extraction

Afterwards, median filter is applied to remove noises like random occurrences of black and white pixels.

The next step is edge detection. Edges in images are areas with strong intensity contrasts, which represent a boundary between different regions. Detecting the edges of an image significantly reduces the amount of data and it helps in filtering out the useless information.

Primary investigation of this research shows that Sobel edge detection has better results on the Sudanese vehicles dataset. The Sobel edge detector applies a 3x3 mask on the input image and gives the resultant binary image as presented in Figure 4.4 (a). Then, dilation operation with disk structural element is performed to thicken the edges; that is due to edge's lines do not completely cover the region of interest. Figure 4.4 (b) shows the resultant image.

(a)

(b)

Figure 4.4: (a) Edge Detection (b) Thicken Edge

4.2.2 Regions of Interest Filtration

Filtration process is performed either to select regions that satisfy some particular features or eliminates unwanted regions on the image [3]. Filtration get the main aim of this step done, which is to obtain a filtered image has as possible all LP contents except its boundaries. The step begins with removing the very small regions based on the number of white pixels of each one (Region Area). Afterwards, all regions in the resultant image were detected; their widths and heights used as features to select regions have a specific width and height. Although LP contents are successfully well segmented, but there are some regions belong to the background are also selected, as shown in Figure 4.5.

Figure 4.5: License Plate Contents Selection.

Thus, those unwanted regions should be removed or reduced. This is achieved by filling each region in the image and calculating their areas. Then, the region is selected if its area is greater or equal to A_{min} and less or equal toA_{max}, otherwise the region is removed, where:

$\boldsymbol{A_{min}}$**:** Minimum Region Area

$\boldsymbol{A_{max}}$**:** Maximum Region Area

A_{min} and A_{max} have been set during the experiments. Figure 4.6 shows the resultant image.

Figure 4.6: Remove Unwanted Regions

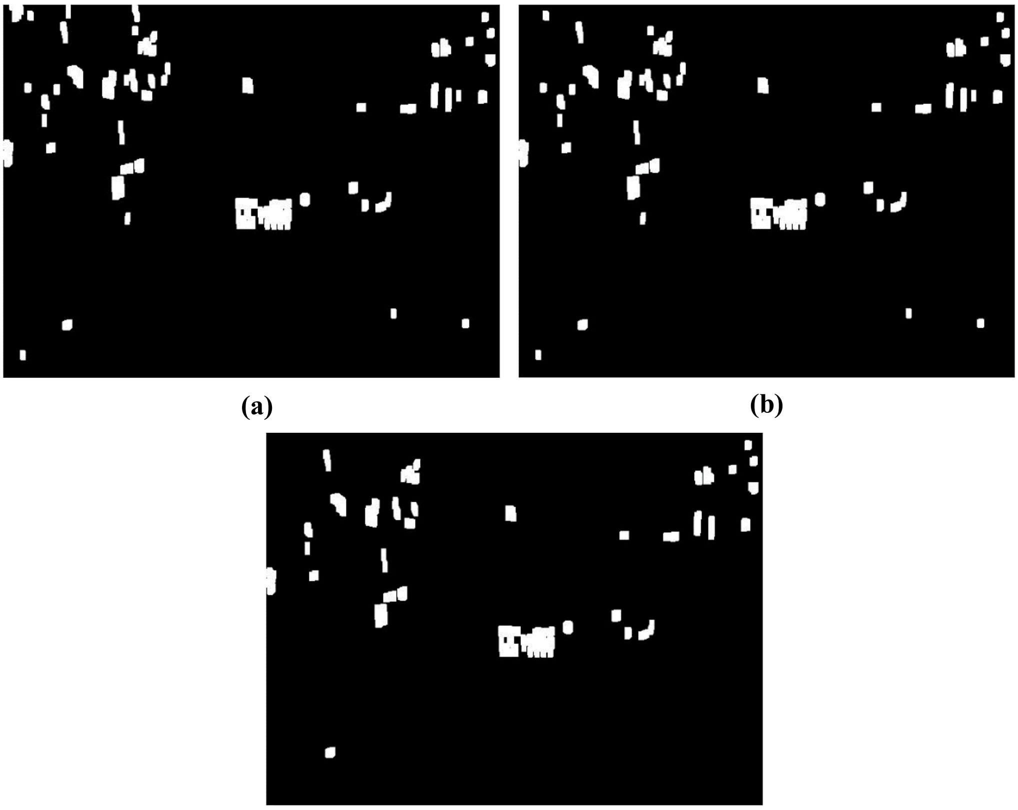
4.2.3 Dilation and Candidate Regions Detection

The aim of this step is to obtain the candidate regions that might be the LP region. It is based on the idea of merging the closed regions as well as removing unwanted regions. Therefore, the morphological operation dilation has been used with a specific structuring element (SE) to expand the regions. When regions expand, the gaps reduced.

According to the Sudanese vehicle LP layout as mentioned in chapter I, the dilation operation is employed three times with different SE values to merge each group of the LP components separately. For instance, suppose that the LP is divided into two parts vertically from the metallic bar, and then each part (Left/Right) contains three rows of characters as illustrated in Figure 4.7.

Figure 4.7: Visualization of How the Plate Vertically Divided

First performing dilation with a SE value of size 30×15 pixel to merge the three rows of characters of each left and right part separately. Then removing any regions contiguous to the border of the resulting image and others regions those their areas less than the expected area of each of the merged two parts as in Figure 4.8.

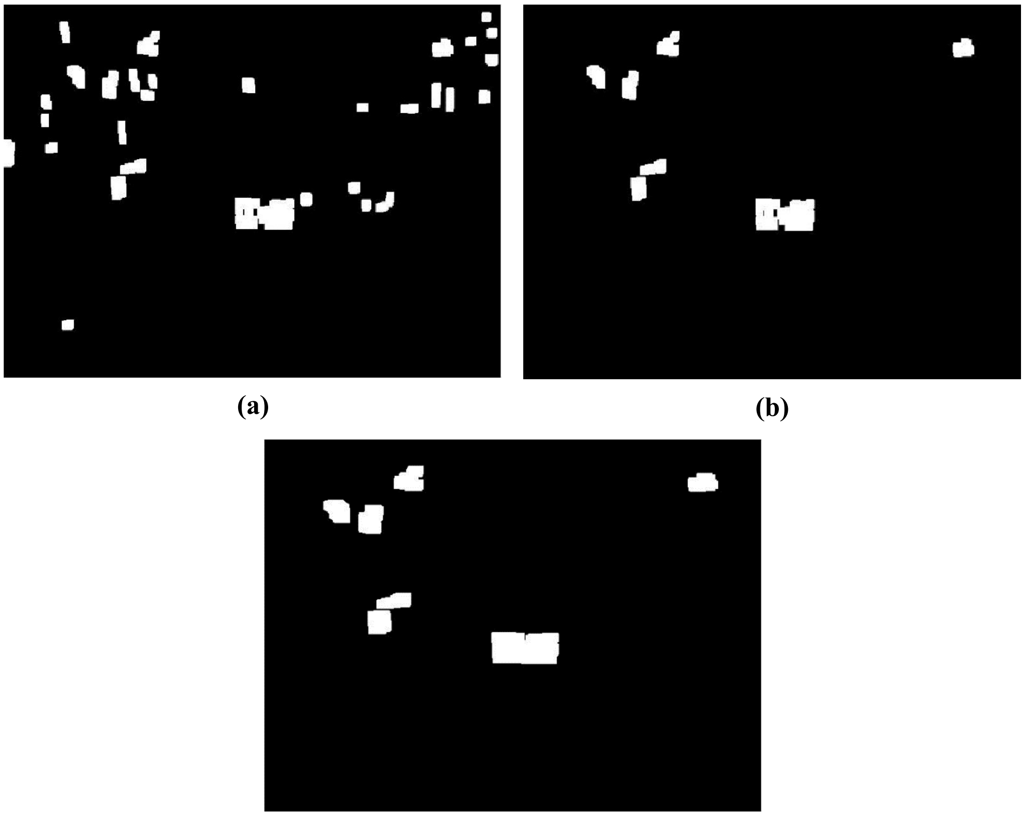


(a) **(b)**

(c)

Figure 4.8: Perform First Dilation. (a) First Dilation. (b) Removing Regions Contiguous to the Image Border. (c) Removing Small Regions.

The purpose of second and third dilation is to join the two parts horizontally. This is achieved by using a special single row-SE to restrict the expansion of regions along the horizontal direction only. After the second dilation, the bigger regions than a specific area value were selected, and then third dilation performed as shown in Figure 4.9.



(a) **(b)**

(c)

Figure 4.9: Perform Second and Third Dilation (a) Second Dilation.
(b) Selecting Regions Bigger Than A specific Area. (c) Third Dilation.

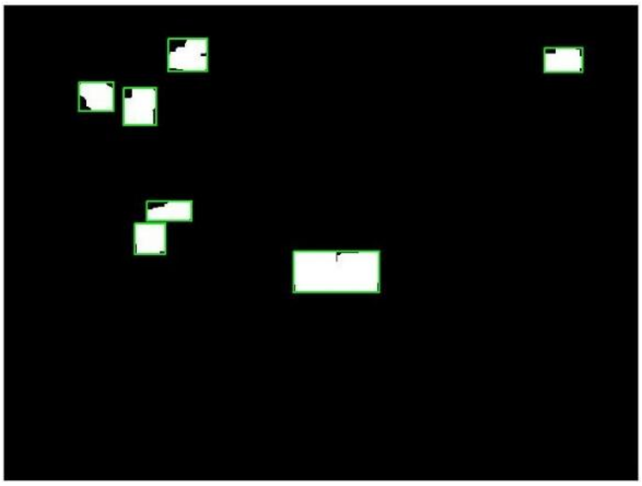
4.2.4 Accurate Plate Detection and Extraction

The license plate detection and extraction step identifies the accurate region of the LP. The connected components (regions) analysis is performed to identify each region in the resulting binary image from the previous stage. For each connected component in the image, some features are calculated in order to identify the LP region. While each connected component surrounded by smallest rectangle as illustrated in Figure 4.10 (a). Figure 4.10 (b) shows the corresponding rectangle on RGB image. The features are explained as follows:

a. Height to width ratio (aspect ratio).

b. The rectangle area (height × width).

c. The possible number of white pixels in the rectangle.



(a)

(b)

Figure 4.10: Connected Components. (a) Connected Component Surrounded By Smallest Rectangle. (b) Corresponding Rectangle on RGB image.

Beside beforehand mentioned features, the accurate plate region is detected if the region position in the lower two third of the image. Figure 4.11 shows the result of this stage.

