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An enhanced contextual DTW based system for online signature verification using Vector Quantization☆

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ABSTRACT

This work presents an enhanced Dynamic Time Warping (DTW) based online signature verification system by utilizing the code-vectors generated from a Vector-Quantization (VQ) strategy. The DTW algorithms in the literature use only the distance score, obtained between the test signature and the genuine enrolled signatures, for the decision rule. The optimal warping path is constructed by placing constraints between the pairs of the sample points of the signatures, that are to be aligned. Hence, at times, sole dependence of the DTW scores may not be effective to discriminate the genuine and forgery signatures of an user, especially, when their values are very close. In order to alleviate this issue, we propose a novel scheme of scoring/voting the aligned pairs in the warping path by a set of code-vectors constructed from a VQ step. We subsequently fuse this score with that of the DTW, by popular score combination strategies, for verifying a test signature. As a second contribution, we consider the incorporation of contextual information in the formulation to reduce the equal error rate of the verification system. The experiments on the publicly available SVC 2004 and MCYT 100 databases confirm the efficacy of our proposal. To the best of our knowledge, this work is the first of its kind, that exploits the characteristics of the warping path for online signature verification.

1. Introduction

In a signature verification biometric, we compare the features of a test signature against those from a set of genuine signatures of an user enrolled to the system. A decision is made to either accept the claimed signature as genuine or to reject it as a forgery [14]. In online signature verification, we make use of the temporal functions of attributes captured during the signing process. The input comprises a set of strokes, each of which in turn are a sequence of points. A stroke starts with a pen-down and ends with the next pen-up status signal.

The strategies to extract features from an on-line signature data are the global and the local-based approaches. With regards to the classifier structures, there are distance and model based techniques. Distance-based technique match the test signatures with the set of enrolled signatures by employing dynamic programming algorithms - especially when the number of sample points of the signatures being compared are not equal. Model based approaches, on the other hand, describe the distribution of the data by the use of generative-based classifiers like Hidden Markov Models [5] and Gaussian Mixture Models [17] or discriminative ones such as Multi Layer Perceptrons [8] and Support Vector Machines [15].

In this work, we propose an online signature verification system, in line with the distance based methods. The pioneering work on such techniques is that of the Dynamic Time Warping (DTW) approach, proposed in [21] for the problem of speech recognition. With regards to online signature verification, DTW has been explored in [14], where a local-based feature approach is used to compute the similarity between the trace of an input signature with the reference set of genuine signatures. A variant of DTW termed 'extreme point warping' is presented in [4], where-in the matching is done on only selective points of the online trace. A similar work by Gupta and Joyce [11] considers a string edit distance algorithm for aligning a sequence of position extremal points between a test input and the set of enrolled signatures.

In [15], the test signature is compared against a set of reference signatures using the DTW algorithm. Thereafter, a set of three distances from the test signature to the reference signatures are derived and subsequently normalized, resulting in a three-dimensional feature vector. This feature vector is then fed to a SVM, that is trained on both genuine and forgery signatures. Subsequently, the output of the SVM is used to decide on the authenticity of the signature. The same authors in [25] suggest

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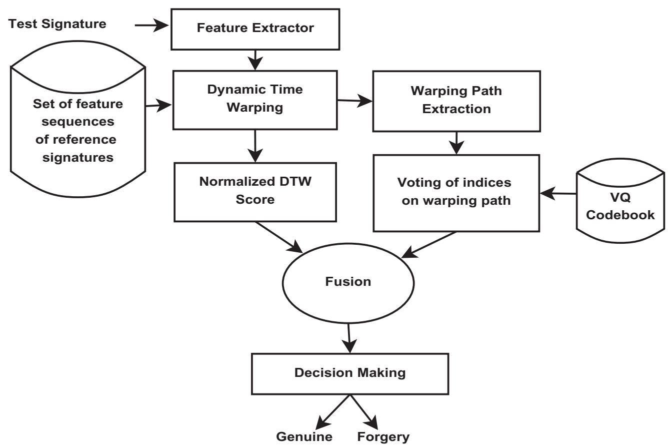

Fig. 1. Block diagram of proposed verification scheme.

on improving a verification system built using Fourier Descriptors by combining it with a DTW-based framework. A set of length normalization methods based on three re-sampling techniques (namely spatial based, temporal based and mean based) are employed in [24], to allow for an easy computation of the similarity of the test signature with the enrolled reference signatures. A matching between signatures, based on the concept of Longest Common Sub-Sequence is proposed in [1], wherein a sequence of turning angle based features are derived at each sample point of the online trace.

