Generation and Analysis of Handwriting Script With the Beta-Elliptic Model

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Abstract : Recent developments in the field of human movements modelling supply new ways in which to view complete models for analysing and understanding complex movements.

Based on a kinematic theory and an algebraic Beta-elliptic model, a new way for understanding the inherent mechanisms that govern handwriting movement generation is presented here. This paper describes an approach for analysing simple as well as complex movements such as cursive handwriting. Cursive handwriting is described as the superimposition of basic strokes with elliptic form that results from the algebraic summation of Beta velocity profiles. The overall approach is based upon the hypothesis that complex human movements can be segmented into basic and simple strokes. Each stroke is totally described by a set of ten parameters that characterizes the movement both in the kinematics and the static domains. The paper then treats the extraction of the model parameters using the Beta profiles, and its application to the case of both simple rapid human movements and complex handwriting movements.

Keywords: Handwriting movement modelling, Handwriting scripts, Beta-elliptic model, Parameters extraction, On-line handwriting.

I- INTRODUCTION

Handwriting stands among the most complex tasks presented by literate human beings.

Handwriting is affected by sensory motor control mechanisms, which are in turn influenced by emotions and communications. As such, the study of the generation of handwriting movements constitutes a very broad field that permit researches with various backgrounds and interests to collaborate and interact at multiple levels with different but complementary objectives.

In the literature, the study of hand movements was based on proposed models. Several modelling techniques were used to derive motor driving signals and to simulate the handwriting process. Two general methodologies of handwriting modelling become apparent from the review of the literature. The first methodology taken into account computational models which are aimed to replicate some features of Human handwriting movements such as velocity profiles and some relations between different aspects of the movements dynamics; such as curvature and curvilinear velocity. Such methodology includes oscillators models, optimization models [7, 8], etc...

The second methodology of handwriting modeling focuses on psychologically descriptive models. Such methodology includes models that usually summarize many of the requirements of a handwriting system by addressing as much data as possible. Consequently they do address such issues as learning, movement memory, which are often omitted from the first methodology.

In this paper, we are interested in understanding handwriting generation movement at the global neuromuscular level, focusing mainly on the development of a stroke generation model which is sufficient to explain the origin of some basic psychophysical laws of simple human movements and to show how human subjects can take advantage of this representation to control the sensory motor interaction involved in the generation of more complex trajectories. The general case of complex movements is thus considered as an algebraic overlapping of simple strokes. Each stroke is totally described by a set of parameters that characterises the movement both in the kinematics and the static domains.

In fact, kinematic properties involved in this paper perform to joint angle trajectory, which obeys an elliptic form. The parameters characterizing an elliptic trajectory are performed according to the Beta curvilinear velocity profile [5, 6].

This article deals with two themes. Firstly, in section 2, we describe the handwriting-generated scripts in the context of kinematic and static points of view that obey both the Beta law and the elliptic form [4]. Simple stroke movements, as well as complex handwriting movements are considered.

Finally, in Sections 3, we discuss the adequacy of the Beta elliptic model for the case of complex handwriting movements and examine some computer simulations. With different handwriting scripts, we show their fitting with the Beta elliptic theory, both in dynamic and statistic domains.

II- HANDWRITING GENERATION THEORY: THE BETA-ELLIPTIC MODEL

The main goal of the experiments reported in this work is to further the investigation of the constraints between trajectory and kinematics, which provide a clue to both the degrees of freedom problem and the computational complexity problem.

The handwriting generation theory is aimed essentially at understanding the generation of simple and complex handwriting movements. Several approaches have been shown in the past few years such as the delta-lognormal theory proposed by Plamondon [9, 10].

The proposed model is based upon some assumptions: Firstly, it considered that handwriting movement, like any other highly skilled motor process, is partially programmed in advance. Secondly, it supposes that movements are represented and planned in the velocity domain, since the most widely accepted invariant in movement generation is the Beta shape of the velocity profiles.

As in the Delta Lognormal theory of Plamondon and Guerfali, we have suggested that a neuromuscular synergy is composed of two parallel and global systems that represent, respectively, the set of neural and muscular networks involved in the generation of the agonist and antagonist activities resulting in a specific movement.

