An Active Recognition of Handwritten Isolated Arabic Characters

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This paper introduces a new approach for recognizing cursively handwritten isolated Arabic characters. The approach is based on an active analysis of human handwriting movements, which was proposed and discussed extensively by the authors in a previous paper¹⁾. The handwriting process is modeled through autoregressive moving average (ARMA) model. Model Reference Adaptive Control System (MRACS) theory is applied, in order to extract control pulses of the handwriting movements. The control pulses, which describe in details the handwriting movement's behavior, are then used for recognizing the shape of the cursively handwritten character. Although the presented approach is proposed for recognizing handwritten Arabic characters, it can, however, be applied equally well to actively recognize any other cursively handwritten scripts.

Key words : Arabic characters recognition, cursive handwritten character recognition, active analysis/recognition, modeling

1. Introduction

Recognition system for typewritten text are practically available for several latin based languages, mainly for English. However, systems for handwritten text still impose several constraints on writers to achieve acceptable recognition rates. Besides, cursive script recognition remains one of the most challenging unsolved problems in the field of character recognition.

On the other hand, in spite of the progress of recognition techniques for Latin, Kana and Chinese characters during the past three decades, the recognition of Arabic characters has remained almost untouched. Although Arabic characters are used in writing many widespread languages (Arabic, Persian (Farsi), Urdu, etc....), only few works have been published so far about handwritten Arabic characters recognition⁴⁾⁻⁹⁾. The recognition systems proposed in these works were generally based on matching the characteristics related to the geometrical properties of the strokes.

The present paper introduces a new approach for recognizing cursive handwritten isolated Arabic characters. This approach is based on an active analysis

of handwriting movements, which was proposed and discussed in depth by the authors in a previous paper¹⁾. The handwriting process is modeled through an autoregressive moving average (ARMA) model. Model Reference Adaptive Control System (MRACS) theory is applied to extract control pulses of the handwriting movements. The control pulses, which describe in detail the handwriting movement, are then used for recognizing the shape of cursive handwritten characters. Although the presented approach is proposed for recognizing handwritten Arabic characters, it can be applied equally well to recognize any other cursive handwritten scripts.

2. Active Analysis of the Handwriting Movement

The content of this section is a brief review of the active recognition scheme proposed and discussed extensively by the authors in the reference¹⁾.

2.1 Fundamental Concept

One of the traditional and common cases for understanding handwritten characters is gathering and analyzing statistics related to their variations in shapes, slants, stroke numbers, orders, directions and so forth, which we have called as *passive* analysis. Another insight for understanding them may come from modeling the human handwriting generation

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and studying the perceptual aspects of the generated handwriting samples, which we call here as *active* analysis in contrast to the previous one. **Figure 1** shows the human handwriting process, which includes 4 basic levels of signal representations: 1. symbol, 2. motor command, 3. pencil-point movement and 4. handwritten character. For generating handwritten characters, we make a forward trace through the neurological and dynamical transformations from the top to the bottom level to have the characters in the final form. The recognition of cursive handwritten characters can be seen as an inverted process of generation. We say that the recognition system is active if and only if it does involve in itself some generation process of the patterns to be recognized, otherwise passive.

2.2 Handwriting System

Figure 2 shows our basic idea: the system-theoretic representation of the handwriting process. The system has no feedback involved at all and is supposed to be driven by a hypothetical input signal - *control pulse*, to give the handwriting signal at its output. To model the handwriting process, handwriting system is considered to be divided into two subsystems, *muscular system M* and *hand system H*.

The transfer function of the muscular system could be modeled by a moving average (MA) process, the all-zero model: $B(k, z^{-1})$. This is because the effects of both the inter- and intra-muscular frictions are expect-

ed to result in certain energy absorption in some particular range of frequency components of the signal output from the muscular system. And this makes the muscular system *M* to be expressed by a kind of filter that receives the control pulse at the input and gives the muscular force at the output (Fig. 2).

The hand system could be expressed by an auto-regressive (AR) model, having the transfer function with all-pole: $1/A(k, z^{-1})$. Thus the input-output relation of the overall handwriting system can be expressed by an Auto-Regressive Moving Average (ARMA) model having the following form:

$$y(k+1) = \frac{B(k, z^{-1})}{A(k, z^{-1})} v(k) = H(k, z^{-1}) v(k), \quad (1)$$

$$A(k, z^{-1}) = 1 + a_1(k)z^{-1} + a_2(k)z^{-2} + \dots + a_m(k)z^{-m}, \quad (2)$$

$$B(k, z^{-1}) = b_0(k) + b_1(k)z^{-1} + b_2(k)z^{-2} + \dots + b_n(k)z^{-n}. \quad (3)$$

$v(k)$ and $y(k+1)$ is the input control pulse and the output handwriting signal, respectively. z^{-1} denotes the operator of a unit time delay.

