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Handwriting Velocity Modeling by Artificial Neural Networks

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***Abstract*—**The handwriting is a physical demonstration of a complex cognitive process learnt by man since his childhood. People with disabilities or suffering from various neurological diseases are facing so many difficulties resulting from problems located at the muscle stimuli (EMG) or signals from the brain (EEG) and which arise at the stage of writing. The handwriting velocity of the same writer or different writers varies according to different criteria: age, attitude, mood, writing surface, etc. Therefore, it is interesting to reconstruct an experimental basis records taking, as primary reference, the writing speed for different writers which would allow studying the global system during handwriting process. This paper deals with a new approach of the handwriting system modeling based on the velocity criterion through the concepts of artificial neural networks, precisely the Radial Basis Functions (RBF) neural networks. The obtained simulation results show a satisfactory agreement between responses of the developed neural model and the experimental data for various letters and forms then the efficiency of the proposed approaches.

***Keywords*—**ElectroMyoGraphic (EMG) signals, Experimental approach, Handwriting process, Radial Basis Functions (RBF) neural networks, Velocity Modeling.

I. Introduction

THE study of the handwriting process is a way to explore the different properties of the biological system which produces it and the main factors involved in it namely the upper membranes movements, the generation of nervous stimuli, the muscles study, the pen displacement on a writing surface, the handwriting velocity, etc.

Considering the complexity of the biological handwriting process, several researches have been conducted to enrich our knowledge on the functioning and organization of this biological system. At first analysis, Van Der Gon has developed a mathematical model characterizing this phenomenon [1]. An electronic version was then presented by Mc Donald [2], who considered the handwriting system as a mass moving in a viscous environment. The movement of this mass is described by a linear differential second order equation. A model governed by a system of two nonlinear differential equations of the second order was developed by Yasuhara which integrated the effect of the frictional force between the pen tip and the writing surface [3]. He presented then the identification and the decomposition of a fast writing system. In 1987, Edelman and Flash proposed a model based on the study of the hand trajectories [4]. Linear modelling approach derived from experimental data was proposed by Sano and al in 2003 [5].

Using unconventional approaches, several models were proposed for the characterization of the handwriting process. These models are based on the concepts of the artificial neural networks, fuzzy logic, genetic algorithms… [6]-[9].

Other research have focused on velocity as the main criterion for handwriting modelling [10]-[12].

The main contribution of this paper appears through a new approach of neural modeling of the handwriting system based on the writing velocity and the ElectroMyoGraphic (EMG) signals recordings. First of all, a description of the experimental study is conducted in order to collect experimental measurements which will be used to develop a database based on the handwriting velocity criterion from the traces of Arabic letters and geometric shapes according to the x and y axis. Thereafter, the developed base will allow the handwriting velocity modelling through the elaboration of a new modelling approach by radial basis functions artificial neural networks for different letters and forms. Finally, a validation of the proposed models is performed.

II. Experimental Study Description

The handwriting can be considered as a process whose parameters vary according to several factors including the writer, his age, his habits, his ability, his physical and psychological state (tiredness, nervousness, etc..), the instrument used in writing, the writing velocity, the positions relative to the writer forearm as well as the pen orientation.

During the act of writing, the movements performed can be described like displacements in the two-dimensional space of the writing plan. In the literature, multiple researches proved that the natural component of the graphic trace corresponds to space displacements of the pen during the trajectory elaboration. In spite of the complexity of the effector system including the articulations of the shoulder, the elbow, the wrist and the hand, for a total of forty three muscles, the study presented in [3] identified four principal muscles for the hand control. In order to characterize this biological process, an experimental study carried in [5], has recorded ElectroMyoGrahic signals (EMG) during the act of writing, Fig. 1.

Starting from the surface electrodes used per pair and having a common mass, the experimental study allowed recording electromyograhic signals during the writing time. These signals are obtained from the two most active muscles of the forearm, namely the “abductor pollicis longus” and the

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"extensor capri ulnaris" which are the most active and are opposed in movement; when one contracts the other extends. This experience allowed recording the positions of the pen tip in the plan (x, y), the EMG signals, and the pressure P exerted by the pen on the writing table.