Supposing that each of these two systems is composed internally of *n* neuromuscular subsystems characterized by an impulse response that is real normalized and non-negative. If *n* is sufficiently large, applying the central limit theorem, the global impulse response can be described by a Beta function $\beta(t, t_0, t_1, p, q)$ where t_0 is the starting time, t_1 is the ending time, *p* and *q* are intermediate parameters, as shown in equation (1), [1, 2, 3].

with:

$$\beta(t,t_0,t_1,p,q)=\left(\frac{t_1-t}{t_1-t_c}\right)^p\left(\frac{t-t_c}{t_c-t_0}\right)^q \qquad (1)$$

and $$t_c = \frac{p * t_1 + q * t_0}{p + q} \qquad (2)$$

t_c is the instant where the curvilinear velocity reaches its maximum.

Exhaustive comparisons with other models using large database have been done previously, demonstrating the advantages of the Beta model for an accurate description of a velocity profile. Comparing to the Delta-lognormal model, it appears that the more general hypothesis of the Beta model leads to a velocity profile description that is more flexible, and therefore that can fit better the diversity of the experimental data. The Delta-lognormal function puts some constraints on the shape of the profile because it's an unbounded function [9, 10]. However, the Beta function allows some variation of its symmetry, which depends on the values of the two parameters p and q.

A Beta shape is intrinsically asymmetric as compared, for example, with the symmetrical velocity profiles of the minimum jerk models or minimum snap [7], sinusoidal functions, or the models that use cubic splines.

Motor control research focuses on the process that produces handwriting and tries to establish the hidden parameters. Many researchers use 'significant' or 'critical' points to split the pen-path into smaller entities. Commonly used significant points are local extrema in horizontal or vertical direction, local extrema in velocity, local extrema in curvature, and points of inflexion. For our case we have used both local extrema and points of inflexion in velocity profiles.

In this context, a stroke executed from an arbitrary starting position is characterized by five parameters. A part from these four parameters of the Beta function, each elementary component called "stroke" is also characterized in the space domain by five statistic parameters which globally reflect the geometric properties of the set of muscles and joints used in a particular handwriting movement: a and b are respectively the dimensions of the large and the small axes of the elliptic shape, x_0 and y_0 are the Cartesian coordinates of the elliptic center relative to the orthogonal reference (o, x, y). The angle θ defines the deviation of the elliptic portion according to the orthogonal reference (o, x, y).

Consequently, a single movement, also called stroke is represented in the space and velocity domains by a curvilinear velocity starting at time t_0 at an initial point in the domain space, and moving along an elliptic path. This elliptic path obeys a variable curvature C not a constant one as it was proposed by few models in this direction by the literature [10]. Since characters are drawn by using conic arcs and straight segments, it has been shown that the arc of circle has enough descriptive power to substitute curves of different shapes but with the same semantic value.

Analysing the curvature function, we remark that: firstly, the curvilinear velocity varies with handwriting cycle: curvilinear velocity decreases for the parts of small curvature of handwriting and increases for the parts of large curvature, secondly, if the trajectory of the hand is a circle or a combination of circles, then the horizontal and vertical components of the movement are necessarily harmonic functions of equal frequency and amplitude, which is not usually verified experimentally.

As reported in the early eighties, the correlation that exists between the kinematics handwriting and the movement trajectory was formalized in terms of equation, known as the 1/3 power law. This law links the radius of curvature $R(t)$ which is the inverse of curvature C and the tangential velocity $V(t)$ of the handwriting movement by a 1/3 power [13].

So we have proposed this more general structure of the contour curvature: not the circular path but an elliptic path verifying equation 3 [2], where $X(t)$ and $Y(t)$ are the cartesian coordinates of a point M along the elliptic stroke. a and b are the small and large axis dimensions.

$$\frac{X^2}{a^2} + \frac{Y^2}{b^2} = 1 \qquad \textbf{(3)}$$

III- SIMULATION RESULTS

Theoretically, to design an elliptic stroke, we must have at least 5 points: we are based on the dynamic aspect of this stroke, in other words the Beta velocity profile fitting the original curvilinear velocity signal.

