

# Arabic Optical Text Recognition: A Classified Bibliography

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**Abstract** A classified bibliography and a lexicographically-indexed table of 260 items of literature pertaining to the optical recognition of Arabic texts, including Hindi numerals' recognition, are provided. The limited number of items cited in this bibliography highlights two points. First, the difficulties facing researchers in collecting dispersed references pertinent to this research area, which was in the first place a major incentive to working on this paper. Second, the limited efforts and resources expended in promoting this branch of research, evident from comparing the volumes of reported OCR research works and products on Latin and other languages with those on Arabic. A keyword-based classification scheme whose results may help in locating papers of interest in a certain research subtopic is implemented. An appendix provides a classified table highlighting the features of each of the included literature items, offering a glimpse of an overall picture.

**Indexing Terms:** *Arabic Optical Text Recognition Arabic Optical Character Recognition  
AOTR AOCR OCR Classified Bibliography*

## Introduction

The authors have been collecting literature on the subject of Arabic optical text recognition (AOTR) for more than two years<sup>3</sup>. To the authors' knowledge, this is the first attempt to produce a classified bibliography on AOTR.

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The published work on Arabic optical text recognition is comparatively limited in number and scattered in many places. Due to this status, researchers in the field face considerable difficulties in locating reports of the previous efforts in this field. To make their task easier, and to help them concentrate on the job they need the literature for, we have expended time and effort in collecting, classifying, and producing this bibliography.

All the papers, theses, and reports that we could trace are included. The references that the authors could not lay hands on a copy of, are marked with an asterisk (\*) following their entry in the AOTR bibliography. Readers should not expect the classification of such references to be as complete as that of the available references. Classifying the unavailable ones is based either on their title if the title is indicative and/or informative, or on other researcher's comments on them, if available. Farsi, Kurdi, Urdu, and historical Ottoman texts use the Arabic alphabet set with few additions or modifications. Hence few papers on the recognition of texts in Farsi and historical Ottoman could be obtained and are included. The language of all these literature items is English save 11 items in Arabic; 11 in French; two in Japanese; and only one item in Russian.

### **Classification Results**

Readers who prefer to bunch literature items relevant to each research topic and/or subtopic in the field of Arabic optical text recognition, will find their needs satisfied in this section before the compiled AOTR bibliography. Table (1) highlights the statistics of the collected literature items. Meanwhile, readers interested in having a concise picture of each literature item in this classified collection are referred to the table given in Appendix A.

In the appendix, some symbolic information on each of the items of the bibliography are arranged in one row of the table. Some light is first shed, in Appendix A, on the classification scheme concocted to fill up the entries of that table. With the help of that scheme the symbolic information on each of these references can be decoded and made available.

**Table (1) Statistics of the Literature Items  
of the AOTR Bibliography**

<b>Type</b>	<b>Available</b>	<b>Non- available</b>	<b>Sum</b>
<b>General Review Papers</b>	<b>7</b>	<b>3</b>	<b>10</b>
<b>Research Papers</b>	<b>153</b>	<b>61</b>	<b>214</b>
<b>Research Reports</b>	<b>1</b>	<b>11</b>	<b>12</b>
<b>Theses (Ph. D. &amp; Master)</b>	<b>7</b>	<b>16</b>	<b>23</b>
<b>Books</b>	<b>0</b>	<b>1</b>	<b>1</b>
<b>Total Number</b>	<b>168</b>	<b>92</b>	<b>260</b>

## **Review Papers**

Two of the review papers cited in this bibliography, namely [Govindan90] and [Mantas86], are not confined to AOTR. Nevertheless, the first of them is a very informative, well-written, broad-scope review paper. The second gives a historical background and a general review of industrial recognisers and scanning devices. The two papers looked into some research works on AOTR, and included some of these works among their references. We recommend any novice to start his readings on the subject with these two papers. A recent and far more comprehensive survey paper that critically looked into the AOTR systems available in the marketplace is [AlBadr95]. [Ahmed94] has looked into the problem of the non-standard test data sets and evaluated the performance of systems and published research works in AOTR spanning more than the last two decades (1981-1992). Including the aforementioned papers, the following are the review papers cited in this bibliography, divided into two groups: 10 general review (GR) papers and 17 limited review (LR) papers.

### **a. General Review Papers:**

[Ahmed94]; [AlBadr95]; [Amin85a]; [Ghuwar94]; [Govindan90]; [Jambi91b]; [Mantas86]; [Nouh94]; [Parhami77]; and [Shoukry89].

### **b. Limited Review Papers:**

A limited review paper is a research paper or report that discusses and/or compares the performance of a limited number of published techniques and reports in the field. The following are papers that fall under this category.

[AbdElGwad90]; [AlOhal96]; [Amin85b]; [Amin87]; [Fakir91]; [Nouh88b]; [Ramsis88]; [SharafEldin88]; [Tikhonova92]; [Tolba87a]; [Tolba88a]; [Tolba88b]; [Tolba89]; [Tolba90]; [Yalabik88]; [Youssef89]; and [Youssef93].

## **Nature of Application and Hardware Implementation**

There are three general points applicable at this juncture:

- First, on-line recognition techniques are generally deemed comparatively simpler than off-line techniques. This is mainly due to the availability of important temporal information inherent of on-line handwritings.
- Second, the recognition of characters is always simpler than that of cursive text, due to the attendant problems of segmenting such texts into words, subwords, and eventually in most of the cases into characters.
- Last point is that, due to variability of the human writing both in style and size, handwritten texts are far more difficult to recognise compared to machine-printed texts.

## **i. On-line**

### **a. Handwritten Character Recognition**

[Amin79]; [Amin80]; [Amin85b]; [Amin87]; [Amin88b]; [ElSheikh89a]; [ElSheikh90a]; [ElSheikh90c]; [ElWakil87]; [ElWakil88]; [ElWakil89]; and [Nouh87c].

### **b. Handwritten Cursive Text Recognition**

[AbdelAzim96]; [AlEmami90]; [Amin82a]; [Amin82b]; [Amin83]; [Amin84]; [Amin85b]; [Amin85c]; [Amin87]; [Amin88c]; [ElSheikh90b]; [Nouh87c]; [Seddik89]; and [Shaheen90].

### **c. Handwritten Hindi Numerals Recognition**

[ElSheikh90c] and [Nouh87c].

## **ii. Off-line**

### **a. Printed Character Recognition**

[AbuHaiba90]; [AbuHaiba91]; [Aiih88]; [AlBaiaty86]; [AlEmami88]; [Ali89]; [AlShebeili97]; [AlTuwaijri94b]; [AlTuwaijri94c]; [AlTuwaijri95b]; [AlTuwaijri96]; [AlYousefi92]; [Badie78]; [Belghith90]; [Bouhlila88]; [ElRamly89b]; [ElRamly89c]; [ElShbiny76]; [ElSheikh88a]; [ElSheikh89b]; [Fayek92]; [Goneid87]; [Goneid88]; [Ismail93a]; [Jambi97]; [Khella94]; [Khemakhem87a]; [Khemakhem87b]; [Khemakhem88]; [Khemakhem89]; [Khemakhem93]; [Kurdy92]; [Mahdi87]; [Mahdi89]; [Mahmoud91]; [Mahmoud94]; [Nabawi94]; [Namane90]; [Nazif75]; [Nouh80]; [Nouh84]; [Nouh87b]; [Nouh87c]; [Nouh88a]; [Nouh88b]; [Nouh88c]; [Nouh88d]; [Nouh89]; [NurulUla87]; [NurulUla88a]; [NurulUla88b]; [Sabri86]; [Sanossian96]; [SharafElDin88]; [Sharkawy88]; [Taconet89]; [Tolba86]; [Tolba87a]; [Tolba87b]; [Tolba87d]; [Tolba88a]; [Tolba88b]; [Tolba89]; and [Tolba90].

