

Arabic Character Recognition: Progress and Challenges

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Abstract. An optical character recognition (OCR) system may provide a solution to the data entry problems, a bottleneck for the data processing industry. Therefore, OCR systems are being developed for almost all major languages and Arabic language is no exception to it. During the past three decades, considerable research and development works have been done towards the development of an efficient Arabic optical character recognition (ACR) system. In this paper we present a comprehensive review of ACR techniques and evaluate the status of the ACR system development and an up to date bibliography.

Keywords: Character recognition; Arabic language; Arabic character recognition; Arabic text recognition; Digital document processing; Pattern recognition.

1. Introduction

Optical character recognition (OCR) systems are being developed for almost all major languages and Arabic language is no exception to it [1-199]. Like other languages, Arabic language poses its own challenging problems to the developers of Arabic optical character recognition (ACR) systems. During the past three decades, considerable research works have been done towards the development of an efficient ACR system. Many research articles and technical reports on this topic have appeared in leading conference proceedings and journals (e.g., [32;157;177]).

The objective of this paper is to review the ACR literature and evaluate the status of the ACR system development. We believe that the review should prove helpful in identifying and solving problems that are being faced in developing a practical ACR system. Although we have compiled a comprehensive bibliography yet this review is based on the research articles that are available to us. In this paper we have developed a set of criteria for categorizing the ACR techniques. The criterion set is based on the

detailed lists of features definition and extraction, and classification methods that are frequently being experimented with by *ACR* researchers. Besides this, we have tabulated recognition result summary that can be readily used to compare and contrast the performance of respective recognition techniques. Result tabulation has been a problem as some research articles did not provide complete information about the test data that they have used and the environment under which the recognition experiments were conducted.

We have also analyzed characteristics of Arabic text with the recognition point of view. This analysis may give a better understanding of Arabic text and should prove beneficial in assessing the complexities that they may pose in developing an *ACR* system. We present these characteristics in Section 2. General factors that affect *ACR* system development are discussed in Section 3. A set of criteria that we have used to categorize the existing *ACR* techniques is presented in Section 4. Recent advances in *ACR* system design are reviewed in Section 5. Recognition performance issues are discussed in Section 6. The current status of the test data that is being used and its relevance in developing an *ACR* system are examined in Section 7. A conclusion of our study is presented in section 8.

2. Characteristics of Arabic Text

An Arabic text is composed by placing linearly character blocks of varying sizes from right to left. The peculiar characteristic of the Arabic text is that the shape of characters may significantly vary within a word. This variation depends on: the position of the character within a word and its adjacent characters. On the basis of this characteristic we divide Arabic character shapes into two categories: The *primary* category that consists of twenty-eight characters (Table 1) and the *secondary* category that consists of eight characters (Table 2). There are four characters that do not fit into this categorization, therefore, they form a special category (Table 3). The characters shown in Table 2 and Table 3 are explained below.

The character Hamzah (ء) causes some confusion. At certain positions it is considered as a sub-component of a character, e.g., Kaf (ك) and at some other positions it is considered as an independent isolated character. The character Alif-Maqhsura (ﺀ) is pronounced as the character Alif while its shape resembles the character Ya (ﻱ). Like the character Alif, it cannot be connected to the succeeding character. The character Tamarbotah (ﻪ) is pronounced as the character Ta (ﺕ) while its shape resembles the character Ha (ﻩ). Unlike Ta (ﺕ) and Ha (ﻩ), it can't be connected to the succeeding character.

Table 1. Primary category character set

SN	Character name	Shape position				SN	Character name	Shape position			
		End	Middle	Begn.	Isold.			End	Middle	Begn.	Isold.
1	Alif	ا			ا	15	Dhad	ض	ض	ض	ض
2	Ba	ب	ب	ب	ب	16	Tua	ط	ط	ط	ط
3	Ta	ت	ت	ت	ت	17	Zua	ظ	ظ	ظ	ظ
4	Tha	ث	ث	ث	ث	18	Ain	ع	ع	ع	ع
5	Jim	ج	ج	ج	ج	19	Gain	غ	غ	غ	غ
6	HHA	ح	ح	ح	ح	20	Fa	ف	ف	ف	ف
7	KHA	خ	خ	خ	خ	21	Qaf	ق	ق	ق	ق
8	Dal	د			د	22	Kaf	ك	ك	ك	ك
9	Thal	ذ			ذ	23	Lam	ل	ل	ل	ل
10	Ra	ر			ر	24	Mim	م	م	م	م
11	Zai	ز			ز	25	Non	ن	ن	ن	ن
12	Sin	س	س	س	س	26	Ha	ه	ه	ه	ه
13	Shin	ش	ش	ش	ش	27	Waw	و			و
14	Sad	ص	ص	ص	ص	28	Ya	ي	ي	ي	ي

Table 2. Secondary category character set

SN	Character name	Shape position		
		End	Middle	Isolated
1	Hamzah	ء		ء
2	Alif-Muqsoorah	آ		آ
3	Ta-Marbotah	ة		ة
4	Hamzah-Waw	ؤ		ؤ
5	Hamzah-Ya	أ	أ	أ
6	Hamzah-Alif	إ		إ
7	Hamzah-Alif	أ		أ
8	Alif-Mad	آ		آ

