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Towards robust writer verification by correcting unnatural slant ☆

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ABSTRACT

Slant is a salient feature of Western handwriting and it is considered to be an important writer-specific feature. In disguised handwriting however, slant is often modified. It was tested whether slant is indeed an important factor and it was tested whether the distorting effect of deliberate slant change can be countered by a simple shear transform. This was done in two off-line writer verification experiments in image processing conditions of slant elimination and slant correction. The experiments were performed using three features based on statistical pattern recognition, including the state-of-the-art features Fraglets and Hinge. A new public dataset was created and used, containing natural and slanted handwriting by 47 writers. A striking result is that the average natural slant value is much less important for biometric systems than is usually assumed: eliminating slant yields just a 1–5% performance loss. A second result is that the effects of deliberate slant change cannot be fully countered by a simple shear transform: it raises performance on the distorted handwriting from 53–68% to 64–90%, but this is still lower than normal operation on natural handwriting: 97–100%.

1. Introduction

A salient property of Western handwriting is *slant*: the dominant angle of near-straight downstrokes with respect to the horizontal. Slant is caused by the choice of pen grip and the relative contributions of wrist and finger movements. It has been modeled as the effect of locally using a single actuator (muscle) in a two-dimensional neuromuscular apparatus (Dooijes, 1986). Slant seems to be a key feature for writer verification: it plays an important role in biometric systems, as it is a major constituent of angular features (Bulacu and Schomaker, 2003; Crettez, 1995; Maarse, 1987). For example, the state-of-the-art Hinge feature (Bulacu and Schomaker, 2007) is based on angular frequencies; it is influenced by both curvature and slant. Furthermore, forensic document examiners and paleographers use this feature as a discriminatory characteristic (Burgers, 1995; Hardy and Fagel, 1995). These facts suggest that slant is a key feature for writer verification. However, it is not known to what extent slant contributes as an isolated factor to the performance of biometric systems for handwriting and its value may be overestimated.

In particular, slant is not a valuable feature in (possibly) disguised handwriting. In such a case, the handwriting was produced in a deliberately modified style, with the intention to avoid recognition of the writer's identity. Disguised handwriting is often used in threatening or stalking letters. In some cases, the mutilation of shapes successfully disturbs handwriting examination by forensic experts (Found and Rogers, 2005). Moreover, disguised handwriting cannot be handled by state-of-the-art systems for handwriting biometrics (writer verification and identification): computational features that are invariant to disguise do not exist. This is one of the reasons why systems for handwriting biometrics are not fully suitable for application in the forensic domain yet. Other unmet requirements are explainability of the system, robustness for variation in background effects, and robustness for forgery. Those issues have been addressed to some extent (Brink et al., 2007, 2008; Cha and Tappert, 2002; Franke and Köppen, 2000), but computational robustness against disguise is a largely untouched problem area.

A strategy to handle disguise is by applying an image operation to undo the effect of disguise, resulting in handwriting that is close to natural. This seems possible for the most frequently used kind of handwriting disguise: a change of slant. It is not surprising that slant modification is the most frequently used kind of disguise (Harris, 1953; Koppenhaver, 2007; Morris, 2000; Nickell, 2007), since humans can easily modify the slant during writing, and the effect on the visual appearance is dramatic (Koppenhaver, 2007). Therefore, an important step in making biometric systems robust for disguise is by correcting the slant. An obvious approach is to perform the correction by transforming the image with the *shear* operation, possibly resulting in the writer's natural handwriting.

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The objective of this study is twofold. The first objective is to determine how much information about the writer's identity is contained in the slant characteristic of natural handwriting. This will be tested in the first experiment by eliminating the slant in natural handwriting (*slant elimination*) and measuring to what extent the performance of automatic writer verification degrades. This experiment contributes to the theoretical basis of computational writer features based on directionality, such as the Hinge feature (Bulacu and Schomaker, 2007). The result will direct the design of future features.

The second objective is to determine the effectiveness of the shear transform in correcting handwriting disguised by slant change, when used as a preprocessing step before applying features such as Hinge (Bulacu and Schomaker, 2007) and Fraglets (Schomaker et al., 2004). Hinge and Fraglets are state-of-the-art features, based on statistical pattern recognition, which show impressive performance in test conditions.

At the same time, the underlying question will be answered: to what extent is a change of slant during human production of handwriting functionally equivalent to a shear transform? Slant change may result in more than just a shear effect, since it requires a non-habitual movement of the finger-wrist system, which may affect curvature. It has been suggested that there must also be an effect on writing speed, pressure, connecting strokes, style, construction, and size (Morris, 2000). Furthermore, disguised handwriting is less consistent (Harris, 1953; Koppenhaver, 2007; Morris, 2000). In the second experiment, it will be quantitatively determined to what extent such other effects occur. This will be done by shearing slanted text back to the supposed writer's natural slant angle (*slant correction*), and determining the performance of writer verification using state-of-the-art features. This is a first step in designing new biometric systems that are robust to disguise. To the best of our knowledge, no similar experiment has been performed before.