### **b. Printed Cursive Text Recognition**

[AbdelAzim87]; [AbdelAzim88]; [AbdelAzim89a]; [AbdelAzim89d]; [AbdelAzim89e]; [AbdelAzim90a]; [AbdelAzim90b]; [AbdelAzim92a]; [AbdelAzim92b]; [AbdelAzim93]; [AbdelAzim95]; [Ahmed92]; [AlBadr92]; [AlBadr93]; [AlBadr95b]; [AlBadr95c]; [AlBadr96]; [AlJabri91]; [AlJabri92]; [Allam94]; [AlOhali96]; [AlSuwaiyel91]; [Amin85c]; [Amin86]; [Amin88a]; [Amin89]; [Amin91a]; [Amin91b]; [Badie80a]; [Badie80b]; [Barber88]; [Berbar94]; [Bouhlila89]; [ElDabi90]; [ElGowely89]; [ElGowely90]; [ElKhaly90]; [ElRamly89a]; [ElSheikh88b]; [Emam93]; [Emam94]; [Fakir91]; [Fakir92]; [Fakir93]; [Fehri94]; [Ghuwar95]; [Goraine89]; [Goraine90]; [Goraine92a]; [Goraine92b]; [Goraine94]; [Guindi87]; [HajHassan85].

[HajHassan88]; [HajHassan90]; [HajHassan91]; [Hashish85]; [Hassibi93]; [Hassibi94]; [Hyder88a]; [Hyder88b]; [Ismail93b]; [Jambi90]; [Kamel90]; [Khella92]; [Khemakhem88]; [Khemakhem89]; [Khemakhem93]; [Kurdy93]; [LaPre96]; [Makhoul96]; [Margner92]; [Nouh87a]; [Nouh87c]; [Nouh88a]; [Parhami81]; [Ramsis88]; [Rashid96]; [Saleh75a]; [Saleh75b]; [Saleh77]; [Shoukry83]; [Shoukry91]; [Yalabik88]; [Youssef89]; and [Youssef93].

### **c. Printed Hindi Numerals Recognition**

[Ali89]; [ElHamalawy88]; [Mahmoud86]; [Mahmoud87]; [Nouh87c]; [Nouh88a]; and [Parhami81].

### **d. Handwritten Character Recognition**

[Abdelgwad90]; [AbuHaiba90]; [AbuHaiba95a]; [AbuHaiba95e]; [AbuHaiba96b]; [AlEmami88]; [Ali79]; [AlYousefi88]; [AlYousefi89]; [AlYousefi90]; [AlYousefi92]; [Badie82a]; [Badie82b]; [ElDesouky91]; [ElDesouky92]; [Nouh87c]; [Nouh93]; [NurulUla88a]; [NurulUla88b]; [Rashwan94]; [SaadAllah85]; [Tolba86]; [Tolba87b]; [Tolba87d]; [Zaki86a]; and [Zaki86b].

### **e. Handwritten Cursive Text Recognition**

[AbdelAzim89b]; [AboSamra97]; [AbuHaiba93]; [AbuHaiba94a]; [AbuHaiba94b]; [AbuHaiba94c]; [AbuHaiba95b]; [AbuHaiba95c]; [AbuHaiba95d]; [AbuHaiba96a]; [AbuHaiba96b]; [AlMuallim87]; [AlTuwaijri94a]; [AlTuwaijri95a]; [AlYousefi92]; [Ameur93]; [Amin91b]; [Amin92]; [Badie82a]; [Badie82b]; [Jambi91a]; [Jambi92]; [Jambi93]; [Jambi95]; [Jambi96]; [Nouh87a]; [Nouh87c]; [Rahho86]; [Shoukry94]; [Zahour89]; [Zahour90]; [Zahour91]; and [Zahour92].

### **f. Handwritten Hindi Numerals Recognition**

[Abbas86]; [AbdelAzim89c]; [Abdulla88]; [AlQaisy85]; [AlQaisy87]; [AlQaisy89]; [AlTikrity84]; [AlTikrity85]; [Assal91]; [Assal92]; [Bansal84]; [Braham92]; [Goneid92a]; [Goneid92b]; [Goneid92c]; [Mahmoud86]; [Mahmoud87]; [Nouh87c]; and [Yousef86].

### **iii. Multifont Recognition:**

[AbdelAzim89a]; [Ahmed94]; [AlBadr92]; [AlBadr95a]; [Allam94]; [AlTuwaijri94a]; [AlTuwaijri95a]; [Amin86]; [Amin88a]; [Amin89]; [Amin91a]; [ElGowely89]; [ElGowely90]; [ElSheikh89b]; [Fayek92]; [Fehri94]; [Goraine89]; [Govindan90]; [Hassibi94]; [Kurdy92]; [Kurdy93]; [LaPre96]; [Makhoul96]; [Namane90]; [NurulUla88a]; [NurulUla88b]; [Ramsis88]; [Rashid96]; [Tolba89]; and [Tolba90].

#### **iv. Hardware Implementation**

Most of the techniques used in the AOTR field are implemented in software, availing from the high processing speeds and huge storage capacities of the new machines. Nonetheless, continuous leaping advances in both chip technology and computer architecture enable implementing some of these techniques, wholly or partly, in hardware. Parallel processing techniques and their hardware implementation have opened new vistas for realising connectionist neural nets and employing some other techniques used in the character recognition field in hardware form.

[Abbas86] and [Khemakhem93].

### **Pre-processing and Segmentation Techniques**

#### **i. Pre-processing Techniques**

The first step to be taken before processing a character is to have its image acquired using video cameras, scanners, or the like, and transformed into a digitised form suitable for recognition. The recognition efficiency depends -- in its major part -- on the quality of this digitised image and on how faithfully it represents the original image (or strictly the document in this case). Noise in such a document representation is there with any black pixel(s) representing an extraneous signal, whatever its source may be, in the digitised image.

Pre-processing techniques are used to theoretically eliminate, or practically reduce, both noise and variations in the digital image. For example, eliminating variations leads to a digital image of the handwritten character independent of the writer's personal style. The pre-processing techniques are aimed at minimising the effects of the unwanted noise and variations through using one or more of many operations. These techniques include, among others, binarization (thresholding), scaling, filtering and smoothing, thinning (skeletonization), slant normalisation, deskewing leading to baseline detection, and stroke width estimation.

#### **a. Noise Reduction (Smoothing)**

Work has been continuing on this topic since OCR systems started to be at the focus of researchers' attention. This is justified since it is a long-held view that were it not for noise with its diverse sources, the recognition of isolated printed characters would have been a trivial issue. Noise reduction techniques are numerous, with some of them more suited to either on- or off-line applications. They encompass, after binarization (thresholding) of the character image, conditioning steps like low-pass filtering and smoothing. The latter steps are needed to minimise variations that are a by-product of the image acquisition process. Image traversal

removes isolated pixels and fills gaps. Mathematical morphological operations may also be used for smoothing the character binary image.

[Abbas86]; [AbdelAzim89c]; [AbuHaiba90]; [AbuHaiba91]; [AbuHaiba93]; [AbuHaiba94a]; [AbuHaiba94b]; [AbuHaiba94c]; [AbuHaiba95a]; [AbuHaiba95b]; [AbuHaiba95c]; [AbuHaiba95d]; [AbuHaiba96a]; [AbuHaiba96b]; [Ahmed92]; [AlBadr95b]; [AlBadr95c]; [AlBadr96]; [AlBadr92]; [Ali89]; [AlShebeili97]; [AlTuwaijri94b]; [AlTuwaijri95a]; [AlTuwaijri95b]; [AlTuwaijri96]; [AlYousefi88]; [AlYousefi89]; [AlYousefi90]; [AlYousefi92]; [Ameur93]; [Amin80]; [Amin82a]; [Amin82b]; [Amin83]; [Amin84]; [Amin85b]; [Amin85c]; [Amin86]; [Amin87]; [Amin88a]; [Amin88b]; [Amin88c]; [Amin89]; [Amin91a]; [Amin91b]; [Amin92]; [Badie82a]; [Badie82b]; [Braham92]; [ElGowely90]; [ElHamalawy88]; [ElKhaly90]; [ElRamly89a]; [ElRamly89b]; [ElRamly89c]; [ElSheikh88a]; [ElSheikh88b]; [Emam93]; [Emam94]; [Fakir93]; [Fayek92]; [Fehri94]; [Ghuwar95]; [Goneid92b]; [Goneid92c]; [Goraine92b]; [Goraine94]; [HajHassan91]; [Hassibi94]; [Jambi90]; [Jambi91a]; [Jambi97]; [Khella92]; [Khella94]; [KKurdy93]; [Lapre96]; [Mahmoud94]; [Makhoul96]; [Nabawi94]; [Namane90]; [Nouh87a]; [Nouh87b]; [Nouh88d]; [Nouh93]; [NurulUla88a]; [Parhami81]; [SaadAllah85]; [Saleh75a]; [Saleh75b]; [Shaheen90]; [Shoukry91]; [Taconet89]; [Tolba89]; [Tolba90]; [Zahour89]; [Zahour91]; [Zahour92]; [Zaki86a]; and [Zaki86b].