Table 3. Special category character set

SN	Character name	Shape position	
		End	Isolated
1	Lam-Alif	لا	لا
2	Lam-Alif	لا	لا
3	Lam-Alif	لا	لا
4	Lam-Alif	لا	لا

The character Hamzah-waw(ﻱ) is pronounced as the character Hamzah(ء) while its main component resembles the character Waw(ﻭ). It cannot be connected to succeeding characters. The character Hamzah-ya (ﻱ) is pronounced as the character Hamzah(ء) while its main component resembles the character Ya(ﻱ). Like Ya(ﻱ), it is connectable to succeeding characters. The characters Hamzah-alif(ﺍ) are pronounced as the character Hamzah(ء) while their main components resemble the character Alif(ﺍ). They cannot be connected to succeeding characters. The main component of the character Alif-mad(ﻻ) resembles the character Alif(ﺍ). It cannot be connected to succeeding characters. Each of the characters Lam-Alif (ﻻ، ﻻ، ﻻ، ﻻ), for computer applications (mainly because of the segmentation problem between the Lam(ﻻ) and Alif(ﺍ)), is considered as a new single character in the character set.

In addition to this criteria, the Arabic characters set can also be categorized on the basis of number of constituent components as some Arabic characters are formed by more than one component. Such characters contain one main component and one or more sub-components. The subcomponents are *Noqtah*, *Hamzah* and Mud-sign Table 4.

A *Noqtah* is a dot like sub-component. The count and the position of *Noqtah* relative to the main component form different characters. The maximum count of *Noqtah* in a character is three. The possible combinations of *Noqtah* count and its position relative to the main components in a text are shown in Table 5.

Like *Noqtah*, the appearance of *Hamzah* at a specific position forms different characters. A *Hamzah* may appear: above the characters *Hamzah-waw*(ﻱ) and *Hamzah-ya*(ﻱ); above or below the characters *Hamzah-alif*(ﺍ) and *Lam-Alif*(ﻻ); inside the characters *Kaf*(ﻙ) and *Hamzah-ya*(ﻱ) or it may appear as a single isolated character (ء). If it is isolated then it is considered as a main component (see Table 6).

Table 4. Special category

Component type	Relative position to main-shape		
	Above	Below	Inside
Dot	خ ض غ ف ن ذ ز	ب ج	ح ظ ن
Two Dots	ت ق ة	ي	ت
Three Dots	ث ش		ث
Hamzah	الألف	إ	ك ي
Mud-sign	آ		

Table 5. Noqtah count

Position	1 dot	2 dots	3 dots
Above the main component	خ ص غ ف ن ذ ز	ت ق ة	ث ش
Below the main component	ب ج	ي	
Inside the main component	ن ج ظ	ت	ث

Table 6. Characters formed by hamzah

Position	Different Character formation
Above the main component	أ و لا إ
Below the main component	ي
Inside the main component	ك
Single component	ء

The appearance of *Tushkeel* (diacritics) sub-component affects the pronunciation and/or meaning of Arabic words. Its appearance does not form new characters. Different types of diacritics in Arabic text, together with their names are explained below:

Fut'hah: A small horizontal line above character([َ]); *Kusrah*: A small horizontal line below character(_ِ); *Dumah*: A small comma above character([ُ]); *Tunween*: Double *fut'hah* above character([ً]), double *dumah* above character(_ٍ), or double *kusrah* below character(_ٍ); *Shaddah*: A small "w" ([ّ]) above a character. It could be combined with any of the above types. In such a case, the other vowel position will be relative to the *shaddah* instead of the main shape, i.e., a *kusrah* will be under the *shaddah*; *Sokon*: A small circle above the character([◌]); *Mud-sign* : A small approximation sign appear above the *Alif*(^ا) or above *Lam-Alif*(^آ). These two shapes can be seen as another characters in the Arabic language by those who consider the *hamzah-alif* as a different character than *Alif*. *Mud-sign* can appear above any character in some Arabic fonts (e.g., Othmani font).

Diacritics shapes and corresponding examples are shown in Table 7. An Arabic text may contain punctuation marks and special symbols. Frequently used punctuation marks and special symbols are: a period represented as dot " . "; an exclamation mark

any character remain unchanged in every textual form. Shapes of connectivity forming characters vary drastically (see Table 1). Unlike the development of an OCR system for Latin alphabet based languages, this shape variation poses many problems in developing an *ACR* system for Arabic alphabet based languages.

In addition to characters, an *Arabic* text contains symbols that represent numerals and punctuation marks. Currently used numerals in the Eastern Arab countries are the set of ten Indian digits (See Table 8). In this set, all digits, except the digits 2 and 3, have only one shape form. The digits 2 and 3 are written in two ways in handwritten documents. The decimal point is written as the character *Waw*(,).