Figure 4.11: Extracted License Plate

4.3 Experimental Results and Discussion

Experiments have been carried out under MATLAB R2013a (Version 8.1.0.604) environment to test the proposed method and to measure its accuracy. The computer used for running the experiment is a notebook, with an Intel core i5 2.2 GHz CPU and 4 GB RAM. 375 color images with size of 2048 × 1536 pixels used for testing the method. Tested images have been captured in the real scene, and the distance between the camera and the vehicle varied from 2 up to 3 meters.

The results of the experiments are presented in Table 4.1. It shows the detection and extraction of the plate region accuracy is 98.6%.

Table 4.1: LP Detection and Extraction Experiments Results

Total Number Of Images	Successful Extraction	Unsuccessful Extraction
375	370	5
%	98.6%	1.4%
Processing Time	0.97 to 1.47 Seconds	

Based on these results, the method shows satisfactory and encouraging results, making it efficient to cope with some difficulties, such as, variations of the lighting conditions and complex background, as well as some other drawbacks. Figure 4.12 shows several results of LP detection and extraction by using our method, which could be discussed as follows:

- Figure 4.12 (a) shows a typical Sudanese private vehicle with a LP containing stickers and surrounded by a black decorative frame.
- The plate region is perfectly extracted even though in very poor illumination or nearly dark image, as in Figure 4.12 (b).
- The reflection of the sun either on the camera or on the plate region, as illustrated in Figure 4.12 (c) and (d) respectively.
- Furthermore, in Figure 4.12 (e) and (f), the LPs were accurately extracted even though some difficulties, such as, sun reflection and a silver frame around the plate region, and damaged plates or faded plate's characters respectively.

On the other hand, the failure in detection and extraction as illustrated in Figure 4.13 could be due to the following

- Damaged plates or faded plate's characters (Similar to background color) as in Figure 4.13 (a).
- Decorative items covered the plate region as in Figure 4.13 (b).
- The reflection of the sun on the plate region as in Figure 4.13 (c).
- Vehicle with characters around plate region, which are similar in fonts to LP components, and that causes not detecting the precise plate location as illustrated in Figure 4.13 (d).
- Extremely poor illumination produces a very dark image as in Figure 4.13 (f).

(a) (b)

(c) (d)

(e) (f)

Figure 4.12: The Results of License Plate Detection and Extraction for Several Vehicles

(a) **(b)**

(c) **(d)**

(f)

Figure 4.13: Failure in LP Detection (a) Completely Fading Characters Color. (b) LP Covered by Decorative Items. (c) Reflection of The Sun on the Plate Region. (d) Vehicle with Characters Similar in Fonts to LP. (f) Extremely Poor Illumination

4.4 Summery

This chapter presents a method for an automatic vehicle license plate detection and extraction. The proposed method is mainly designed for Sudanese LP, according to the literature, it is considered as the first of its kind for Sudanese vehicle LPs.

According to the state of the art of vehicle LP extraction, the proposed method is implemented through four stages: green channel and edge detecting, region of interest filtration, dilation and candidate regions detection and accurate plate detection/extraction.

The proposed method succeeds in detecting and extracting the plates efficiently and accurately with high rate percentage 98.6.

CHAPTER V

LICENSE PLATE CHARACTER SEGMENTATION

5.1 Introduction

After the License Plate (LP) is successfully detected and extracted, as mentioned in the previous chapter. So, before the recognition of LP process starts, the characters on the LP image should be segmented. Therefore, this chapter describes the LP character segmentation stage.

LP character segmentation is a significant stage in VLPR system. The main objective of this stage is to find the individual characters (digits and alphabets) and extracting those characters from the plate image. The study focuses on segmenting the English characters and Indian numbers as shown in Figure 5.1.

Figure 5.1: English characters and Indian numbers within Sudanese Private Vehicle License Plate

Thus, the English characters and Indian numbers are considered as the regions of interest (ROI). According to Sudanese LP design, the selected ROI has many features compared with the corresponding region of the same plate image in order to prevent complexities of characters segmentation and characters recognition; this could be explained as follows:

- Indian numbers much larger and clearer. Moreover, it occupies the center of the plate and less affected by changes or damages.

- English characters do not contain similar characters as in the Arabic characters (for instance: خ ‘ ج ‘ ح) which causes the complexity of recognition. In addition, unlike the region of Arabic characters, the screws for fitting the plate on vehicle are rarely found in the region of English characters.

However, there are many difficulties in this stage, such as the influence of image noise, plate frame, plate screw, plate skew and illumination variance, the segmentation process is constructed in two steps: skew correction and character segmentation in order to overcome these problems. Each step composes of sub steps as explained in the next sections.

5.2 Skew Correction

The LP can be rotated and skewed in many ways due to the positioning the vehicle towards the camera. Since the skew LP considerably has a great influence on the accurate character segmentation and recognition [41, 43, 44], it is important to implement an additional mechanism, which detects and corrects skewed LP. Vehicle LP has horizontal and vertical skew [43, 44]. Figure 5.2 shows un-skewed, positive and negative skewed LP image respectively. Where α and β are horizontal and vertical skew angle respectively.

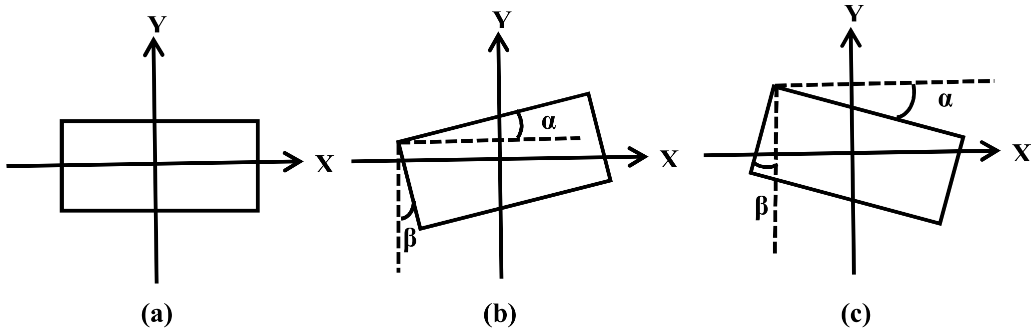


Figure 5.2: Skew Angle, (a) Un-skewed Image. (b) Positive skewed Image. (c) Negative skewed Image. [43]

According to the state of the art of VLPR system, the basic problem of skew correction is to determine an angle, under which the LP is skewed. There are several satisfactorily accurate techniques available in the literature to calculate the skew angle such as Least Square and Centroid method [7, 33], Connected Component Analysis [50], Principal Component Analysis [43, 44], Hough Transform method [13, 42] and Radon Transform method [12, 40]. There are problems faced by most of the skew correction techniques, for instance, depending on LP layout and type or size of fonts, depending on LP upper and lower boundaries which mostly are not clear or damaged and high computational cost.

Therefore, to correct the skew of Sudanese vehicle LP image, a simple and fast method to compute the skew angle is proposed, which based on detecting the starting and ending points of the middle horizontal line that split the LP into upper and lower parts as illustrated in Figure 5.3.

Figure 5.3: The Middle Horizontal Line

The proposed skew correction method involves several steps, which are contrast enhancement and binary conversion, filtering unwanted regions, and computing skew angle. The following subsections describe each step individually.

5.2.1 Contrast Enhancement and Binary Conversion

Contrast Enhancement and Binary Conversion are the first step and considered as a pre-processing step. The input to the method is a gray scale LP image, which acquired from the LP Detection and Extraction stage, see Figure 5.4 (a). In order to improve the contrast in the LP image Contrast-Limited Adaptive Histogram Equalization (CLAHE) is used as illustrate in Figure 5.4 (b). CLAHE operates in small regions in the image, called tiles, rather than the entire image [49, 51, 52]. Each individual tile's is processed using histogram specification. In our experiments, CLAHE provides better results for enhancing low-illumination LP images than other contrast enhancement techniques.

In binary conversion, the enhanced grayscale image is converted into binary scale image (Black & White). It is important to use an effective technique for binarization in order to clearly separate the plate contents in the LP image from the background. Therefore, our method performs this task using a well-known Otsu's method [53]. The Otsu's method calculates the optimal global threshold value for binarization process, which is widely used for binarizing the gray-scale images due to its accurate results and high speed [48]. As a result, the plate characters and boundaries are properly segmented and appeared clearly after binarization, as shown in Figure 5.4 (c).

(a) **(b)** **(c)**

Figure 5.4: Contrast Enhancement and Binary Conversion (a) Gray-scaled Image (b) Contrast Enhancement by CLAHE (c) Binary-scaled Image

5.2.2 Filtering Unwanted Regions

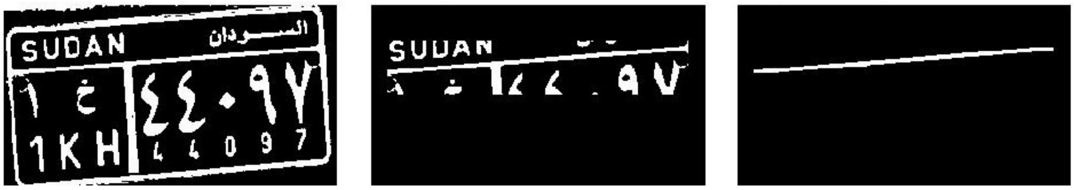
The main aim of this step is to eliminate plate characters and its four side boundaries (Upper, Lower, Left and Right) and keep the middle horizontal line as the region of interest. Based on the size of the LP image being processed, LP boundaries are eliminated by replacing white pixels by black pixels in specific parts of the LP image as follows:

- Upper Boundary: Scan the First fifth part of the LP image horizontally, and change pixel values to Zero.
- Lower Boundary: Scan the last third part of the LP image, and change pixel value to Zero.

- Left Boundary: Scan the first fifteenth columns in the LP image, and change pixel values to Zero.
- Right Boundary: Scan the last fifteenth columns in the LP image, and change pixel values to Zero.

Working on the complement of the binary-scaled image as in Figure 5.5 (a). The resultant image after eliminating the four boundaries is shown in Figure 5.5 (b). In addition, it is clear that, most of the characters or considerable parts of characters have been reduced.

As obvious in Figure 5.5 (b), above and below the middle line, there are some regions belong to the plate characters, which are handled as unwanted regions. So, in order to filter out those unwanted regions, morphological opening operation with linear Structuring Element (SE) of length 20 is implemented. Then, based on the number of pixels (Region Area) that forming each region in the result image, regions smaller than *m* pixels are removed. The value of *m* has been set during the experiments to 160 pixels. Figure 5.5 (c) illustrated the resultant image.