2. Problem formulation

The traditional DTW algorithms for online signature employ only the distance scores, obtained between the test signature and the genuine enrolled signatures, in formulating the decision rule [9]. Either the minimum or average of scores are compared to a threshold, to authenticate the veracity of a signature. The scores obtained correspond to the distance values/distortions, accumulated along the warping path. The warping path is obtained by placing constraints on the alignments between pair of sample points of the two signatures being compared. However, at times, the sole dependence on the DTW score may not be sufficient in discriminating the forgery signatures from the genuine. This is quite likely, when the signature patterns belonging to genuine and forgery, exhibit values, that are quite close to each other. The decision on the scores (based on the threshold), may lead to either genuine signatures getting rejected and/or forgery signatures getting accepted.

We believe that the analysis of the characterization of the distortions on the warping path in the cost matrix may provide us additional cues, that can be possibly exploited for reducing the false acceptance of forgery and rejection of genuine signatures. The traditional DTW algorithms however, do not consider this aspect in the scoring of the test signature. This is the research gap from literature that we address in our proposal.

Accordingly, as our contribution, we derive a score that determines the proportion of the aligned pairs that provide a low distortion value, relative to the length of the warping path, obtained from DTW. For computing this proportion, we consider utilizing a code-book of appropriate size, built from a Vector Quantization (VQ) model. We subsequently fuse this score with that of the DTW, (by popular score combination strategies), for authenticating the veracity of a test signature. In addition, we attempt capturing the contextual information in the formulation of the proposed ‘DTW-VQ’ strategy and show improvement of the verification system.

The application of VQ in literature has been devoted to the problem of signature recognition. In [2], the quantized feature vector of the test signature, of a claimed user, is matched against those of the enrolled reference signatures. The main focus for quantization of the feature vector was from the viewpoint of enhancing the privacy of the biometric system, so that hackers find it difficult to replicate the biometric data from the extracted features transmitted. The subsequent works by Faundez-Zanuy and Pascual-Gaspar [3] and Pascual-Gaspar et al. [20] consider using separate code books across multiple sections of signature, obtained by partitioning the online trace into equal number of segments for signature recognition.

Our proposal on ‘DTW-VQ’ strategy differs from the above works, in that the VQ step is used to enhance the efficacy of the DTW based system. To the best of our knowledge, this is the first work in the area of online signature verification that addresses the limitation of DTW by analyzing the trend of values along the warping path with the code-vectors of a VQ model.

3. Proposed signature verification system

Fig. 1 illustrates the overview of our proposal. The input test signature is first passed through a feature extractor module. Subsequent to that, we use the DTW matching technique to compare it against those of the enrolled reference signatures of an user. The feature vectors corresponding to the warping path indices are then voted, based on the code vectors to which they are assigned. The code vectors are obtained from a code book, generated through a VQ model. The score from the votes are then combined with that of DTW, and compared to a threshold for determining the veracity of the test signature.

3.1. Feature extraction

A set of features are extracted at each sample point of the online trace of the signature [14,15]. These include the differences of x co-ordinate, y co-ordinate and pressure between consecutive points, as well as angle-based features.

Difference of basic features: For $i = 1, 2, \ldots, n-1$,

$$\Delta x(i) = x(i+1) - x(i)$$
$$\Delta y(i) = y(i+1) - y(i)$$
$$\Delta p(i) = p(i+1) - p(i)$$

Sine and cosine measures: of the angle computed with respect to horizontal axis, defined for $i = 1, 2, \ldots, n-1$ as,

$$\sin(\theta(i)) = \frac{\Delta x(i)}{\sqrt{(\Delta x(i))^2 + (\Delta y(i))^2}}$$
$$\cos(\theta(i)) = \frac{\Delta y(i)}{\sqrt{(\Delta x(i))^2 + (\Delta y(i))^2}}$$

Subsequent to extraction, each feature is normalized to have zero mean and unit variance. Let $\{S_1, S_2, \ldots, S_N\}$ denote the N enrolled genuine signature of an user. The feature matrix $\mathbf{F}_p$ used to represent any signature S_p (comprising n_p points) is given as $\mathbf{F}_p = \{\mathbf{f}_p^1, \mathbf{f}_p^2, \ldots, \mathbf{f}_p^{n_p-1}\}$. Here $\mathbf{f}_p^i$ denotes the five dimensional feature vector extracted at the ith sample point of S_p.

3.2. DTW based matching

Consider matching two signatures T (denoting test signature) and S_p, represented with a feature vector sequence of length $n_T - 1$ and $n_p - 1$ points respectively. We construct a $(n_T - 1) \times (n_p - 1)$ cost matrix (denoted by C), whose (i, j)th element contains the measure of dissimilarity $d(i, j)$ between the ith point of T with the jth point of S_p. An optimal warping path $\mathcal{W}_p$ is selected in