Arabic text reproduction method—a linguistic factor—affects design of an *ACR* system. *Arabic* text is written from right to left and it is cursive in nature. Moreover, an *Arabic* word consists of one or more connected components where every component consists of one or more characters. The number of components in a word depends on the number and connectivity property of its characters. *Arabic* words cannot be hyphenated, thus they are written as one unit.

Table 8. The set of Indian digits

Digit as words	Digit as numeral
Zero	۰
One	۱
Two	۲
Three	۳
Four	۴
Five	۵
Six	۶
Seven	۷
Eight	۸
Nine	۹

4. Classification of Arabic Character Recognition Techniques

A combination of pattern recognition techniques are being devised to produce an efficient *ACR* system. We classify these techniques into different classes on the basis of the criteria: Textual data acquisition mode; Text style; Text segmentation; Feature definition, extraction and representation; Classification and Post processing.

4.1 Textual data acquisition mode

The on-line and off-line are the two possible modes of data acquisition. An on-line *ACR* system recognizes handwritten text by capturing the pen positions in real time.

Research works for developing an efficient on-line character recognition system are described in section 5.1. An off-line *ACR* system recognizes an existing text. In such a system, digital images of existing texts are produced by scanning them line by line or page by page. Afterwards these images are processed and analyzed. An off-line *ACR* system may be built to recognize handwritten and typewritten Arabic texts. Recent advances in the development of an efficient off-line *ACR* system are presented in section 5.2.

4.2 Text style

An Arabic text can be produced in any of the following styles.

- a) **Unconstrained non-isolated handwritten text:** The natural Arabic text—the cursive handwritten text produced without imposing any constraint on writers. The recognition scheme that recognizes this text requires both the word and character level segmentation (a process that breaks a sentence into isolated words and characters). An example of unconstrained non-isolated handwritten text is shown below:

- b) **Unconstrained isolated handwritten text:** The cursive unconstrained handwritten text produced where writers are expected to write isolated non-overlapping characters like (ص ب) required for the post office box in a mailing address.
- c) **Constrained non-isolated handwritten text:** The text produced under some constraints like using writing guidelines or writing the text at a fixed position. Filling a printed form is an example of such a text (shown below)

الاسم الكامل	خالد	الأول	محمد	اسم الأب
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For this type of text, word and character segmentation schemes are required to represent characters to the recognition module.

- d) **Constrained isolated handwritten text:** Isolated characters produced under constrained environment. Filling a form where characters should be written in specified boxes is an example of such text (shown below)

خ	ا	ل	د	م	ح	م	ب	ص
---	---	---	---	---	---	---	---	---

- e) **Uniform typewritten text:** Typewritten text that involves only one font.
- f) **Multifont typewritten text:** Typewritten text involving many fonts.

Each text style mentioned above poses problems of its own and each requires a separate recognition scheme. The recognition schemes developed for solving the problems posed by various text styles are reviewed in section 5.2.1.

4.3 Text segmentation

A text segmentation process extracts the basic constituents from a given text. The basic constituents of an Arabic text are: *a word, the complete shape of an isolated character and the partial shape of a character*. In research works where the focus of the research was on the recognition technique only, the segmentation process was ignored. In such works we assume that the test data were manually segmented. However, the segmentation process is an essential step in automating an *ACR* system, therefore, several segmentation approaches were developed. Commonly used approaches for Arabic text segmentation are reviewed in section 5.2.2.

4.4 Feature definition, extraction and representation

A feature describes the characteristics of an underlying character, its partial structure or the structure of the whole word. Like OCR techniques, *ACR* techniques can also be distinguished from one another on the basis of feature definitions that they employ and the way they extract and represent features. In *ACR* research works, both the statistical (quantitative) and structural (qualitative) features are used.

4.5 Classification

In an attempt to obtain a good recognition score, almost all classification techniques: mathematical, statistical, syntactical, graph-theoretic, neural network based, heuristics and so on are used for Arabic character recognition. A comparative performance analysis of these techniques are presented in section 5.2.5.

For some reasons, decision tree (a hierarchical graph-theoretic technique) based classification techniques are popular among *ACR* researchers [4-7; 36; 42; 55; 60-63; 68; 76; 108; 114; 117; 199]. Occasionally, some researchers have referred to this technique as syntactic technique which is a misleading term. Statistical techniques are the second frequent choice [85; 91; 113; 166, 183].

4.6 Post processing

The post processing is a process that uses properties of natural languages to enhance the recognition reliability. Recently, use of well established Markov model based post processing approaches for improving the reliability of an *ACR* system has appeared in *ACR* literature [83].

5. Arabic Character Recognition (*ACR*) System Design: Recent Advances

During the past two decades, attempts to design both the on-line as well as off-line *ACR* systems were intensively made, but as compared to research efforts for devising an off-line *ACR* system, the research efforts for devising an on-line *ACR* system are very little. Major on-line *ACR* techniques developed during the past two decades and their performance are presented in Section 5.1. Off-line *ACR* techniques are reviewed and discussed in Section 5.2.

