Handwritten Recognition based on Hand Gesture Recognition using Deterministic Finite Automata and Fuzzy Logic

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***Abstract*— Hand Gesture Recognition (HGR) is one of the most interesting branches in computer vision with lots of applications in mobiles, tablets, personal computers, and interactive platforms. The aim of this technology is to efficiently relate facilitate the people's communication with gadgets. Tracking hand movement in order to understand the desired operation can play an important role in the recognition of the hand gesture. In this paper, we propose a new approach for handwritten recognition in the context of hand gesture recognition. Our approach relies on the hand movements by means of its edge information and the movements directions. The next contribution is also minimizing the uncertainty of the handwritten recognition using fuzzy logic and deterministic finite automata (DFA). The uncertainty of the handwritten is due to the similar movements of the hands during writing the characters that we decreased it using our technique. The experimental result on real-world activities shows the success and usefulness of our approach.**

***Keywords*—** *Hand Gesture Recognition, Handwritten Recognition, Deterministic Finite Automata, Fuzzy Logic*

I. INTRODUCTION

The Hand Gesture Recognition (HGR) is one of the fascinating topics in Computer Vision and Human-Computer Interaction (HCI). This topic deals with the facilitation of human-intelligent system communication. Because of the simplicity of the work in which only human hands are involved, it is considered a useful way to communicate with intelligent systems, especially for the people who have a disability for the regular life activities. The applications of the hand gesture recognition are heavily expanding in mobile, tablets, personal computers, educational products, home appliances, robotics, computer games, medical devices, etc. [1, 2].

The HGR interface based on the machine vision is desirable because it does not require expensive additional hardware, except a camera to launch simple programs. HGR methods based on machine vision appear in two parts: three-dimensional based methods and outline-based approaches. Three-dimensional models describe hand position shifting precisely, but they are costly to use. Of course, in recent years, methods such as PCA-ICA and ISOSOM have been proposed for 3D image recognition by a two-dimensional outline model [3, 4].

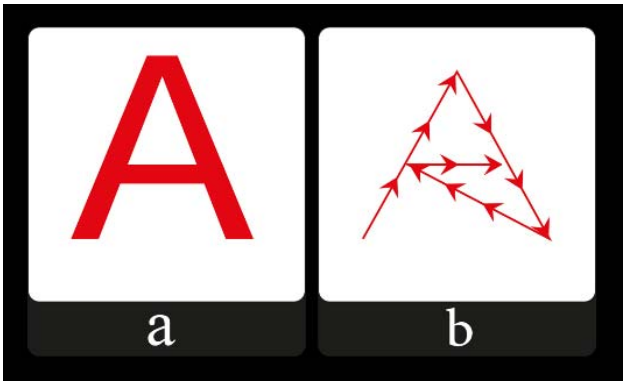

Figure 1: Displaying the letter "A" and the path to write it by human

To recognize hand gesture, it is necessary to determine the location of the hand among the image. Many methods have been proposed to recognize the location of the hand, Thomas et al. do this by recognizing the hand skin [5, 6], edge detection is also a good way to find the exact location of the hand in an image. Among the proposed methods for edge detection, the Sobel is a basic and very popular method [7, 8]. After recognizing the location of the hand, recognizing hand gesture in order to explore written character can be detected in different ways. For instance, there are approaches that segmenting the recognized hand image [9, 10 and 11]. Moreover, there are online approaches that use speed, angle, and location features [12-16]. More detail about the related works is introduced in the following section.

As seen in Figure 1, to write the letter "A", the human hand will have a movement similar to specific, by using this method, we generalize this issue to all capital letters to examine how to draw all the English letters. Then we use our fuzzy expert system due to the different handwriting and the uncertainty in the proposed method to obtain a relative synchronization in recognizing the direction of hand movement in writing. Therefore, we perform a non-text-dependent language and deterministic finite automaton (DFA) to analyze an image and achieve the correct character in handwriting.

In this paper, we propose to detect the hand gesture and follow its movement by means of a supervised edge detector

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proposed by Dollar et al. [7] and provide DFA to analyze possible sequences of the hand movements along with a fuzzy expert system to decrease hand movements uncertainty. Further details are described in section 4 and 5. According to the aforementioned issues, our algorithm follows:

1. Calculating the angle of hand movement from the points found.
2. Recognition the optimal motion by means of the fuzzy system.
3. Insert the name of the movement on the automata bar to change its position.
4. Recognition the final status of the automata and the written letter.