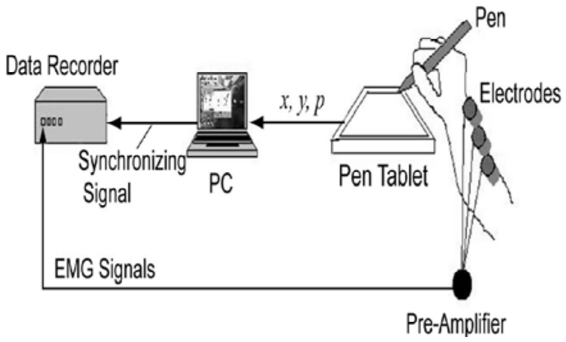


Fig. 1 Experimental assembly

ElectroMyoGraphy (EMG) is a method that allows collecting the myoelectric signals; it is based on the excitability of the muscle cell. The stimulation of the muscle cell with a motoneuron induces membrane depolarization (muscle action potential), associated to an ions movement, which spreads along the membrane and causes the muscle contraction. This is the electrical activity detected by electromyography during muscle contraction. Some authors define electromyography as the muscle functional study through the collection and analysis of the electrical signal generated by muscle contraction [13], [14].

The electromyographic signal features depend on many factors. However, it is possible to extract several information from the EMG signal, especially when the experimental protocol helps to reduce these factors influence. Thus, a proper placement of the electrodes may contribute to have a better electromyographic signal. Indeed, the electrodes placement, their situation and positioning on the muscle and their alignment with the muscle fibers affects the EMG signal [15]. Close to tendons, the signal amplitude decreases and the power spectrum tends towards high frequencies. In addition, misalignment of the electrodes influences the signal too, Fig. 2.

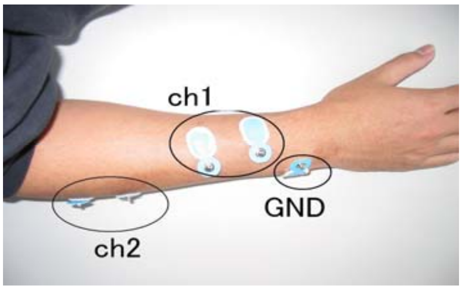


Fig. 2 The electrodes position on the writer forearm

The experimental study was carried out by eight writers aged between twenty-two and twenty-three years old in order to obtain a database containing several Arabic letters, namely the letter (SIN), the letter (HA) and letter (AYN), and several basic geometrical forms namely horizontal line, vertical line, curve, triangle and circle.

Parasites due to noise are one of the most harmful factors to acquire as much information as possible of the EMG signal. Indeed, the EMG signals recorded during the experimental protocol correspond to the spatial-temporal summation of action's potentials emitted during muscle contraction.

These signals present transitory phenomena or disturbed segments and other disturbing signals due to various sources such as electromagnetic phenomena of the sector and the parasites associated with electrodes and measurement uncertainties [16]. This requires the introduction of the biomedical signal processing approaches to obtain a signal easy to study which is the Integrated ElectroMyoGrahic signal (IEMG).

After the recovery of the EMG signal's full wave (Full Wave Rectification) calculating the absolute value of the EMG signal, the obtained signal is then divided into time intervals of fixed duration, and then integrated for each interval. An interpolation is finally carried out between the various values in order to obtain the curve noted IEMG for two channels; channel 1 (CH1) and channel 2 (CH2).

Fig. 3 illustrates an example of the Arabic letter "AYN". Fig. 4 shows the full-wave rectified EMG and IEMG for (CH1) and (CH2) (a) in addition to the wave form of integred electromyograhic signals IEMG (CH1) and IEMG (CH2) (b), both for the Arabic letter "AYN".

