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Analysis of velocity profile to detect primitives of handwriting script

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***Abstract*—The study of human handwriting process shows that its velocity's profile is constituted by a superposition of bell-shapes. In this paper, we show the influence of the velocity, considered as individual propriety, on the production of a handwriting traces and its ability on the description of this biological act. Basing on the analysis of the velocity's profiles, we prove that its main bell-shapes correspond to primitives of the writing shape and present a significant change in the direction of writing. Besides, the velocity's profile can contains information on the type and nature of the drawn shape, and it can be used to reconstruct the pen-tip trace. This analysis can be considered to facilitate the study of this complex and rapid human process. To improve this study, a new algorithm for the detection of handwriting script's primitives is proposed. This approach is based on the analysis of the decomposition of the velocity profile, calculated from an experimental data of various arabic letters and geometric forms, written by different peopole**.

Keywords — human handwriting process, velocity's profile, superposition of bell-shapes, detection of handwriting script's primitives.

I. INTRODUCTION

The handwriting process is a dynamic system playing a prominent role in human life and in communication. It's a subject of several studies and research in various fields. Some of them have focused on one of the individual proprieties of this process, the writing velocity. Those studies investigate its role on the characterization and modeling of handwriting process, [1, 2, 3, 4, 5, 12].

A Gaussian model based on the velocity profile is presented in [3] and [4]. The investigation in [5] confirmed that the velocity profiles of this process are approximately bell shaped. In [6], a velocity model with lognormal function is proposed. A beta-elliptic approach is proposed in [7] to reconstruct the handwriting trajectory and velocity. In [8] is presented a mathematical structure characterizing the process of writing by hand, based on the pen tip velocity moving on (x,y) plane. Other investigations focused also on the modeling of the handwriting velocity, [9, 10, 11].

However, these researches present a lack of correspondence between the responses of the proposed models and the original writing form to produce.

Indeed, handwriting shapes presents many intermediate zones that corresponds to directions' change of the writing shapes. Therefore, these previous studies need more improvement, especially in the intermediate zones.

In this context, an experimental base is built in [12] containing Arabic letters and geometric shapes. Due to its cursive form, the studied shapes contain many complications. This makes its reconstruction more difficult.

To facilitate the study and modeling of this process, it is necessary to consider the cursive nature of Arabic letters and geometric shapes as well as their changes of direction during the handwriting movement. The importance of these critical properties in the writing is manifested in its velocity profile.

Because of its importance in the characterization of this complex biological act, a new approach for detecting of handwriting primitives is proposed in this paper. Based on the analysis of the handwriting speed profile, this novel approach provides information on the type and nature of the produced form. This can be useful for control and modeling of the studied biological process.

The first section of this paper presents the experimental approach proposed and each device for the data recording of an experimental basis.

The next section is focused on the analysis of velocity profile relative to the handwriting movement. Then, in section three, the primitive detection approach of graphic traces is proposed and applied to several Arabic letters and simple geometrical forms. Finally, a conclusion and perspective of this work are presented.

II. EXPERIMENTAL APPROCH AND DATA RECORDING

In 2003, Sano proposed an experimental approach in the context of the characterization of handwriting process. It's a simultaneous record of the coordinates of some graphic traces on (x,y) plane and two muscles activities of the forearm, named electromyography signals, involved in the production of writing, [12].

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These signals are obtained using surface electrodes, to calculate two muscles activities of the forearm, namely "abductor pollicis longus" and "extensor capri ulnaris". The first is responsible for the vertical movement and the second for the horizontal one.

This experimental study is carried out at the University of Hiroshima City. The production of graphics traces is made by different Japanese writers, men and women, aged between 22 and 23 years. These writers comfortably sitting use a light pen to store in the computer the locations of the write path at a fixed frequency. EMG signals are measured by electrodes placed on the surface of the forearm writer. Several Arabic letters, and eight basic geometric shapes, were produced by these writers, table I.

