



Slant estimation and core-region detection for handwritten Latin words



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ABSTRACT

In this paper, we present a new technique that estimates the slant in handwritten words while a new word core-region detection method is introduced as part of the proposed technique. The proposed core-region detection algorithm can be also used independently to detect the upper and lower baselines of a word. Our method takes advantage of the orientation of the non-horizontal strokes of Latin characters as well as their location regarding to the word's core-region. As a first step, the word core-region is detected with the use of novel reinforced horizontal black run profiles which permits to detect the core-region scan lines more accurately. Then, the near-horizontal parts of the document word are extracted and the orientation and the height of non-horizontal remaining fragments as well as their location in relation to the word's core-region are calculated. Word slant is estimated taking into consideration the orientation and the height of each fragment while an additional weight is applied if a fragment is partially outside the core-region of the word which indicates that this fragment corresponds to a part of the character stroke that has a significant contribution to the overall word slant and should by definition be vertical to the orientation of the word. Extensive experimental results prove the efficiency of the proposed slant estimation method compared to current state-of-the-art algorithms.

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1. Introduction

In order to proceed with optical character recognition (OCR), document image preprocessing is essential for any system. The task of preprocessing mainly includes the removal of noise as well as image normalization in order to remove unwanted variations of handwritten words. It can be divided into several steps such as binarization, slant and skew correction, core-region detection (upper and lower base-line), noise removal etc. In this paper, we focus on the tasks of core-region detection and slant correction in handwritten documents.

The core-region is the region of a word image that does not contain neither ascenders nor descenders and is bounded by the upper and the lower baseline which are the reference lines of the word (see Fig. 1a). The accurate estimation of the core-region is of great importance in cursive handwriting recognition since it determines the area that a word contains most of its information which is essential, while it serves for a variety of operations such as slant and skew removal, feature extraction, character segmentation and recognition.

Another crucial step in order to improve segmentation and recognition accuracy of handwritten words is the estimation and

correction of word slant. By the term "word slant" we refer to the average angle in degrees clockwise from vertical at which the characters are drawn in a word. Word slant estimation can be very helpful in handwritten text processing. Knowing the value of the slant, we can correct it in order to normalize the word image and facilitate processing and recognition. In addition, the character slant is considered to be very important information which can help to identify the writer of a text.

In this paper, two methods are presented; a novel word core-region detection method and a new technique that estimates the slant in handwritten words, based on the information extracted from the first method. Our core-region detection algorithm takes advantage of the fact that most of the word information is included between the reference lines of a word and it is based on the analysis of an innovative reinforced horizontal black run profile histogram which is introduced. The proposed word slant estimation technique takes advantage of the orientation of the non-horizontal strokes of Latin characters, as well as their location regarding to the word's core-region. This work is an extension of Bozinovic and Srihari (1989) and Papandreou and Gatos (2012) with extensive experimental results in both real and synthetic test sets that prove the efficiency of the proposed slant estimation method compared to current state-of-the-art algorithms.

The remainder of the paper is organized as follows. In Section 2 the related work is discussed. Section 3 focuses on the proposed methodologies and it provides a detailed analysis of the steps involved. In particular, in Section 3.1 the core-region detection

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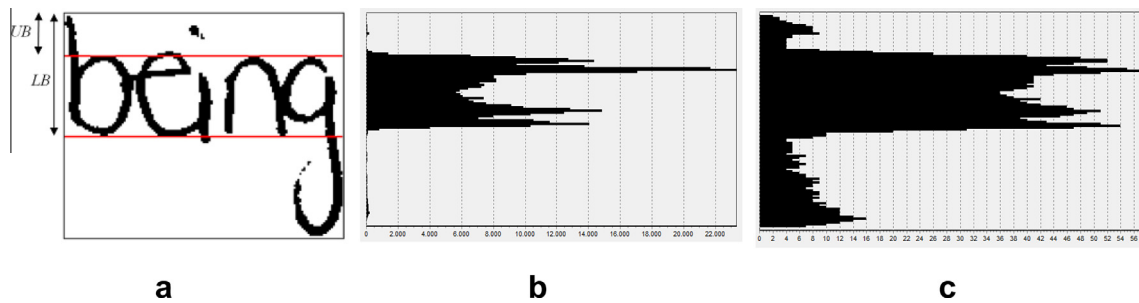