II. Related Work

Stern et al. [2] proposed segmentation operations after receiving the image from the camera for Steady states of hand, then the image is recognized using the hand gesture classification methods and according to that, the operation is done in this state. The complexity of the images in different states is the challenge of this method, although, high-speed processing is the strength of the method. Molchanov et al. [3] proposed to receive images in 3D and the extractable features from these images turn to the one of the gesturing hand by training a Convolutional Neural Network. The training time in this system is long and time-consuming and for training should have a lot of data. This system has fairly acceptable accuracy. Kato and et al. [4] reduced the dimensions of the problem to recognize hand gesture after extraction of features and using the Principal Component Analysis (PCA) method and then it recognizes the sensitive points of the hand, such as the intermediate phalanges, etc. Ohn-Bar et al. [5] suggested a way to recognize the direction of motion of the fingers and gestures drawn on the interface. Finally, they use classification methods to increase the accuracy of the work. In the airline industry to communicate with the pilot when the aircraft is preparing to move and stationary, the person standing in front of the aircraft and by the movements of the hand and body will coordinate with the pilot. Song and et al. [6] also proposed using the three-dimensional recognition of the body and hands, and the direction of their movement, and finally, with the Support Vector Machine (SVM) Algorithm for Classification, identify the movement.

To recognize the gestures drawn on the mobile page using registering the direction of finger movement, the behavior of fingers on the screen and the machine learning algorithms, we teach the Gestures. The proposed method of Li and et al. [7] is presented in this field. Zhao and et al. [9] in their method, first, after receiving the image with the skin detection algorithms, look for areas in which there are skin areas, with obtaining of these areas, they began to find a part of that contains a hand and then using the edge detection, the extraction function operation is done using the Principle Component Analysis (PCA). Finally, the operation ends with a classifier and a dictionary containing hand gestures and corresponding letters. Marium et al. [12] have presented a method using a webcam that can initially recognize the region where the hand is present there and then find the hand gesture according to the angles of fingers. Then, according to the amount of displacement and hand movement, the next image is recognized. Huang et al. [15] For hand gesture recognition, after getting the image from the input, founds the location of the hand in it using Skin Detection and then converts it into a binary image by a threshold. To recognize the hand gesture with less error, the image is rotated to the nearest same image in the database with a specific angle, and then crop the segment that hand in it. Using the Gabor-Filtered image, it converts the image into a Gabor Feature Vector, using the Principal Component Analysis (PCA) to perform Feature Extraction, and finally to identify the mode using the Support Vector Machine (SVM). This algorithm, despite the relatively good accuracy, does not have high speeds compared to other methods, and the complexity of the algorithm is also high.

III. Our Approach

In this section, we describe our preliminary processing including hand detection and its movement direction, etc.

A. Directions

First, we need to recognize the hand movement in different directions. To this end, we first define the important directions as introduced in Table 1. This means that if the hand moves to write a part of a letter to the right, we assume it to a zero-degree angle and assign the name of the move “a” or if the hand is moving “g” this means that the movement is downward, This issue is illustrated in Figure 2.

To recognize the direction of hand movement, we define a time interval for processing frames that by doing different experiments we have come to the conclusion, we need to recognize and save the current location of the hand every 8 frames (i.e., about three frames per second) once processed the image, then, in the next frame and with the new coordinates of the hand, we obtain the angle of motion using equation (1). To get the current coordinates of the hand, we have to apply the edge detection algorithm on the image.

