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Temporal evolution in synthetic handwriting

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ABSTRACT

New methods for generating synthetic handwriting images for biometric applications have recently been developed. The temporal evolution of handwriting from childhood to adulthood is usually left unexplored in these works. This paper proposes a novel methodology for including temporal evolution in a handwriting synthesizer by means of simplifying the text trajectory plan and handwriting dynamics. This is achieved through a tailored version of the kinematic theory of rapid human movements and the neuromotor inspired handwriting synthesizer. The realism of the proposed method has been evaluated by comparing the temporal evolution of real and synthetic samples both quantitatively and subjectively. The quantitative test is based on a visual perception algorithm that compares the letter variability and the number of strokes in the real and synthetic handwriting produced at different ages. In the subjective test, 30 people are asked to evaluate the perceived realism of the evolution of the synthetic handwriting.

1. Introduction

Handwriting is a common tool for communication between human beings. It involves both cognitive and motor skills. Following the motor equivalence model presented in [1], the handwriting process can be divided into two stages: the effector independent stage, where the text trajectory plan is build up at cognitive level and the effector dependent stage, where the handwriting is performed by the neuromuscular system. These processes are developed during childhood by repeating patterns. Once children learn the basic patterns and are able to reproduce them, they develop their own style and evolve it up to their adulthood [2].

Aging involves some changes in handwriting characteristics. It is easy to appreciate the different writing styles between child and adult writers (see Fig. 1). In children's handwriting the pen velocity is smaller and the number of strokes greater than in the adult case [3,4]. With aging, the handwriting tends to become slower again like that of children who are starting to write [2].

The research on handwriting synthesis has many motivations. Among them, is to provide large handwriting corpuses to the biometric community to evaluate automatic signature verifiers or writer identifiers and to avoid legal problems on privacy [5]. It is also worth mentioning that an accurate human like synthesis mechanism could help improve the understanding of the underlying processes in human handwriting production or even answer questions related to intra and inter personal variability, as well as to help understand the variability due to different diseases, such as Parkinson's, Alzheimer's or ALS. In the future, artistic creation and CAPTCHA (Completely Automated Public Turing test to tell Computers and Humans Apart) generation may have other motivations [5,6,7,8,9,10].

There are different ways to generate synthetic handwriting. Some produce duplicates of a given handwritten sample. These duplicates can be generated by simple affine distortion or stroke wise distortion, as proposed by [11,12,13,14]. A second way of generating synthetic handwriting is the glyph-based method, which records individual letters or words from one user, applies geometric deformation to simulate a new user and joins them to create a new version of the handwriting [15,7]. Other methods generate handwriting samples by modifying the parameters of a handwriting generation model. Handwriting models have also been developed in the frequency domain [16] or from a neuromotor perspective [17,18]. None of the above have studied the temporal evolution of handwriting nor included handwriting evolution models in the synthesizer.

This paper is aimed at synthesizing handwriting by taking into account the *graphic maturity* of the synthetic writer for emulating its temporal evolution from childhood to adulthood. Graphic maturity is defined as the time a healthy person has been practicing his handwriting [19]. Specifically, the paper tries to answer the question: how could the writing script of writers of different graphic maturity be synthesized automatically in a common framework?

Related research has been performed on age estimation from handwriting [20] and on studying the effects of aging in signature

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Fig. 1. Handwritten sample from a child (above) and an adult (below) writing the sequence a, e, i, o and u.

recognition [21,22]. It is expected that studying handwriting evolution from the synthesis point of view will deepen our understanding of the human handwriting process and its influence in designing automatic writer and signature verifiers.

As the maturity process involves both the cognitive and the motor system, the synthesizer most suitable for modelling the temporal evolution of the handwriting is the one proposed in [17], which allows actions at both cognitive and motor level. Specifically, actions at cognitive level are related to the modification of the letter engram trajectories through the spatial grid, as evident in [23]. At motor level, actions to take into account the maturity modify the Plamondon Kinematic model [24].

The model presented here is verified for three important ages: 5, 10 and adult. This is because these three ages are distinct in terms of behavioural adjustment and related to the maturation process of the neuromotor system in human beings. At the age of 5, children start to learn the motor programs required to write with pre-handwriting letter patterns. The motor programs for cursive handwriting are fully developed and integrated around age 10 but need more deliberate practice [2,4]. By the time children reach adulthood, handwriting movements are fully mastered.