5.1 On-line *ACR* techniques

The first step in an on-line *ACR* technique is to extract features from the strokes that are formed using stylus as a writing tool in real-time. These features are extracted by segmenting the characters into strokes. Commonly used structural features are: open and closed curve segments, vertical and horizontal strokes, cusp and inflection points, and dot counts [58; 60-63]. However, some researchers have also used hybrid features, i.e., a combination of structural and statistical features. In a system described in [36] the authors have used hybrid features. They formed features by combining the structural feature: direction code with the statistical features: segment length, segment slope, coordinates of each segment point and dot counts.

In all on-line *ACR* techniques reviewed here, a decision tree was used as a classifier without post processing [58; 60]. The salient features of these techniques are summarized in Table 9.

The system described in [58] was tested on 400 characters and 80% correct recognition score was recorded. The system described in [36] uses thirteen different characters. They conducted three experiments. In the first experiment, four words were repeatedly formed using these thirteen characters and used as inputs. The system recognized all the occurrences (390) of these words by recognizing the thirteen training characters at every position. The second experiment was conducted on 50 words (150 characters). In this experiment 86% correct recognition score was recorded. In the third experiment, 50 words of the second experiment were produced by imposing writing constraints. In this experiment 100% correct recognition score was recorded. A summary of the results of these experiments and experiments of other research efforts is given in Table 10.

Table 9. On-line ACR systems: summary of recognition techniques

Ref.	Feature type	Classifier	System parameters			Comments
			Segmentation method	Input data	Recognition type	
[60]	<i>Qualitative</i> 1. Open curve 2. Closed curve 3. Vertical strokes 4. Horizontal strokes 5. Cusp points 6. Inflection points 7. Group of dots	A tree Classifier	Stroke Segmentation	Character	Character and word Recognition	It is a real system. It recognizes a word using character recognition.
[61]						Refer to [60]
[58]						Refer to [60]
[36]	Hybrid Features <i>Qualitative</i> 1. Direction code 2. Dots <i>Quantitative</i> 1. Segment length 2. Segment slope 3. Coordinates of each segment point	A tree Classifier	Stroke segmentation by slope & length measurements	Characters	Character recognition only	It is a simulated system.

Table 10. On-line ACR systems: summary of recognition results

Ref.	Training set			Test set			Over all C%	Speed	Comments	
	Sample size	C%	E%	R%	Sample size	C%				E%
[60]	-	-	-	-	-	-	-	-	-	Real system
[61]	-	-	-	-	-	-	-	-	-	Refer to [60]
[58]	-	-	-	-	400c	80	-	-	-	Refer to [60]
[36]	13c	-	-	-	390c	100	-	-	-	Exp1. This experiment was conducted on 390 occurrences of 13 training set characters in four repeated words.
					150c	86	-			Exp2. This experiment was conducted on 50 different words formed by 13 training set characters.
					150c	100	-			Exp3. In this experiment the fifty words of the experiment 2 were produced by imposing some constraints on writers

C: Correct

E: Error

R: Reject

5.2 Off-line ACR techniques

On the basis of information given in the research articles available to us, we categorize research works on off-line ACR systems into four categories. Category I consists of research articles that explicitly state that the technique was developed for off-line ACR system. Categories II and III consist of research articles on typewritten and handwritten characters respectively. Although the term off-line was not explicitly mentioned, yet from the text we guess that techniques described in there were intended for the off-line recognition. Category IV consists of research articles where the textual style of the test data was not mentioned at all. Techniques belonging to these categories are summarized in Tables 11-14 respectively. Using the criteria listed in section 4 these techniques are analyzed below.

Table.11. Off-line ACR systems: summary of recognition techniques

Ref	Feature type	Classifier	System parameters				Comments
			Segmentation method	Input data	Recognition type	Hand/ type written	
[198]	<i>Qualitative</i> 1. Branch attributes. 2. Loops. 3. Topological description 4. Topological relations <i>Quantitative</i> 1. Branch point counts.	Tree structured dictionary of sequence of primitive coding of characters.	Stroke segmentation by skeleton following.	Letters	Word recognition	Hand written	
[117]	<i>Qualitative</i> 1. Chain code strokes (primitives) 2. Dot position 3. Connection points 4. End points 5. Junction point 6. Secondary stroke 7. Loop frame 8. Layout context <i>Quantitative</i> 1. Dot numbers 2. Relative distance between stroke's starts and end points.	Stagewise classification: • Primary classification involves stroke identification • Secondary classification: combines strokes and recognizes a character. • Postprocessing using dictionary lookup.	Stroke segmentation by curve following.	Letters	Character and word recognition	Hand written.	
[197]	<i>Qualitative</i> 1. Branch attributes. 2. Loops. 3. Topological description. 4. Topological relations. <i>Quantitative</i> 1. Branch point counts.	Tree structured dictionary of sequence of primitive coding of characters.	Stroke segmentation by following direction of writing.	Letters	Word recognition	Hand written.	