(a) **(b)** **(c)**

Figure 5.5: Filtering Unwanted Regions Step (a) Complement of the Image
(b) Plate's Four Boundaries Elimination
(c) Open Operation and Removing Specific Regions

5.2.3 Computing Skew Angle

The main goal of this step is to compute the skew angle (Slope Angle). According to the prior knowledge in mathematical concepts about the Linear Function, the slope of a line is defined as follows: Let (x_1, y_1), and (x_2, y_2) be distinct points on the line. Then the slope (m) of the line is given by:

$$m = \frac{y_2 - y_1}{x_2 - x_1} = \frac{change\ in\ y}{chang\ in\ x} \qquad \text{.................................. (1)}$$

Then the slope angle Ө is given by

$$\Theta = tan^{-1} m = tan^{-1} \frac{y_2 - y_1}{x_2 - x_1} \qquad \text{.............................. (2)}$$

Regarding to the Sudanese plate skew problem, the previously mentioned, the mathematical concept is utilized to compute the skew angle. Therefore, the image in Figure 5.5 (c) is processed in this step to detect the two points on the horizontal middle line, which represent its starting and ending points. Consequently, the entire image has been fully scanned vertically from the first column up to the last column, and recording the coordinate of the first pixel and the coordinate of the last pixel.

Figure 5.6 (a) shows the line that connects the two detected points on the middle line and Figure 5.6 (b) shows the corresponding line on the original gray-scaled image. By detecting the two points, the skew angle Ө was computed directly from Equation (2). Finally, rotate the entire original input image in reverse direction by the computed angle, as shown in Figure 5.6 (c).

(a) **(b)** **(c)**

Figure 5.6: Computing Skew Angle Step (a) The Red Line Connects The Two Points. (b) The Red Line on The Original Gray Image. (c) Skew Corrected Image.

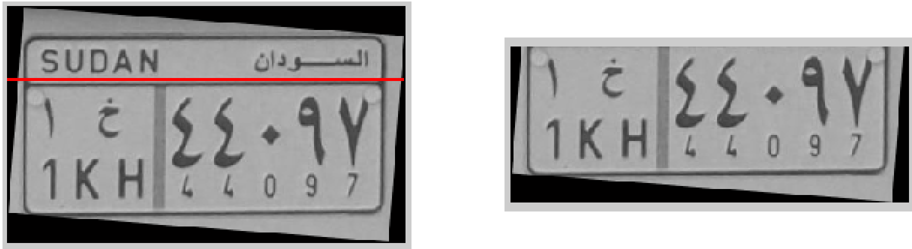
5.3 Character Segmentation

The skew corrected gray-scale image is passed to this step in order to find the individual characters (Indian digits and English characters) and extracting characters on the plate image. Regarding the difficulties facing this task as mentioned previously, the influence of image noise, plate frame and screw, plate skew and illumination variance. Plate skew had been solved in section 5.2; the other factors are solved in this step. Techniques such as morphological operation, Vertical and Horizontal Projection Profile, prior knowledge of the LP and connected components analysis are used in order to achieve the segmentation task. The character segmentation algorithm works in four major steps, which are Eliminating LP upper part and detect LP boundaries (Frame), Regions of Interest Extraction based on Bottom-hat filter, Indian numbers segmentation and English characters segmentation. Each step discussed separately in the next subsections.

5.3.1 Eliminating LP Upper Part and Detect LP Boundaries (Frame)

Depending on the research scope, the upper part of the Sudanese vehicle LP contains the word "SUDAN" and the word "السودان" which are unuseful information. On the other hand, it is observed that, most of the plate images have an inequality distance between the image border and the plate boundaries (Frame). In this step, the gray skew corrected plate image is processed to eliminate the upper part of the LP, then keeping the plate frame as possible contagious to the image border, this is useful for the subsequent sub steps.

In order to eliminate the upper part, the larger value of the two detected points in the skew correction step is used. As these two points identify the location of the middle line that separates between the upper part and lower part, so the upper part is eliminated by cutting the original image horizontally in half based on that point, and keeping the lower half for further processing. Figure 5.7 (a) shows the middle horizontal line on the skew corrected image, and the resultant image is shown in Figure 5.7 (b).

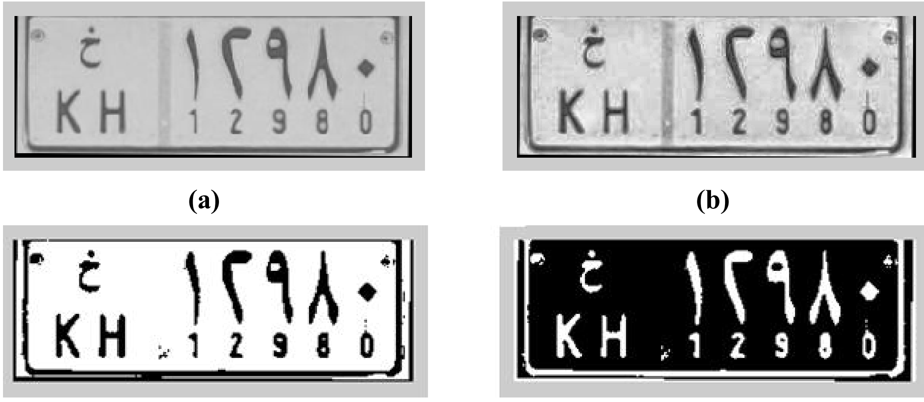


(a) **(b)**

Figure 5.7: Eliminating LP Upper Part (a) Middle Line on Skew corrected Image. (b) The Result Image.

Next, based on Vertical Projection and Horizontal Projection the three plate's boundaries (Left, Right and Bottom) are detected and the plate image is cropped along with these plate boundaries coordinates. Vertical projection and horizontal projection are very useful in this case if the plate boundaries are appearing clearly, so some enhancement techniques should be implemented. CLAHE method is used to improve plate image contrast, and then Otsu method [53] is used in the conversion to binary scale, these two methods are used in the same way as mentioned in section 5.2.1. As a result, the plate boundaries appear clearly after improving contrast and binarization, as shown in Figure 5.8 (a), Figure 5.8 (b) and Figure 5.8 (c).

The complement of the binary image is obtained as in Figure 5.8 (d) in order to apply both vertical projection and horizontal projection to detect vertical lines (the left and right boundaries) and horizontal lines (Bottom boundary) respectively.



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

Figure 5.8: (a) Input Gray Image. (b) Contrast Enhancement by CLAHE. (c) Binary Image. (d) Complement of the Binary Image.

Suppose that, the plate image is divided vertically into four parts for accurate and sufficient detection of left and right plate's boundaries, then the vertical projection is performed for the first and last parts to detect left and right boundaries respectively, the algorithm is explained as follows:

1. Start
2. LeftBoundary = 0
3. RightBoundary = 0
4. Get the size of the plate image, (NoRows, NoColumns)
5. VP = the vertical projection of the plate image
6. cols = floor(NoColumns /4)
7. for i = col down to 1 do
   if VP(i) > (NoRows - 28)
      LeftBoundary = i + 1
      break for
8. if LeftBoundary = 0
   LeftBoundary = the position of max value of VP(1 : cols)
9. for j = 3*cols up to NoColumns do
   if VP(j)) > (NoRows - 18)
      RightBoundary = j + 1;
      break for

10. if RightBoundary = 0

RightBoundary = The position of max value of VP(3*clos : NoColumns)

11. End

Where, the constant values in (NoRows - 28) and (NoRows - 18) are set during the experiments. When applying this algorithm the best position of columns that are forming the left boundary and right boundary are set. In the same way, the horizontal projection is applied to detect the bottom boundary, but the plate image is assumed to be divided horizontally into three parts, then the horizontal projection is performed to the third part, the following algorithm describes the way it works:

1. Start

2. BottomBoundary = 0

3. Get the size of the plate image, (NoRows, NoColumns)

4. HP = the horizontal projection of the plate image

5. rows = floor(NoRows /3)

6. for i = 2* rows up to NoRows do

if HP(i)) > (NoColumns - 100)

BottomBoundary = i + 1;

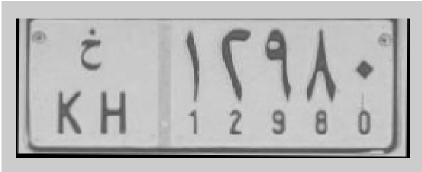
break for

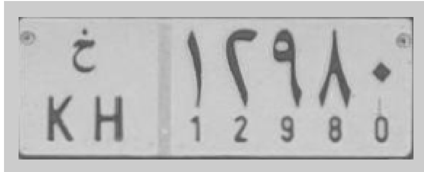
7. if BottomBoundary = 0

BottomBoundary = the position of max value of HP(2*rows : NoRows)

8. End

Where, the constant value in (NoColumns - 100) is set during the experiments. As LeftBoundary, RightBoundary and BottomBoundary values represent new positions of left and right columns and bottom row of the plate image, so it cropped according to new coordinates as illustrated in Figure 5.9 (a) and Figure 5.9 (b).





(a) **(b)**

Figure 5.9: (a) Input Gray Image (b) Result after Detecting LP Boundaries

5.3.2 Regions of Interest Extraction Based on Bottom-hat Filtering

This step focuses on segmenting the English characters region and Indian numbers region, which are considered as ROI as mentioned previously in section 5.1. Therefore, this achieved through contrast enhancement, binary conversion and prior knowledge of Sudanese private vehicle LP.

It is necessary to increase the contrast of images first to provide a better transform representation for later image analysis steps. In the proposed algorithm, morphological bottom-hat transforms is utilized to perform the contrast enhancement. The bottom-hat operation involves subtracting the input image from the result of performing a morphological closing on the image itself [49]. The Bottom-hat filter with disk structure element is applied to the gray image of Figure 5.9 (b). The results are illustrated in Figure 5.10 (a) and Figure 5.10 (b). In the next step, image contrast is improved using Equation (3), by subtracting the result image of performing a morphological bottom-hat from the input image of Figure 5.9 (b). Consequently, as illustrated in Figure 5.10 (c) the plate characters appear darker and effectively isolated from the background. Mathematically, the difference image I_{Result} between two images $I_{Original}$ and $I_{Bottom-hat}$, is generated by computing the difference 't' between all pairs of corresponding pixels in $I_{Original}$ and $I_{Bottom-hat}$ [49], as formulated in Equation (3).

$$I_{Result}(x,y) = \begin{cases} t & if\ I_{Original}(x,y) - I_{Bottom-hat}(x,y) > 0 \\ 0 & Otherwise \end{cases} \quad \ldots\ldots (3)$$

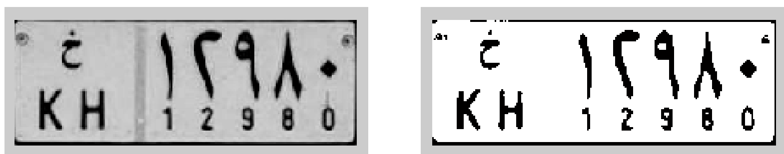
(a) **(b)** **(c)**

Figure 5.10: (a) The Input Gray Image. (b) After Performing Bottom-hat.
(c) The Result Image of Subtraction Operation.