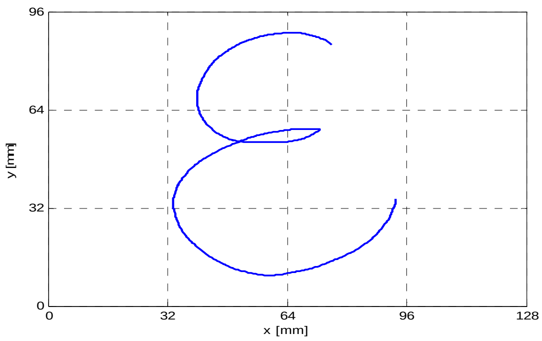
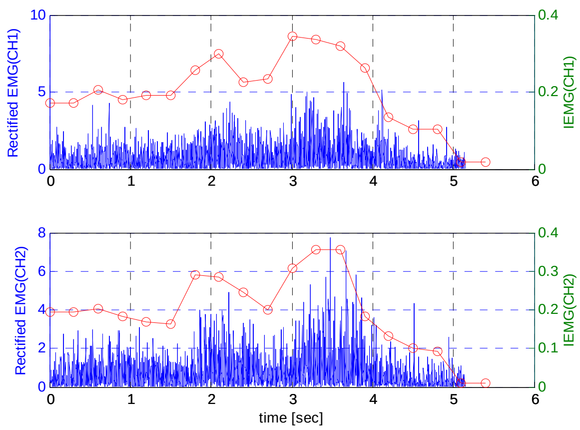
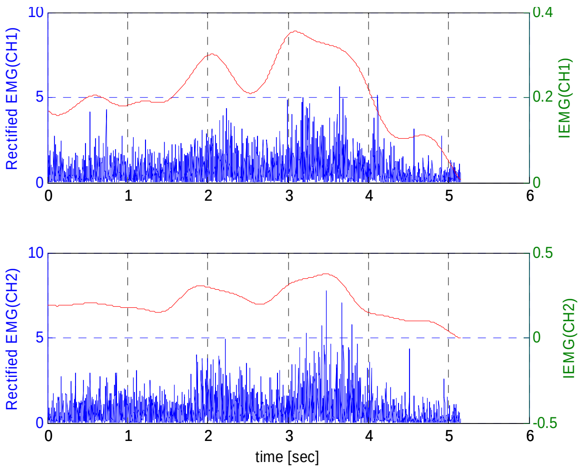


Fig. 3 The Arabic letter "AYN" form



(a)



(b)

Fig. 4 The Arabic letter "AYN" (a) Full-wave rectified EMG and IEMG signals, (b) Wave form of integred EMG signals (IEMG)

III. Handwrinting Velocity Study and Modeling by Artificial Neural Networks

In the literature, some studies were interested in the analysis of the intrinsic properties of handwriting process in terms of speed, amplitude and direction of the produced form, [12], [17]. However, when the velocity which is considered as individual characteristic increases; the handwritten form degrades gradually. This phenomenon leads to produce forms slant to the right for the right handers and to the left for left-handers. The speed influence has inspired several researchers to investigate its role in the handwriting production.

A. Computing the Writing Velocity

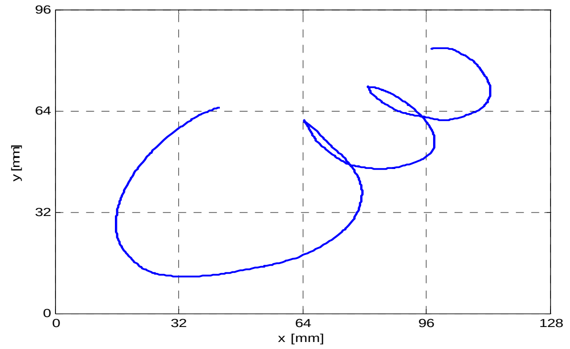
The study of the velocity profile of the handwriting movement shows that writing can be decomposed into a sequence of forms bell shapes. This overlapping can contain information about the nature and type of the handwritten graphic trace; these ones correspond to the set of features characterizing the written form.