Table 12. Typewritten ACR systems: Summary of recognition techniques

Ref.	Feature type
[89]	<p><i>Quantitative</i></p> <ol style="list-style-type: none"> 1. Character height 2. Character width 3. Number of dots 4. Character area. 5. Pin length—length of a short vertical stroke. 6. Character weight above and below the base line.
	<p><i>Qualitative</i></p> <ol style="list-style-type: none"> 1. Character position relative to the base line. 2. Dot position 3. Character connectivity 4. Outer boundary shape. 5. Position and value of peaks and valleys in horizontal projection
[85]	<p><i>Quantitative</i></p> <ol style="list-style-type: none"> 1. Six moments invariant
[143]	<p><i>Quantitative</i></p> <ol style="list-style-type: none"> 1. Contour segment length 2. Difference between the x and y coordinates of contour segments end points. 3. Angles formed at the intersection point of tangents drawn at two segments end points.
[68]	<p><i>Quantitative</i></p> <ol style="list-style-type: none"> 1. Crossing number 2. Character width
[30]	<p><i>Qualitative</i> (Morphological features)</p>
[166]	<p><i>Quantitative</i></p> <p>Six moments invariant</p>
[95]	<p><i>Quantitative</i> (Twelve Fourier descriptors)</p>
[68]	<p><i>Quantitative</i></p> <ol style="list-style-type: none"> 1. Horizontal and vertical projection 2. Number of dots.
	<p><i>Qualitative</i> Connected component code</p> <ol style="list-style-type: none"> 1. Dot positions 2. Zigzag shape positions 3. Vertical and horizontal bars 4. North, South, East, West and close curves.
[91]	<p><i>Quantitative</i> (Seven moment invariant descriptors)</p>
[67]	<p><i>Qualitative</i> (Freeman code)</p>
[163]	<p><i>Quantitative</i></p> <ol style="list-style-type: none"> 1. Quadrants with maximum and minimum daek pixels. 2. Major connectivity directions. 3. Mid point position 4. Single, two and three segment row and columns. 5. Dot count.
	<p><i>Qualitative</i></p> <ol style="list-style-type: none"> 1. Dot position. 2. Loop positions.
[178]	

I. D. = Input Data R. T. = Recognition Type L=Letters A=Alphanumeric N=Numerals C=Character W=Word

Table 12. (Continued) Typewritten ACR systems: Summary of recognition techniques

Ref.	Classifier	System parameters			Comments
		Segmentation method	I. D.	R. T.	
[89]	Classification tree	Histogram based segmentation	L	C	Multi font
[85]	Minimum distance classification	Accumulative Invariant Moments performing: • Line , word, character, segmentation. • Character segmentation is performed during the recognition	L	C	The approach is similar to the approach described in [41]
[143]	Quantitative decision function classifier	Outer contour based segmentation	L	C	
[68]	Classification tree	No	L	C	Isolated characters
[30]	Mathematical Morphology	No	L	C	No practical results
[166]	Minimum distance classification	Accumulative Invariant Moments performing: • Line , word, character, segmentation. • Character segmentation is performed during the recognition	L	C	The approach is similar to the approach described in [60]
[95]	Multi category classification scheme	Outer contour method	A	C	
[68]	Tree classification and Morphological word recognizer	Using connected component codes.	L	CW	
[91]	Minimum distance classifier.	1.Word segmentation by span computing. 2.Character segmentation by recognition.	L	C	
[67]	1.Decision tree for character recognition. 2.Viterbi Algorithm for word recognition.	Segmentation by projection.	L	CW	
[163]	Description matching.	Character segmentation by potential and actual connection column	L	C	Farsi characters recognition
[178]	-	Character segmentation using run length	L	-	Only segmentation

I. D. = Input Data R. T. = Recognition Type L=Letters A=Alphanumeric N=Numerals C=Character W=Word

Table 13. Handwritten ACR systems: Summary of recognition techniques

Ref.	Feature type	Classifier	System parameters			Comments
			Segmentation method	Input data	Recognition type	
[113]	<i>Quantitative</i> 1. Pixel count.	Distance and feature distribution.	No Segmentation	Numerals	Character Recognition	
[114]	<i>Qualitative</i> 1. Crossing code	Tree classifier	No Segmentation	Numerals	Character Recognition	Tested with different sizes.
[74]	<i>Quantitative</i> 1. Aspect ratio 2. Peak values of projection profile histogram.	Tree classifier.	No Segmentation	Numerals	Character Recognition	
[55]	<i>Qualitative</i> 1. Crossing code <i>Quantitative</i> Nine moment invariant descriptors.	Linear & Quadratic discriminate function	Character segmentation using histograms	Characters	Character Recognition	Features used Classification rate 1-4 81% 1-6 87.5% 1-7 93% 1-9 98.79% Letter position Classification rate Beginning 97.5% Middle 99.17% End 100% Isolated 98.5%
[129]	<i>Qualitative</i> • Branch, corner and end point counts. • Dot counts. • Loop count • Aspect ratio. • Character position.	Unspecified	Character segmentation using vertical histograms	Characters	Character Recognition	
[42]	<i>Qualitative</i> Strokes	Multistage classifier	Stroke segmentation by curve following	Characters	Character Recognition	
[76]	<i>Qualitative</i> Strokes as basic shapes	Tree classifier	Stroke segmentation by contour tracing	Characters	Character Recognition	
[5]	<i>Qualitative</i> Crossing point as a basic feature.	Hidden Markov model and decision-tree classifier	No Segmentation	Numerals	Character Recognition	