TABLE I.
CONSIDERED ARABIC LETTERS AND GEOMETRIC FORMS

Number	Description of the shape	Form of the shape	Number	Description of the shape	Form of the shape
1	Horizontal line (1) (left/right/left)		6	Circle (2) (to the left)	
2	Horizontal line (2) (right/ left / right)		7	Triangle (1) (to the right)	
3	Vertical line (1) (up/down/up)		8	Triangle (2) (to the left)	
4	Vertical line (2) (down/ up / down)		9	Arabic letter (SIN)	
5	Circle (1) (to the right)		10	Arabic letter (HA)	
			11	Arabic letter (AYN)	

Fig.1 resumes the experimental setup and equipment used for the acquiring of a database. It also shows the positioning of the electrodes on the forearm of the writer. A computer is required for recording *x* and *y* positions and the pressure *P* of the pen tip on the writing plane.

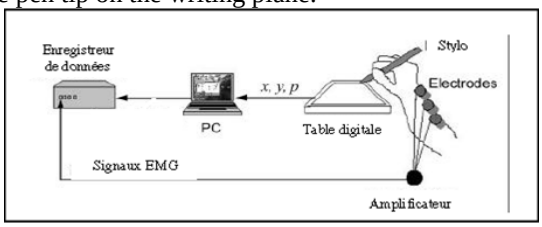
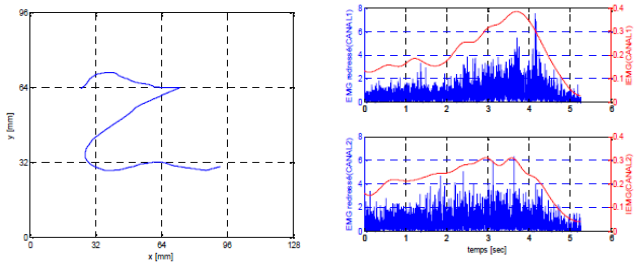


Fig. 1. Measuring System of Pen-Tip Movement and EMG Signals of the forearm

These recordings were obtained using a numerical table of the brand "Wacom KT-0405-RN" as writing plane, a data logger, such as "TEAC AR C2EMG1". The electrodes brands that were used for this experiment are "Medicotest, Blue Sensor N-00-S".

The obtained EMG signals present transients or noisy phenomena and other disruptive electronic or physical signals. These perturbations are caused by electromagnetic phenomena sector and noise associated with the electrodes and the measurement uncertainty, [11]. This requires the introduction of treatment approaches for biomedical signal for the obtaining of a legible one, which is the Integrated EctroMGyographic(IEMG).

Fig. 2.(b) reports example of EMG and IEMG recorded for the two selected muscles signals for the arabic letter "HA".



(a) *(b)*

Fig. 2. EMG and IEMG recorded for the arabic letter "HA"
(a) Arabic letter "HA", (c) EMG signals (blue line) and IEMG signals (red line)

III. CORRESPONDENCE BETWEEN HANDWRITING VELOCITY PROFILE AND SHAPE'S PROPRIETIES

Each individual has his own writing style and a personal direction during this movement. The velocity of the handwriting is one of the most influential properties of the handwriting movement, and from one individual to another, it may vary depending on several factors, namely, sex, cultural level, occupation, how to hold the pen of the writer, age, attitude, mood, the plan writing and of others psychological and physical reasons, etc. [14]

Several researchers have demonstrated the value of the velocity profile in analyzing the handwriting process, [3], [4], [6] and [8]. Indeed, there is a correspondence between the handwriting velocity and the path of the pen tip. For this, a series of shapes is proposed in the constitution of the experimental basis. It contains complex horizontal forms, vertical, Arabic letters, slow and fast movements. The velocity profiles of these forms are calculated as follow in "(1)" to "(3)", with respect to different measures of displacement of the pen-tip along the axes *x* and *y*.