Relying on this analysis, it is interesting to develop a new approach based on computing the handwriting velocity. From the experimental data produced during the previous experimental study, a database was rebuilt considering mainly the writing speed.

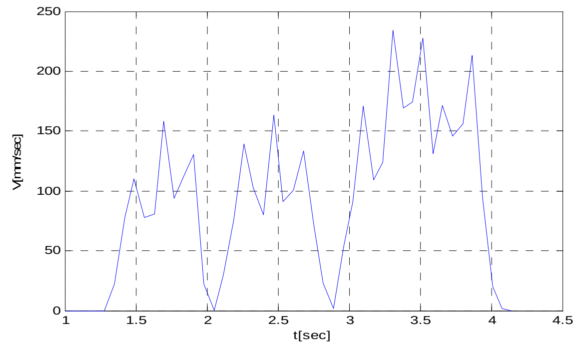
Based on the movement traces of the pen tip along the x and y axis, the writing velocity are computed according to the following equation:

$$\|V(t)\| = \sqrt{\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2} = \sqrt{V_x(t)^2 + V_y(t)^2} \qquad (1)$$

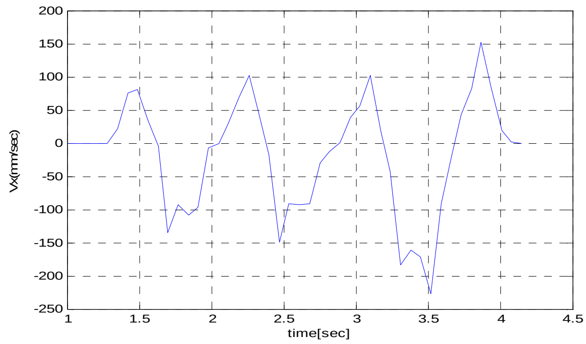
Fig. 5 illustrates the writing velocity for an example of the Arabic letter "SIN". (a) shows the letter form, (b) the global letter writing velocity as well as the velocities according to x and y axis (c) and (d):



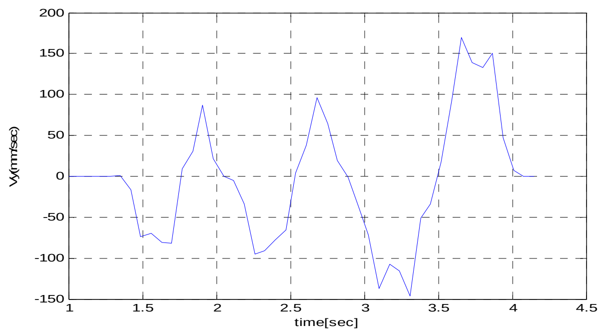
(a)



(b)



(c)



(d)

Fig. 5 The Arabic letter "SIN" (a) Form, (b) The global letter writing velocity, (c) Writing velocity according to x-axis, (d) Writing velocity according to y-axis

B. RBF Neural Networks Proposed Model

The functions approximation is one of the main uses of multilayer neural networks and namely radial basis function neural networks. For a set of input/output data, the problem is to find a relationship between these two sets of variables. It is a question of developing an approximator of this often unknown relation by choosing its structure and by calibrating it properly so that it best represents the dependence between its inputs and outputs.

The new proposed model synthesis is based on computing the pen tip velocity during its displacement in the (x, y) plan namely the speeds V_x and V_y, from both Integrated ElectroMyoGraphic signals of the forearm, IEMG1 and IEMG2.

The proposed model is based on an unconventional approach namely RBF neural networks [18]. Its structure is a closed loop network with one hidden Gaussian kernels layer. The inputs of the neural model are the IEMG signals of the two considered muscles, delayed at times: k, k-1, k-2 and k-3 as well as the writing velocities: V_x and V_y at k, k-1, k-2 and k-3. The outputs are the writing speeds along x and y axis namely V_x and V_y at time k+1, Fig. 6.