The next step is to cut out the ROI that mentioned in section 5.1 based on the prior knowledge of LP [2, 54, 55, 56]. For different Sudanese private vehicle images acquired from various kinds of scenes, the sizes of the LP images are different. Thus, the prior knowledge of Sudanese private vehicle LP can be described with respect to different plate image size, as follows:

- The ROI location within the LP image, taking into consideration the aspect ratio of the LP image.
- The size of the area occupied by the ROI within the LP image.
- Ratio of the interval between plate's components.

The advantage of this technique is simple and efficient, to eliminating most of noise and unwanted regions such as the plate frame, the metallic bar or the vertical text, Arabic characters and Arabic numbers. The ROI is extracted from a binary-scaled image for subsequent individual characters isolation and extraction. So, Otsu method [53] is utilized to convert the enhanced image of Figure 5.10 (c) into a binary image as shown in Figure 5.11 (a) and Figure 5.11 (b).



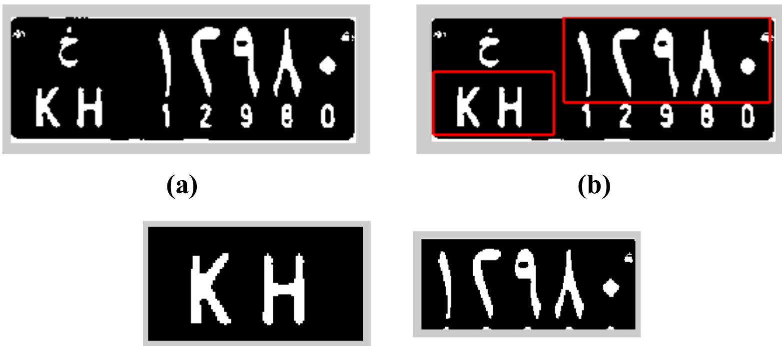
(a) **(b)**

Figure 5.11: Binary Image Conversion (a) Enhanced Image.
(b) Binary-scaled Image.

Therefore, the complement of the result binary image of Figure 5.11 (b) is used to extract the ROI based on the prior knowledge of the LP as mentioned above. Figure 5.12 (a) shows the complement of the plate image. As obvious in Figure 5.12 (b), the interested two regions represent a rectangle shape, therefore, in order to get the regions correctly from the image, the coordinates of top left corner and bottom right corner for each region are set upon the prior knowledge as follows:

- English Characters region (Left Part) coordinates are (w * 0.44, h * 0.01) and (w * 0.95 , h * 0.36)
- Indian Numbers region coordinates (Right Part) coordinates are (1, h * 0.385), and (w * 0.72, h * 0.99)

Where, w and h denote, respectively, the width and height of the plate image. The results are shown in Figure 5.12 (c) and Figure 5.12 (d).



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

Figure 5.12: (a) Complement of the Image. (b) ROI Surrounded by a Red Rectangle. (c) English Characters Image. (d) Indian Numbers Image.

5.3.3 Indian Numbers segmentation

The principal objective of this step is to isolate and extract each number in Figure 5.12 (d) based on Connected Components Analysis [6, 8, 18, 37]. Some regions such as screws and other leftover noises can influence segmentation accuracy. Therefore, it is necessary to remove all these undesired regions. Following are the sub steps that are performed to achieve accurate Indian numbers segmentation, which are handled Indian numbers image in Figure 5.13 (a):

1. Morphological opening operation with disk SE is performed twice. First, on the first five rows of the image, and second, on the last five columns of the image. This is due to some screws are contagious to a number and image's upper border as well, or contiguous to the last number and image's right border as well. The result is illustrated in Figure 5.13 (b).

2. As in Figure 5.13 (c), any region contiguous to the border of the image is removed using morphological reconstruction [49]. Thus, we can eliminate unnecessary regions, while the numbers will not be affected because a black background surrounds them.

(a) **(b)** **(c)**

Figure 5.13: Removing Regions Contiguous to the Image Border
(a) Indian Numbers Image. (b) Result After Morphological Open.
(c) Result after Removing Regions Contiguous to the Image Border.

3. A specific filter is used for eliminating only screws contiguous to the numbers, which directly influence the accuracy of the number segmentation. This filter processes the gray-scaled image of Figure 5.10 (a) to locate the screw position. The following sub steps describe how it works, which are handling the image shown in Figure 5.14 (a) as a representative sample for this case:
   a. The gray-scaled image is converted into a binary-scale by using Otsu method [53], but the value of the threshold is reduced by Equation (4) in order to insure that no existence of contiguity between adjacent regions as far as possible.

$$T_{new} = T_{Otsu} * 0.9 \qquad \text{..........................} \quad (4)$$

Where, T_{new} and T_{Otsu} are the new threshold and the threshold that calculated by Otsu method respectively. Figure 5.14 (b) shows the resultant image.

b. Crop the Indian numbers region in the resulted binary image by using the same coordinates calculated previously in section 5.3.2. Figure 5.14 (c) shows the result image.

c. Find the location of the screw region in the resultant Indian numbers image as shown in Figure 5.14 (d), and then remove the screw region in the corresponding location in the original Indian numbers image, which illustrated previously in Figure 5.13 (c). Figure 5.14 (e) shows the original Indian numbers image of the representative sample, in addition, Figure 5.14 (f) shows the result of removing screw region in the corresponding Indian numbers image of Figure 5.14 (e). The searching of screw location algorithm has been designed, taking into consideration the following points, which have been observed and investigated during the experiments:

- There is a space between adjacent Indian digits, this mean, each digit region start and ends by different column value.
- The digit zero in Indian “٠” has the same features as a screw.

The following algorithm describes how to find screw's position:

a. For all regions in the image do

1. If region area <= 250 pixels and not connected to lower image border then

1.1 startCl = First column of the region.

1.2 endCl = Last column of the region.

1.3 for all remaining regions .

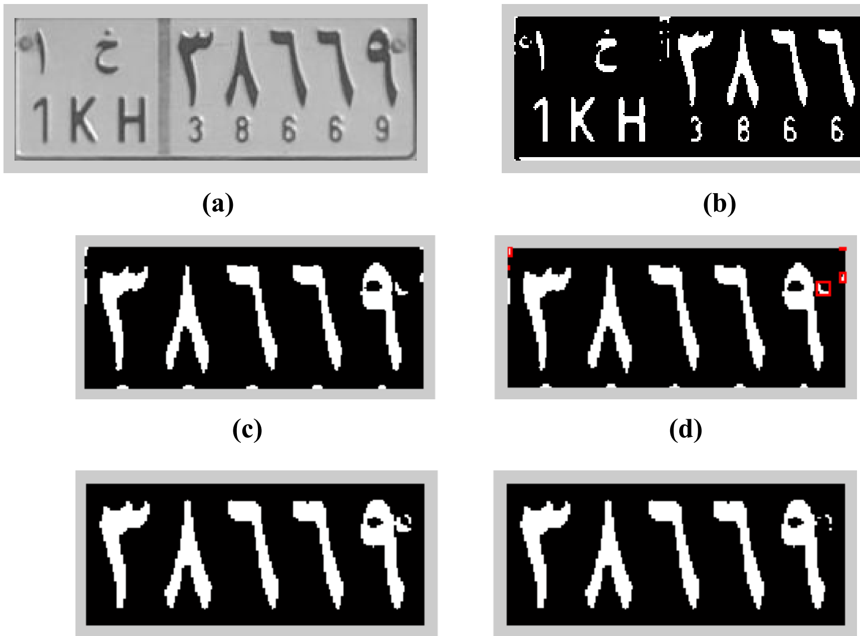
1.3.1 if startCl , endCl or both are shared with other regions (except the regions connected to lower image border).

- Get region coordinates.

1.4 End for loop

1.5 Eliminate the corresponding region in the original Indian numbers image.

b. End for loop



(a) **(b)** **(c)** **(d)** **(e)** **(f)**

Figure 5.14: Eliminating screws contiguous to the Indian number (a) Gray-scaled Image. (b) Binary-scaled Image. (c) Indian Number Region. (d) Location of screw in red. (e) Original Indian Number Image. (f) Removing Corresponding Screw Region.

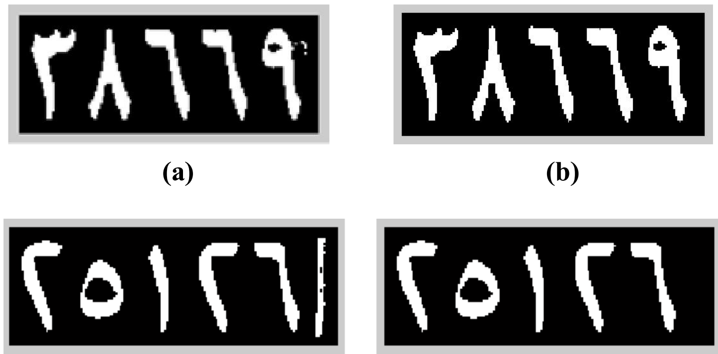
Although, this algorithm is successfully removed screws contiguous to numbers. However, a few unwanted regions are existing such as isolated screw and some regions forming a vertical line, which is leftover from plate frame. The next two steps to attempt to remove such regions.

d. Remove any region has a specific number of pixels, which is calculated as a ratio of the image size using Equation (5) as below:

Region area = (w/11) * (h/12) ……………………..…….. (5)

, where w and h represent the width and height of the image, respectively. The constant values in Equation (5) are set during the experiments in order to prevent removing interested regions like "٠" unintentionally.

e. The unwanted vertical line is removed through detecting all regions, then retained region's coordinates if the region width is less than or equal to 5. This small value is due to the vertical line is leftover form the plate frame. Where, it is observed that the plate frame is thinner than other plate components. The resultant image of the last two steps is shown in Figure 5.15.

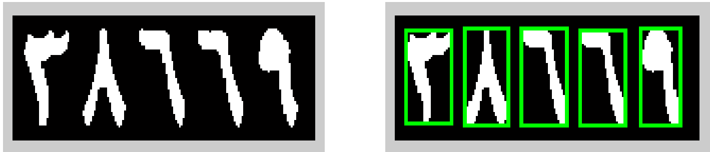


(a) **(b)**

(c) **(d)**

Figure 5.15: Removing Noise and Vertical Lines.
(a) Leftover Noises, (B) Removing Noise.
(b) An Image with Unwanted Vertical Line.