Summing up, this paper proposes a novel procedure through the use of a synthetic handwriting model to emulate the temporal evolution of real handwriting. A review of the basic handwriting synthesizer which our method relies upon is presented in Section 2, while the proposed temporal evolution model and its integration into the basic synthesizer is described in Section 3. The performance evaluation is described in Section 4. This reports the quantitative experiments based on speed profiles and stroke distributions of real and synthetic handwriting samples at different ages. It also describes surveys on subjective opinion about the temporal evolution of synthetic handwriting. Section 5 closes the paper with the conclusions.

2. Overview of the basic synthesizer

The basic handwriting synthesizer is founded on the equivalence model that divides human handwriting into two steps: the working out of an action plan (effector independent) and its execution via the corresponding neuromuscular path (effector dependent). Once the action plan is learnt, most of the variability arises from the effector-dependent component [25].

The synthesizer simulates the action plan through a trajectory plan which is a tessellation of a sequence of grid nodes. The neuromuscular path is calculated by the inverse model [26] as a sequence of kinematic filters that imitate the sequence of motor commands. Finally, an ink deposition model is applied. The block diagram of the synthesizer is shown in Fig. 2.

The trajectory plan is built by concatenating letter trajectory plans which describe the sequence of grid points necessary to write each letter. The letter trajectory plan defines the temporal order of the principal targets of the pen movement [27], emulating how letters are memorized [15]. An example of trajectory for letter "a" is shown in Fig. 2, where each grid point is labeled with a number. For instance, the letter trajectory plan for the letter "a" is defined as the following sequence of grid points: {25, 24, 17, 10, 11, 12, 19, 26, 25, 26 and 33}.

Once the trajectory plan is defined, an inverse model for motor control is applied to obtain a realistic human text trajectory. In short, two kinematic filters, which are heuristically related to the finger and wrist, are applied as follows:

1. The grid points of the trajectory plan are linked by straight lines and divided into strokes;
2. The finger velocity profile is estimated using the kinematic theory of rapid movements, developed in [28]. This theory shapes the velocity profile of a simple stroke with a lognormal function scaled by the variable D and time-shifted by the variable t_0:

$$\left|\vec{v}_j\left(t;t_{0j}\right)\right| = D_j \Lambda_j\left(t;t_{0j},\mu_j,\sigma_j\right) = \frac{D_j}{\sigma_j\sqrt{2\pi}\left(t-t_{0j}\right)} e^{\left(\frac{-\left[\ln\left(t-t_{0j}\right)-\mu_j\right]^2}{2\sigma_j^2}\right)} \tag{1}$$

   where μ and σ are the location and scale parameters, respectively, and j indicates the stroke number.
3. The finger velocity obtained with the kinematic theory is used to select the length of the inertial Kaiser filter that programs the finger control motor. The finger filter stops in each minimum of the velocity profile which could be seen as stroke limits. Conversely, the wrist moves continuously when writing and therefore the wrist inertial filter runs between penups without stopping.

The handwriting synthesizer described above is not able to simulate the learning process by which the handwriting evolves from being composed of short, imprecise, individual strokes drawn one after the other, as when a child begins to write, to the fluent movement observed in an adult, when handwriting is fully mastered. In the following section we describe the changes to the basic synthesizer to incorporate within it such temporal evolution.

3. Temporal evolution synthesis

Children usually start their handwriting practice using printed worksheets. These worksheets contain writing lines that guide the handwriting. At the beginning, the text trajectory plan is learned by repeating the writing on the worksheets. In a first stage, the children repeat simple traces such as small straight and then curved movement. Once children learn the basic traces, in a second stage, they combine them into complex ones (letters and numbers) by overlapping the movements. In these cases children still overwrite or copy the guide lines with short, imprecise and slow movements. Finally, once the handwriting skills are fully acquired, they are capable of selecting an ordered sequence of target points to perform fluent and personalized writing.

The synthesizer proposed in [17] is oriented towards mature and fluent handwriting because the handwriting letter shape is worked out by filtering the original trajectory plan with inertial filters that relate to adult kinematics. It does not consider a child's short and slow, unskilled movements.

Also the sigma-lognormal model used to analyze the kinematics of real handwriting movements [24] is useful in reconstructing fast and well learned movements but it is not able to fit faithfully children's dynamics and therefore obtains a poor signal-to-noise ratio in the reconstruction process [2,4]. So a new model that enables the possibility of automatically generating dependable adult and child handwriting in terms of shape and dynamics from a trajectory plan is needed to improve the reliability and applicability of handwriting synthesizers.

3.1. Analysis of simple straight and curved movements

To help model children's handwriting, two basic or simple movements are defined, as suggested in [29]: *straight movement,*