$$V(t_k) = \sqrt{V_x(t_k)^2 + V_y(t_k)^2} \quad (1)$$

$$V_x(t_k) = (x(t_{k+1}) - x(t_k))/(t_{k+1} - t_k) \quad (2)$$

$$V_y(t_k) = (y(t_{k+1}) - y(t_k))/(t_{k+1} - t_k) \quad (3)$$

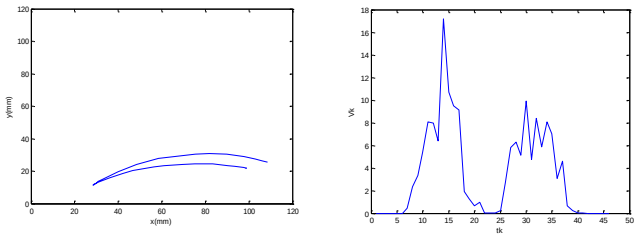
with:

V	: Velocity of the pen-tip,
V_x, V_y	: velocity of the pen-tip movement according to x and y axes, respectively,
x, y	: pen-tip movement according to x and y axes, respectively,
t_k	: discrete time of handwriting movement.

The study begins with an analysis of the calculated velocity profile for simple movement, geometric shape and finally an arabic letters.

A. Case of simple movement

In this case, the studied form is an horizontal go and back movement (right/left /right) shown in fig.3.(a). The velocity profile as shown in fig.3.(b) has two distinct bells shapes with different amplitudes and almost equal length. The first bell shape is the result of a movement (right/left) while the second one concerns the movement (left/right). The speed is zero value at the beginning and the end of the movement, and during a change of movement, it is almost zero.

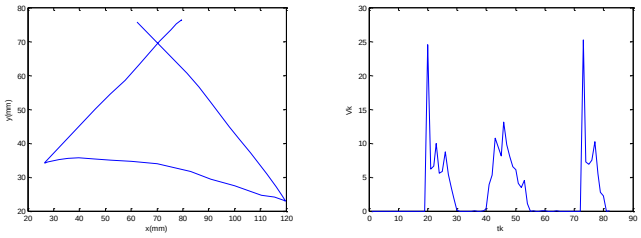


(a) *(b)*

Fig.3. Form and velocity profile of a simple horizontal movement

B. Case of geometric shape

The study on this section is focused on the form "triangle" shown in fig.4.(a). The velocity profile, fig.4.(b), is composed of three principals bells shapes, each one of these forms corresponds to a segment of the triangle. From this, every single movement in the graphical trace is represented by a bell shape of different amplitudes, with a definite time during tracing. The first and third bell shape, correspond to both sides of the triangle, as they have almost the same amplitude and form. While the second bell shape is relative to the base of the triangle, which is a horizontal line. Indeed, due to the structure of the first bell shape, which has more changes compared to the third, it proves that the first corresponds to a downward movement and the last a mounted movement. Therefore, as the drawn shape contains more complications (poorly drawn line, rotary structure, etc.), the speed profile contains peaks.

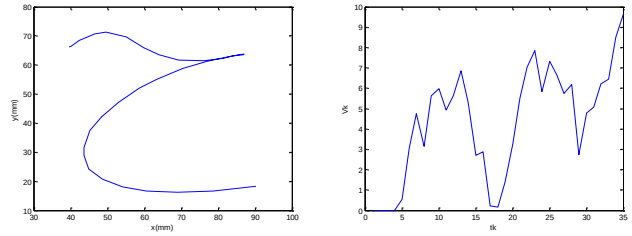


(a) *(b)*

Fig. 4. Form and velocity profile for the geometric form "triangle"

C. Case of an arabic letter

The velocity profile of the arabic letter **"**HA**"** shown in fig.5.(b) is a superposition of two bells shapes of different durations of movement and amplitudes. The first bell shape, composed of minima and maxima, corresponds to the first part on the written form, a horizontal line slightly wavy. During the transition to the second portion of the letter, a large half-circle, the velocity reaches an almost zero significant minima. The second bell shape is larger than the first in terms of duration and amplitude. Indeed, it contains more peaks (extrema) than the first shape due to the rotating shape of the primitive corresponding thereto in the letter.



