Mathematical Morphology and Weighted Least Squares to Correct Handwriting Baseline Skew

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Abstract

An approach to correct the baseline handwritten word skew in the image of bank check dates is presented in this article. The main goal of such approach is to reduce the use of empirical thresholds. The weighted least squares approach is used on the pseudo-convex hull obtained from the mathematical morphology.

1. Introduction

There are several research works in the area of handwritten word recognition in search of still undiscovered solutions. Such research is not a trivial pursuit, in view of several factors, among which we may mention the complexity inherent to human handwriting, because of its variability. To reduce that variability, many handwritten word recognition systems correct the handwriting baseline skew, so that the extraction of that line may be performed correctly, minimizing error in the recognition phase, as proposed in El Yacoubi's work in [15].

Because of the complexity of handwriting, several works demand the use of empirical thresholds, rendering analysis and implementation more complex. It will be shown that it is possible to reduce the use of thresholds in the correction of the handwriting baseline skew by employing a pseudo-convex hull from the mathematical morphology.

The state of the art in terms of handwritten word skew correction will be presented in section 2. The morphological pseudo-convex hull technique to reduce the use of heuristics will be presented in section 3. The approach developed to detect and eliminate undesirable minima in the handwriting baseline on the basis of the weighted least squares approach [1] will be presented in section 4. The approach to correct the handwriting baseline skew in bank check images on the basis of pseudo-convex hulls [11] will be presented in Section 5. Some results achieved will be presented in section 6.

2. State of the Art

Only a few authors in the literature described in detail the approach used to correct the handwriting baseline skew. On the basis of the papers studied, it was perceived that the use of heuristics is frequent. Many works [7] [9] [15] [2] [1] are found in the literature that deal with detection and correction of the handwriting baseline skew employing several empirical thresholds. This reality might adversely impact the development of automatic processes regardless of the type of application (dates, addresses, amounts in writing, etc..). The main goal of this work is to reduce the use of thresholds when filtering undesirable minima to correct the handwriting baseline skew. In previous studies [13] [12], following the processing philosophy proposed by El Yacoubi, the pseudo-convex hull notion and the least squares technique were employed. The approach in this paper is to enhance the previous approach using the weighted least squares.

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3. Morphological pseudo-convex hull

The mathematical morphology consists in extracting information about the geometry and topology of an unknown set in an image from a known set named structuring element SE [14] [4].

There are several ways to obtain the convex hull [5] [6]. By definition, the X set convex hull corresponds to the smallest convex set containing X. In the case of handwritten words processing, just the pseudo-convex hull, that reduces the minima in a word, will be used but to a lesser degree than the convex hull, as may be observed in Fig. 1(b),(c) and (d). In the approach developed, the pseudo-convex hull employed is being extracted in two ways. The process utilized to obtain the first pseudo-convex hull in Fig. 1(c) consists in the horizontal dilation of the word in the original image (set X), followed by the vertical conditional dilation, where the basic structuring elements employed were $B_{hor} = \{\bullet \bullet \bullet\}$ and $B_{ver} = \left\{\begin{smallmatrix}\bullet\\ \bullet\\ \bullet\end{smallmatrix}\right\}$. The second pseudo-convex hull is obtained by inverting only the structuring elements in the operations described above, as shown in Fig. 1(d). Thus, the pseudo-convex hull operation that is being used in this case may be given by:

$$\text{pseudo-convex-hull}(X) = \rho^{B_2}_{(\delta^{B_1}(X))}(X)$$

where B_1 and B_2 represent, respectively, B_{hor} and B_{ver} or vice-versa. And where $\rho^B_S(Z)$ is the reconstruction of the binary set S from Z with the SE B.