After estimating the parameters of both AR and MA of the ARMA model, it becomes possible to extract the control pulses of the handwriting movements by applying the MRACS theory. The way to extract the control pulses is discussed in detail in the reference¹⁾

2.3 Control Pulse

The movements involved in the actual handwriting are so much complicated that an attempt to interpret them in terms of a simplified model might be point less if we are to make precise physiological investigations about the actual human handwriting process. However, it must be rather contributory to our present studies to take a simplified model into account. To begin with, we consider the following two assumptions³⁾: (1) the handwriting movements are resolved into three principal components, namely, X,

Fig. 1 Human handwriting process

Fig. 2 System-theoretic representation of handwriting process

Y and Z directions (the Z -component, writing pressure, is neglected for simplification), (2) the muscles involved in each component of the movements are grouped together into a pair to cause them to generate the forces to antagonistic directions having the prescribed magnitude and timing's. Under these basic assumptions, we introduce the definition of control pulse, which plays an essential role in this study.

The cursive characters are written by a rapid sequence of motions caused by different applications of the magnitude and timing's of muscle activities. It is shown experimentally in the reference³⁾ that the shapes of characters are coded only in time, i.e., by the durations, not by the magnitude of muscle contraction. It is also shown that the magnitude of the force determines the general size of the characters written. We, therefore, assume that the control signal of the handwriting can be represented by the square waveform having three magnitude levels, which we call *control pulses* (Fig. 3). The level 1 and level -1 mean ON activities of the group of muscles to the positive and the negative directions, respectively, and 0 means OFF activity (abbreviated in later as *ON-pos*, *ON-neg* and *OFF*). T_i 's are *control-timing's* at which the muscular activity changes from one level to another. It is the control timing information (not the magnitude) of the force used that we do need to extract from the original handwritten characters.

We think of the control pulses to be the representation of the handwriting movement at the motor command level shown in the Fig. 1. They are expected to be more direct representations, namely, at the higher level of handwriting process, than are the pencil-point

movements. The control pulses are then expected to describe in detail the behavior of the handwriting movements. Thus the extracted control pulses makes it easy for us to catch which characters are being written.

3. Properties of the Arabic Characters

Arabic script is always written cursively from the right to the left. Arabic alphabet (Fig. 4) has many differences from other systems of characters. The main characteristics of Arabic characters are as follows:

- Dot is one of the main features of the Arabic characters. Most characters involve a main stroke (body of the character) and complementary one or more dots (up to three dots). These dots can be located below or above the body of the character.
- Other than the dots mentioned above, some characters contain a secondary stroke, which may be a vertical line or a zigzag mark.
- Width and length of the Arabic characters differ from one character to another.
- Some isolated Arabic characters are written in a single stroke with no need to lift up the pen.
- Many characters have exactly the same body (longest continuous portion of the character which is written before lifting up the pen); however, they are distinguished from each other by the additional dots or other secondary strokes.

4. Approach to Active Recognition

This section assumes that control pulses related to considered handwritten characters have already been extracted for both X and Y axis. Further, to simplify the notations, we will use *x-pulses* and *y-pulses*, to indicate "control pulses corresponding to the X axis" and "control pulses corresponding to the Y axis", respectively.

The approach starts by classifying a considered character according to the number of strokes involved in it. By stroke we mean portion of the character that is written without lifting up the pen-point from the surface of the writing tablet. This way, the whole set of isolated Arabic characters can be divided into four subsets: namely the characters consisting of one, two, three and four strokes.

Fig. 3 Control pulses sequence of handwriting movement

No.	Character	Shape	Sequence
1	Alif	ا	ا
2	Ba	ب	ب
3	Ta	ت	ت
4	Tha	ث	ث
5	Jim	ج	ج
6	Ha	ح	ح
7	Kha	خ	خ
8	Dal	د	د
9	Dhal	ذ	ذ
10	Ra	ر	ر
11	Zayn	ز	ز
12	Sin	س	س
13	Shin	ش	ش
14	Ṣad	ص	ص
15	Ḍad	ض	ض

No.	Character	Shape	Sequence
16	Ṭa	ط	ط
17	Ḍha	ظ	ظ
18	Ayn	ع	ع
19	Ghayn	غ	غ
20	Fa	ف	ف
21	Qaf	ق	ق
22	Kaf	ك	ك
23	Lam	ل	ل
24	Min	م	م
25	Nun	ن	ن
26	Hha	ه	ه
27	Waw	و	و
28	Ya	ي	ي
29	Hamza	ء	ء
30	Ta-Marbuta	ة	ة