Fig. 1. Word image horizontal profiles: (a) original word image and its core-region area; (b) the proposed horizontal black run profile $H()$ (values in the horizontal axis ranges from 0 to 14,000) and (c) the classical horizontal profile (values in the horizontal axis ranges from 0 to 56).

method which also consists of the first step of the slant estimation technique is detailed, while in Sections 3.2 and 3.3 the calculation of the orientation and height of non-horizontal fragments and the estimation of the overall word slant are respectively presented. Experimental results indicating the performance of the proposed methodology compared with other state-of-the-art methods are discussed in Section 4, while conclusions and remarks on future directions are drawn in Section 5.

2. Related work

Regarding the word core-region detection, the techniques proposed in the literature fall broadly into two main categories. In the first category, techniques focus on analyzing the horizontal density histogram by finding the lines with the highest horizontal density of foreground pixels per line (Bozinovic and Srihari, 1989). The core region lines are in fact expected to be more dense than the others. The horizontal density histogram is analyzed looking for features such as maxima and first derivative peaks, but these features are very sensitive to local characteristics and many heuristic rules are needed to find the actual core region lines. In the second category, the proposed techniques analyze the density distribution rather than the density histogram itself in order to make statistically negligible the influence of local strokes (Cote et al., 1998; Vinciarelli and Juergen, 2001). However, these methods may fail due to the presence of erratic characters and multiple characters that contain long horizontal strokes such as the letter “t”, “f”, “h” etc. (Blumenstein et al., 2002).

In the proposed core-region detection method we focus on the horizontal black runs of the word image and introduce a reinforced horizontal black run profile histogram. The motivation for proposing this profile is the need to stress the existence of long horizontal black runs as well as of the number of horizontal black runs in every line of the word image. The parts outside of the core-region are most of the times vertical strokes with no significant width or horizontal strokes that are in a sparse area with no significant concentration of foreground pixels. On the other hand, in the core-region, where most of the information can be found, there are more black runs than outside of the core region.

Regarding slant estimation the following main categories of methodologies appear in the literature: estimation by averaging angles of near-vertical strokes (Bozinovic and Srihari, 1989; Papandreou and Gatos, 2012; Kim and Govindaraju, 1997) by analyzing projection histograms (Vinciarelli and Juergen, 2001; Kavallieratou et al., 2001) and by using statistics of chain code contours (Kimura et al., 1993; Ding et al., 2000; Ding et al., 2004).

Concerning near-vertical stroke techniques, according to Bozinovic and Srihari (1989), for a given word all horizontal lines which contain at least one run of length greater than a parameter (depending on the width of the strokes) are removed. Additionally, all horizontal strips of height less than a parameter

are also removed. By deleting these horizontal lines, the remaining parts of the word are contained in windows separable by vertical lines. For each letter, the parts that remain are those that have relatively small slant. For each such window, with non empty upper and lower halves, the angle between the vertical line and the line joining the centers of gravity of the two halves is computed and the mean value of all windows is the overall slant of the word. In (Papandreou and Gatos, 2012), Papandreou and Gatos propose an extension method of Bozinovic and Srihari (1989) by integrating information of the location and the height of the remaining parts by adding specific weights favoring long parts that are outside the core-region. In the approach of Kim and Govindaraju (1997) the whole page is considered as input; and the global slant is estimated by averaging over all lines. Vertical and near-vertical lines are extracted with a chain code representation of the word contour using a pair of one dimensional filters. Coordinates of the start and end points of each vertical line extracted provide the slant angle. Global slant angle is the average of all the angles of the lines, weighed by their vertical direction since the longer line gives more accurate angle than the shorter one.