The proposed experimental model was built basing on the principle of construction algorithms of artificial neural networks. Indeed, starting from a small network with five Gaussian kernels neurons, network construction is then completed by adding at each step of building five new neurons in the hidden layer until reaching the desired performance. After several experimental tests, the choice was fixed on the addition of five neurons at each new step of construction and not less in order to avoid the slow learning and especially the overlearning of the network [19]-[22].

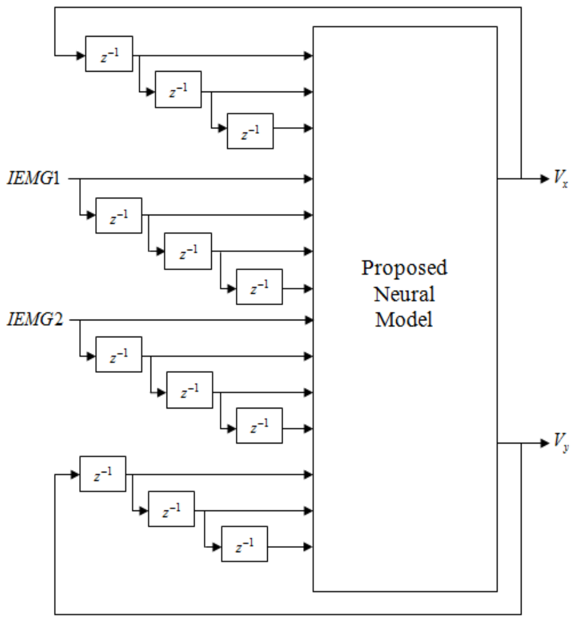


Fig. 6 The proposed neural model for handwriting velocity modeling

Considering a given writer, a neural model is developed to reproduce writing velocities V_x and V_y, relative to Arabic letters or simple geometric forms.

Figs. 7-10 show the learning performance of the developed neural network for example of the geometric form Triangle , as well as its response to learnt experimental data.

ED is the Experimental Data and NMR is the Neural Model Response.

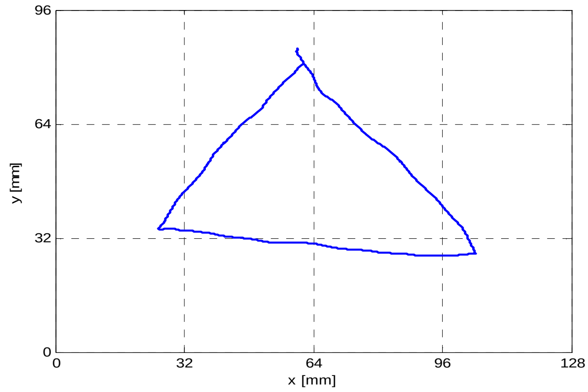


Fig. 7 The geometric form "Triangle"

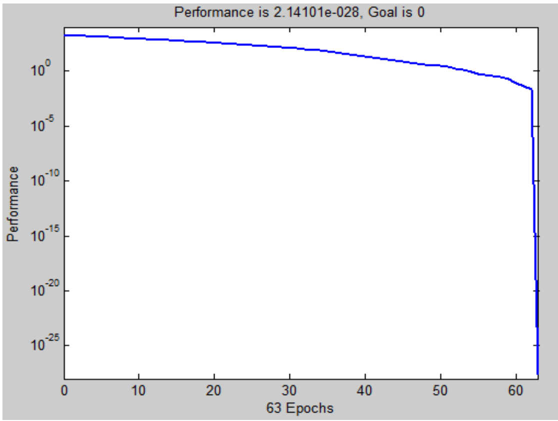


Fig. 8 Learning performance for the geometric form "Triangle"