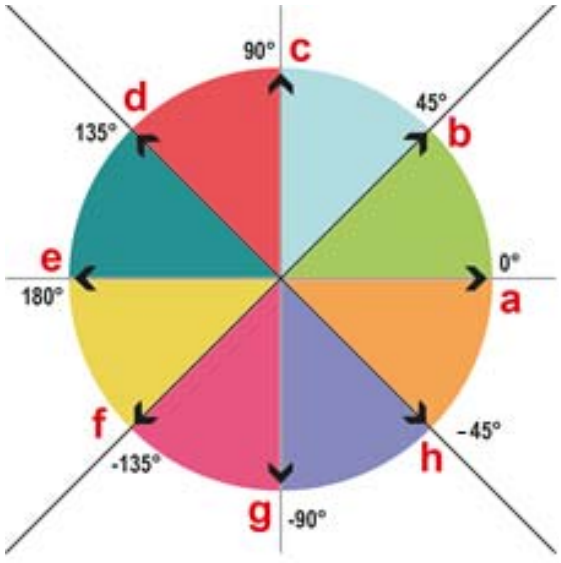

Figure 2: Direction of hand movement at different angles and the name of each movement

Table 1: Important directions of hand movement, equivalent angle and the name of movements

Directions	Angle	Name
Right	0	**a**
Right-Up	45	**b**
Up	90	**c**
Left-Up	135	**d**
Left	180	**e**
Left-Down	-135	**f**
Down	-90	**g**
Right-Down	-45	**h**

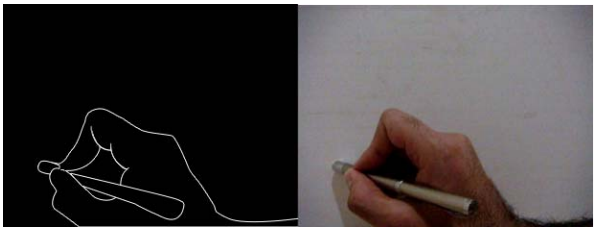

Figure 3: The image of a writing hand (right) and the detected edge of the image by the Dollor's method [7] (left)

$$\deg = \tan^{-1}\frac{\Delta y}{\Delta x} \qquad (1)$$

B. Edge Detection

One of the popular edge detector applications in image processing is finding objects that are in the pictures. So, we employ this technique to find out the current location of the hand. There are many ways to apply the edge detection on images, the proposed method uses the edge detection technique provided by Dollor et al. [7]. This technique is such that it is a machine learning with an observer, in the different designed photos. After training the system, the probability that each pixel will be edge checked and if it was an edge, we would highlight it, the output of this method is shown in Figure 3. We define and store the highest point of the hand as its current point after edge detecting. More detail about Dollor's edge detection can be found in [7].

IV. FUZZY SYSTEMS

The fuzzy logic can be effective in reducing the uncertainty associated with hand movements' recognition. Fuzzy expert systems can create this ability which uses the knowledge of an expert to decide on and control a real system. The most common use of the fuzzy logic is in modeling relationships in complex environments or wherever a clear and obvious system model which is not available as it is considered like a Black Box and, based on a number of inputs and their output, made conclusions and make decisions for the system. Nevertheless, it is not easy to recognize the correct direction of hand movement. Not moving the hand on a smooth line or the obvious angles, as well as the similarities between the lines drawn in different directions, cause the uncertainty about the direction of the hand movement. For example, if the hand angle is 20 degrees, it is not certain that motion “a” has occurred or move “b”.

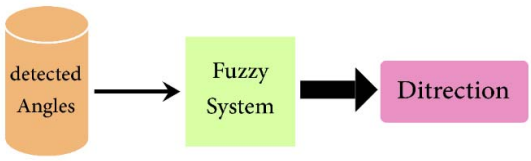

Figure 4: Recognition fuzzy model of the hand movement direction from the obtained angle of motion

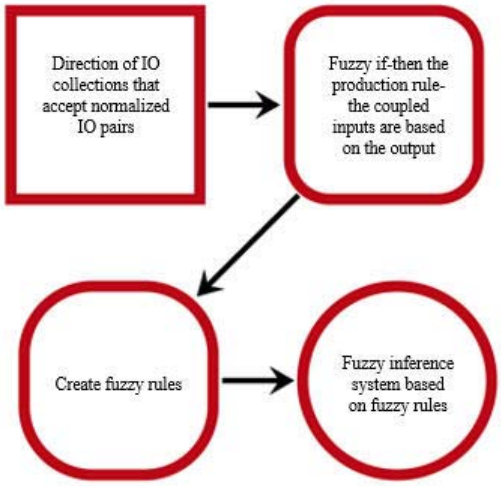

Figure 5: Our fuzzy expert system Flowchart

In Figure 4, the general schema of the comparative recognition model of the hand movement direction using fuzzy system has been demonstrated. The most important idea in using the fuzzy system is the absence of a specific angle of the hand movement direction continuously and also the closeness of some of the directions to each other.