## **b. Thinning (Skeletonization) & Contour Detection**

This process of thinning, or reducing, the character image into a skeleton is an essential step for OCR systems that require the expression of structural relationships for the sake of recognition. Obviously these relationships reduce both the space and processing time exacted by such systems. Thinning algorithms are very convenient for OCR systems aimed at recognising handwritten text and/or characters to combat the inherent variations in the human writing styles. Clustering algorithms implementing fuzzy approaches are also used to reduce characters into skeletons, but they are slow and suitable only for isolated characters. Contour detection helps also in scaling characters into a fixed size, and then centring the character inside the box prior to the recognition stage. This is generally useful in systems sensitive to variations in character size and position, like template matching and correlation methods. It has to be born in mind that such thinning techniques should preserve the secondaries of the Arabic characters, such as dots, zigzags, and the like. This information is vital for recognising Arabic, since many characters have the same main body and can only be differentiated using these secondaries.

[Abbas86]; [AbdelAzim92a]; [AbdelGwad90]; [Abdulla88]; [AbuHaiba90]; [AbuHaiba91]; [AbuHaiba93]; [AbuHaiba94a]; [AbuHaiba94b]; [AbuHaiba94c];

[AbuHaiba95a]; [AbuHaiba95b]; [AbuHaiba95d]; [AbuHaiba96a]; [AbuHaiba96b]; [Ali89]; [Allam94]; [AlMuallim87]; [AlTiktiti85]; [AlTuwaijri94b]; [AlTuwaijri95a]; [AlTuwaijri95b]; [AlTuwaijri96]; [Ameur93]; [Amin89]; [Amin91b]; [Amin92]; [Badie82a]; [Badie82b]; [ElDesouky91]; [ElDesouky92]; [ElHamalawy88]; [ElKhaly90]; [ElRamly89a]; [ElRamly89b]; [ElRamly89c]; [ElSheikh88a]; [ElSheikh88b]; [ElSheikh89a]; [ElSheikh90a]; [ElWakil87]; [ElWakil88]; [ElWakil89]; [Emam94]; [Fakir93]; [Fehri94]; [Goneid92b]; [Goneid92c]; [Goraine89]; [Goraine92b]; [Goraine94]; [HajHassan91]; [Hassibi94]; [Jambi91a]; [Jambi92]; [Jambi93]; [Jambi95]; [Khella92]; [Khella94]; [Mahdi87]; [Mahdi89]; [Mahmoud91]; [Mahmoud94]; [Margner92]; [Namane90]; [Nouh89]; [NurulUla88a]; [Parhami81]; [SaadAllah85]; [Shaheen90]; [Tolba89]; and [Tolba90].

### **c. Restoration of Temporal Information from Off-line Handwritten Texts**

Some research work do not fit under one of the previous subheadings but still fall under the broad banner of pre-processing. Some researchers have decided to get hold of the temporal information missing from the handwritten texts produced in off-line environments. For this purpose they suggested a new technique to extract such information from off-line texts in order to render on-line text recognition techniques applicable to off-line handwritten texts.

The advantage here is the relative ease with which on-line recognition techniques are applied compared to off-line ones. Restoration of temporal information may be achieved by skeletonizing the connected words/subwords of the text, then representing each one of them in a way suitable for extracting the needed temporal information. This information include the number of strokes, their order, and the direction of writing of each stroke.

[AbuHaiba93]; [AbuHaiba94b]; [AbuHaiba95b]; and [AbuHaiba96b].

### **ii. Segmentation**

Although some optical character recognition (OCR) systems do not necessarily need segmentation, this stage is deemed indispensable for many OCR systems. In these latter systems, segmentation is mostly carried out directly after pre-processing. In the segmentation stage individual characters of the text words are isolated prior to recognising them. Nevertheless, the segmentation task is naturally carried out after page decomposition into its logical elements that are not necessarily all text. Segmentation of the text elements first into words and/or subwords and then into characters (or even into strokes or primitives) is important, and is deemed a decisive step to the success of most text recognisers. A most common method used to achieve the identification of text lines, then the segmentation of each line into words and/or subwords, is the horizontal



and vertical projection histograms, respectively. Some other methods are used either to supplement this, or to succeed it in case of failure. Contour tracing, thinning, traversing an energy-like curve, skeleton tracing, and connected component labelling are some of these methods. Arabic texts in particular suffer from the presence of horizontal ligatures and vertical overlapping that aggravate both the segmentation and recognition phases.

[AbdelAzim88]; [AbdelAzim89a]; [AbdelAzim89c]; [AbdelAzim89d]; [AbdelAzim90b]; [AbdelAzim92a]; [AbdelAzim96]; [AboSamra97]; [AbuHaiba95c]; [Ahmed92]; [AlEmami90]; [AlMuallim87]; [AlOhal96]; [AlTuwaijri94a]; [AlTuwaijri95a]; [AlYousefi88]; [AlYousefi90]; [AlYousefi92]; [Ameur93]; [Amin82a]; [Amin82b]; [Amin83]; [Amin84]; [Amin85b]; [Amin85c]; [Amin86]; [Amin87]; [Amin88a]; [Amin88b]; [Amin88c]; [Amin89]; [Amin91a]; [Amin91b]; [Amin92]; [Assal92]; [Bouhlila89]; [ElDabi90]; [ElGowely90]; [ElKhaly90]; [ElSheikh88b]; [ElSheikh90b]; [ElSheikh90c]; [Emam93]; [Emam94]; [Fakir93]; [Fehri94]; [Goneid92c]; [Goraine89]; [Goraine92b]; [Goraine94]; [HajHassan85]; [HajHassan88]; [HajHassan90]; [HajHassan91]; [Hassibi94]; [Jambi90]; [Jambi91a]; [Jambi92]; [Jambi93]; [Jambi95]; [Khella92]; [Kurdy93]; [Margner92]; [Nabawi94]; [Nazif75]; [Parhami81]; [Ramsis88]; [Rashid96]; [Saleh75a]; [Saleh75b]; [Shoukry91]; [Tolba89]; [Tolba90]; [Zahour89]; [Zahour91]; and [Zahour92].

## **Feature Extraction Approaches**

The history of optical character recognition pivots itself around the notion of how the human ability to recognise written texts can lend itself to a machine, but expectedly at a faster pace. Many approaches are available, but from an Artificial Intelligence (AI) viewpoint the template matching approach is dispensed with. Other approaches are less sensitive to noise and lend themselves more suitably to problems emanating from variability of font size and handwriting styles. Most of these approaches invariably need suitable features of every character of the learning set to be decided upon, extracted, and stored in a features' vector. In the subsequent stage of the recognition process, these features will be used to classify, or recognise, the unknown input characters.

### **a. Template Matching and Correlation**

This technique emulates a mechanical template by comparing a given unknown character pattern, pixel-by-pixel, to a stored set of pattern templates. The given pattern is considered to belong to the class of the stored template with a minimum distance, or error. Albeit being direct to implement, this technique suffers from hypersensitivity to distortion. Many researchers use wide variations of this technique when other employed methods fail to recognise some input characters.

[AbdelAzim88]; [AlBaiaty86]; [Nazif75]; [Nouh80]; [Nouh84]; [Nouh87b]; [Nouh88d]; and [Nouh93].

## **b. Statistical Distribution of Points**

These features describe the given character using a set of characteristic measurements extracted from its pattern. These features include Zoning, Crossings, n-tuples, Distances and Moments, just to name some of them. Systems using such features may be automatically trained for new fonts of the character set, since they generally tolerate moderate noise and variation in the character image to some extent. They provide high speed and diminished implementation complexity. However, for such features the mask making is generally difficult.