4. Finally, fill any holes in the image; a hole is defined as an area of black pixels surrounded by white pixels. The result illustrated in Figure 5.16 (a). Then, connected component analysis is performed to label and detect each digit in the image. In this step, the numbers on the image should have a unique label. Figure 5.16 (b) shows each segmented number within a green rectangle.



(a) **(b)**

Figure 5.16: (a) Filled Image. (b) Each Indian Number in a green Rectangle.

5.3.4 English Characters Segmentation

The main aim of this step is to isolate and extract each character in Figure 5.12 (c) based on Connected Components Analysis [6, 8, 18, 37]. Some unwanted regions can influence segmentation accuracy. Therefore, it is necessary to remove all these undesired regions. Following are sub steps that are performed in characters segmentation step. Figure 5.17 (a) shows a representative sample of English characters image as input image to this step:

1. Morphological opening operation with disk SE is performed on the last three rows of the image. Therefore, any unwanted pixels that connected a character with the image lower border are removed. The reason behind using this step is to make sure that each character is surrounded by black pixels, which in turn ensures that, the next step is work working properly. The result is illustrated in Figure 5.17 (b).

2. Morphological reconstruction [49] is used to remove any region contiguous to the borders of the image. Figure 4.17 (c) shows the resultant image.

(a) **(b)** **(c)**

Figure 5.17: (a) Input Cropped Image (b) Result of Morphological Open (c) Result of Removing Contiguous Region to Image Border

3. Remove any region has a specific number of pixels, which is calculated as a ratio of the image size using Equation (6) as below:

$$\text{Region area} = (w/7) * (h/9) \quad \text{……………………..…….. (6)}$$

, where, w and h represent the width and height of the image, respectively. The constant values in Equation (6) are set during the experiments in order to prevent removing interested regions like "1" unintentionally. Figure 5.18 (a) and (d) shows the resultant image for two different LP.

4. Finally, fill any holes in the image as illustrated in Figure 5.18 (b) and (e). Then, connected component analysis is performed to detect each character. Same as the final step in Indian numbers segmentation. Figure 5.18 (c) and (f) shows each character in a green rectangle.

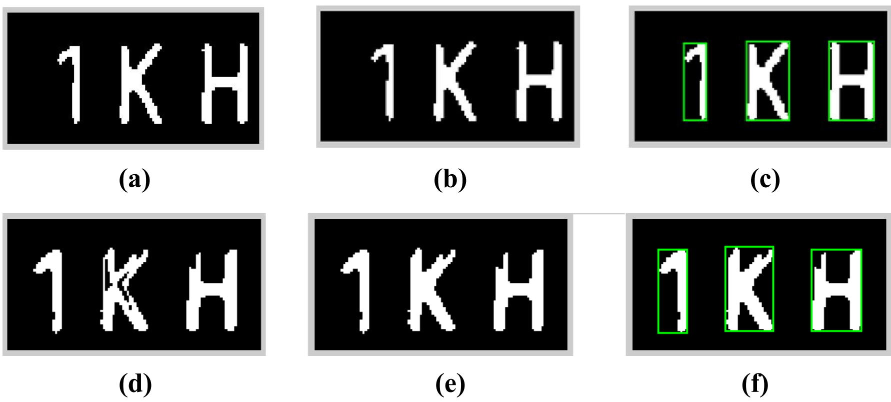


Figure 5.18: Connected Component Analysis to Detect Each Character
(a) and (d) Result of Removing Regions with Specific Size.
(b) and (e) Filling Holes.
(c) and (f) Isolated Characters Surrounded by a Green Rectangle.

5.4 Experimental Results and Discussion

All successfully extracted LP images are used as the data set for this stage. Therefore, this section discusses the experiment results through the stage's steps, which are, skew correction and characters segmentation, due to their importance to the recognition stage.

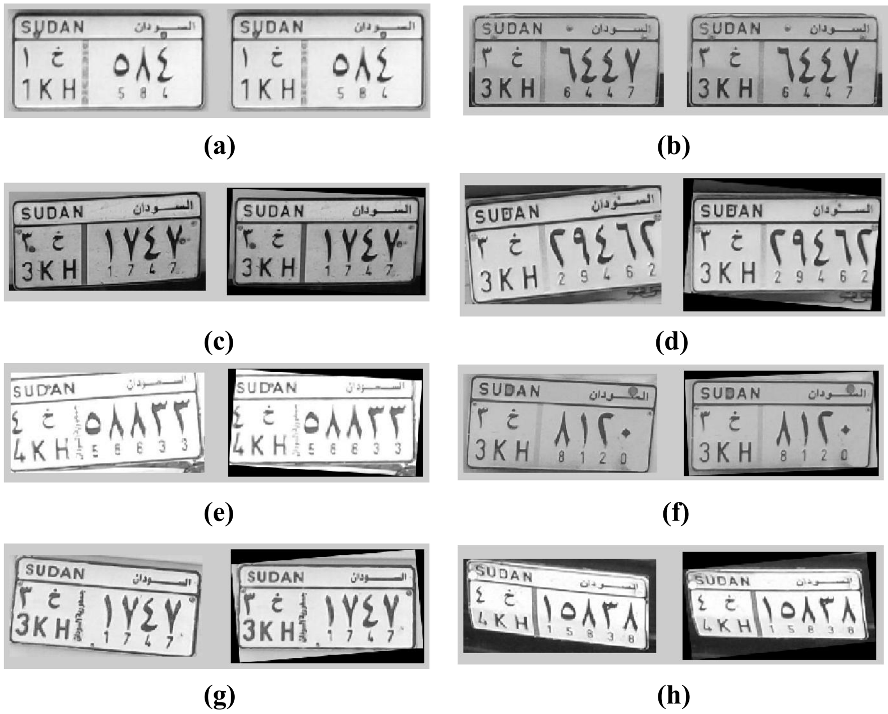
5.4.1 Skew Correction

The Skew correction guarantees the successful of character segmentation. Different gray images in size and illumination were taken for testing, which are received from the LP detection and extraction stage. Results show that the method works very well on positive and negative skewed images. Moreover, it gives reliable results with less computation complexity as presented in Table 5.1. It is shown that, the skew correction method accuracy is 100%.

Table 5.1: LP Skew Correction Experiments Results

Total Number Of LP Images	Successful Skew Correction	Unsuccessful Skew Correction
370	370	0
%	100.0 %	0.0 %
Number of Unskewed LP	38	
Number of Positive Skew	197	
Number of Negative Skew	135	
Processing Time	0.017 to 0.035 Seconds	

Some of the representative images shown in Figure 5.19 are successfully skew corrected even though some difficulties, such as, variation in contrast and size. Unskewed images were left unchanged as shown in Figure 5.19 (a) and (b). Positive skewed images were accurately corrected as illustrated in Figure 5.19 (c), (d) and (e), as well as negative skewed images shown in Figure 5.19 (f), (g) and (h).



(a) (b) (c) (d) (e) (f) (g) (h)

Figure 5.19: Several Results of Skew Correction Method

5.4.2 Character Segmentation

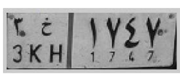
The skew corrected image is submitted to character segmentation step. Directly, a higher percentage of accurate character recognition can be obtained upon each character within plate is perfectly and accurately segmented. Therefore, experimental results had been proven that by obtaining 99.5% of successfully character segmentation, furthermore, it gives reliable results with less computation complexity, as presented in Table 5.2.

Table 5.2: LP Character Segmentation Experiments Results

Total Number Of LP Images	Successful segmented characters	Unsuccessful segmented characters
370	368	2
%	99.5 %	0.5 %
Processing Time	0.065 to 0.099 Seconds	

Table 5.3 presents some of the representative plate images, and illustrates the results of involved four sub steps in character segmentation step, which are, removing LP upper part and detect LP boundaries, Regions of Interest Extraction Based on Bottom-hat Filtering (Left Part and Right Part), Indian numbers segmentation, and English characters segmentation. Experiment results show that, each individual character is successfully segmented (Rectangles enclosing the characters are drawn in green) even though some difficulties, like variation in size, screws as in (d, e and f) and different contrast as in (a, b and c).

Table 5.3: Several Results of Character Segmentation Step

Corrected Plate Image	**Eliminating Upper Part & Boundaries**	**ROI Extraction**		**Segmentation**	
		Left Part	**Right Part**	**Left Part**	**Right Part**
 **(a)**					
 **(b)**					
 **(c)**					
 **(d)**					
 **(e)**					
 **(f)**					

On the other hand, Table 5.4 shows failed character segmentation due to some faded characters or damaged plates such as in (a) and (b).

Table 5.4: Failure in Character Segmentation

Corrected Plate Image	**Eliminating Upper Part & Borders**	**ROI Extraction**		**Segmentation**	
		Left Part	**Right Part**	**Left Part**	**Right Part**
 **(a)**					
 **(b)**					

5.5 Summery

This chapter presents a detailed explanation of the LP character segmentation method that has been designed for Sudanese private vehicles. The main objective of this method is to find the individual characters (digits and alphabets) and extracting those characters from the plate image. The study focused on segmenting the English characters and Indian numbers in Sudanese vehicle LP.

The LP character segmentation stage is constructed in two main steps, which are, skew correction and character segmentation in order to overcome problems, such as, the influence of image noise, plate frame, plate screw, plate skew, and illumination variance. The skew correction step is based on detecting the starting and ending points of the middle horizontal line that split the LP into upper and lower parts, then the mathematical concepts of the linear function is used to compute the slope angle. The character segmentation step, techniques such as morphological operation, Vertical and Horizontal Projection Profile, prior knowledge of the LP and connected components analysis are used in order to isolate individual characters.

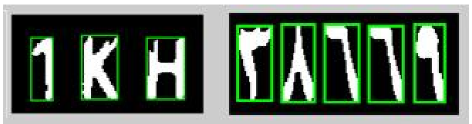
The experiments showed that skew correction method achieved a higher percentage of successfully corrected skewed plates, as well as character segmentation method. Based on the results, the method shows satisfactory and encouraging results, making it efficient to cope with previously mentioned difficulties.

CHAPTER VI

LICENSE PLATE CHARACTER RECOGNITION

6.1 Introduction

The license plate character recognition stage recognizes numbers or alphabets from a character image, by which a character's image is converted into an editable text [2]. Therefore, this would be the aim of this stage, where each segmented character is recognized individually [37]. The input to this stage is the coordinates of the top left and bottom right corners of the each character and number in English character image and Indian number image respectively, as shown in Figure 6.1. These coordinates are obtained from character segmentation stage, which are used to crop each and single character or number at a time and submit it to the recognizer.



(a) **(b)**

Figure 6.1: The Input to LP Character Recognition Stage
(a) English Characters Image. (b) Indian Numbers Image.