As the angles are deposited into a fuzzy expert system, the system translates this to a direction.

A. Basic concepts of the fuzzy expert system

We use the fuzzy rules in the form of equation (2) to model the concepts of this category:

$$\text{If } x_1 \text{ is } A^l_1, \ldots, x_m \text{ is } A^l_m \text{ Then } y = B^l \qquad (2)$$

All employed membership functions are triangular due to the simple computations but their number of variables are different, this difference stems from the natural nature of the parameters, such as not moving the hand in a perfectly straight line.

The most important reasons in using a fuzzy system are:

1. Excessive real-world complexity results in an approximate description or a fuzzy system for modeling.

2. The need for a model to formulate human knowledge in a legal way and putting it into real systems.

In our work, we propose to recognize the direction of hand movement with the aid of a fuzzy expert system. In order to construct this fuzzy model, due to the importance of the angle in recognizing the direction of movement, use the angle obtained from the hand movement, and with that, we will determine and recognize the direction of movements. Therefore, we have considered Figure 5 to show our fuzzy expert system flowchart.

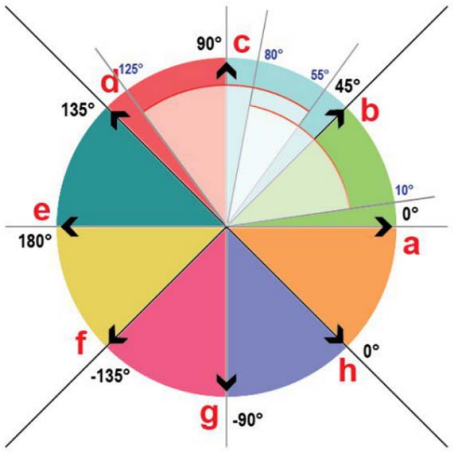

Figure 6: Input-Output parameters of fuzzy system

B. *I/O Parameters of Fuzzy System*

As mentioned earlier, in this system, the obtained angle from the hand movement is as an input of the system which should be used for the output that is the hand movement direction. Therefore, according to the mentioned items and the input-output parameters of the system, we can introduce Figure 6 to represent the used fuzzy system. Moreover, As shown in Figure 7, in this system, if the hand moves at an angle between 10 and 80 degrees (red lines) system output will be "b" direction and, if the hand moves at an angle between 55 and 125 degrees (blue lines) system output will be "c" direction. By generalizing this case on all angles, we can map the fuzzy membership functions of this system as shown in Figure 7. Table 2 also specifies the output directions according to the input angles.

Table 2: Recognized angle interval for any direction of motion by the fuzzy system

Angle Interval	Name
(-35, 35)	**a**
(10, 80)	**b**
(55, 125)	**c**
(100, 170)	**d**
(145, -145)	**e**
(-170, -100)	**f**
(-125, -55)	**g**
(-70, -10)	**h**

Table 3: Grouping characters including the first movement in writing them

First movement	Angle	Letters
a	0°	Z, I
b	45°	A, M, N
e	180°	C, E, F,G,S
g	-90°	B, D, H, J, K, L, P, R, T, U
h	-45°	O, Q, V, W, X, Y

V. DETERMINISTIC FINITE AUTOMATA (DFA)

A DFA is a mathematical model for finite-state machines which defined as M = (Q, Σ, δ, q_0, F), where:

Q is a finite set that the name of machine states located on it.

Σ is a finite set that the name of machine symbols located on it.