Analyzing projection histograms, Vinciarelli and Juergen (2001) have proposed a deslanting technique based on the hypothesis that the word has no slant when the number of columns containing a continuous stroke is maximum. On the other hand Kavallieratou et al. (2001) have proposed a slant removal algorithm based on the use of the vertical projection profile of word images and the Wigner–Ville distribution (WVD). The word image is artificially slanted and for each of the extracted word images, the vertical histogram as well as the WVD of these histograms are calculated. The curve of maximum intensity of the WVDs corresponds to the histogram with the most intense alternations and as a result to the dominant word slant.

Techniques based on statistics of chain code contours can estimate average slant of a handwritten word by using the 4-directional chain code histogram of border pixels according to Kimura et al. (1993). This method tends to underestimate the slant when its absolute value is close or greater than 45° . To solve this problem, Ding et al. (2000) proposed a slant detection method using an 8-directional chain code. Chain code methods of 12 and 16 directions are also examined in Ding et al. (2004) but the experimental results show that these methods tend to overestimate the slant. In (Ding et al., 1999), new methods are proposed for evaluating and improving the linearity and accuracy of slant estimation based on chain contours.

Additionally a slant estimation method for handwritten characters by means of Zernike moments has been proposed by Ballesteros et al. (2005) which is based on the average inclination of the Zernike reconstructed images for low moments. It is claimed that this method improves the slant estimation accuracy in comparison with the chain code based methods.

The proposed word slant estimation technique can be applied to Latin texts and is based on calculating the weighted sum of average angles of the near-vertical stroke. The proposed technique takes advantage of the orientation of the strokes of Latin characters that lay inside and outside the word core-region (see Fig. 1a). It is mainly motivated by the method of Bozinovic and Srihari (1989) while it is an extension of Papandreou and Gatos (2012). The main differences between the proposed technique and the method presented in (Bozinovic and Srihari, 1989) are the following: (i) the new technique introduces automatic parameter setting and (ii) the contribution of all word image segments to the estimation of the dominant word slant is weighted based on their height and position relative to the core-region. Comparing the proposed method with the one presented in (Papandreou and Gatos, 2012), it incorporates a new technique for core-region detection, which improves the results since the method is core-region-dependent, it has more accurate parameter setting, while it reduces the involved parameters concerning the part of the algorithm that is based on Bozinovic (Bozinovic and Srihari, 1989).

3. Proposed methodology

The proposed slant estimation and core-region detection method consists of three steps. At a first step, the word core-region is detected with the use of novel horizontal black run profiles. Then, the orientation and the height of non-horizontal fragments of the word as well as their location in relation to the word core-region are calculated. Finally, the word slant is estimated taking into consideration the orientation and the height of each fragment while an additional weight is applied if a fragment is outside the core-region of the word which indicates that this fragment corresponds to a part of character stroke that has a significant contribution to the overall word slant.

3.1. Core-region detection

Let $I(x,y)$ be the binary word image having 1s for black (foreground) pixels and 0s for white (background) pixels and I_x and I_y be the width and the height of the word image. The word core-region is defined as the region between the upper-baseline and the lower-baseline of the word image (see Fig. 1a). In order to detect the word core-region, we focus on the horizontal black runs of the word image and introduce reinforced horizontal black run profile $H()$. The motivation for proposing this profile is the need to stress the existence of long horizontal black runs as well as the number of horizontal black runs of every line of the word image. The parts outside of the core-region are most of the times vertical strokes with no significant width or horizontal strokes that are in a sparse area with no significant concentration of foreground pixels. On the other hand, the core-region is the main area of the word where most of the information can be found while in this area there are more black-white transactions than outside of the core-region. The horizontal black run profile $H()$ is defined as it follows:

$$H(y) = [B(y)]^2 \sum_{i=0}^{B(y)} \sum_{j=0}^{L(i,y)} j \quad (1)$$

where $B(y)$ is the number of black runs in the horizontal scan of line y and $L(i,y)$ is the length of the i th black run of line y . A comparison of the proposed horizontal black run profile $H()$ with the standard horizontal profile is given in Fig. 1. It can be observed that $H()$ can better serve as a function for discriminating core from non-core word regions.