[Abbas86]; [AbdelAzim88]; [AbdelAzim89a]; [AbdelAzim89b]; [AbdelAzim89c]; [AbdelAzim89d]; [AbdelAzim90a]; [AbdelAzim90b]; [AbdelAzim92a]; [AbdelAzim92b]; [AbdelAzim93]; [AbdelGwad90]; [Ahmed92]; [AlBadr92]; [Allam94]; [AlQaisy85]; [AlQaisy89]; [AlTikrity85]; [AlTuwaijri94a]; [AlTuwaijri95a]; [AlYousefi88]; [AlYousefi89]; [AlYousefi90]; [AlYousefi92]; [Belghith90]; [Braham92]; [ElDabi90]; [ElHamalawy88]; [ElKhaly90]; [ElRamly89b]; [ElRamly89c]; [ElSheikh90c]; [Emam94]; [Fayek92]; [HajHassan91]; [Jambi97]; [Kamel90]; [LaPre96]; [Mahmoud86]; [Mahmoud87]; [Makhoul96]; [Nabawi94]; [Nouh88b]; [NurulUla88b]; [Ramsis88]; [Rashid96]; [Rashwan94]; [Saleh75a]; [Saleh75b]; [Saleh77]; [Sanossian96]; [SharafEldin88]; [Shoukry94]; [Tolba86]; [Tolba87a]; [Tolba87b]; [Tolba87d]; [Tolba88a]; [Tolba88b]; [Tolba89]; [Tolba90]; [Zaki86a]; and [Zaki86b].

## **c. Global Transformations & Series Expansion**

These techniques produce features that are insensitive to global deformation such as rotation, scaling, and translation. They also help to simplify the features' vector. Many researchers have used Walsh, Fourier, Hough, 1-D slice of the character spectrum, Projections, and other transforms. Chains of direction coding have also been used in different schemes. However, these techniques sometimes require the support of using additional features to improve the recognition rates. Like the statistical features, they may also automate the recogniser training for new fonts.

[Abbas86]; [AlQaisy87]; [AlShebeili97]; [ElKhaly90]; [ElSheikh88a]; [ElSheikh88b]; [Fakir93]; [Ismail93a]; [Khella92]; [Khella94]; [Khemakhem88]; [Khemakhem89]; [Khemakhem93]; [Mahmoud94]; [Nabawi94]; and [Sharkawy88].

## **d. Structural (Geometrical) & Topological Features**

As the name implies, these features are directly dependent on, and extracted from, the geometry, or topology, of the given character yielding its global (topological) and local (geometrical) properties. These features include, but are not restricted to, strokes, bays, loops, number of crossing

points, branching points, end points, dots, and zigzags. They are highly tolerant of distortions and variations in writing styles, but are not always easy to extract from the character images. This is simply because these features require the pattern structure to be quantifiable, a task that is not always easy. Mask generation is also difficult for these types of features.

[AbdelAzim89a]; [AbdelAzim89b]; [AbdelAzim89c]; [AbdelAzim92a]; [AbdelAzim96]; [AbuHaiba90]; [AbuHaiba94a]; [AbuHaiba94b]; [AbuHaiba94c]; [AbuHaiba95a]; [AbuHaiba95b]; [AbuHaiba95e]; [AbuHaiba96b]; [AlBadr96]; [AlEmami90]; [Ali79]; [AlMuallim87]; [AlOhal96]; [AlTikrity84]; [Ameur93]; [Amin80]; [Amin82a]; [Amin82b]; [Amin83]; [Amin84]; [Amin85b]; [Amin85c]; [Amin86]; [Amin87]; [Amin88a]; [Amin88b]; [Amin88c]; [Amin89]; [Amin91a]; [Amin91b]; [Badie82a]; [Badie82b]; [Bansal84]; [ElDesouky91]; [ElDesouky92]; [ElGowely90]; [ElRamly89a]; [ElSheikh88a]; [ElSheikh88b]; [ElSheikh89a]; [ElSheikh90a]; [ElWakil87]; [ElWakil88]; [ElWakil89]; [Fakir93]; [Fehri94]; [Ghuwar95]; [Goneid92b]; [Goneid92c]; [Goraine89]; [Goraine92b]; [Goraine94]; [HajHassan91]; [Hassibi94]; [Hyder88a]; [Hyder88b]; [Ismail93a]; [Jambi90]; [Jambi91a]; [Jambi92]; [Jambi93]; [Jambi95]; [Khella94]; [Kurdy93]; [Margner92]; [Nazif75]; [Parhami81]; [SaadAllah85]; [Shaheen90]; [Zahour89]; [Zahour91]; and [Zahour92].

## Classification Approaches

The recognition system is trained using the training set(s) on the features of the elements of the character set to be recognised, then comes the classification, or recognition phase. When an unknown character (after being segmented from the text, if not originally separate) is introduced, the recognition system should extract its features. These are then compared to the stored ones, using the specific classification algorithm. Consequently, the recognition system should come out with the best possible match, which hopefully is the right character class.

Classification approaches directly represent the character recognition schemes. These recognition schemes may be broadly classified into two main streams: statistical and structural approaches. Nevertheless, in order to allow the reader to pinpoint his sought references without delay, these two streams are available as broad headings. Some other specific approaches, that may not always exactly fit under one of them, are singled out. Hybrid classifiers are always possible to improve both the system's reliability and the recognition rate.

### **a. The Statistical Approach**

Statistical classifiers are **decision-theoretic** approaches that span a diverse number of either deterministic or probabilistic methods. The former type of methods encompasses deterministic or distance classifiers. These classifiers have to map a fixed-length features' vector into a partitioned space. This process is equivalent to clustering in the vector space, where the decision rule is mainly a non-exact matching based on distance calculations to centres of clusters. The unknown input pattern

(character) is compared, then decided upon using many techniques. These include distance classifiers (to class means), nearest-neighbour (ranging from 1-nearest neighbour to k-nearest neighbour classifiers), and Bayesian (probabilistic) classifiers. Decision-tree classifiers are also statistical in nature. They range from using simple trees to using multiple-trees in order to improve the recognition accuracy. Statistical classifiers are generally capable of being automatically trained.

[Abbas86]; [AbdelAzim88]; [AbdelAzim89a]; [AbdelAzim89d]; [AbdelAzim90a]; [AbdelAzim90b]; [AbdelAzim92a]; [AbdelGwad90]; [AlBadr92]; [AlBaiaty86]; [Allam94]; [AlQaisy89]; [AlShebeili97]; [AlTikrity85]; [AlYousefi88]; [AlYousefi89]; [AlYousefi90]; [AlYousefi92]; [ElDabi90]; [ElHamalawy88]; [ElKhaly90]; [ElRamly89b]; [ElRamly89c]; [ElSheikh88a]; [ElSheikh88b]; [ElWakil87]; [ElWakil88]; [ElWakil89]; [Fakir93]; [Fayek92]; [HajHassan91]; [Kamel90]; [Khella92]; [Khella94]; [Khemakhem88]; [Khemakhem89]; [Khemakhem93]; [Mahmoud86]; [Mahmoud87]; [Mahmoud94]; [Margner92]; [Nabawi94]; [Nazif75]; [Nouh80]; [Nouh84]; [Nouh87b]; [Nouh88b]; [Nouh88d]; [Nouh93]; [NurulUla88b]; [Ramsis88]; [Saleh75a]; [Saleh75b]; [Saleh77]; [SharafEldin88]; [Tolba86]; [Tolba87a]; [Tolba87b]; [Tolba87d]; [Tolba88a]; [Tolba88b]; [Tolba89]; [Tolba90]; [Zaki86a]; and [Zaki86b].

## b. The Syntactical Approach

The syntactical or **language-theoretic** classifiers are based on the grammar concept borrowed from the theory of formal language. For some of these classifiers to be implemented, the unknown input words should be successively segmented into smaller identifiable primitives. These primitives should then be parsed according to a given set of these syntactical rules. The unknown pattern, represented by a string of primitives, is classified as being a member of a certain class if it is successfully parsed by its grammar. In some cases such a string may not be completely parsed, then a stochastic grammar using probabilities may be used to solve the problem.

[AbdelAzim89a]; [Ali79]; [Amin80]; [Amin82a]; [Amin82b]; [Amin83]; [Amin84]; [Amin85b]; [Amin86]; [Amin87]; [Amin88a]; [Amin88b]; [Amin88c]; [Amin91b]; [ElDesouky91]; [ElDesouky92]; [ElGowely90]; [ElSheikh88a]; [ElSheikh88b]; [ElSheikh90c]; [ElWakil87]; [ElWakil88]; [ElWakil89]; [Emam94]; [Fakir93]; [Fehri94]; [Goneid92b]; [Goneid92c]; [Goraine89]; [Goraine92b]; [Goraine94]; [HajHassan91]; [Kurdy93]; [SaadAllah85]; [Shaheen90]; [Zahour89]; [Zahour91]; and [Zahour92].