Table 14. ACR systems: Summary of recognition techniques

Ref.	Feature type	Classifier	System parameters			Comments
			Segmentation method	Input data	Recognition type	
[140]	<i>Quantitative</i> 1. Ten Fourier Descriptors. 2. Curvature Features <i>Qualitative</i> 1. Dots and holes.	Minimum distance classifier	No	Letters	Character Recognition	
[83]	-	Neural Network	No	Numerals	Character Recognition	
[70]	-	-	Using Freeman codes	-	-	Only segmentation
[149]	-	Lookup table	-	-	-	

5.2.1 Text style

Research works to build *ACR* systems capable of recognizing text styles ranging from printed and standardized characters to totally unconstrained handwritten text are being carried out. Techniques are devised to recognize handwritten words [197; 198] handwritten characters as well as words [117], handwritten characters [42; 54; 129]; and handwritten numerals [4-7; 74; 113; 114]. Similarly, recognition techniques are being devised for typewritten multifold character recognition [89] and unifont character recognition [67; 68; 85; 91; 108; 143; 164; 166] typewritten alphanumeric recognition [96] and numeral recognition [83]. Some studies emphasize on the development of techniques, hence the text style is not specified [140; 149].

5.2.2 Text segmentation

The text segmentation techniques are explicitly presented by some researchers. However, several researchers, who focus their attention on the development of feature extraction and classification modules only, have limited discussion on segmentation related issues. They assumed that the input to their systems were single isolated characters [4-7; 74; 83; 108; 113; 114; 140]. There are cases where the entire segmentation process is completely ignored [149]. Although text segmentation is a major issue, yet very little effort have been made to study the segmentation problem in isolation [178].

Most of the segmentation processes are described as a preprocessing step. After analyzing the segmentation techniques, we group them into: stroke based segmentation [42; 117; 192; 197] histogram based segmentation [54; 89; 129] outer contour analysis based segmentation [95; 96; 143] connected component based segmentation [68] projection based segmentation [67] potential and actual column connection based

segmentation [164] segmentation techniques using run length [178] segmentation using Freeman code [70] word segmentation by span computing [91] and segmentation during recognition [91; 166].

5.2.3 Feature definition, extraction and representation

To obtain an accurate recognition performance, both the quantitative (statistical / numerical) and qualitative (structural / topological) features were defined and used in *ACR* research. Commonly used features are discussed below.

5.2.3.1 Quantitative features

The simplest feature is the black pixel count. In this category there are two features: one is the simple black pixel count in the entire region [113], another is the maximum and minimum pixel counts in a marked region like the quadrants [164]. Other features are: character height [89] character width [89; 108] character area [89], Pin length (the pin length is defined as a short vertical stroke) [89] short line segment count (rows and columns containing a single, two or three pixels long lines) [164]; character weight above and below the base line [89] dot counts (the total number of Noqtah's) [68; 89; 117; 129; 164] aspect ratio (relationship between width and height of a character) [74; 129] projection (peak of projection profile and peak value of x/y histogram of crossing) [74] horizontal and vertical projections [68]; moments and moments invariant [55; 85; 91; 166]. Fourier descriptors [95; 96; 148] major connectivity directions [164] contour segment length [143] difference between the x and y coordinates of contour segment end points [129] angle formed by the two tangents drawn at two end points of a segment [143] the relative distance between the start and end points of a stroke [117] chain coded strokes [117].

5.2.3.2 Qualitative features

The qualitative features represent the structure of the entire character or the stroke. Ideally, feature forming structures are assigned a code instead of a value. Examples of the qualitative features are : the branch point count codes [129; 197; 198] branch attributes [197; 198] closed curves [68] open curves [71] corner point count codes [129] crossing code [74; 114] crossing point [4-7]; crossing number: [108]; Freeman code [67] dot positions [68; 89; 117; 163]; end-point codes [117] end-point count code [129] junction points [117] loops [71; 72; 197; 198] loop frame [117; 164] loop counts [129], loop position; [164] strokes [42; 144] secondary strokes [117]; topological relations (relations are defined by the nature of endpoint primitives) [197; 198] topological description (combinations of topological relations) [197; 198] layout context (base line information and location of one character with respect to its neighbors) [117] (character position relative to the base line) [89]; character's position within a word (first, last, middle, or isolated character) [129] character connectivity [89]; boundary analysis (outer boundary shape) [89] projection profile (position of peaks and valleys in the horizontal projection) [89] connected component analysis (connected component code) [68] vertical and horizontal bars [68] curves (north, south, east and

west facing curves) [68] geometric (direction and curvature features) [194] midpoint position (coordinates of midpoint between uppermost/leftmost and lowermost/rightmost dark points) [164].