Two different recognizers are used to recognize the Indian numbers and English characters separately. The advantage of using two different recognizer is that it speeds up the processing due to the limited number of comparisons [6]. In Indian number recognition, a novel approach is proposed based on a heuristic rules adopted from some salient features for each Indian digit, in order to identify each digit separately. On the contrary, English character is recognized using Template Matching technique. The next two sections give a detailed explanation of each Indian number recognition and English character recognition.

6.2 Indian Numbers Recognition

This section explores the feature extraction method for Indian digit and a novel approach for its recognition. Moreover, it investigates the using of extracting features can achieve satisfactory results in number recognition. As mentioned in the previous chapter, the reason behind of choosing Indian numbers part is, it is much larger and clearer, occupies the center of the plate and less affected by changes or damages. The following subsections describe the features of Indian numbers and it is recognition method.

6.2.1 Indian Numbers Features

Each Sudanese vehicle LP have 1 to 5 Indian digits of 10 different Indian numbers which illustrated in Figure 6.2.

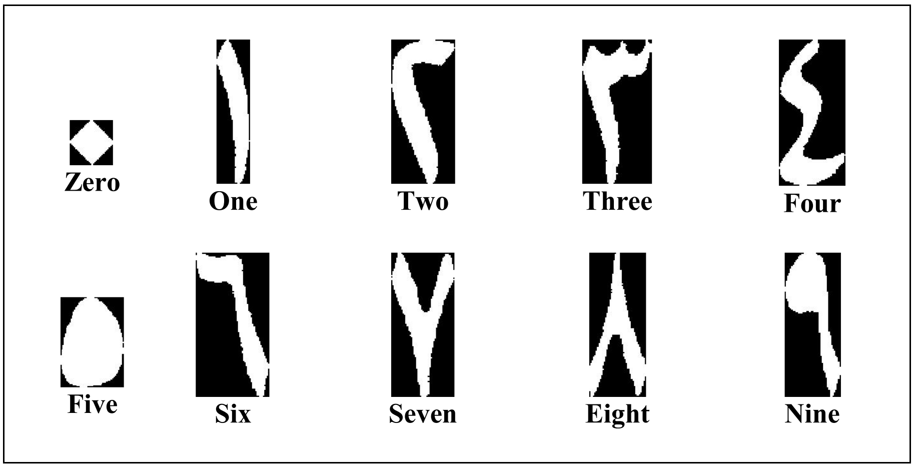


Figure 6.2: Indian Numbers.

In the feature extraction process, Indian digits have been divided into five groups on the basis of having the same salient features, these groups are [٠, ١, ٥] , [٤] , [٦, ٩] , [٢, ٣] and [٧, ٨]. Moreover, these groups facilitate the recognition process and more effective in recognizing. According to Indian digits groups, features are investigated for each group based on aspect ratio, the following explains the features of each group:

● **Digits Zero, One and Five**

Those digits occupy a small area in the Indian number image at different rates, as well as their own width to height ratio (aspect ratio). Therefore, the two features are utilized to distinguish each digit in this group.

● **Digit Four**

Suppose that, the digit's four image has been vertically split into two halves, then the right part is picked as a region of interest as illustrated in Figure 6.3, and then, the number of regions in the ROI image is calculated. Therefore, the number of regions is used as a feature to identify digit four, which could be as follows:

- Three regions (Region 1, Region 2 and Region 3) as in Figure 6.3, which is a unique feature of the digit four.
- Two regions (Region 2 and Region 3), when region 1 is lost due to plate image quality or in the character segmentation stage. The following measures are calculated to identify the digit four:
  - The area of region 2 is smaller than the area of region 3.
  - Region 2 starts at the upper second third of the ROI image, and region 3 starts at the lower remaining third of the ROI image.

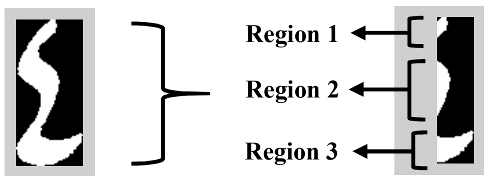
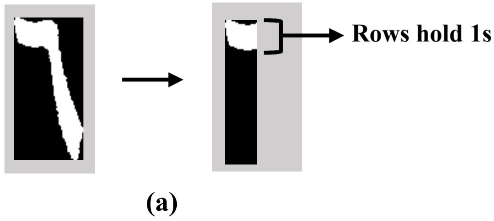


Figure 6.3: Digit Four Features.

● **Digits Six and Nine**

Suppose that, six or nine image has been vertically split into two halves, then the left part is picked as a region of interest as illustrated in Figure 6.4. In order to distinguish between the digit six and nine, calculate the ratio of the number of rows those hold the white pixels to the total number of the rows.



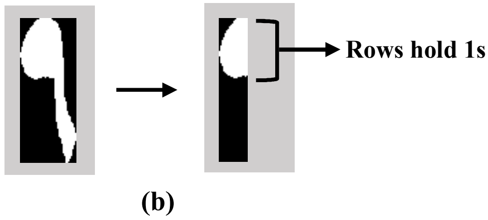


Figure 6.4: Digits Six and Nine Features
(a) The Six's Image. (b) The Nine's Image

● **Digits Two and Three**

Here the digit's image has been horizontally split into two halves at the row that holds a greater number of white pixels, then the upper part is picked as a region of interest as illustrated in Figure 6.5. Accordingly, in order to distinguish between two and three the following two features are calculated:

- The number of regions in each row in the ROI image.
- The density ratio (The ratio of the number of pixels to the area of the ROI image).

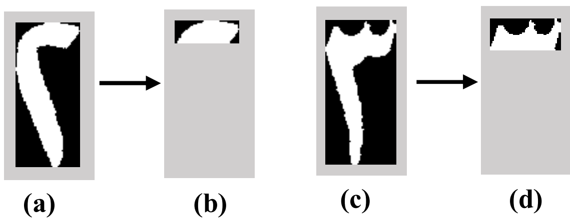


Figure 6.5: Digits Two and Three Features (a) The Two's Image.
(b) The Three's Image.

● **Digits Seven and Eight**

The images were carefully investigated, therefore, it is observed that digits seven and eight have a special and unique feature, which could be clarified as follows:

Let the image of the digit is scanned row by row from the top down to the bottom, and counting the number of regions containing consecutive pixels with value 1 in each row as illustrated in Figure 6.6, then it is easy to distinguish between seven and eight as follows:

- **Digit Seven:** Each row in the upper first third of the image composed of two regions, and each row in the lower two third composed of one region as illustrated in Figure 6.6 (a).
- **Digit Eight:** Each row in the upper two third of the image composed of one region, and each row in the lower third composed of two regions as illustrated in Figure 6.6 (b).

(a) (b)

Figure 6.6: Digits Seven and Eight Features
(a) The Seven's Image. (b) The Eight's Image.

6.2.2 The Recognizer

This subsection goes through the Sudanese LP Indian numbers recognition process. The recognizer handles only a single digit image at a time, and which in turn goes through feature extraction, then compare the extracted feature with the corresponding feature values of a specific Indian digit group. These feature values are expressed in ratio values, which have been carefully investigated and set during the experiments. The following algorithm describes how the Indian digit recognizer works, moreover, Figure 6.7 illustrates the flowchart of the algorithm:

1. Start

2. Input The Indian Number Image
3. Number of Segmented digits = K
4. For I = 1 to K do
    - **4.1** Extract group[٠ ,١,٥] feature for image(I)
    - **4.2** If a close match to one of the group[٠ ,١,٥] is found
      Go to 4.12
    - **4.3** Else, Extract group[٤] feature for image(I)
    - **4.4** If a close match to [٤] is found
      Go to 4.12
    - **4.5** Else, Extract group[٦ ,٩] feature for image(I)
    - **4.6** If a close match to one of the group[٦,٩] is found
      Go to 4.12
    - **4.7** Else, Extract group[٢ ,٣] feature for image(I)
    - **4.8** If a close match to one of the group[٢ ,٣] is found
      Go to 4.12
    - **4.9** Else, Extract group[٧ ,٨] feature for image(I)
    - **4.10** If a close match to one of the group[٧ ,٨] is found
      Go to 4.12
    - **4.11** Else, Digit = 'X'
    - **4.12** Store Results
5. End loop for
6. Display LP Number
7. End