## c. The Relational Graph-matching Approach

The **graph-theoretic** classifiers built according to this approach are sometimes called hierarchical classifiers. In such cases, characters are represented as a tree where its internal nodes are the primitives and the

leaves are the character labels. When recognition fails in the forward direction towards one of the leaves, due to missing or extraneous primitives, reverse direction recognition is there to be tried as an alternative.

The Fuzzy Approach is sometimes useful in such cases, where the fuzzy-set theory of directions is used to model unknown handwritten characters as fuzzy attributed graphs. These graphs are then compared to those of the models to arrive at the correct recognition decision. Such fuzzy techniques are more helpful when the issue at hand is the recognition of handwritten characters with their attendant problems. It is futile, or at least too disadvantageous in such cases, to depend on structural approaches. Variability of the handwriting is very difficult to anticipate, and hence to describe, when the strict mathematical constraints set by the theory of formal languages are at work.

[AbdelAzim89c]; [AbdelAzim96]; [AbuHaiba90]; [AbuHaiba94a]; [AbuHaiba94b]; [AbuHaiba95a]; [AbuHaiba95e]; [AbuHaiba96b]; [AlBadr96]; [AlEmami90]; [AlMuallim87]; [AlTikrity84]; [Ameur93]; [Amin89]; [Amin91a]; [Badie82a]; [Badie82b]; [Bansal84]; [ElRamly89a]; [ElSheikh89a]; [ElSheikh90a]; [Hyder88a]; [Hyder88b]; and [Parhami81].

#### **d. The Neural Network Approach**

Artificial Neural Networks, known as Neural Nets (NNs), are interconnected networks of simple non-linear units aimed at modelling some functions of the human brain. They are treated as black boxes and are trainable using several algorithms. Since their advent, they have been successfully applied to a wide class of problems that are otherwise difficult to deal with. This state of affairs prevails due to several reasons. They are adaptive, learn from examples, and they can also generalise.

NNs are used here for the purpose of classification. They may also be used for feature extraction and statistical clustering as well. Specialised hardware is becoming more available to apply NNs in a way more fruitful than traditional methods. Many researchers yet claim that the discriminating power of NNs is still weak and more work is needed to settle this issue. Some workers in the field are experimenting with NNs, and the interest is mounting.

[AbdelAzim95]; [AbdelAzim96]; [Ahmed92]; [AlTuwaijri94a]; [AlTuwaijri94b]; [AlTuwaijri94c]; [AlTuwaijri95a]; [AlTuwaijri95b]; [AlTuwaijri96]; [Braham92]; [Emam94]; [Hassibi94]; [Nabawi94]; [Rashid96]; [Rashwan94]; [Sanossian96]; and [Walker??].

#### **e. The Hidden Markov Model Approach**

Many researchers maintain the view that most of the problems remaining in the OCR field are still associated with thresholding and segmentation.

This is especially true, when dealing with hand-written cursive script recognition. Hidden Markov models (HMMs) qualify as a suitable tool for such situations for many reasons. First, they are stochastic models that can cope with noise and variations in the hand-written patterns. Next, the number of tokens representing the unknown input word may be of a variable length. Moreover, the segmentation problem may be avoided. By directly working on the grey-level image of the words, HMMs may be employed to recognise an entire connected word and/or subword at a time. According to this approach, a sequence of grey-level feature vectors is extracted using HMMs. HMMs are used to describe any of the following as the need arises: single characters, parts of a character, or several characters together. The sequence of feature vectors is (Viterbi) matched against all possible combinations of the models using dynamic programming techniques. It is worth noting that the essence of this technique is carried to character recognition from the area of speech recognition research.

[AbdelAzim89b]; [AbdelAzim89c]; [AbdelAzim92b]; [AbdelAzim93]; [LaPre96]; [Makhoul96]; and [Shoukry94].

#### **f. Table Look-ups and Others**

These are simpler classification algorithms that cannot also be categorised as falling under statistical or syntactical types of classifiers. Dictionary look-up classifiers, rule-based classifiers, and hand-crafted classifiers are examples of this type of non-hierarchical classifiers which do not use a decision tree. The table look-up, for example, requires segmenting a word into characters. Determining the frame window of each character follows, where it is divided into small windows prior to searching for appropriate features. These include end points, intersection points, corners, etc., as well as their respective locations within the character window. The aspect ratio of the character window itself is also used as a feature. The unknown character is then recognised by finding a match in the look-up table.

[AlOuali96]; [Jambi90]; [Jambi91a]; [Jambi92]; [Jambi93]; and [Jambi95].

### **Post-processing Techniques**

As the name implies, this is the final stage in the recognition process. The recognition stage is meant for recognising the unknown input character. However, this is not always the case, since in some recognition systems primitives of the unknown characters are recognised first, and then the characters are identified in a post processing stage. Sometimes classification, or recognition, of the input character fails, thus producing either a misclassification (substitution) or, at its best, a rejection. For such cases a post-processing technique is to be applied. Some researchers opt to apply some of the other recognition techniques that were not used in the recognition stage, as a post-processing stage. Some of the post-

processing techniques are applied not to the misclassified and/or rejected character(s) but to the whole word(s) containing it(them). These techniques improve the word recognition rate via exploitation of character frequencies and probabilities, lexical rules and matrices, and table look-ups for the purpose of word proofing and correction. It has to be stressed here that the word recognition rate is generally lower than the character recognition rate, since a certain word, whatever its length is, needs correction if only one of its characters is misrecognised or rejected.

Some researchers concentrate on studying words in dictionaries, to extract probabilities of the incidence of each character with respect to other characters in available used words. These probabilities are to be used to decide the best candidate character to fill up a gap in a certain word suffering from rejections in the recognition phase. Some other techniques are there to be exploited. These, among some others, are mentioned below.

### **a. Spell Checking and Correction**

This technique is mainly interactive, requiring manual intervention of the user to decide on the most proper substitute for a suspected word in the recognised text, from the given choices available in an appropriate dictionary.

[AbdelAzim92a]; [AbdelAzim92b]; [AlFedaghi88a]; [Goraine92b]; [Goraine94]; [Hashish92]; [Hassibi94]; [Kurdy93]; and [Mahgoub92].

### **b. Syntactic & Semantic Analyses**

Syntactic and semantic analyses may be carried out to correct the words rejected or misclassified by the recognition stage. Lexicons, lexical matrices, and context-free grammars are some of these methods aimed at improving the word recognition rate which is generally lower than its character counterpart. Some of these analyses are stochastic in nature depending on the probability of occurrence of each character of an alphabet in conjunction with the other characters of the same alphabet. Estimates of the entropy of the language are obtained based on either letter frequencies, or word frequencies and roots count. Some other analyses use the syntax of the language in which the text is written to analyse and validate the output of the recognition system. In this case, the misrecognised or rejected words may be corrected depending on their roots, after removing prefixes and suffixes. This may be sometimes applied to all words of the recognised sentence to check their correctness, even when no misclassifications or rejections are reported.

[AbdelAzim88]; [AbdelAzim89a]; [AbdelAzim89d]; [AbdelAzim90b]; [AbdelAzim92a]; [AlJabri91]; [AlJabri92]; [AlSuwaiyel91]; [Amin84];

[Amin85b]; [Amin87]; [Amin88c]; [Amin89]; [ElGamal91]; [ElSheikh90c]; [Emam94]; [Fehri94]; [Hashish88]; [Hashish92]; [Hassibi94]; [Hyder88a]; [Hyder88b]; [LaPre96]; and [Parhami81].

### **c. The Viterbi Algorithm**

This technique may be used here, as a post-processing stage, to enhance the recognition results of systems employing other recognition strategies. This may be carried out by applying the Viterbi algorithm to words containing rejected characters, in order to correct such words.

[AlJabri92]; [AlSuwaiyel91]; and [Amin89].