(a) *(b)*

Fig. 5. Form and velocity profile of the arabic letter "Ha"

In conclusion, the handwriting velocity profile is simply the superposition of bell-shapes distributed by area with different duration and amplitude. Each area corresponds to a primitive of the written letter or form. It also shows a succession of extrema. The zero value indicates the beginning, the end and the change of movement direction.

If the scripter produces a shape or line without an indicated direction, the performance is less accurate and more unstable. Thus, the handwriting velocity is reduced if the shape produced is more curved and increases and if it is less curved.

A bell-shape of the velocity profile is achieved through a local minimum; this is due to the change of direction of rotation of a joint during writing movement. This shift is characterized by a braking initially caused by the antagonistic muscles then resumed with acceleration. This results in an instantaneous cancellation of the joint's velocity in question without the pen stops. The pen is now driven by the joints of orthogonal axes. Hence the velocity passes through a non-zero local minimum, [5].

IV. THE PROPOSED ALGORITHM OF HANDWRITING PRIMITIVE'S DETECTION

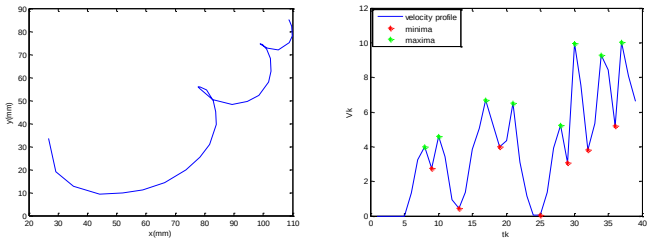
The study of the handwriting velocity profile has shown that it's the result of superposed bell- shapes that correspond to the primitive of the trace produced. It has also demonstrated the importance of the minima of the velocity profile to distinct a change in path during the writing movement. This decomposition of letters and forms into primitives provides information on the type, nature and direction of the graph, useful for the study and modeling of this biological process.

In this section, after the detection of the extrema of handwriting velocity, an algorithm is proposed to detect primitives of handwriting script.

A. Step 1-Detection of the velocity minima

According to the importance of the minima of the velocity profile, the first part, step1, indicated in the flowchart bellow of fig.7 presents the main steps of the proposed algorithm for the detection of local extrema of the handwriting velocity. The extrema values are obtained by a comparison of two velocities at two successive instants. The detection results of smaller values correspond to the minima of the speed, $minv_k$ as well as their positions, $posmin_k$. The biggest detected values are the local maxima, $maxv_k$ and their positions $posmaxv_k$.

The result of this proposed algorithm are shown in fig.6.(b) for the chosen arabic letter "SIN".



(a) *(b)*

Fig. 6. Local extrema detected for the arabic letter "SIN"
(a) Arabic letter "SIN", (b) Extrema of the velocity profile

B. Step 2 - Detection of handwriting script primitives

The second part of the flowchart in fig.7, step2, focuses on the proposed algorithm steps for the handwriting script primitive detection. Indeed, starting from the velocity profile analysis, it turns out that the speed is decomposed into a set of area (bell shapes), separated by main minima and these areas can be reproduced as primitives of the script produced. Thus, is necessary to identify those main minima, representing a significant change of writing direction, from the local minima detected. Comparing two local minima at two successive instants leads to the detection of the smallest among the minimum values, $minminv_k$, and their positions $pmin_k$.

Therefore, the handwriting script primitives can be detected applying the algorithm presented in step2 of the flowchart shown in fig.7.