The transfer function δ (state change) of a machine defines as:

$$Q \times \Sigma \rightarrow Q$$

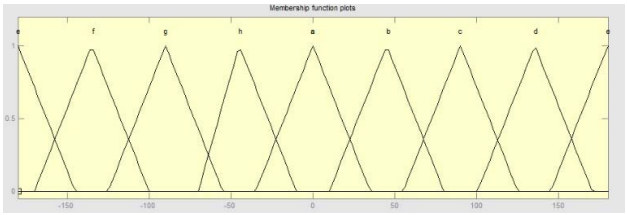

Figure 7: Fuzzy system diagram according to the angles and hand movement directions

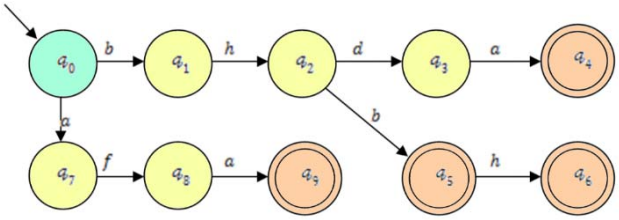

Figure 8: The equivalent graph of the automata designed to recognize the letters A, M, N, Z

Where q_0 is a member of Q, which starts as the *state* and F is a subset of Q, which is the final State (s).

A DFA has begun reading a series of symbols in Q of an initial state (q_0) and change the state based on a particular set of rules (transfer function) and if the string of Symbols is over and the machine is in a special case in F, the machine has accepted the string. In our work, we use this type of machine to achieve the optimal answer for recognizing handwritten characters. To do this, we first divide the characters into their groups, taking into account their first movement in writing. The result of this grouping can be found in Table 3. As we know, the language of these automata consists of the letters (a, b, c, d, e, f, g, h). Considering this issue, we now begin to construct the transfer function to recognize the letters. Because Σ = (a, b, c, d, e, f, g, h) is, considering q_0 as State, the start of the transfer function for the letters A, M, N, Z is defined as follows.

$$\delta = \{$$
$$(q_0, \mathrm{b}) \rightarrow q_1$$
$$(q_0, \mathrm{a}) \rightarrow q_7$$
$$(q_1, \mathrm{h}) \rightarrow q_2$$
$$(q_2, \mathrm{b}) \rightarrow q_5$$
$$(q_2, \mathrm{d}) \rightarrow q_3$$
$$(q_3, \mathrm{a}) \rightarrow q_4$$
$$(q_5, \mathrm{h}) \rightarrow q_6$$
$$(q_7, \mathrm{f}) \rightarrow q_8$$
$$(q_8, \mathrm{a}) \rightarrow q_9$$
$$\}$$

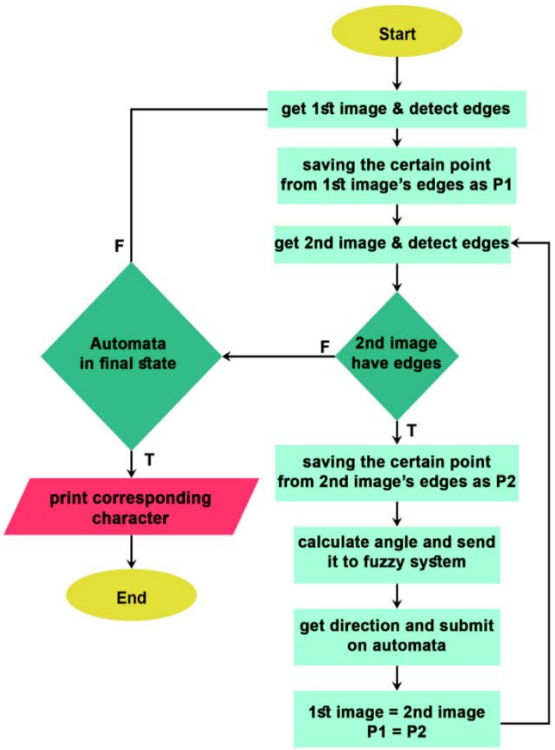

Figure 9: The flowchart for recognize handwritten letter from hand movement with fuzzy logic

Where the set $F = \{q_4, q_5, q_6, q_9\}$ is the graphical form of these automata, which recognizes 4 letters A, M, N, Z, is shown in Figure 8.

If after reading all the characters that came out of the hand movement, the machine was in the final state q_4, This means that the letter writing by hand is the letter A and if q_5, q_6, q_9 were in one of the final states, it would represent the letters N, M, Z, respectively. Now it is enough to design these automata to recognize all of the original letters of the machine. Full recognition flowchart of the letters is shown in Figure 9. Moreover, Figure 10 shows how to write capital English letters.