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## Bibliography Classification Table

No.	Author's Name & Year of Publication	Nature of Application	Fonts/ Char. Sets	Pre-process. & Segm.	Feature Extraction	Classification Method	Post processing
1	Abbas86	9,10	--	1,2	2,3	1	--
2	AbdelAzim87*	5	1,3	u/a	u/a	u/a	u/a
3	AbdelAzim88	5	1,3	4	1,2	1	2
4	AbdelAzim89a	5	2,3	4	2,4	1,2	2
5	AbdelAzim89b	8	3,4	--	2,4	5	--
6	AbdelAzim89c	9	--	1,4	2,4	3,5	--
7	AbdelAzim89d	5	1,3,4	4	2	1	2
8	AbdelAzim89e*	5	1,3	u/a	u/a	u/a	u/a
9	AbdelAzim90a	5	1,3	--	2	1	--
10	AbdelAzim90b	5	1,3	4	2	1	2
11	AbdelAzim92a	5	1,3	2,4	2,4	1	1,2
12	AbdelAzim92b	5	1,3	--	2	5	1
13	AbdelAzim93 *	5	1,3	u/a	2	5	u/a
14	AbdelAzim95 *	5	1,3	u/a	u/a	4	u/a
15	AbdelAzim96	2	1,3	4	4	3,4	--
16	AbdelGwad90	LR,7	1,3	2	2	1	--
17	Abdulla88	9	4	2	--	--	--
18	AboSamra97	8	3	4	--	--	--
19	AbuHaiba90	4,7	1,3	1,2	4	3	--
20	AbuHaiba91	4	1,3	1,2	--	--	--
21	AbuHaiba93	8	3	1,2,3	--	--	--
22	AbuHaiba94a	8	3	1,2	4	3	--
23	AbuHaiba94b	8	3	1,2,3	4	3	--
24	AbuHaiba94c	8	3	1,2	4	--	--
25	AbuHaiba95a	7	3	1,2	4	3	--
26	AbuHaiba95b	8	3	1,2,3	4	--	--
27	AbuHaiba95c	8	3	1,4	--	--	--
28	AbuHaiba95d	8	3	1,2	--	--	--
29	AbuHaiba95e	7	3	--	4	3	--
30	AbuHaiba96a	8	3	1,2	--	--	--
31	AbuHaiba96b	7,8	3	1,2,3	4	3	--
32	Ahmed92	5	1,3	1,4	2	4	--
33	Ahmed94	GR	2,3	G	G	G	G
34	Aiih88 *	4	3	u/a	u/a	u/a	u/a
35	AlBadr92	5	2,3	1	2	1	--
36	AlBadr93 *	5	1,3	u/a	u/a	u/a	u/a

GR = general review, LR = limited review, G = generally addressed, -- = not addressed, and u/a = unavailable.

No.	Author's Name & Year of Publication	Nature of Application	Fonts/ Char. Sets	Pre-process. & Segm.	Feature Extraction	Classification Method	Post processing
37	AlBadr95a	GR	2,3	G	G	G	G
38	AlBadr95b *	5	1,3	1	u/a	u/a	u/a
39	AlBadr95c	5	1,3	1	4	3	--
40	AlBadr96	5	1,3	1	4	3	--
41	AlBaiaty86 *	4	1,3	u/a	1	1	u/a
42	AlEmami88 *	4,7	1,3	u/a	u/a	u/a	u/a
43	AlEmami90	2	3	4	4	3	--
44	AlFedaghi88a *	u/a	3	u/a	u/a	u/a	1
45	Ali79 *	7	3	u/a	4	2	u/a
46	Ali89	4,6	1	1,2	--	--	--
47	AlJabri91	5	3	--	--	--	2
48	AlJabri92	5	3	--	--	--	2,3
49	Allam94	5	2,3,4	2	2	1	--
50	AlMuallim87	8	3	2,4	4	3	--
51	AlOhalil96	LR,5	1,3	4	4	6	--
52	AlQaisy85 *	9	--	u/a	2	u/a	u/a
53	AlQaisy87 *	9	--	u/a	3	u/a	u/a
54	AlQaisy89	9	--	--	2	1	--
55	AlShebeili97	4	1,3	1	3	1	--
56	AlSuwaiyel91	5	3	--	--	--	2,3
57	AlTikriti84 *	9	--	u/a	4	3	u/a
58	AlTikriti85	9	--	2	2	1	--
59	AlTuwaijri94a	8	2,3	4	2	4	--
60	AlTuwaijri94b	4	1,3	1,2	u/a	4	u/a
61	AlTuwaijri94c*	4	1,3	u/a	u/a	4	u/a
62	AlTuwaijri95a	8	2,3	1,2,4	2	4	--
63	AlTuwaijri95b	4	1,3	1,2	u/a	4	u/a
64	AlTuwaijri96 *	4	1,3	1,2	u/a	4	u/a
65	AlYousefi88	7	3	1,4	2	1	--
66	AlYousefi89	7	3	1	2	1	--
67	AlYousefi90	7	3	1,4	2	1	--
68	AlYousefi92	4,7,8	1,3	1,4	2	1	--
69	Ameur93	8	3	1,2,4	4	3	--
70	Amin79 *	1	3	u/a	u/a	u/a	u/a
71	Amin80	1	3	1	4	2	--
72	Amin82a	2	3	1,4	4	2	--
73	Amin82b	2	3	1,4	4	2	--
74	Amin83 *	2	3	1,4	4	2	--
75	Amin84	2	3	1,4	4	2	2

GR = general review, LR = limited review, G = generally addressed, -- = not addressed, and u/a = unavailable.

No.	Author's Name & Year of Publication	Nature of Application	Fonts/ Char. Sets	Pre-process. & Segm.	Feature Extraction	Classification Method	Post processing
76	Amin85a *	GR	3	G	G	G	G
77	Amin85b	LR,1,2	3	1,4	4	2	2
78	Amin85c *	2,5	1,3	1,4	4	u/a	u/a
79	Amin86	5	2,3	1,4	4	2	--
80	Amin87	LR,1,2	3	1,4	4	2	2
81	Amin88a	5	2,3	1,4	4	2	--
82	Amin88b *	1	3	1,4	4	2	--
83	Amin88c *	2	3	1,4	4	2	2
84	Amin89	5	2,3	1,2,4	4	3	2,3
85	Amin91a	5	2,3	1,4	4	3	--
86	Amin91b	5,8	1,3	1,2,4	4	2	--
87	Amin92	8	3	1,2,4	--	--	--
88	Assal91 *	9	--	u/a	u/a	u/a	u/a
89	Assal92	9	--	4	--	--	--
90	Badie78 *	4	1,3	u/a	u/a	u/a	u/a
91	Badie80a *	5	1,3	u/a	u/a	u/a	u/a
92	Badie80b *	5	1,3	u/a	u/a	u/a	u/a
93	Badie82a	7,8	3	1,2	4	3	--
94	Badie82b	7,8	3	1,2	4	3	--
95	Bansal84 *	9	--	u/a	4	3	u/a
96	Barber88 *	5	1,3	u/a	u/a	u/a	u/a
97	Belghith90 *	4	1,3	u/a	2	u/a	u/a
98	Berber94 *	5	1,3	u/a	u/a	u/a	u/a
99	Bilal76 *	u/a	3	u/a	u/a	u/a	u/a
100	Bouhlila88 *	4	1,3	u/a	u/a	u/a	u/a
101	Bouhlila89	5	1,3	4	--	--	--
102	Braham92	9	--	1	2	4	--
103	Dewachi75 *	u/a	3	u/a	u/a	u/a	u/a
104	EIDabi90	5	1,3	4	2	1	--
105	EIDesouky91	7	3	2	4	2	--
106	EIDesouky92	7	3	2	4	2	--
107	EIGamal91 *	--	3	--	--	--	2
108	EIGowely89 *	5	2,3	u/a	u/a	u/a	u/a
109	EIGowely90	5	2,3	1,4	2,4	2	--
110	EIHamalawy88	6	--	1,2	2	1	--
111	EIKhaly90	5	1,3	1,2,4	2,3	1	--
112	EIRamly89a	5	1,3	1,2	4	3	--
113	EIRamly89b	4	1,3	1,2	2	1	--
114	EIRamly89c	4	1,3	1,2	2	1	--

GR = general review, LR = limited review, G = generally addressed, -- = not addressed, and u/a = unavailable.