Fig. 4 Isolated Arabic characters

Further, the system classifies the handwritten characters inside each of the four subsets by using several features in a sequential form. Let us now consider these features

4.1 Time-duration of Control Pulses

To investigate promptly the shape of a considered handwritten character, the system focuses on certain parts of x -pulses and/or y -pulses (see Fig. 5). Behavior of the handwriting movement represented by these control pulses is compared with fragments that distinguishes the shape of a character-candidate. The behavior of a handwriting movement is analyzed by estimating the *time-duration* (TD) related to each of the 3 muscular activities, namely $ON-pos$, $ON-neg$ and OFF , inside of the focused group of control pulses:

$$TD_{ON-pos} = \sum_{i=f}^l ON-pos, \quad (4)$$

$$TD_{ON-neg} = \sum_{i=f}^l ON-neg, \quad (5)$$

$$TD_{OFF} = \sum_{i=f}^l OFF, \quad (6)$$

Fig. 5 Investigating control pulses of sample Sad

f and l are, respectively, the first and the last pulses of the focused group of control pulses. By comparing TD_{ON-pos} , TD_{ON-neg} and TD_{OFF} , within the focused part of x -pulses and/or y -pulses, the system determines the orientation of the handwriting movement.

Figure 5 shows x -pulses and y -pulses representing the handwriting movement that is performed to shape the character $\bar{S}ad$. Note that the first (left) part of y -pulses is clearly dominated by $ON-pos$. Domination of $ON-pos$ should meet the following:

$$\begin{cases} TD_{ON-pos} > TD_{ON-neg}, \\ TD_{ON-pos} > TD_{OFF}. \end{cases} \quad (7)$$

This shows that the handwriting movement, represented by the first part of y -pulses, was oriented to the positive direction of Y axis, towards drawing the first fragment of the character *Sad*.

Such investigations allow a detailed understanding of the nature of the handwriting movements that led to the shaping of different fragments of a considered character.

4.2 Pit

We call *Pit* a group of ON-neg control pulses which exists between two groups of ON-pos and/or OFF control pulses. *Pit* represents the changing of a handwriting movement's direction from the positive to the negative direction, and back. This double change of the handwriting movement results in having a minima on the drawn shape.

Arabic script is mostly written cursively through semi-circular movements oriented "down $\rightarrow$ left $\rightarrow$ up". Thus the number of these *Pits*, especially by Y axis, helps recognizing the shape of the considered characters. Figure 5 shows 2 *Pits* at x -pulses and 2 *Pits* at y -pulses.

4.3 Ratio of ARMA Parameters

The parameter b_0 (Eq. 3), which was estimated while modeling the handwriting system, should be available at this step. Ratio between the parameters b_0 related to X and Y signals gives an idea about the

proportion between the width and the length of the corresponding handwritten character.

5. Recognition Algorithm

This section presents an algorithm for recognizing handwritten isolated Arabic characters. This algorithm makes use of all the features discussed above.

As mentioned before, first, the system starts by looking up the number of strokes involved in the character which is currently considered for recognition. According to this, a current character may be classified as a one-, two-, three- or four-strokes character (Fig. 6).

Further, the system classifies the considered handwritten characters inside each of the four subsets (one-, two-, tree- and four-strokes subsets).

5.1 One-stroke Characters

The set of one-stroke characters includes twelve characters (*Alif*, *Ha*, *Dal*, *Ra*, *Sin*, *Sad*, *Ayn*, *Lam*, *Mim*, *Hha*, *Waw* and *Hamza*). These characters are divided into two groups, depending on the number of *Pits* in y -pulses (Fig. 7) :

1. The first group includes characters *Sin*, *Sad*, *Ayn*, *Ha*, *Waw*, *Hamza* and *Mim*. The y -pulses for these characters should involve more than one *Pit*. To write a character from this group, the handwriting movement should change its direction more than once by Y axis.
2. The second group includes characters *Alif*,

Fig. 6 Classifying characters by the number of involved strokes

Fig. 7 Classifying one-stroke characters

Dal, *Ra*, *Lam* and *Hha*, *y*-pulses of which should involve at most one Pit. To write a character from this group, the handwriting movement should change its direction by *Y* axis at most once.

Further, one-stroke characters are classified within each of these two groups.

5.1.1 First group of one-stroke characters

As shown in Fig. 7, if the *y*-pulses involve 3 Pits, i.e., the handwriting movement changes its orientation down-up 3 times, then this character should be *Sin*. Indeed, the shape of the character *Sin* includes 3 distinguishing minima along *y*-axis.