In order to detect the scan lines that belong to the core-region, we first define the Boolean horizontal profile $H_B()$ as follows:

$$H_B(y) = \begin{cases} 1, & \text{if } H(y) > T_h \\ 0, & \text{otherwise} \end{cases} \quad (2)$$

where T_h expresses a threshold for the $H(y)$ values defined as follows:

$$T_h = \frac{0.15}{I_y} \sum_{y=0}^{I_y-1} H(y) \quad (3)$$

where I_y is the number of lines of the image, while 0.15 is a small number that can be used to safely distinguish the small noncore-region values from the significantly larger core-region ones and its efficiency is experimentally verified.

Although in the majority of the cases, successive 1s of $H_B()$ correspond to the scan lines of the core region (see Fig. 2(c)), it is also possible to have successive 1s of $H_B()$ that correspond to scan lines out of this region (see Fig. 2(f), 2(i), 2(l)). For this reason, we calculate all successive 1s of $H_B(y)$ that start from $y = s_i$ and end at $y = e_i$, and define the core-region limits upper baseline UB and lower baseline LB as illustrated below:

$$\{UB, LB\} = \{s_k, e_k\} \text{ where } k = \arg \max_i \left(\sum_{y=s_i}^{e_i} H(y) \right) \quad (4)$$

Examples of word core-region detection are given in Fig. 2.

3.2. Calculation of the orientation of non-horizontal fragments

As a next step we remove all scan lines that contain either horizontal or almost horizontal strokes. For a given document image word, we remove all scan lines which contain at least one black run with length greater than M where M is defined as follows:

$$M = 2.5l \quad (5)$$

where l is the modal value of all horizontal black run lengths $L()$ and corresponds to the character stroke width. Parameter value 2.5 is used in order not to exclude neighboring connected strokes with width approximately $2l$. An example of removing word image scan lines is shown in Fig. 3(b).

Portions of each strip separable by vertical lines are isolated in boxes (see Fig. 3(c)). For each box, the centers of gravity for its upper and lower halves are computed and connected. In case of an empty half, with no foreground pixels, the whole box is disregarded. A box is also disregarded if its height is less than 3 pixels. (see Fig. 3(d)). The slant s_i of the connecting line defined by the centers of gravity for upper and lower halves of box i corresponds to the slant of this box.

3.3. Overall word slant estimation

The weighted average of s_i for all boxes, is used to calculate the slant S of the word image as follows:

$$S = \frac{\sum_{i=1}^b s_i h_i c_i}{\sum_{i=1}^b h_i c_i} \quad (6)$$

where b is the number of valid boxes, h_i the height of box i and c_i a parameter used to weigh the contribution of box i based on its position in relation to the word core-region. Parameter c_i is used to assign a weight of 1 if the box is entirely inside the core-region and 2 otherwise (see Eq. (7)). The rationale behind this parameter is that character parts outside the core-region have a significant contribution to the overall word slant. As we observe in Fig. 4 the boxes that bound the largest fragments and are outside the core region contain the strokes that should be vertical to the orientation of the word