No.	Author's Name & Year of Publication	Nature of Application	Fonts/ Char. Sets	Pre-process. & Segm.	Feature Extraction	Classification Method	Post processing
115	ElShbiny76 *	4	1,3	u/a	u/a	u/a	u/a
116	ElSheikh88a	4	1,3	1,2	3,4	1,2	--
117	ElSheikh88b	5	1,3	1,2,4	3,4	1,2	--
118	ElSheikh89a	1	3	2	4	3	--
119	ElSheikh89b *	4	2,3	u/a	u/a	u/a	u/a
120	ElSheikh90a	1	3	2	4	3	--
121	ElSheikh90b	2	3	4	--	--	--
122	ElSheikh90c	1,3	3	4	2	2	2
123	ElWakil87	1	3	2	4	1,2	--
124	ElWakil88	1	3	2	4	1,2	--
125	ElWakil89	1	3	2	4	1,2	--
126	Emam93 *	5	1,3	4	--	--	--
127	Emam94	5	1,3	1,2,4	2	2,4	2
128	Fakir91 *	LR,5	3	u/a	G	u/a	u/a
129	Fakir92 *	5	3	u/a	u/a	u/a	u/a
130	Fakir93	5	3	1,2,4	3,4	1,2	--
131	Fayek92	4	2,3	1	2	1	--
132	Fehri94	5	2,3	1,2,4	4	2	2
133	Ghuwar94 *	GR	G	G	G	G	G
134	Ghuwar95	5	1,3	1	4	--	--
135	Goneid87 *	4	1,3	u/a	u/a	u/a	u/a
136	Goneid88 *	4	1,3	u/a	u/a	u/a	u/a
137	Goneid92a *	9	--	u/a	u/a	u/a	u/a
138	Goneid92b	9	--	1,2	4	2	--
139	Goneid92c	9	--	1,2,4	4	2	--
140	Goraine89	5	2,3	2,4	4	2	--
141	Goraine90 *	5	3	u/a	u/a	u/a	u/a
142	Goraine92a *	5	3	u/a	u/a	u/a	u/a
143	Goraine92b	5	1,3	1,2,4	4	2	1
144	Goraine94	5	1,3	1,2,4	4	2	1
145	Govindan90	GR	2,3,4	G	G	G	G
146	Guindi87 *	5	3	u/a	u/a	u/a	u/a
147	HajHassan85	5	1,3	4	--	--	--
148	HajHassan88	5	1,3	4	--	--	--
149	HajHassan90	5	1,3	4	--	--	--
150	HajHassan91	5	1,3	1,2,4	2,4	1,2	--
151	Hashish85 *	5	1,3	u/a	u/a	u/a	u/a
152	Hashish88 *	--	3	--	--	--	2
153	Hashish92	--	3	--	--	--	1,2

GR = general review, LR = limited review, G = generally addressed, -- = not addressed, and u/a = unavailable.

No.	Author's Name & Year of Publication	Nature of Application	Fonts/ Char. Sets	Pre-process. & Segm.	Feature Extraction	Classification Method	Post processing
154	Hassibi93 *	5	1,3	u/a	u/a	u/a	u/a
155	Hassibi94	5	2,3	1,2,4	4	4	1,2
156	Hyder88a *	5	3	--	4	3	2
157	Hyder88b	5	3	--	4	3	2
158	Ismail93a *	4	1,3	u/a	3,4	--	--
159	Ismail93b *	5	1,3	u/a	u/a	u/a	u/a
160	Jambi90 *	5	1,3	1,4	4	6	--
161	Jambi91a	GR,8	G	1,2,4	4	6	--
162	Jambi91b	GR	G	G	G	G	G
163	Jambi92	8	1,3	2,4	4	6	--
164	Jambi93	8	1,3	2,4	4	6	--
165	Jambi95 *	8	1,3	2,4	4	6	--
166	Jambi96 *	8	3	u/a	u/a	u/a	u/a
167	Jambi97	4	1,3	1	2	--	--
168	Kamel90 *	5	1,3	u/a	2	1	u/a
169	Khalidov85 *	u/a	3	u/a	u/a	u/a	u/a
170	Khella92	5	1,3	1,2,4	3	1	--
171	Khella94	4	1,3	1,2	3,4	1	--
172	Khemakhem87*	4	1,3	--	u/a	u/a	u/a
173	Khemakhem87*	4	1,3	--	u/a	u/a	u/a
174	Khemakhem88*	4,5	1,3,4	--	3	1	--
175	Khemakhem89	4,5	1,3	--	3	1	--
176	Khemakhem93	4,5,10	1,3	--	3	1	--
177	Kubba80 *	u/a	3	u/a	u/a	u/a	u/a
178	Kurdy91 *	u/a	3	u/a	u/a	u/a	u/a
179	Kurdy92 *	4	2,3	u/a	u/a	u/a	u/a
180	Kurdy93	5	2,3,4	1,4	4	2	1
181	LaPre96	5	2,3	1	2	5	2
182	Mahdi87 *	4	1,3	2	--	--	--
183	Mahdi89	4	1,3	2	--	--	--
184	Mahgoub92 *	u/a	3	u/a	u/a	u/a	1
185	Mahmoud86	6,9	3	--	2	1	--
186	Mahmoud87	6,9	3	--	2	1	--
187	Mahmoud91	4	1,3	2	--	--	--
188	Mahmoud94	4	1,3	1,2	3	1	--
189	Makhoul96	5	2,3	1	2	5	--
190	Mantas86	GR	G	G	G	G	G
191	Margner92	5	1,3	2,4	4	1	--
192	Murad84 *	u/a	3	u/a	u/a	u/a	u/a

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No.	Author's Name & Year of Publication	Nature of Application	Fonts/ Char. Sets	Pre-process. & Segm.	Feature Extraction	Classification Method	Post processing
193	Nabawi94	4	1,3	1,4	2,3	1,4	--
194	Namane90	4	2,3	1,2	--	--	--
195	Nazif75	4	1,3	4	1,4	1	--
196	Nouh78 *	u/a	3	u/a	u/a	u/a	u/a
197	Nouh80	4	1,3	--	1	1	--
198	Nouh84	4	1,3	--	1	1	--
199	Nouh86a *	u/a	3	u/a	u/a	u/a	u/a
200	Nouh86b *	u/a	3	u/a	u/a	u/a	u/a
201	Nouh87a	5,8	3	1	--	--	--
202	Nouh87b	4	1,3	1	1	1	--
203	Nouh87c	1-9	3	--	--	--	--
204	Nouh88a *	4,5,6	3	u/a	u/a	u/a	u/a
205	Nouh88b	LR,4	1,3	--	2	1	--
206	Nouh88c *	4	3	u/a	u/a	u/a	u/a
207	Nouh88d	4	1,3	1	1	1	--
208	Nouh89	4	1,3	2	--	--	--
209	Nouh93	7	3	1	1	1	--
210	Nouh94	GR	3	G	G	G	G
211	NurulUla87 *	4	u/a	u/a	u/a	u/a	u/a
212	NurulUla88a	4,7	2,3	1,2	--	--	--
213	NurulUla88b	4,7	2,3	--	2	1	--
214	Parhami77 *	GR	3	G	G	G	G
215	Parhami78a *	u/a	3	u/a	u/a	u/a	u/a
216	Parhami78b *	u/a	3	u/a	u/a	u/a	u/a
217	Parhami81	5,6	3	1,2,4	4	3	2
218	Rahho86 *	8	3,4	u/a	u/a	u/a	u/a
219	Ramsis88	LR,5	2,3	4	2	1	--
220	Rashid96	5	2,3	4	2	4	--
221	Rashwan94	7	3	--	2	4	--
222	SaadAllah85	7	3	1,2	4	2	--
223	Sabri86 *	4	3	u/a	u/a	u/a	u/a
224	Saleh75a	5	1,3	1,4	2	1	--
225	Saleh75b	5	1,3	1,4	2	1	--
226	Saleh77	5	1,3	--	2	1	--
227	Sanossian96	4	1,3	--	2	4	--
228	Seddik89 *	2	3	u/a	u/a	u/a	u/a
229	Seflan75 *	u/a	3	u/a	u/a	u/a	u/a
230	Shaheen90	2	3	1,2	4	2	--
231	SharafElDin88	LR,4	1,3	--	2	1	--