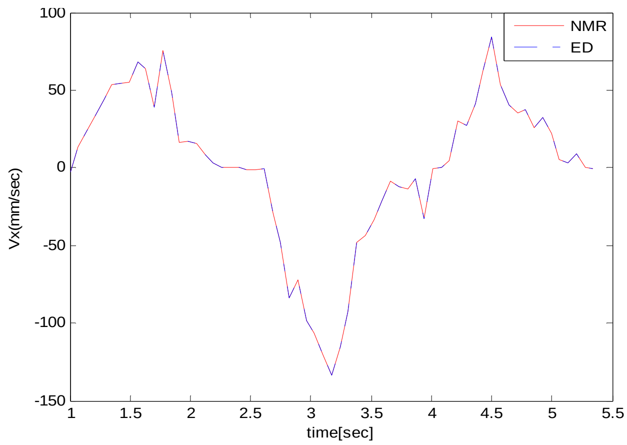


Fig. 9 Proposed model responses of the writing velocity trace along the x axis for learnt data of the "Triangle" shape

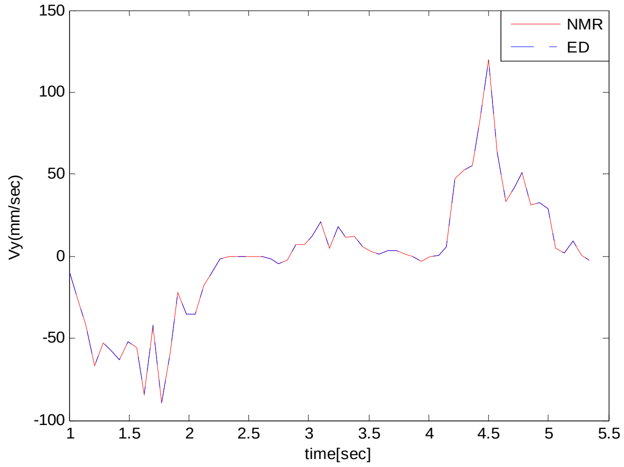


Fig. 10 Proposed model responses of the writing velocity trace along the y axis for learnt data of the "Triangle" shape

The above figures show comparison examples between the real trajectory of the pen tip velocity and that reconstituted by the proposed neural model for learnt data. A substantial compliance is observed between these two trajectories for simple geometric shapes as well as the Arabic letters.

As part of the validation of developed neural model, unlearnt data were considered for the different neural networks relative to geometric forms and Arabic letters. Indeed, for a given writer, the validation of the proposed neural model consists in simulating unlearnt data for a given letter or geometric shape by the neural model already learnt for this letter or form, Figs. 11-14 are for the Arabic letter "SIN" and Figs. 15-18 for the geometric shape Circle.

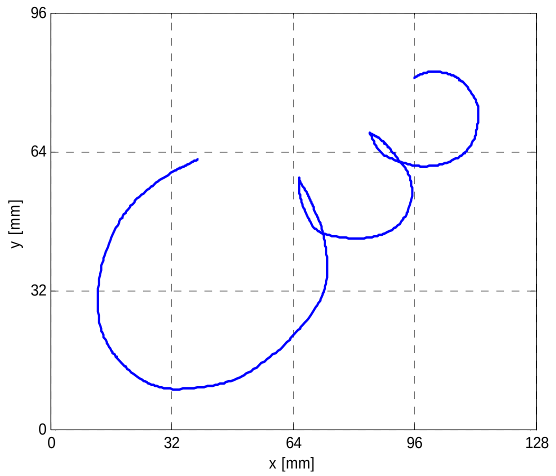


Fig. 11 The Arabic letter "SIN"

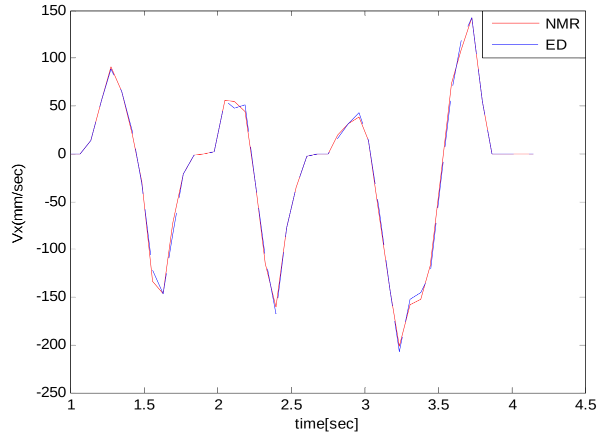


Fig. 12 Proposed model responses of the writing velocity trace along the x axis for unlearnt data of the "SIN" letter