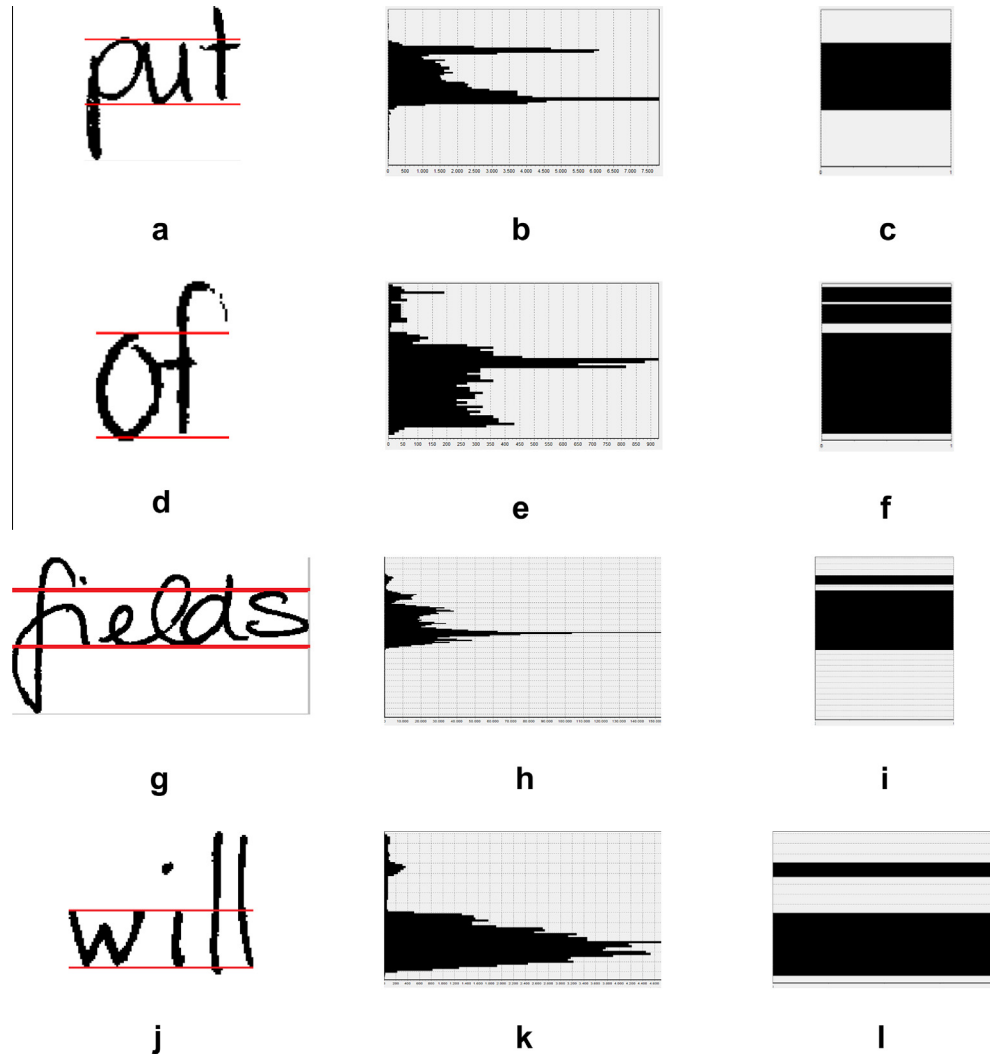


Fig. 2. Examples of word core-region detection: (a), (d), (g), (j) original word images and the detected core-regions; (b), (e), (h), (k) the horizontal black run profiles $H()$ and (c), (f), (i), (l) the Boolean horizontal profiles $H_B()$.

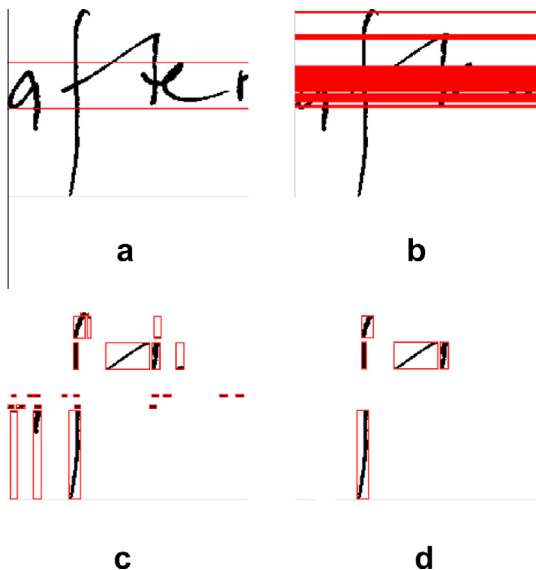


Fig. 3. Image boxes that contribute to word slant: (a) original word images and the detected core-region; (b) scan lines removed; (c) detected image boxes and (d) valid image boxes.

and consequently our algorithm considers such strokes as dominant. Parameter c_i is defined as follows:

$$c_i = \begin{cases} 1, & \text{if } (yb_i < LB) \text{ AND } (yt_i > UB) \\ 2, & \text{otherwise} \end{cases} \quad (7)$$

where yt_i , yb_i are the top and bottom vertical coordinates of box i and UB , LB the word core-region limits defined by Eq. (4).