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No.	Author's Name & Year of Publication	Nature of Application	Fonts/ Char. Sets	Pre-process. & Segm.	Feature Extraction	Classification Method	Post processing
232	Sharkawy88 *	4	1,3	u/a	3	u/a	u/a
233	Shoukry83 *	5	1,3	u/a	u/a	u/a	u/a
234	Shoukry89	GR	3	G	G	G	G
235	Shoukry91	5	1,3	1,4	--	--	--
236	Starner94 *	8	3	u/a	2	5	u/a
237	Taconet89 *	4	1,3	1	u/a	u/a	u/a
238	Taraghi78 *	u/a	3	u/a	u/a	u/a	u/a
239	Tikhonova92	LR	3	--	--	--	--
240	Tolba86	4,7	1,3	--	2	1	--
241	Tolba87a	LR,4	1,3	--	2	1	--
242	Tolba87b	4,7	1,3	--	2	1	--
243	Tolba87c *	u/a	3	u/a	--	--	--
244	Tolba87d	4,7	1,3	--	2	1	--
245	Tolba88a	LR,4	1,3	--	2	1	--
246	Tolba88b	LR,4	1,3	--	2	1	--
247	Tolba89	LR,4	2,3	1,2,4	2	1	--
248	Tolba90	LR,4	2,3	1,2,4	2	1	--
249	Walker?? *	u/a	3	u/a	u/a	4	u/a
250	Yacu85 *	u/a	3,4	u/a	u/a	u/a	u/a
251	Yalabik88	LR,5	3	--	--	--	--
252	Yousef86 *	9	--	u/a	u/a	u/a	u/a
253	Youssef89	LR,5	3	G	G	G	--
254	Youssef93	LR,5	3	G	G	G	--
255	Zahour89	8	3	1,4	4	2	--
256	Zahour90 *	8	3	u/a	u/a	u/a	u/a
257	Zahour91	8	3	1,4	4	2	--
258	Zahour92	8	3	1,4	4	2	--
259	Zaki86a	7	3	1	2	1	--
260	Zaki86b	7	3	1	2	1	--

GR = general review, LR = limited review, G = generally addressed, -- = not addressed, and u/a = unavailable.

## **Appendix A**

### **Classification Scheme & Table of the Bibliography**

The following table is set up for the benefit of those readers interested in having an overall, yet concise picture of each literature item in this AOTR bibliography. But before looking into the table, some hints on how to read each one of its rows is given here. This table has been also used as a tool for classifying the literature items collected in the AOTR bibliography. The table comprises 8 columns, the first of which is reserved for the reference serial numbers. For easy handling of the literature items they are lexicographically indexed using the first author's surname and year of publication. This surname is here concatenated with the last two digits of the publication year, followed by a lower-case character of the alphabet if there is more than one reference by the same author(s) published in the same year. The contents of the other six columns are mainly numbers whose interpretations run as follows:

#### **Nature of Application: (Column 3)**

- 1: On-line Handwritten Character Recognition;
- 2: On-line Handwritten Cursive Text Recognition;
- 3: On-line Handwritten Hindi Numerals;
- 4: Off-line Printed Character Recognition;
- 5: Off-line Printed Cursive Text Recognition;
- 6: Off-line Printed Hindi Numerals;
- 7: Off-line Handwritten Character Recognition;
- 8: Off-line Handwritten Cursive Text Recognition;
- 9: Off-line Handwritten Hindi Numerals;
- 10: Hardware Implementation.

#### **Addressed Fonts & Character Sets: (Column 4)**

- 1: Single-font;
- 2: Multifont;
- 3: Arabic Character set;
- 4: Latin Character set.

#### **Pre-processing and Segmentation Techniques: (Column 5)**

- 1: Noise Reduction (Smoothing);
- 2: Thinning (Skeletonization) & Contour Detection;
- 3: Restoration of Temporal Information from Off-line Handwritten Texts;
- 4: Segmentation.

#### **Feature Extraction Methods: (Column 6)**

- 1: Template Matching and Correlation;
- 2: Statistical Distribution of Points;
- 3: Global Transformations & Series Expansion;
- 4: Structural (Geometrical) & Topological Features.



### **Classification Approaches: (Column 7)**

- 1: The Statistical Approach;
- 2: The Syntactical Approach;
- 3: The Relational Graph-matching Approach;
- 4: The Neural Network Approach;
- 5: The Hidden Markov Model (HMM) Approach;
- 6: Table Look-ups and Others.

### **Post-processing Techniques: (Column 8)**

- 1: Spell Checking and Correction;
- 2: Syntactic & Semantic Analyses;
- 3: The Viterbi Algorithm.

### **Notes on the Classification Table:**

1. The convention of using the asterisk (\*) to denote unavailable literature items in the AOTR bibliography is applicable to the second column of the classification table given here. Their corresponding rows in the table may have (u/a) to denote unavailable information.
2. As stated earlier in the abstract, few items in this bibliography are not on Arabic texts, but on either Farsi or historical Ottoman. Nevertheless, since both languages use the Arabic alphabet set with additions and/or modifications, these items will be treated here as those on Arabic texts.
3. Hindi numerals are those numerals used all over the Arab world, with the exception of the western Arab countries (west of Egypt, i.e. Libya, Tunis, Algeria, Mauritania and Morocco) where Arab numerals are used. The Hindi numerals are different from the Arab numerals used all over the western world. The Arab numerals are the ones used in reporting this AOTR bibliography.
4. The attributes single-font and multifont used in the fourth column is valid only for machine-printed characters and/or texts. The other attribute, that is being only in Arabic or in Arabic/Latin is applicable to both machine-printed and handwritten characters and/or texts, not to numerals.
5. As for columns 3, 4, 5, 6, 7, and 8, research work reported in some literature items happens to use more than one of the mentioned techniques/approaches. In such cases some of the respective entries in the table may have more than a single number with a comma separator (,) between them.
6. General and limited Review papers, denoted by (GR) or (LR) in column 3, will be classified as follows. GR papers may have, under each of the table headings, one of the following symbols:  
(G) denoting general coverage and discussion of the research topic under this heading;  
or  
(--) denoting the absence of any review of the topic altogether.  
LR papers, on the other hand, will be classified as stated for the other items of the bibliography.
7. The symbol (--) applies also to all other bibliography items, under any table heading, where the specific topic is not-addressed.

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## تَمْيِيزُ النُّصُوصِ العَرَبِيَّةِ ضَوْئِيًّا: ثَبَتُ مَرَاجِعِ مَبُوبَةٍ

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### ملخص:

تم جمع ٢٦٠ بحثاً في مجال التمييز الضوئي للنصوص العربية، وكذا للأرقام الهندية، وتبويبها حسب موضوعاتها العلمية. وتلقي قضية قلّة عدد البحوث والمراجع، في هذا المجال البحثي، الضوء على نقطتين:

النقطة الأولى هي المصاعب الجمة التي تواجه الباحثين في جمع المراجع في هذا المجال، على أهميته، وذلك لقلة عددها وتفرقتها في بطون الدوريات والحواليات ومطبوعات المؤتمرات العلمية وبعض الكتب، وهو السبب الرئيس الذي دفع الباحثين إلى بذل الجهد وتجشم المشاق لجمع وتبويب هذه المراجع تيسيراً على الباحثين العاملين في هذا المجال الحيوي الهام.

أما النقطة الثانية فهي قلة كل من الجهود البحثية والموارد المتاحة لتطوير هذا الفرع من البحوث، بشقيه النظري والتطبيقي بالمقارنة بما ينفق من أموال وما يبذل من جهود لتطوير طرائق وأساليب لتمييز النصوص المكتوبة باللاتينية وغيرها، وذلك رغم أهمية هذا الموضوع التي يتزايد إدراكها في أوساط الباحثين والتطبيين.

وقد استخدمنا نظام تبويب لهذه المراجع يعتمد على كلمات مفتاحية في هذا المجال البحثي، مما يساعد الباحثين على سرعة الوصول إلى أسماء المراجع المطلوبة للبحث في النقاط المتفرعة عن هذا المجال البحثي الهام. ولقد زدنا القارئ كذلك بملحق يحتوى جدولاً يلقي الضوء على محتويات كل بحث، مما يعطي لمحة سريعة عن مجال ومحتوى كل من هذه المراجع على حدة.