A. Error Reduction

Despite the use of the fuzzy system and the DFA automata to recognize the letters, this solution has problems and errors that we will try to reduce by providing the right solution. The first problem that occurs in recognizing letters is considering the speed of human's writing that is different and should make them somehow equal. For this purpose, we use the loop method to use states. For example, Figure 11 shows the graph corresponding to the automata designed to recognize the letter Z. This method will be independent of speed because by the hand movement in the direction "a", the machine changes from q_0 to q_7 and as long as the hand moves in direction "a", the machine stays in the same position. When the hand changes direction and begins to move in another direction if there were a corresponding state change with that in the motion function, the machine changes the state and it will go through the next state to reach the final state.

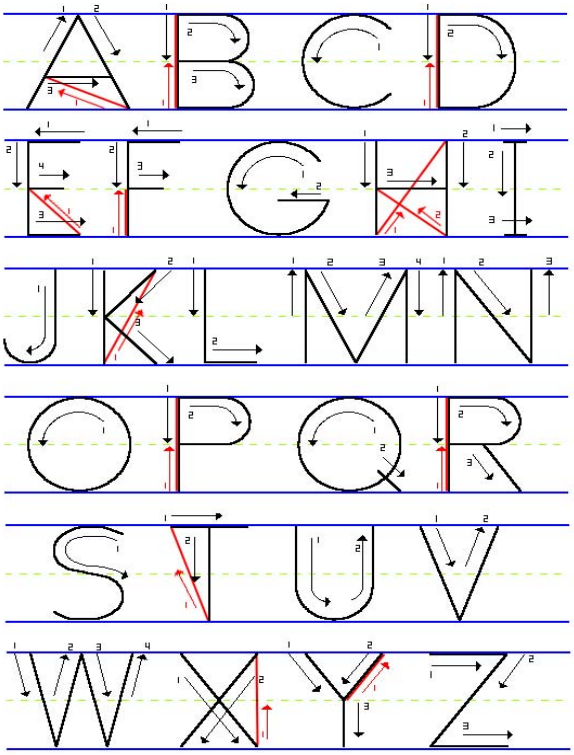

Figure 10: How to write capital English letters

Another problem that causes an error is when the angle obtained in the joint area of two moves adjoins. In this case, the fuzzy system recognizes two directions. Initially, the priority is in a direction that has a greater amount in the fuzzy function but this does not always make the right choice. The reason for that is uncertainty about human's hand movement always exactly in one direction. If the machine does not reach the final state, checking and navigating other paths will reduce the error in true recognition.

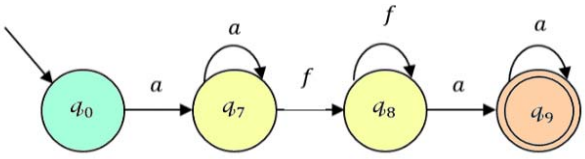

Figure 11: Equivalent graph of the automata designed to recognize the letter Z along with the looping

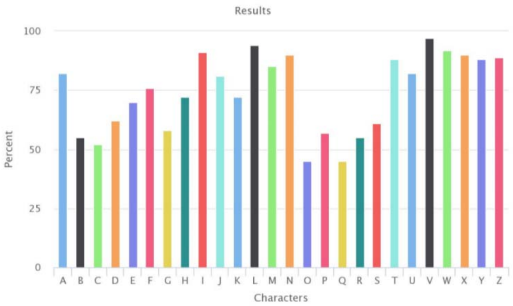

Figure 12: Percentage of success by recognizing letters in testing 100 people by writing each letter 5 times