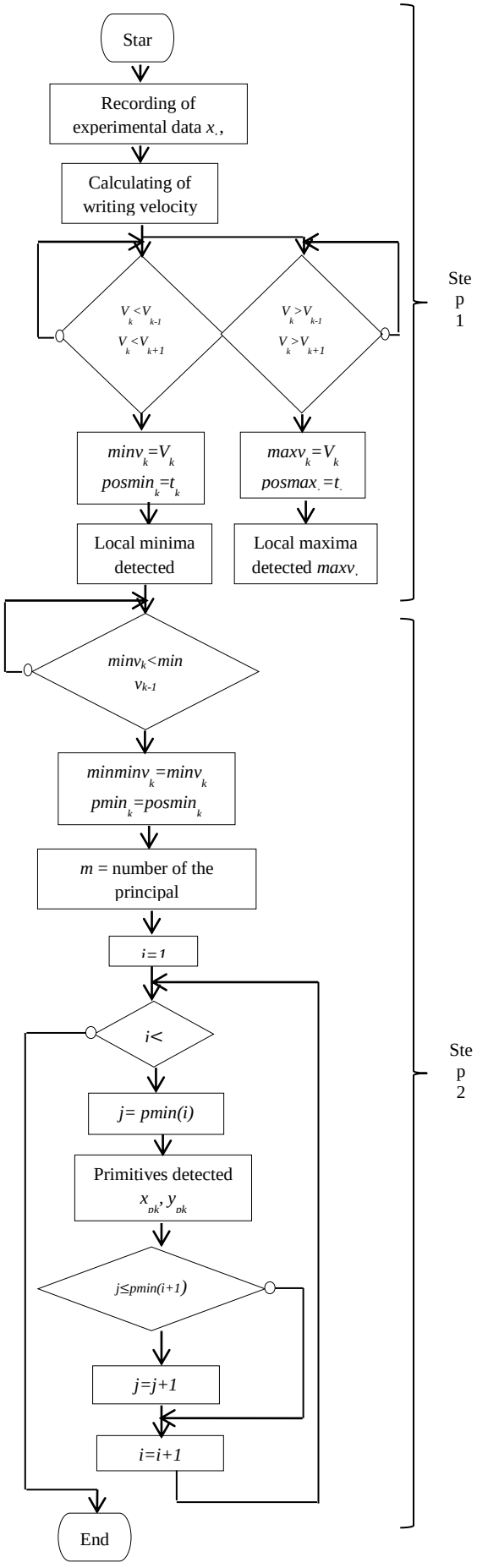
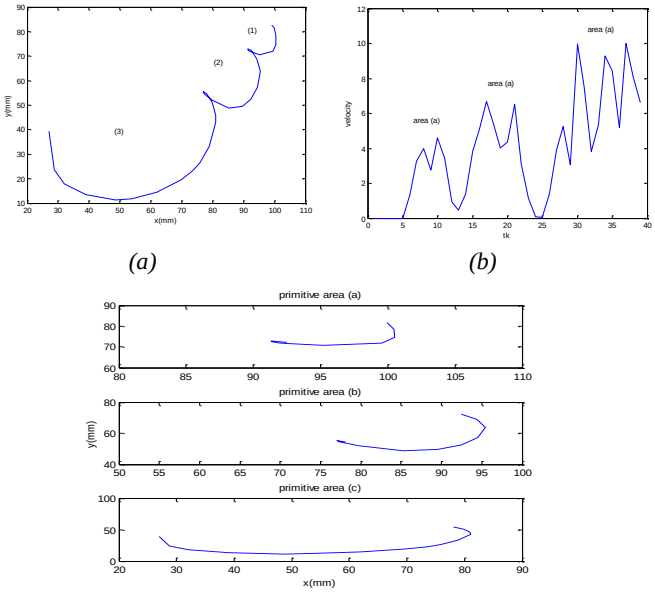


Fig. 7. Flowchart representing the proposed steps for the detection of the handwriting script primitives from the velocity profile

C. Simulation results

The results of this proposed algorithm for the detection of the handwriting script primitives are shown as follow in fig.8 and fig.9. The detected primitives of the Arabic letter "SIN" are shown in fig.8.(c). Its velocity profile, fig.8.(b), contains three main areas and admits two significant minima close to zero. Based on the location of the two minima, the first primitive detected, a circle-arc is related to the first bell shape of the velocity profile, area (a). The second primitive is similar to the first, but with a larger radius, is on the area (b) of the velocity profile. The final primitive, a large arc is related to the third one, area (c), which is larger in amplitude and duration, comparing to the other areas.