4. Experimental results

In order to test the proposed methodology we created two different datasets. Dataset A was based on real data and dataset B on synthetic data, while both datasets are supersets of the datasets

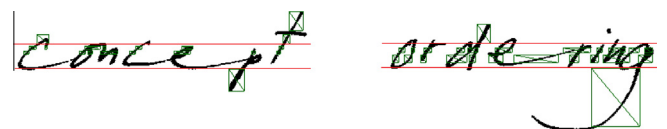


Fig. 4. The fragments the bounding box of which have a significant height and are outside the core region are those that by definition should be vertical to the orientation of the word.

used in (Papandreou and Gatos, 2012) and are available after request.

For the construction of dataset A, we used all the words contained in 9 different documents (712 words) from the IAM database (www.iam.unibe.ch/fki/databases/iam-handwriting, 2012) that were visually checked to have no slant and more than one character length. Those 9 documents were picked so that the proposed method would be tested on various handwriting styles such as cursive and printed handwriting, round and elongated letters, thick and thin strokes, while three different documents (146 words) were written fully in capital letters. The entire word in fully capital letters is considered to be inside the core-region (for words written fully in capitals the parameter c_i has no contribution when the core-region is correctly estimated). We first binarized all words using the adaptive technique of Gatos et al. (2006). Then, we slanted all words using the shear transform in 91 different angles from -45° to 45° with 1° step. In that way we formed a dataset of 64,792 real words for which the ground-truth was known. Representative samples of dataset A together with the slant estimation and core detection results using the proposed methodology are given in Fig. 5.

In order to form dataset B, we obtained all the instances (266 words) from a random list of feeling words found in (<http://www.psychpage.com/learning/library/asse>, 2012) and we used Bradley Hand ITC fonts to construct a synthetic printed handwritten-like dataset. 16 of the words in that list are written fully in capital letters. Again, we slanted them using the shear transform in 91 different angles from -45° to 45° with 1° step and formed a dataset of 24,206 synthetic words with known slant ground truth. Dataset B compared to dataset A contains words with more accurate ground truth as well as with uniformly slanted characters. Representative samples of dataset B together with the slant estimation and core detection results using the proposed methodology are given in Fig. 6.

In order to make a comparison with current state-of-the-art slant estimation techniques we also implemented (i) the Bozinovic and Srihari (Papandreou and Gatos, 2012), (ii) the Papandreou and

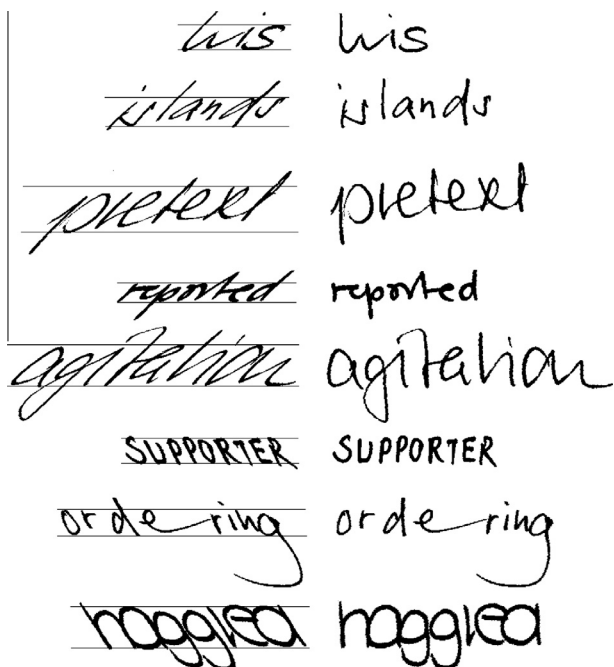


Fig. 5. Representative samples of dataset A together with the slant estimation and core detection results using the proposed methodology.