The experiments will be performed on a newly created public dataset: the *TriGraph slant dataset*, containing both natural and slanted handwriting of 47 subjects. It is described into more detail in the next section. In Sections 3 and 4, methods for slant estimation and feature extraction are described; these are preliminaries for the experiments. Experiment 1 will show that slant is not as informative as is usually assumed; it is described in Section 5. Experiment 2 will show that deliberate slant change is not equal to a simple shear transform; it is described in Section 6. Section 7 summarizes the conclusions.

2. TriGraph slant dataset

A new dataset was created, the *TriGraph slant dataset*: a unique collection of clean, deliberately slanted handwriting in conjunction with each writer's natural handwriting. It consists of 188 scanned images of handwritten pages, written by 47 untrained Dutch subjects, aged 27 on average. This dataset is relatively small compared to other datasets such as Firemaker (Schomaker and Vuurpijl, 2000) (251 writers), IAM (Marti and Bunke, 1999) (657) and Srihari's dataset (Srihari et al., 2002) (1500). However, the dataset proved to be large enough to analyze the effect of slant. It can be obtained from http://www.unipen.org/trigraphslant.html. The dataset can be used for both handwriting comparison experiments and handwriting recognition experiments.

The dataset was assembled as follows. The subjects were provided two printed Dutch texts, *text A* and *text B*. Both texts contained approximately 200 characters, including all lowercase letters and many capitals; the distribution of the letters among the two texts was similar. Each subject wrote four pages, such as the one shown in Fig. 1, following these instructions:

1. [*AN*] Copy text A in your natural handwriting.
2. [*BN*] Copy text B in your natural handwriting.
3. [*BL*] Copy text B and slant your handwriting to the *left* as much as possible.
4. [*BR*] Copy text B and slant your handwriting to the *right* as much as possible.

See Fig. 2 for a close look at fragments of the four pages written by one writer. The codes *AN*, *BN*, *BL* and *BR* refer to subsets into which the collected pages of the writers were subdivided. *AN* represents a collection of authentic documents; *BN*, *BL* and *BR* can be seen as collections of questioned documents. To avoid structural effects of fatigue, the order of item 3 and 4 was randomized; half of the subjects wrote the *BR* page before the *BL* page.

3. Slant estimation

Since Experiments 1 and 2 both require a reliable technique to estimate slant, a limited comparison of techniques is included here. A variety of slant estimation methods exists, based on different definitions of 'slant'. For example, it has been defined as the average direction of near-straight or long downstrokes (Maarse and Thomassen, 1983), or "the angle between the vertical direction and the direction of the strokes that, in an ideal model of handwriting, are supposed to be vertical" (Vinciarelli and Luettin, 2001). The methods can be roughly subdivided into two general approaches which could be called the *angle-frequency approach* (AF) and the *repeated-shearing approach* (RS). In AF, which is most popular (Kavallieratou et al., 2001), downstrokes are first located based on a criterion such as a minimal vertical extent or velocity. Next, the angle of the local ink direction is measured at those locations; the resulting angles are agglomerated in a histogram. From this histogram, the slant angle is determined. This general algorithm is shown in Algorithm 1. Variations include computing an edge-direction histogram and finding the maximum or mode in it (Bulacu and Schomaker, 2003) or the peak that is closest to 90° (Crettez, 1995). Another variation computes the average angle in rectangular sub-areas containing vertical structures (Bozinovic and Srihari, 1989).

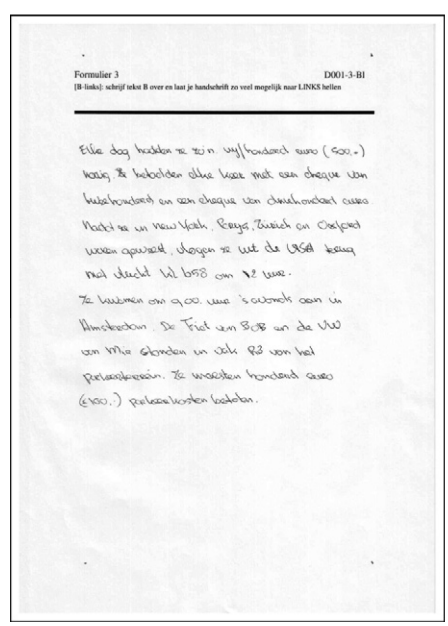

Fig. 1. Example page from the TriGraph slant dataset: page 3 of writer D001. It contains text B, slanted to the left (*BL*).