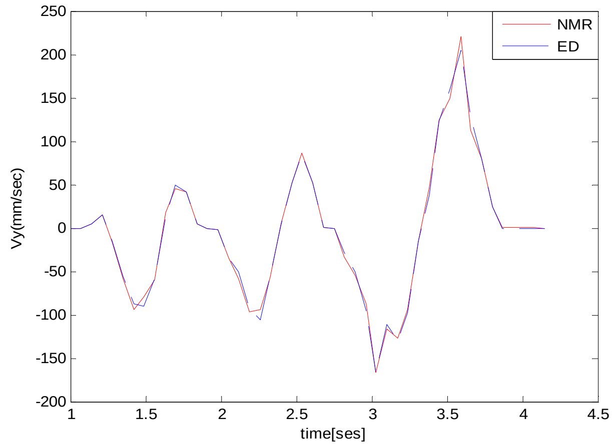


Fig. 13 Proposed model responses of the writing velocity trace along the y axis for unlearnt data of the "SIN" letter

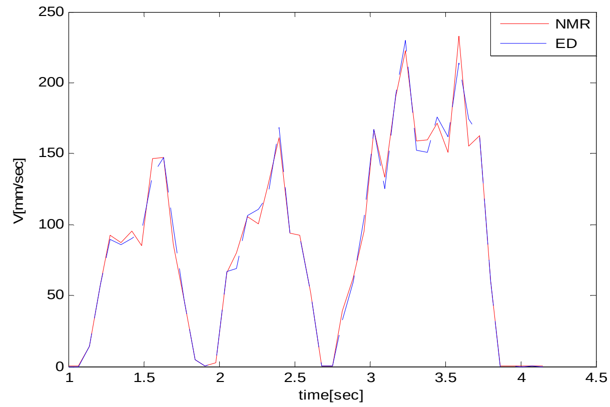


Fig. 14 Proposed model responses of the writing velocity trace for unlearnt data of the "SIN" letter

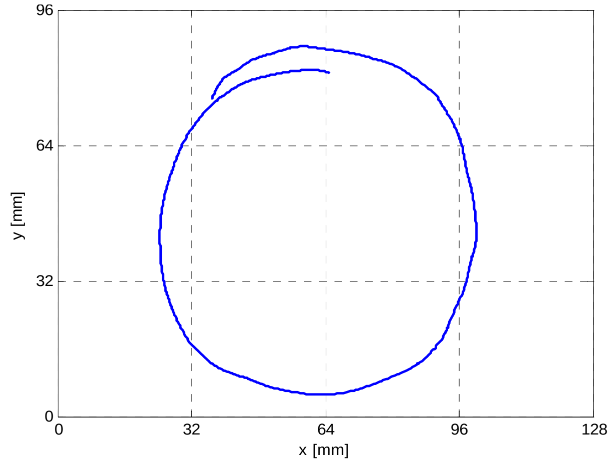


Fig. 15 The geometric form "Circle"