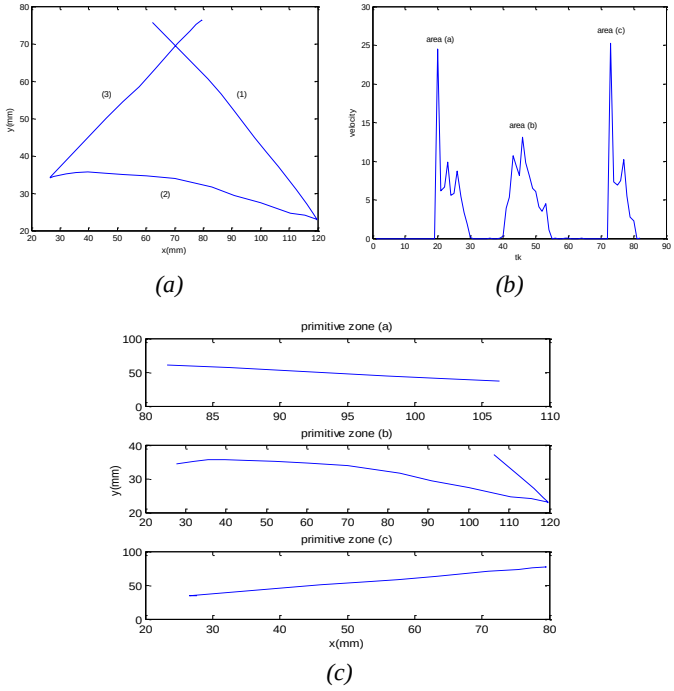


(a) *(b)*

(c)

Fig. 8. Velocity profile and primitive detected for the arabic letter "SIN"

Fig.9.(c) gives the detection results of the geometric shape primitives "triangle". Three primitives are distinguished, same as the number of bell-shapes on the velocity profile. From these results, we can determine the direction of this tracing form, from right to left. The first primitive corresponds to the first segment of the left triangle resulting from a movement of rapid descent, when the third primitive, it is relative to the third segment of the triangle by a trace of mounted movement. Indeed, the peaks are more important in the first and third bell-shapes speed, which explains the complexity of the movements of mounted and descent which for being slower than a horizontal movement.



(a) *(b)*

(c)

Fig. 9. Velocity profile and primitive detected for the geometric form "triangle"

According to these results, we noticed that:

- As the velocity profile contains more peaks, the reproduced form contains curves. The peak may be due to disturbances during writing movement, cursive or non-preferential directions form.
- the values close to zero correspond to an instantaneous velocity stop during the production of the form, which can detect the moment of change of direction in the script,
- The detection of primitive provides more information on written form, namely, the direction to the left or to the right, descending or ascending the execution time, etc.
- The primitive detection is similar to a decomposition of a complex graph plots to a set of simple shapes, easier to study

V. CONCLUSION

The proposed study is based on an individual property of handwriting movement: the velocity. Showing its importance in the production of graphic traces, the analysis of the handwriting velocity profile shows a superposing of bell shapes. This proves its usefulness in the acquisition of information on the nature and type of forms produced, and its necessity in the reproduction of graphic traces. The main minima reflect a change of direction in the graphic trace during the writing act.

The primitive's detection of handwriting traces is proposed in a new approach based on the main minima of the velocity. This primitive detection facilitates the study and modeling of the handwriting process, by providing useful

information on the nature of the form, the degree of complexity, the sense of writing, etc.

To validate this approach, it is advisable to apply it on a reconstructed model of the writing velocity and to compare the results of the primitive detection with the velocity calculated on data collected from an experimental approach

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