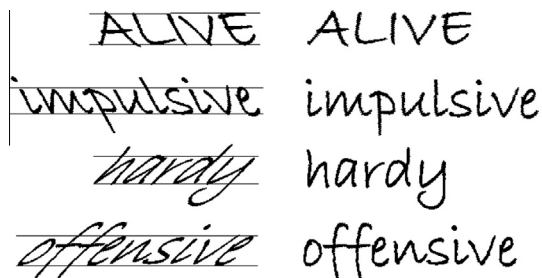


Fig. 6. Representative samples of dataset B together with the slant estimation and core detection results using the proposed methodology.

Table 1
Comparative results showing average slant error deviation in degrees.

Slant estimation technique	Dataset A	Dataset B	Datasets A and B
Bozinovic and Srihari (1989)	8.04	7.97	8.02
Papandreou and Gatos (2012)	7.48	7.02	7.35
Kimura et al. (1993)	23.17	23.44	23.24
Ding et al. (2000)	12.24	13.19	12.5
Proposed method	6.88	6.85	6.87

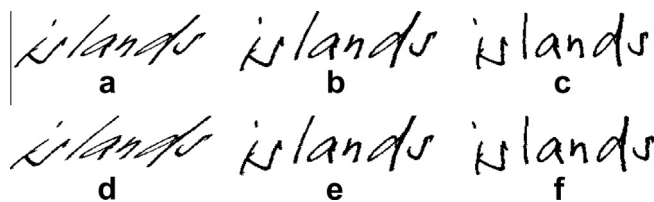


Fig. 7. (a) A representative sample and the slant estimation results using; (b) Bozinovic and Srihari (1989); (c) Papandreou and Gatos (2012); (d) Kimura et al. (1993); (e) Ding et al. (2000) and (g) the proposed methodology algorithms.

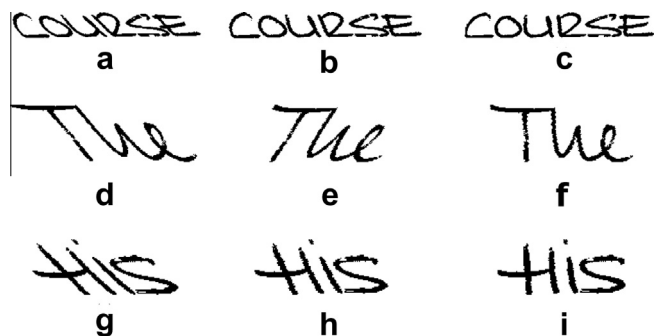


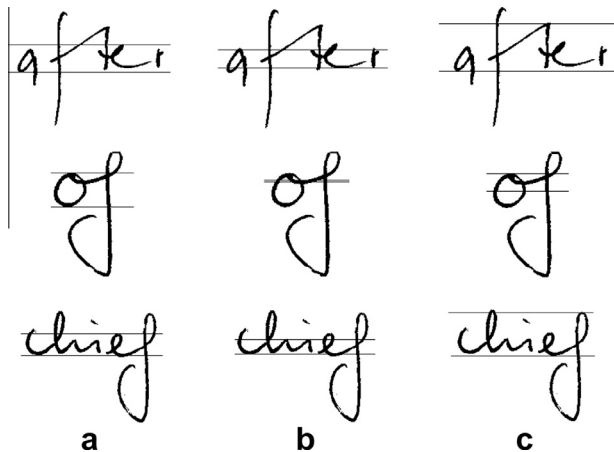
Fig. 8. Representative samples of word images that the proposed algorithm outperforms the algorithm proposed in (Papandreou and Gatos, 2012): (a), (d), (g) the word images; (b), (e), (h) slant estimation results of the algorithm proposed in (Papandreou and Gatos, 2012); (c), (f), (i) results of the proposed algorithm.