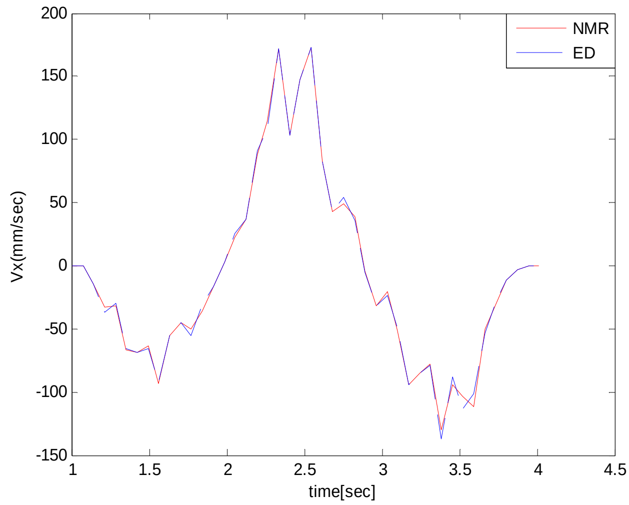


Fig. 16 Proposed model responses of the writing velocity trace along the x axis for unlearnt data of the "Circle" shape

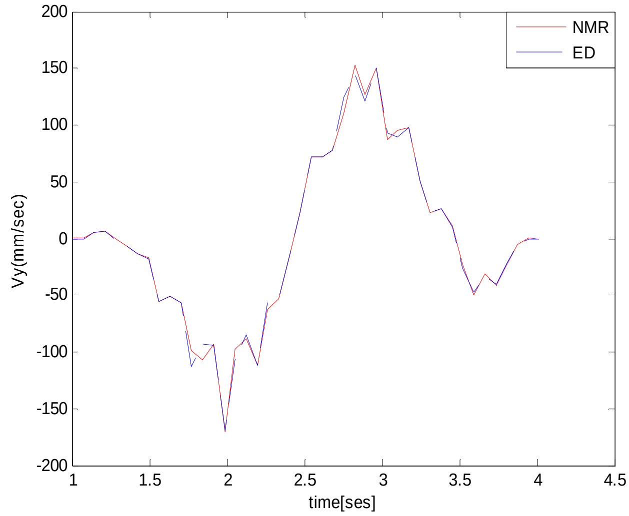


Fig. 17 Proposed model responses of the writing velocity trace along the y axis for unlearnt data of the "Circle" shape

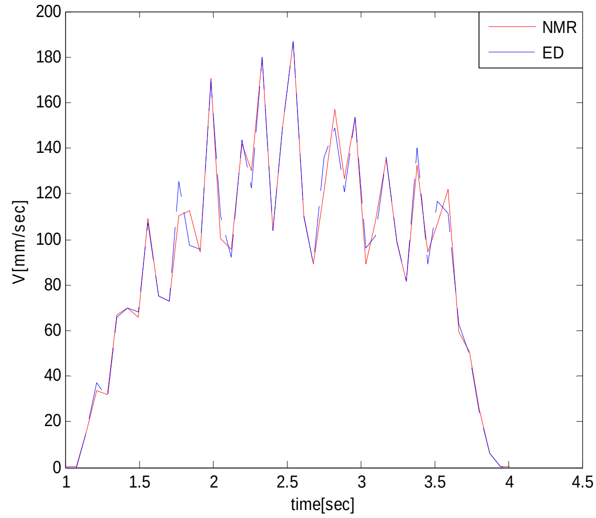


Fig. 18 Proposed model responses of the writing velocity trace for unlearnt data of the "Circle" shape

With a few small differences, the simulation results show a satisfactory agreement between the responses of the developed neural model and the experimental data for the writing velocity trace of various Arabic letters and geometric forms.

IV. Conclusion

The study of the handwriting velocity through the reconstruction of an experimental database of the handwriting system based mainly on the speed criterion as well as the development of a new approach of the handwriting velocity modelling through the concepts of radial basis functions artificial neural networks constitute the main contribution of this paper.

The proposed experimental approach allowed the acquisition of the muscular stimuli and the coordinates of the pen tip moving over the writing surface, according to time. These experimental measurements helped to develop a database based on the writing velocity criterion for different writers which conducted to constitute a learning base for the development of a neural model for the studied process. The simulation results of neural suggested model are satisfactory and their validation for various writers was successful. It is very interesting to apply the study to the medical field to elaborate a system essentially helpful to those who suffer from physical handicaps.

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