If the above condition is not satisfied, the system focuses the last part of *x*-pulses. If, in this part, *ON-pos* is dominating (i.e., the condition in the Eq. 7 is satisfied), then the considered character could be *Ayn* or *Ha*. This is because the last part of the shape is written with a handwriting movement which is positively oriented by *X* axis. The characters *Sad*, *Waw* and *Hamza* meet the opposite situation. Meanwhile, the character *Mim* may be found in both situations. Because, to draw the last part of this character, the handwriting movement should be oriented straightly downward (negatively by *Y* axis). However, this handwriting movement might shift slightly

to the right or the left, leading to the generation of extra *ON-pos* or *ON-neg*.

In the above first case, *Ayn* and *Ha* may be differentiated based on how the first movement starts. To write a *Ayn*, the first movement should be oriented to the negative direction by *X* axis. Whereas it should be oriented to the positive direction for the character *Ha*. Moreover, *x*-pulses corresponding to a *Ayn* should involve 2 Pits.

As for the second case, to differentiate the character *Sad* from *Waw* and *Hamza*, the system investigates the handwriting movement used to draw the first half part of the character body. This handwriting movement should be oriented, for a long while, positively to *X* axis. Therefore, *ON-pos* should be dominating in the first half part of *x*-pulses.

If the above condition is not satisfied, moreover the middle part of *y*-pulses involves a relatively long time-duration of *ON-pos* (TD_{ON-pos}), then the system should be dealing with the character *Waw*. To draw the central part of a *Waw*, the handwriting movement should be oriented to the positive direction by *Y* axis.

If all the conditions imposed so far are not satisfied, meanwhile the width and the length of the character are stretching to be equal, then the considered handwritten character could probably be a *Hamza*.

The character *Mim* has some similarity with *Waw*. However it can be differentiated based on how the second half part of the shape should be drawn. IN this case, y -pulses corresponding to the second half part of the *Mim* should be totally dominated by *ON-neg*.

5.1.2 Second group of one-stroke characters

This group includes characters y -pulses of which involve at most one Pit. To write a character from this group, the handwriting movement should change its direction at most once by Y axis.

This group is also divided into two subgroups depending on the last performed handwriting movement. The first subgroup includes characters written with a final handwriting movement which is oriented positively by Y axis. The last part of y -pulses should be dominated by *ON-pos*. This subgroup includes the characters *Lam* and *Hha*.

The opposite situation corresponds to the second subgroup. IN this case, the last part of y -pulses should be dominated by *ON-neg*. This subgroup includes characters *Alif*, *Dal* and *Ra*.

Concerning the first subgroup, if the spatial length

of the character is almost twice as its width; and the drawing starts at a higher level than where it finishes (by both X and Y axes); moreover the handwriting movement, which shapes the first half part of the character, is oriented straightly downward, then the current character should be a *Lam*.

As for the character *Hha*, the drawing should ends near where it starts (by both X and Y axes). Moreover, the corresponding handwriting movement should be oriented positively by X axis at the beginning as well as at the end of the drawing.

Now let us consider the second subgroup. Here, the system begins by checking up *Alif*'s symptom. In this case, the handwriting movement should not considerably change its direction by X axis, during the whole time of drawing.

If *Alif*'s symptoms is not matched, then the next character to be considered is *Dal*. Here, the handwriting movement behind the first fragment of the character should be oriented mainly to the positive direction by X axis. Thus, the first half part of x -pulses should be dominated by *ON-pos*.

The investigated character could be a *Ra*, if its

Fig. 8 Classifying two-strokes characters

Fig. 9 Classifying three-strokes characters

Fig. 10 Classifying four-strokes characters

corresponding handwriting movement is oriented all the time negatively by both X and Y axes. In this case, both x -pulses and y -pulses should be dominated by $ON-neg$.

At the end, the currently considered one-stroke character is rejected, if it does not match any of the conditions considered so far.

5.2 Other subsets

Further, as shown in the Fig. 8-10, the system uses the same approach to deal with the other subsets (two-, three- and four-strokes isolated Arabic characters).

6. Results and Comments

The algorithm presented above has been developed after observing and investigating a large number of training samples of handwritten Arabic characters. Both x -pulses and y -pulses as well as other features have been studied extensively.

Experimental results and comments

Computer experiments were performed for all Arabic characters shown in Fig. 4. 2400 different samples were used to carry out these experiments; 80 handwritten samples for each Arabic character. Results of the experiments showed an average recog-

nition rate of 98.6% (Fig. 11).