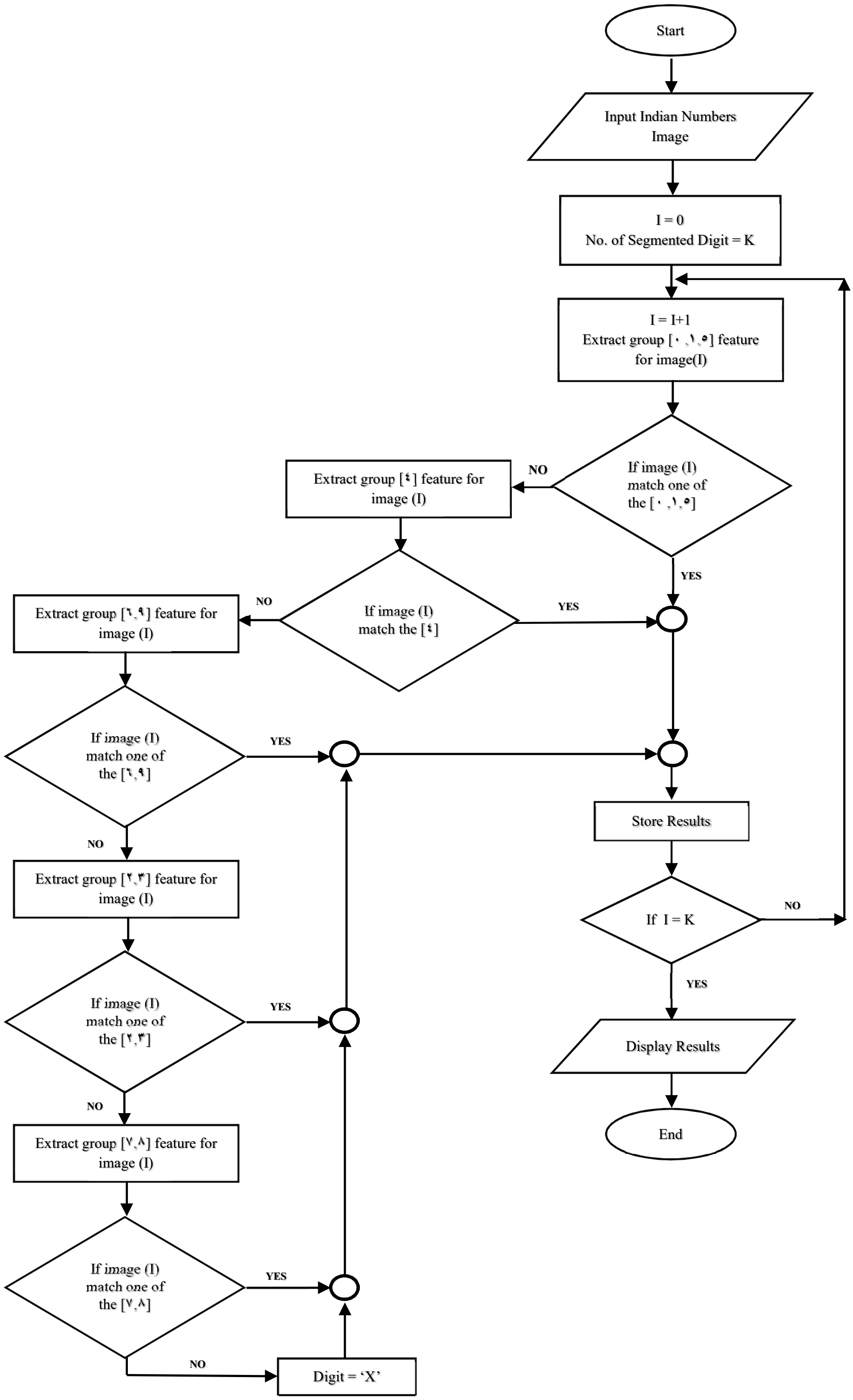


Figure 6.7: The Recognition Process of Sudanese LP Indian Number

6.3 English characters Recognition

This section goes through the recognition of the characters in the English characters image as presented in Figure 6.8, which, as mentioned earlier, consist of English alphabet and Arabic digits. Similarly, the recognizer handles only a single character image at a time.

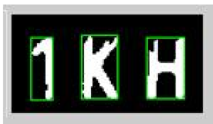


Figure 6.8: English Characters Image.

Due to the research scope focuses on licensed vehicles in Khartoum state, the English alphabet are ‘K’ and ‘H’, which are an abbreviation of Khartoum State, in addition, the Arabic digits so far are ‘1’, ‘2’, ‘3’, ‘4’, ‘5’ and ‘6’. The expected combination of English alphabet and Arabic digits would be ‘KH’, ‘1KH’, ‘2KH’, ‘3KH’, ‘4KH’, ‘5KH’, and ‘6KH’.

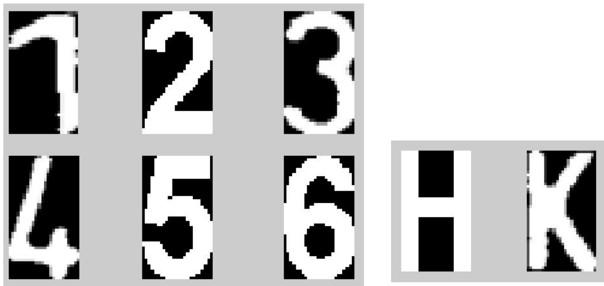
According to the state of the art of VLPR system, a suitable method has been chosen to implement the recognition of English characters image, which is the Template Matching. As in [4, 10, 17, 26, 37] the Template Matching has been successfully implemented in VLPR system for relevant recognition.

6.3.1 The Recognizer

As mentioned in the literature review, Template Matching based on binary images is the simple, straightforward and effective method used in the Optical Character Recognition (OCR) [17, 37]. In Template Matching, the input character image is compared with a set of stored templates (or prototypes) from each character class and the best similarity is measured.

A statistical correlation method is used to measure the similarity and find the best match. There are two forms of correlations: auto-correlation and cross-correlation. Auto-correlation function (ACF) involves only one signal and provides information about the structure of the signal or its behavior in the time domain. On the other hand, cross-correlation function (CCF) is a measure of the similarities or shared properties between two signals [17]. Since there are two signals as unknown input character image and known template image in this system, cross-correlation is used.

Before the recognition algorithm, the templates are constructed by cropping the characters from an image, then normalized to the size 42×24 pixels and stored in the database. The database containing 2 templates for English alphabets and 6 templates for Arabic digits as shown in Figure 6.9.



(a) **(b)**

Figure 6.9: English Characters Templates
(a) 6 Templates for Arabic Digits Image. (b) 2 Templates for English Alphabets

In recognition, the input character image is normalized to the size 42×24 pixels. The similarity between a character image and all templates in the database is measured in order to find the best match. The template having a highest correlation score is considered to be the best match. Where, the result of the cross-correlation function is a value between -1 to 1. As the value approaches to 1, it indicates that the compared images are more likely to be similar and as it approaches to -1, it indicates dissimilarity.

6.4 Experimental Results and Discussion

This section shows the results of the experiments which were carried out based on recognition methods that directly reflect the efficiency and accuracy of the VLPR system. . The detailed analysis of results is also provided.

The resulted image from the character segmentation stage are used for determining the characters recognition rate. The results of the recognition experiments had been explained through a three categories, which are, Indian numbers recognition, English characters recognition and the overall number of recognized LPs.

6.4.1 Indian numbers recognition

To evaluate the efficiency, the proposed recognition method has been tested over 370 binary images with different sizes. The tested images have been obtained from the character segmentation stage. The results of the experiments are shown in Table 6.1 which indicates the recognition rate accuracy is 99.5%. These results were satisfactory and very encouraging to readily extend the recognition method to cope with all types of Sudanese vehicle LPs.

Table 6.1: Indian Number Recognition Experiments Results

No. of Indian Numbers Images	Successful Recognition	Unsuccessful Recognition
370	368	2
%	99.5%	0.5%
Processing Time	0.003 to 0.036 Seconds	

A possible explanation for the 0.5% percentage of unsuccessful recognition is due to the failure in character segmentation as presented in Table 6.2.

Table 6.2: Unsuccessful results of Indian Number Images Recognition

LP Image	Indian Number Image	Character Segmentation	The Recognition
 (a)			**1829**
 (b)			**4XX4X**

In Table 6.2 (a) and (b) there are five digits of Indian number, but only four digits images were given to the recognizer. In addition, Table 6.2 (b) parts of digits were removed, therefore the digit is incomplete.

6.4.2 English characters recognition

The Template Matching method is tested over 370 binary images, which are obtained from character segmentation stage. The results of the experiments are presented in Table 6.3, indicating that the recognition rate accuracy is 98.5%. Based on these results, the Template Matching method shows satisfactory and encouraging results.

Table 6.3: English Character Recognition Experiments Results

NO. Of English Character Images	Successful Recognition	Unsuccessful Recognition
370	366	4
%	98.9%	1.1%
Processing Time	0.022 to 0.037 Seconds	

On the other hand, Table 6.4 illustrates the 1.1% percentage of unsuccessful recognition, which can be explained due to mismatch or incorrect character recognition caused by noise in the original image or physical problems such as dirt or character painting problems, etc.

The result from Table 6.4 (a) can be explained by the fact that the characters were rotated, and that caused the mismatching, while in (b), (c) and (d) the mismatch or incorrect character recognition caused by the noise that affected the shape of the character.

Table 6.4: Unsuccessful results of English Character Images Recognition

LP Image	English Character Image	Character Segmentation	The Recognition
 (a)			**4K6**
 (b)			**4H**
 (c)			**1K1**
 (d)			**2KH**

6.4.3 The overall number of recognized LPs

This section introduces a discussion of character recognition stage experiments results on the basis of the overall rate of recognized LPs. The results obtained from the experiments are presented in Table 6.5. It is apparent from this table that the success rate of recognizing the LP is 98.4%

Table 6.5: LPs Recognition Experiments Results

NO. Of LP Images	Successful Recognition	Unsuccessful Recognition
370	364	6
%	98.4%	1.6%
Processing Time	0.026 to 0.071 Seconds	

The failure of the character recognition stage is due to problems that were mentioned beforehand in sections 6.4.1 and 6.4.2.

Furthermore, the efficiency of the proposed character recognition method was evaluated using our dataset that consist of 375 RGB image. The results of the experiment achieved satisfactory percentage of accurate recognition, which is 97.1%.

6.5 Summery

This chapter has presented the character recognition method that was divided into two different recognizer which are Indian numbers recognition method and English characters recognition method. The advantage of using two different recognizer is to speed up the processing time due to the limited number of comparisons. A novel approach for Indian number recognition has been presented based on salient feature extraction. Likewise, Template Matching method has been used in the recognition of English character.

The results of the experiments have been clarified through evaluating the efficiency of each recognizer separately as well as the overall number of recognized LPs. The results indicate that the proposed recognition methods succeed in recognizing and identifying vehicle LPs efficiently and accurately with high rate percentage.

Overall, these results were satisfactory and encouraging, moreover, provide important insights into future work to handle the recognition of all types of Sudanese vehicle LPs.

CHAPTER VII

CONCLUSION AND FUTURE WORK

7.1 Conclusion

In this thesis work, Vehicle License Plate Recognition (VLPR) system for Sudanese private vehicle License Plate (LP) has been developed. It is considered as the first of its kind for Sudanese private vehicles. The proposed system composed of four stages: image acquisition, license plate detection and extraction, license plate character segmentation, and license plate character recognition.

Images of various parked private vehicles are acquired manually to construct the Sudanese VLPR system. A simple method was developed to detect the accurate location of the license plate among candidate regions through analyzing LP features. The green channel of a vehicle image provides a sufficient contrast, this helps in edge detection, filter interested regions, and detect LP candidate regions using connected components analysis (CCA). The extracted LP image is passed to character segmentation method which uses a method to correct skewed LP as well as combined techniques of morphological operation's bottom-hat, vertical and horizontal projection profile, prior knowledge of Sudanese LP, and CCA to isolate individual Indian numbers and English characters. Each segmented number/character is recognized separately. For Indian number a novel recognizer is developed based on salient features extraction for each of the ten Indian digits. These salient features are simple and easy to compute. For English character, template matching is efficiently recognized the given English character.

To measure the efficiency of the proposed Sudanese VLPR system. A new dataset for Sudanese private vehicles had been prepared. Vehicle images have been captured manually on city streets, or parking lots at various times of the day. Experiments results show that the success rates of license plate detection, segmentation, and recognition are 98.6%, 99.5 % and 98.4% respectively. Based on these results, the system shows satisfactory and encouraging results.

On the other hand, failures in detection and extraction is due to damaged plates or faded plate's characters, plate region is covered by a decorative item or influenced by sun reflection, and dark images. Where, faded characters or damaged plates are caused failures in character segmentation, which in turn affected the accuracy of the character recognition.