For the case of simple handwriting movement, the five points are deduced from the Beta profile approximating the original curvilinear velocity signal; the starting point M_1 where the curvilinear velocity is near 0. The ending point M_3 is defined such as the curvilinear velocity reaches 0. The point that corresponds in the timing space to the maximum velocity characterizes the intermediate point M_2. The lasting two points M_4 and M_5 are constrained to belong to the considered Beta profile, as shown in figure 1 and 2.

the maximum of curvature in the static domain.

Consequently, a stroke is characterized by nine parameters; the first four parameters reflect the global timing properties of the neuromuscular networks involved in generating the movement, whereas the last five parameters describe the global geometric properties of the set of muscles and joints recruited to execute the movement.

As shown previously, the Beta-elliptic model considers a simple movement as the response of the neuromuscular system, which is described by an elliptic trajectory and a Beta velocity profile.

The serial nature characterizing the central representation of a movement is also detectable from a kinematic point of view during the generation of the

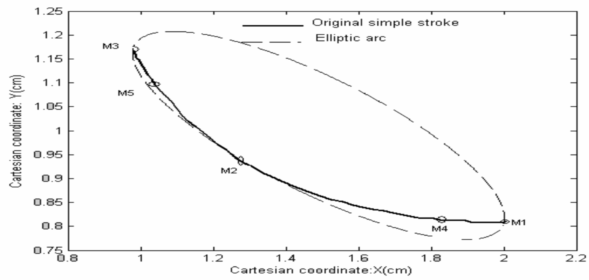

Figure 1: Approximation of simple handwriting stroke by using elliptic contour.

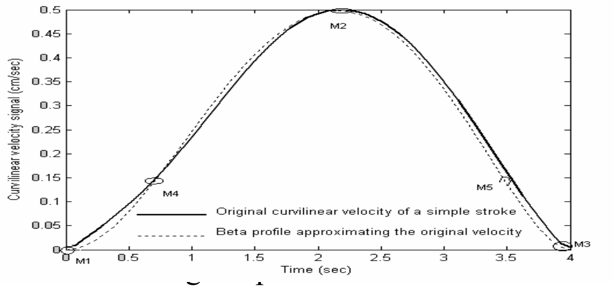

Figure 2: Approximation of curvilinear velocity relative to simple stroke with Beta profile.

Obtaining the 5 points *(M_1, M_3, M_2, M_4,* and *M_5)*, the problem now is to check the different parameters characterising the elliptic segment *(x_0, y_0, a, b, θ)*, which are determined numerically.

In our case, the obtained data are resampled namely, a simple stroke is approximated by a beta profile in the dynamic domain which corresponds in turn to an elliptic arc in the static domain such that M_1M_3 is the large axis dimension a. As reported by Viviani and al. for human drawing curves, that the instantaneous tangential velocity of the hand decreases as the curvature increases [13], and then M_1 and M_3 which are characterized by minimum tangential velocity correspond to

algebraic summation in time of different strokes, such expressed in equation (4), where n stands for the total number of different Beta shape.

$$V(t) = \sum_{i=1}^{n} \beta_i(t)$$

Superimposition of elementary strokes is a common assumption among modelling of handwriting (e.g. Plamondon 1989, Schomaker 1989) [8, 12]. Models differ in the constraints they place on stroke superimposition. Schomaker et al. 1989 [12], as well as Plamondon assumes essentially arbitrary timing relation between onsets of overlapping movement strokes. Whereas, Morasso et al (1982), as well as for our case, constrain stroke superimposition by limiting the number of strokes that are concurrently executed to two.

Usually, handwriting analysis has been limited to direct measurements *x* and *y* sampled at a fixed frequency from digitizing tablets, such for our case.

The overlapping effect was taken into consideration; it is observed each time a particular simple movement *(i)* starts before another simple movement *(i-1)* achieves its final target. Very different shapes can be generated with the same basic movements by changing only the starting time of the second stroke. For the most cases, the starting time of a particular movement *(i)* correspond to a dip in the original curvilinear velocity, when the particular movement *(i-1)* curvilinear velocity is near *0*. If there exists two consecutives maxima -because of the presence of an inflexion point- the starting time of a particular movement *(i)* is equal to the time when the particular movement *(i-1)* reaches its maximum curvilinear velocity.