Inaccuracy in writing was the main cause behind the misrecognized and rejected samples. However, very slow handwriting was also another cause. The recognition system presented here is actually based on our previously published work¹⁾, which focuses on fast handwriting. By *fast cursive handwriting* we mean highly practiced and skilled movements of handwriting which are executed by means of a rapid sequence of motions without instantaneous position feedback¹⁾.

Let us consider some similar works. Reference 4) proposed a structural recognition method making use of geometrical and topological properties of the script, and performed a recognition rate of 91%. Reference 5) classified characters using syntactic strings of primitive directions in the plane, and reported a recognition rate of 93%. Meanwhile⁶⁾ reported a recognition rate of 95.4%, using a structural classification based on coordinates of the strokes. Reference 7) based its classification on a syntactic representation of the characters using geometrical primitives like curves and strokes, but no recognition rate was reported. The highest rate (100%) was reported by Refs. 8) and 9), where the classifications were based on direction codes and other geometrical

	Alif	Ba	Ta	Tha	Jim	Ha	Kha	Dal	Dhal	Ra	Zayn	Sin	Shin	Sad	Dad	Taa	Dha	Ayn	Ghayn	Fa	Qaf	Kaf	Lam	Mim	Nun	Ha	Waw	Ya	Hamza	Ta-Marbuta	Rejected	Recognized (%)
Alif	78																													1	97.5	
Ba		79																					1							1	98.75	
Ta			78																		2										97.5	
Tha				80																											100	
Jim					80																										100	
Ha						79								1																	98.75	
Kha							78								1				1												97.5	
Dal								79													1										98.75	
Dhal									2	78																					97.5	
Ra										1	79																				98.75	
Zayn												80																			100	
Sin													80																		100	
Shin														80																	100	
Sad															78																97.5	
Dad																79															1	
Taa																	79														1	
Dha																		80													98.75	
Ayn																			78												97.5	
Ghayn																				80											100	
Fa																					79										98.75	
Qaf																						79									98.75	
Kaf																							80								100	
Lam																								78							97.5	
Mim																									77						96.25	
Nun																										78					1	
Ha																											78				97.5	
Waw																												78			97.5	
Ya																													80		100	
Hamza																														79	98.75	
Ta-Marbuta																														79	1	98.75

Total Recognition Rate = 98.6 %

Total Recognition Rate = 98.6 %

Fig. 11 Recognition results

features.

Note that the significance of the present work is, however, not only the satisfactory recognition rate which is 98.6%, but the fact is it also attempts to introduce a totally new concept for dealing with handwritten scripts. As it bases its approach on active analysis of handwriting movements, by application of a new way of modeling the handwriting process.

Threshold element

The best SDR value in the reference¹⁾ was searched around the threshold value $\theta=0.6120$, the 3-level Gaussian optimum quantizer. However, in this work we used the threshold $\theta=1$, in order to have the decreased number of small extra pulses(see the following comment).

Comments on the sensitivity

To demonstrate the high sensitivity of the system, Fig. 12 considers a cases where it is rather difficult to recognize the handwritten sample (*Sin*) just by its original x and y data. The 3 vertical maxima characterizing this Arabic character can hardly be noticed by the original data of Y axis(Fig. 12). Meanwhile, these same 3 maxima can be easily noticed through

Fig. 12 High sensitivity of the system

Fig. 13 More on the sensitivity

the control pulses (Y axis).

To have a better idea about the sensitivity of the system, Figure 13 demonstrates system's ability to perceive (when it is necessary) even very small deviations of handwriting movements. The hand vibrations result in generating extra small pulses. Note that the small vibrations are hardly perceived through the original data. Actually this demonstra-

tion was performed intentionally on a sample written slowly (2.8 seconds) using a threshold $\theta=0.62$. The extra small pulses are considered to be caused by a visual feedback involved while the sample has been written slowly.

7. Conclusion

In this work, we have introduced a new solution toward recognizing handwritten isolated Arabic characters. The proposed approach is based on the active analysis of human handwriting movements. The handwriting process is modeled through an autoregressive moving average (ARMA) model. Model Reference Adaptive Control System (MRACS) theory is applied to extract control pulses of the handwriting movements. The control pulses are then used to recognize the shape of cursive handwritten characters.

Finally, it must be kept in mind that it is not necessary for the recognition of handprinted characters to apply such a complicated active method and to extract signals at the higher level of the handwriting process. For handprinted characters a simpler and straightforward method based on passive analysis can be used successfully.

Although the presented approach is proposed to recognize handwritten Arabic characters, it can, however, be applied equally well to recognize any other cursive handwritten scripts.

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