7.2 Future Work

This section presents some recommendations for future work. While many issues related to this area of research remain to be explored, moreover, this thesis could be extended in several directions. These issues and directions can be addressed as follows:

- The Sudanese VLPR system and its related methods can be extended to handle other Sudanese vehicle LP types and other states in Sudan. Since, this research handles private vehicles licensed in Khartoum state.
- A further studies could improve VLPR system so it can be used in real life cases.
- LP detection and extraction method can be improved by including additional features which are unique to the plat region, for instance, horizontal and vertical histogram of the internal region, which shows the presence of characters.
- Further preprocessing refinement is needed to lower processing time of LP detection and extraction.
- Improvement in noise reduction techniques can be suggested in order to improve the segmentation and recognition accuracy.
- Templates of English characters could be added to the database to increase the recognition accuracy rate.
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APPENDICES

APPENDIX A: Simulation of the Developed System

Simulation was carried out to estimate the performance of the developed Sudanese VLPR system. Graphic user interface (GUI) had been designed using MATLAB R2013a (Version 8.1.0.604) environment. The GUIs are explained as follow:

A.1 Main Interface

Figure A.3: Sudanese VLPR System Main GUI

A.2 Load Input Image

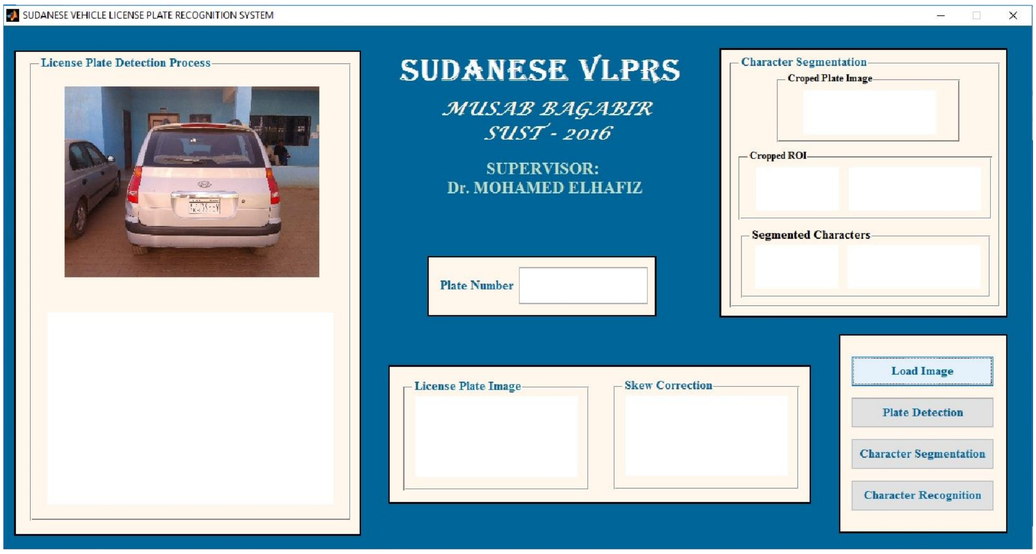

Figure A.4: Loaded Vehicle mage

A.3 License Plate Region Extraction

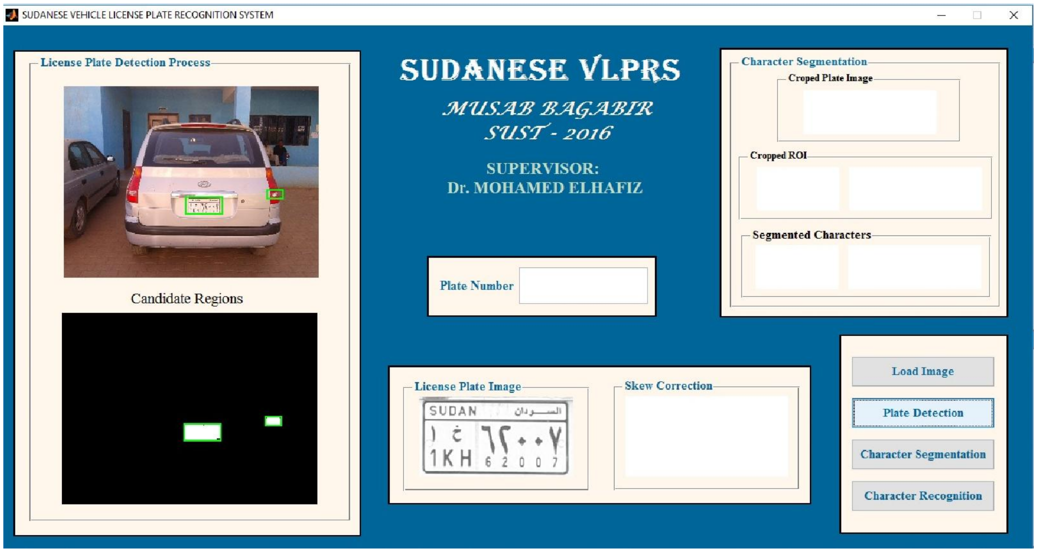

Figure A.5: Extracted License Plate

A.4 License Plate Characters Segmentation

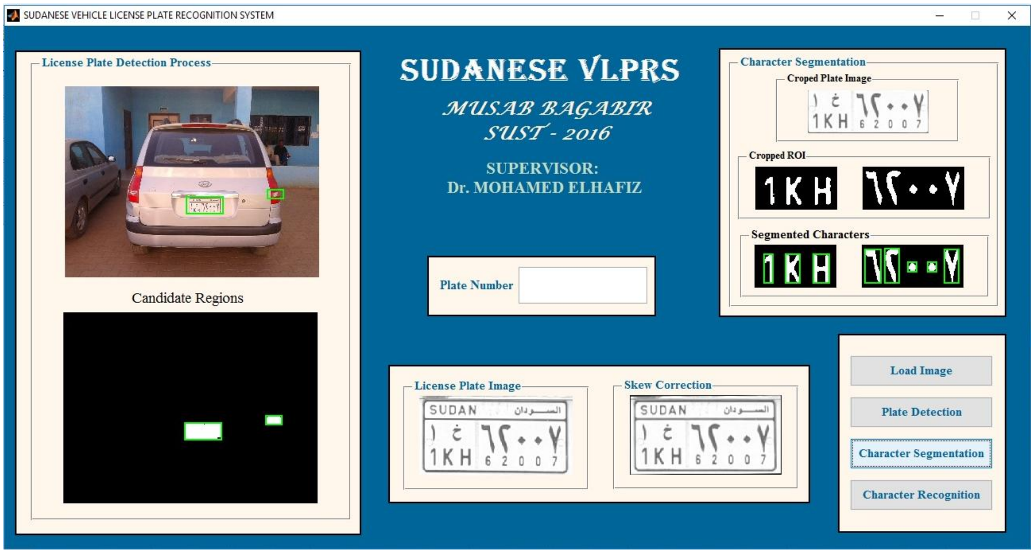

Figure A.6: Segmented Characters

A.5 Recognize License Plate Characters

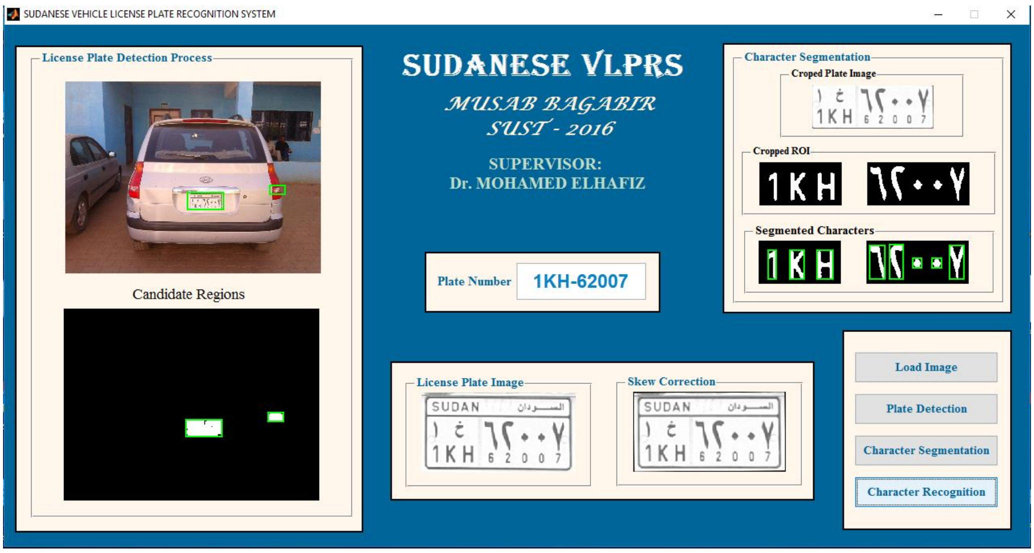

Figure A.7: Recognized License Plate

A.6 Failed License Plate Extraction

Figure A.8: License Plate Extraction Failure

A.7 Failed License Plate Recognition

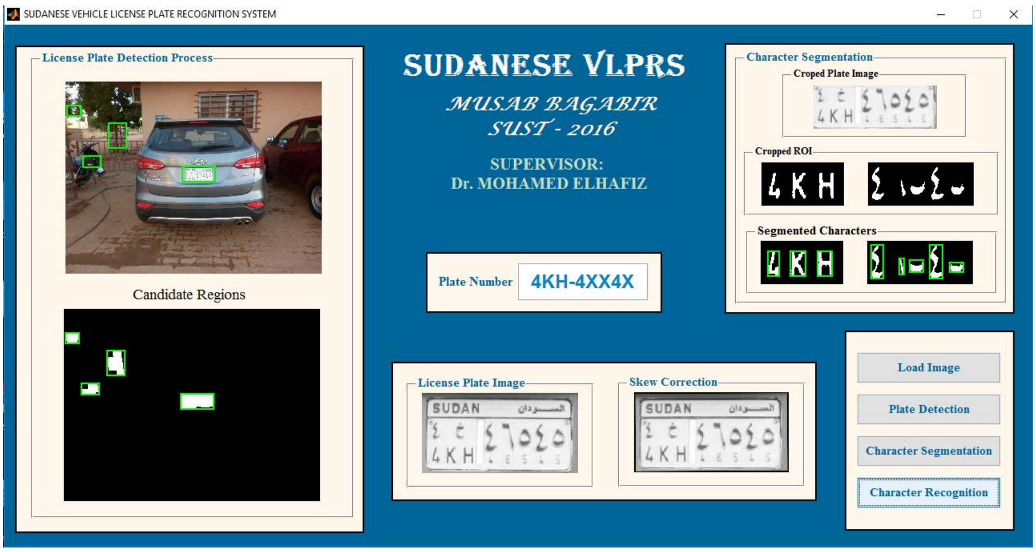

Figure A.9: License Plate Recognition Failure

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