In terms of spatial constraints, two consecutive strokes are superimposed during the time shift between them $t_{1(i)}$ - $t_{0(i+1)}$ to regenerate the handwriting trace for several reasons such as:

- Firstly, stroke superimposition is constrained by limiting the number of strokes that are concurrently executed to two,
- Secondly, the time shift is fixed to $t_{1(i)}$ - $t_{0(i+1)}$ because of the existence of hidden strokes and mainly the existence of inflexion points.

The same modelling procedure was applied with an example of handwritten script, which is the word “Hala” in Arabic acquired by using a digitizer tablet type Wacom4, sampled at 200 Hz.

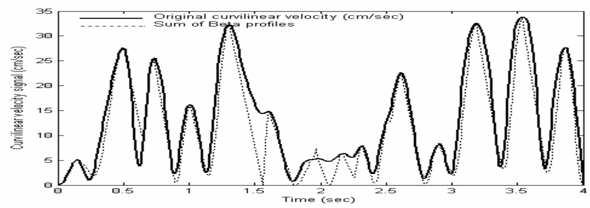

Figure 3: Approximation of the curvilinear velocity of the script “Hala” by Beta profiles.

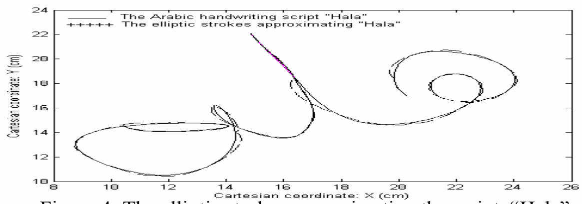

Figure 4: The elliptic strokes approximating the script “Hala”.

As previously, the original data was Using the decomposition scheme, different elliptic strokes are depicted in figure 4. These strokes are not apparent directly in the image of the handwriting script “Hala”. They are partially hidden in the trajectory as a consequence of superimposition process.

Despite the presence of the inflexion points in figure 3, an important error between the original handwritten trace and the 7^{th} stroke was observed in figure 4, compared to the other strokes. This is due to mainly to the fruitful dynamics in this part of the fluent trace.

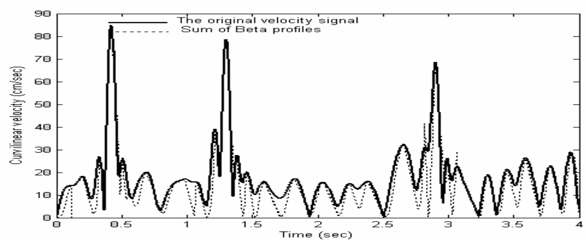

Figure 5: Approximation of the curvilinear velocity of the script “Hala” by Beta profiles

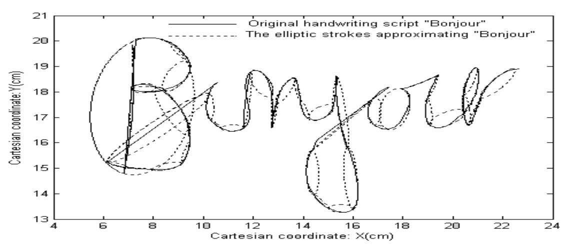

Figure 6: Approximation of the script “Bonjour” by elliptic shapes.

In figure 6, we remark the different ellipses approximating the original handwriting script “Bonjour”. We observe that the dynamics observed in the original curvilinear velocity signal had significant effect on the regeneration of the original script. Consequently, different elliptic strokes will be not apparent directly in the image of the handwriting script “Bonjour”. They are partially hidden in the trajectory as a consequence of superimposition process.

IV- CONCLUSION

In this paper, we present a novel generation modeling approach for the analysis and understanding of online cursive handwriting. Our scheme is based upon a dynamic fitting of the handwriting scripts, both in the static and the kinematic domains, using the Beta-elliptic model.

To represent a simple movement called stroke the model requires a set of ten parameters that describes the movement in both domains.

Complex movements such as handwriting are described by the model as an algebraic summation of time overlapped single strokes. These strokes are not apparent directly in the image of a handwriting script. They are partially hidden in the trajectory as a consequence of superimposition process.

Many models have been applied to French handwriting, but unfortunately, only a few publications have been interested to the modelling of Arabic handwritten scripts so far. It has been shown that the Beta-elliptic model can be applied not only to French handwriting but also to Arabic handwriting words. Nevertheless, it is likely, that we will see more applications to our Beta-elliptic model in the future.

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