Gatos (2012), (iii) the Kimura et al. (1993) and (iv) the Ding et al. (2000) algorithms. For all these methods we calculated the average word slant error estimation in degrees. The results are presented in Table 1 while in Fig. 7 there is a representative example with results of all methods. Table 1 demonstrates that our method outperforms the current state-of-the-art slant estimation methods. For further demonstration of the efficiency of the proposed slant estimation algorithm compared to Papandreou and Gatos (2012) in Fig. 8 the results of the two algorithms for three representative word images are presented.

Table 2

Comparative results showing average slant error deviation in degrees.

Slant estimation technique	Core-Region Detection Method Used	Dataset A	Dataset B	Datasets A and B
Bozinovic and Srihari (1989)	-	8.04	7.97	8.02
Bozinovic and Srihari (1989) method that uses a weighted average of slants based only on the height of each box	-	7.02	7.55	7.17
Proposed method	Bozinovic and Srihari (1989)	7.05	6.90	7.00
	Vinciarelli and Juergen (2001)	7.05	6.94	7.02
	Proposed Core-Region Method	6.88	6.85	6.87

**Fig. 9.** Representative samples of core detection results using: (a) the proposed methodology; (b) Bozinovic and Srihari (1989) and (c) Vinciarelli and Juergen (2001) algorithms.

In order to measure the influence of the different parts of the proposed technique as well as to evaluate our core-region method, apart from comparing the proposing method to the Bozinovic and Srihari (1989) algorithm, we also compared it with (i) the Bozinovic and Srihari (1989) algorithm that uses a weighted average of slants based only on the height of each box (as the proposed method), (ii) the proposed method using the core-detection algorithm of Bozinovic and Srihari (1989) and (iii) the proposed method using the core-detection algorithm of Vinciarelli and Juergen (2001). The core-detection algorithm of Bozinovic and Srihari (1989) analyzes the density histogram while Vinciarelli and Juergen (2001) analyze the distribution of the density values in order to estimate the core-region. The results are presented in Table 2.

From Table 2 it can be observed that the method of Bozinovic and Srihari (1989), is improved when a weighted average of slants based only on the height of each box is used, while it is even more accurate when we take advantage of the core-region information. It should also be noticed that the proposed core-region detection algorithm has better performance compared to other state-of-the-art core-region detection techniques. Examples of core-region estimation for the three algorithms are also demonstrated in Fig. 9.

5. Conclusion

In this paper, two methods are presented; a novel word core-region detection method and a new technique that estimates the slant in handwritten words, which is based on the information extracted from the first method. The proposed slant estimation method is based on the Bozinovic's Bozinovic and Srihari (1989) algorithm which is improved by (i) introducing automatic parameter setting and (ii) applying weight to the contribution of all word image segments based on their height and position in relation to the core-region in order to estimate the dominant word slant. This

work is an extension of Papandreou and Gatos (2012) and it incorporates the new technique for core-region detection, which improves the results since the method is core-region-dependent, it has more accurate parameter setting, while it reduces the involved parameters concerning the part of the algorithm that is based on Bozinovic Bozinovic and Srihari (1989). In fact, the height of the box that bounds each fragment indicates important information about its contribution to the overall word slant whereas the location of each fragment is important since if a fragment is outside the core-region of the word most of the times should be vertical to the orientation of the word.

Extensive testing based on various test-sets has demonstrated that both of the proposed methods outperform the state of art algorithms concerning slant estimation and core-region detection. Moreover, it is demonstrated that the more accurate the core-region detection algorithm is, the better the proposed slant estimation methodology performs.

It is a point of discussion though whether the slant should be locally estimated in order to improve the OCR result of globally estimated in order to be used as a salient feature of writer identification. Consequently as future work we should consider adapting the proposed method to work better for non-uniformly slanted words as much as try to test and adapt it in non Latin alphabet languages.

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