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Myoelectronic signal-based methodology for the analysis of handwritten signatures

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ABSTRACT

With the overall aim of improving the synthesis of handwritten signatures, we have studied how muscle activation depends on handwriting style for both text and flourish. Surface electromyographic (EMG) signals from a set of twelve arm and trunk muscles were recorded in synchronization with handwriting produced on a digital Tablet. Correlations between these EMG signals and handwritten trajectory signals were analyzed so as to define the sequence of muscles activated during the different parts of the signature. Our results establish a correlation between the speed of the movement, stroke size, handwriting style and muscle activation. Muscle activity appeared to be clustered as a function of movement speed and handwriting style, a finding which may be used for filter design in a signature synthesizer.

1. Introduction

In recent years, the use of handwriting on digital tablets has increased exponentially. These new devices have opened new ways of exploiting applications for health, learning, handwriting and biometric signature recognition. Some new handwriting synthesizer models have been based on neuromuscular studies (Ferrer, Diaz-Cabrera, & Morales, 2015; Ferrer, Diaz, Carmona, & Morales, 2017; Galbally, Plamondon, Fierrez, & Ortega-Garcia, 2012; Plamondon & Guerfali, 1998). In this paper we focused on the field of handwritten signatures to assess the dependence of stroke speed, stroke length and handwriting style (text or flourish) on muscle activation amplitude. The term 'stroke' refers to an individual impulsive movement (Ferrer et al., 2017). Estimates of muscle activity can be used to improve signature synthesizer models (Carmona-Duarte, Ferrer, Parziale, & Marcelli, 2017; Ferrer et al., 2015, 2017) in particular to configure an adequate set of filters for the handwriting style (flourish or text) to be synthesized.

The use of EMG to study muscle activation in the process of human movement has been widely accepted in the field of biomechanics to study human voluntary movement. This approach is detailed in the extended review and tutorial by Hug and Dorel (2009) in the field of Sport Sciences and Torres-Peralta et al. (2014). Fast and slow motor units have similar spectral power with high- and low-frequency spectra, respectively, and have been used to investigate patterns of leg muscle activation during walking and running (Wakeling, 2004). In particular, the Heinemann size principle (Desmedt, 1981; Henneman, Somjen, & Carpenter, 1965) dictates that smaller fibers are easier to activate than bigger ones and are therefore engaged earlier. This has been demonstrated in animal and human studies (Bawa & Lemon, 1993; Calancie & Bawa, 1985; Rothwell, Thompson, Day, Boyd, & Marsden, 1991;

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Schmied, Morin, Vedel, & Pagni, 1997). Recently, this concept has been challenged (Gardiner, 2011; Wakeling, Uehli, & Rozitis, 2006) so that each motor unit may have specific contributory roles, with significant variability among units as to their function in different types of contraction and speed, possibly because of differences in central programming for each task. This principle is still, however, considered the basic engagement pattern in human movement (Holt, Wakeling, & Biewener, 2014). Nonetheless, there are other factors to be taken into account to explain voluntary human movement. For instance, a subject will use only some muscle fibers for each movement; or may choose a different range of fibers depending on their capability to create force (Hodson-Tole & Wakeling, 2009). Additionally, the contractile forces of fibers are not synchronized, so voluntary movement is represented as a combination of twitches, semi-fused tetanic contractions and tetanic contractions of fibers. In spite of the fact that they are similarly named, the latter are not exactly equal in application.

Handwriting involves both cognitive resources and muscular procedures that are learned by practicing. Handwriting models are usually divided into two functions (Ferrer et al., 2015): the working out of an effector independent (action plan) and its execution via the corresponding neuromuscular path (effector dependent). Depending on the way an action plan is executed (e.g. writing on a piece of paper or on a blackboard), muscles act differently and with different inertia (Kawato, 1999; Wing, 2000). In this paper, the different muscle configuration used to execute an action plan will be called handwriting style. For instance, a western signature can include both text (readable part) and flourish (drawn part), each of which has different lexical and morphological properties (Diaz-Cabrera, Ferrer, & Morales, 2015). The action plan includes different stroke lengths produced with varying speed and inertia. Naturally, it requires a different muscle activation to define individual handwriting styles. This was modeled by a signature synthesizer which applies different values of the inertia to the action plan. This has been shown to produce reliable results (Ferrer et al., 2015, 2017).

Most studies investigating the muscle configuration required to execute an action plan consider only one handwriting style. For instance, in Plamondon, Djioua, and Mathieu (2013), data was presented on the delays between bursts in EMG signals of antagonist and agonist muscles activated in a single style, during rapid hand movement. Other studies have shown that EMGs of hand and arm muscles can be converted into handwriting patterns (Huang, Zhang, Zheng, & Zhu, 2010; Li, Ma, Yao, & Zhang, 2013; Linderman, Lebedev, & Erlichman, 2009). While these studies provide evidence supporting that muscular EMG signals depend on the characters being written, they ignore the possibilities of muscle activation clustering. In addition, the more realistic case in which an action plan contains different handwriting styles has scarcely been studied. Therefore, the novelty of this study relies on the analysis of the different muscle configurations when the action plan contains divergent handwriting styles, including different stroke lengths within the same signature.

The aim of the study was to investigate whether muscle activation can be clustered into different handwritten styles. We focused on the relationship between muscle configuration, stroke length and speed. We analyzed the different muscle configuration in handwritten signatures, which contain different handwriting styles, by studying the temporal evolution of the EMG signals from the muscles involved and the handwriting speed.

1.1. Neuromotor inspired approach for a signature synthesizer: review

The possibility of different muscle groups acting separately was heuristically suggested in Ferrer et al. (2017) where synthetic handwriting is generated in two steps. This is illustrated in Fig. 1: the effector independent or action plan and the effector dependent or handwriting execution step. The action plan was considered as a sequence of nodes through a grid that approximates the spatial memory, as suggested by Hafting, Fyhn, Molden, Moser, and Moser (2005). The production of the handwriting was approached as in Ferrer et al. (2015) by kinematic filters that smooth the straight lines that link the nodes of the action plan and imitate the muscles' inertia. The longer the kinematic filter, the greater the smoothing of the action plan. The outcome is the acquisition of faster handwriting.

To obtain a reliable result (Ferrer et al., 2015), a multi-level scheme based on several kinematic filters has been suggested. This would simulate the inertia of the different muscle groups used. Heuristically, these kinematic filters were assigned to finger, wrist and forearm muscle groups as follows:

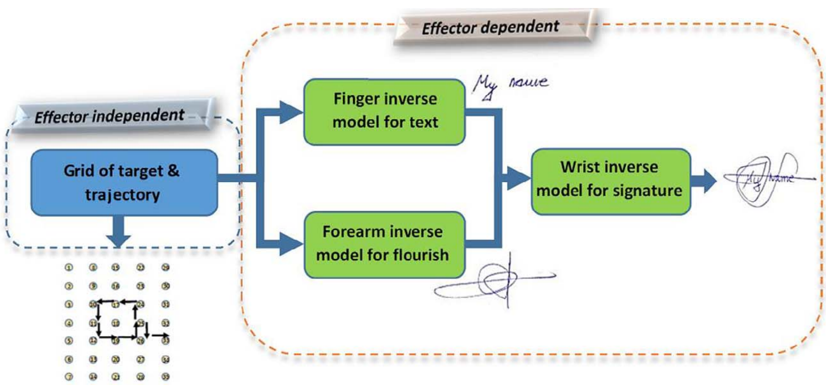

Fig. 1. Motor equivalence approach to synthetic off-line signature generation.