5.2.4 Classification

Classification schemes used in *ACR* research are: Tree classifier [4-7; 67; 68; 72; 74; 108; 117; 197; 198], stage-wise classifier [117] that uses three stages: primary, secondary and post-processing. Basic strokes are identified in the primary stage. Using the information of primary stage, characters are recognized in the secondary stage and finally a word is recognized in the post processing stage. [42] uses a multistage classifier: First they classify strokes, and then they combine each string of strokes into a character. Use of the minimum distance classifier is reported in [48; 85; 115; 140; 166]. Use of a statistical decision function is mentioned in [55; 143] uses linear and quadratic discriminate functions. Other classification methods are: mathematical morphology [30; 68] string matching [164]; Viterbi algorithm for word recognition [67]; Hidden Markov model [4-7; 44; 144]; Neural Network [71; 83] and Table lookup [149].

5.2.5 Post processing

After the character recognition process, there might be rejected character(s). In such cases, post processing can be used for further testing. [67] uses word recognition for post processing. They used a dictionary and a probability of observing a given lattice of characters using different models of a word.

6. Performance Analysis

The performance of the on-line *ACR* systems has been analyzed in section 5.1. In this section an analysis of off-line *ACR* systems is presented. Based upon the representation of results in the *ACR* literature, we categorize these test results into four categories described below.

6.1 Off-line character recognition

This category includes those research articles in which the word 'off-line' is explicitly mentioned [117; 197; 198]. These articles describe systems that can recognize handwritten words and characters, and printed characters. The performance of the *ACR* techniques reported in these articles is summarized in Table 15.

6.2 Typewritten character recognition

In this category, the research articles that explicitly describe systems for typewritten character recognition are included [30; 67; 68; 85; 89; 91; 95; 96; 108; 143; 164; 166]. The performance of these techniques is summarized in Table 16.

Table 15. Off-line character recognition: Result summary

Ref.	Training set				Testing set				Over all	Comments	
	S.S.	C%	E%	R%	S.S.	C%	E%	R%	C%		
[198]	500w	-	-	-	-	-	-	-	-	86	The test words were produced under the constraints: it must be readable; it must be of fixed width and it must be continuous drawing.
[117]	1200c	92	-	-	-	-	-	-	-	-	1200 characters were extracted from 200 printed words written in four different types of fonts.
					600c	90					600 characters were extracted from 180 handwritten words in Naskh fonts by three writers. The wriers were asked to rewrite under limited constraints all 200 words of experiment 1.
[197]	500w	-	-	-	-	-	-	-	-	86	The test words were produced under the constraints: it must be readable; it must be of fixed width and it must be continuous drawing.

S.S.: Sample Size C: Correct E: Error R: Reject

Table 16. Typewritten characters recognition: Result summary

Ref.	Training set				Testing set				Over all	Speed	Comments	
	S.S.	C%	E%	R%	S.S.	C%	E%	R%	C%			
[89]	-	-	-	-	-	94	-	-	-	-	130-240 w/m	Speed depends on the font used.
[85]	900	-	-	-	17	94	-	-	-	-	10.6 c/m	Laser Printed text
[143]	-	-	-	-	4110	99	0.4	0.6	-	-	-	A mixture of 4110 Laser printed and unspecified number of dot matrix printed characters.
[108]	-	-	-	-	-	-	-	-	-	-	-	Isolated input characters
[31]	-	-	-	-	-	-	-	-	-	-	-	No result
[166]	900w	-	-	-	-	-	-	-	-	-	-	No result
[95;96]	-	-	-	-	160w	99	0.5	0.5	-	-	-	Low quality text. 90.04% character recognition yielded 63.1% word recognition. The word recognition rate was improved by 6.9% by applying two post processing operations.
[68]	50w	-	-	-	1000w	90.04	-	-	-	-	-	High quality text. 95.5% character recognition yielded 81.6% word recognition. The word recognition rate was improved by 6.97% by applying two post processing operations.
						63.16w						Recognition result on original data
						4.87w						Recognition result after scaling images by 0.5
						2.03w						Recognition result after scaling images by 0.2
						95.5						Recognition result after thinning the original data.
						81.6w						Recognition result after thinning the scaled images by 0.5
						6.65w						Recognition result after thinning the scaled images by 0.2
						0.32w						No experimental detail is given.
[91]	112	100	-	-	-	-	-	-	-	-	-	No experimental detail is given
	112	98										Only segmentation
	112	95										
	112	95										
	112	87										
	112	82										
[67]	-	-	-	-	-	-	-	-	-	90	3 c/s	No experimental detail is given.
[164]	-	-	-	-	-	-	-	-	-	100	-	No experimental detail is given
[178]	-	-	-	-	-	-	-	-	-	-	-	Only segmentation

S.S.: Sample Size C: Correct E: Error R: Reject

6.3 Handwritten character recognition

The research articles that explicitly describe techniques for handwritten character recognition are the part of this category [4-7; 42; 55; 74; 113; 114; 129]. The performance of these techniques is summarized in Table 17.