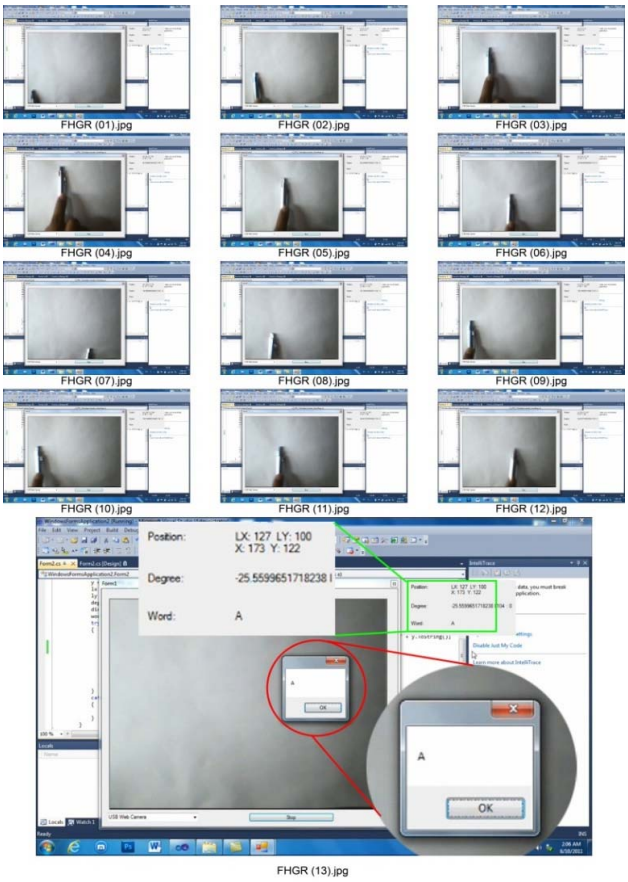

Figure 13: recognition the letter A by the implemented application by hand movement

VI. Implementation and Results

The technique presented in this paper is implemented in the Visual C#.Net programming environment and the recognized percentage of each letter in 100 tests (for each letter) is given in figure 12. As can be seen, the most difficult letters to recognize are Q and O due to the similarity of writing where they both recognized in the rate of 45%. In contrast, the letter of V with 97% accuracy is the easiest letter to recognize with our system. The average rate of recognizing English alphabet letters is 74.19%. The implementation of recognizing the letters "A" and "N" that form the "AN" word is shown in Figures 13 and 14.

VII. Conclusion and Future Works

According to the results obtained, because our proposed method performs handwriting recognition's operation in real time and with good speed, it has an acceptable efficiency. This method is currently only available for capital English letters and can be extended to lowercase letters, numbers, and other languages. In the proposed method, we provide an HGR system to recognize the hand gestures and minimizes the uncertainty in the problem using a fuzzy expert system. Also, solutions are proposed to reduce the error of incorrect identification, which increase the accuracy of the existing technique. The implementation of the proposed technique leads to achieving more favorable results. Therefore, in the proposed method, it is possible to easily implement recognition systems of the handwriting letters based on the handwriting gesture.

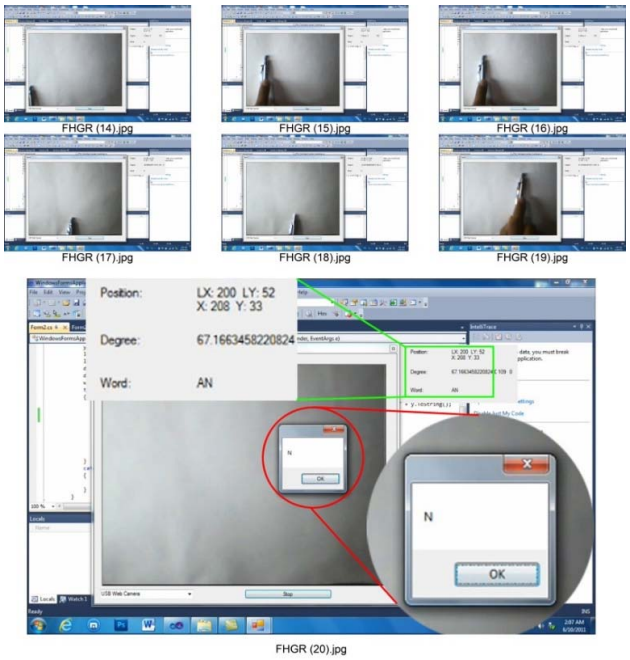

Figure 14: Recognition of the letter "N" by implemented application of hand movement that results in the formation of an "AN" word

The problem of hand movements' recognition is important because of its high utilization and it is supported by numerous academic and executive institutions. Therefore, there are many areas of development. Among them, it is possible to point the development of letters recognition with less error rate, as well as to recognize small letters and recognize the letters of other languages.

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