Table 17. Handwritten character recognition techniques: Result summary

Ref.	Training set				Testing set				Over all C%	Speed	Comments
	S.S	C%	E%	R%	S.S	C%	E%	R%			
[113]	200	-	-	-	2000c	99	1	-	-	-	Numeral recognition
[114]	-	-	-	-	500c	99	1	-	-	-	
[74]	-	-	-	-	150c	99.4	0.6	-	-	-	Numeral recognition. Tested with different sizes and tilts.
[55]	-	-	-	-	-	85.599.5	-	-	-	-	
129]	130w	-	-	-	170w	79	3	5	-	-	Result using linear discriminant function.
[42]	200w	-	-	-	400w	92 ^{81.25}	2	10	91	-	Result using quadratic discriminant function.
[5]	-	100	-	-	-	98	-	-	-	-	170 word = about 656 characters 13% enhanced by learning)
								6.7			Unrecognized due to seg. Errors) 10% rejection due to multiple choices.
											6.7 % no decision due to segmentation errors
											No sample size given

S.S.: Sample Size C: Correct E: Error R: Reject

6.4 Character Recognition.

In some research articles only the term 'character recognition' is mentioned [74; 83; 140; 149]. The recognition results of the techniques described in these articles are summarized in Table 18.

Table 18. Character recognition: Result summary

Reference	Training set				Testing set				Over all C%	Speed	Comments
	S.S.	C%	E%	R%	S.S.	C%	E%	R%			
[140]	500w	99	1	-	5000c	98	2	-	-	-	Estimating number of dots is the major error generator.
[83]	10 10	100 -	- -	- -	- -	- -	- -	- -	- -	- -	
[70]	-	-	-	-	-	-	-	-	-	-	Only segmentation.
[144]	-	-	-	-	-	-	-	-	-	-	

S.S: Sample Size C: Correct E: Error R: Reject

7. Discussion

The importance of the test data in the development of an OCR system for Latin based languages is very well documented and the same is true in the case of *ACR* system. Unfortunately, there is no standard test data set available that may be used to test and compare *ACR* techniques.

In an attempt to locate a test data, we surveyed available research articles. Our findings are summarized in Tables 19-21 below. From Table 21, it can be seen that the largest test data set consists of 5000 characters only, which is insufficient for an authentic conclusion.

Table 19. Arabic word recognition

Research articles	Recognition Score				Over all %.	Test data attributes
	Training data set		Test data set			
	Sample size	Correct recog.%	Sample size	Correct recog.%		
[198]	500	-	-	-	86	Handwritten
[197]	500	-	-	-	86	Handwritten
[129]	130	-	170	79	-	Handwritten
[42]	200	-	400	81.25	-	Handwritten
[166]	900	-	-	-	-	Typewritten
[68]	50	-	1000	63.16	-	Typewritten
			1000	81.60		Typewritten

Table 20. Typewritten arabic character recognition

Research articles	Recognition score				Over all %.	Test data attributes
	Training data set		Test data set			
	Sample size	Correct recog.%	Sample size	Correct recog.%		
[89]	-	-	-	94	86	Alpha
[85]	900	-	17	74	-	Alpha
[143]	-	-	4110	98-99	-	Alpha
[108]	-	-	-	-	-	Alpha
[30]	-	-	-	-	-	Alpha
[91]	112	82-100	-	-	-	Alpha
[67]	-	-	-	-	90	Alpha
[164]	-	-	-	-	100	Alpha

Table 21. Handwritten Arabic character recognition

Research articles	Recognition Score				Over all %.	Test data attributes
	Training data set		Test set			
	Sample size	Correct recog. %	Sample size	Correct recog. %		
[113]	200	-	2000	99.0	-	Numerals
[114]	-	-	500	99.0	-	Numerals
[74]	-	-	150	99.4	-	Numerals
[55]	-	-	-	85.5	-	Numerals
				99.5	-	Numerals
[76]	-	-	-	-	-	Alpha
[6]	-	100.0	-	98	-	Alpha
[114]	500	99.0	5000	98	-	Alpha
[83]	10	100	-	-	-	Alpha
[70]	-	-	-	-	-	Alpha
[149]	-	-	-	-	-	Alpha

The quality and size of the test data set is the only resource which can be used to predict the reliability of an *ACR* technique. A large test data set (more than 1000 character/class) that reflects factors affecting the Arabic text production process is required to estimate the reliability of an *ACR* technique. The common factors that affect the text production process are: font type, pen type, paper texture, paper color, ink color, writing style, writing environment and writers mood.

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التعرف على الحروف العربية : التقدم والتحديات

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ملخص البحث. يمكن لنظم التعرف على الحروف توفير الحلول لمشاكل إدخال البيانات إلى الحاسوب، التي تمثل عنق الزجاجة في كثير من مجالات التصنيع والمعالجة المعلوماتية. ولذلك؛ تمت دراسة وتطوير مثل هذه النظم لكافة اللغات العالمية، ويجب ألا تكون اللغة العربية مستثناة من ذلك. وخلال العقود الثلاثة الماضية، وجد عدد ملحوظ من الأبحاث وأعمال التطوير باتجاه الوصول إلى نظام فعال للتعرف على الحروف العربية. في هذه الورقة، نعرض مراجعة وتقويماً شاملاً للطرق المستخدمة في تطوير أنظمة التعرف على الحروف العربية، إضافة إلى سرد مفصل لأهم المراجع في هذا المجال.