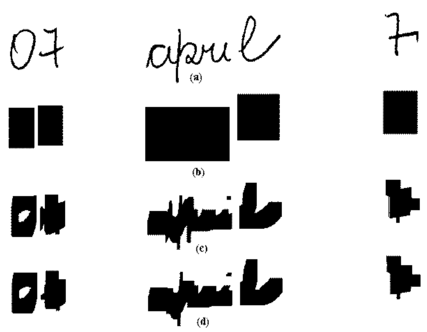

Figure 1. (a) Original image, (b) Convex hull image, (c) and (d) pseudo-convex hull image.

In the case of the pseudo-convex hull images in Fig. 1, 20 iterations were utilized, both in the dilation and in the reconstruction by conditional dilation. Since the number of iterations is reduced, the number of minima increases accordingly, as may be observed in Fig. 1. The best overall results in the handwriting baseline skew correction are generated by using 9 iterations. Both pseudo-convex hull images extracted provided similar but not identical aspects. Therefore, the intersection of those two images provides a pseudo-convex hull image with more details than the horizontal and/or vertical axis.

The result of logic operation Xor between the original image and the pseudo-convex hull, presented in Fig. 2, shows that the application of the pseudo-convex hull wraps the words, without altering the vertical positioning of the most relevant word minima and maxima originating from the lower and upper baselines. This is very important because if the minima alter their vertical positions, the correction of the word undulation may be adversely affected.

Figure 2. Logic operation Xor.

4. Detection and elimination of minima

The main objective of employing the pseudo-convex hull is to decrease the use of empirical thresholds in developing this approach. This technique is being used in a way that reduces the minima in a word so that, when filtering undesirable minima, few empirical thresholds will have to be defined.

Because of the likely fragmentation of the words, from now on the pseudo-convex hull of parts of a word or of a whole word will be called connected component. Fig. 3(a) shows an example where the connected components minima were detected in the inferior contour of the pseudo-convex hull. In the case of Fig. 3(b), the minima were detected in the original inferior contour of words. The utilization of the pseudo-convex hull leads to the detection and storage of just the most relevant minima, so that the insignificant (desirable or undesirable) minima are eliminated, thereby avoiding the use of heuristics to eliminate the undesirable ones. Furthermore, the regular aspect of the pseudo-convex hull helps detecting minima.

Minima are detected in fall/rise transitions from the inferior contour of connected components. Once the minimum points are determined in each connected component using the pseudo-convex hull, such minima must then be adjusted to a straight line. The usual would be to apply the least squares method using the straight line mathematical model $y = ax + b$, where a and b are parameters, a is the straight line skew and b the intercept, x and y are the coordinates of the word minimum points.

The criterion of minimizing the sum of the squares of the remainder, v_k, must be applied when there are more than two minimum points in the handwriting, i.e., $n > 2$. In mathematical notation, the least squares method is defined by:

$$\text{minimize}(\sum_{k=1}^{n} v_k^2) = \text{minimize}_{(a,b\in\Re)}(\sum_{k=1}^{n}[ax_k + b - y_k]^2)$$

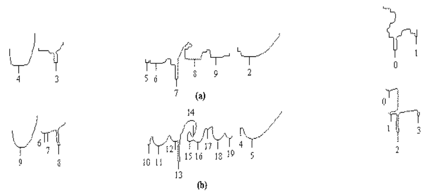

Figure 3. (a) Detection of minima in connected components employing the inferior pseudo-convex hull contour, (b) Example of detection of minima in words, using their original contour.

When different weights are applied to the remainder, the weighted least squares method is defined by minimize $\sum_{k=1}^{n} v_k^2 p_k$, where p_k is the weight of the corresponding remainder v_k. The parameter estimates are obtained, both for the weighted case and for the case in which the weights are considered units, by deriving the above expressions in relation to the parameters and equaling to zero. That procedure will not be demonstrated here because it is considered too trivial.

The undesirable minima detection methodology proposed in this paper is known in Geodesy as the "Danish Method" [10] or "Changing Weights" [8]. It consists in decreasing, at each iteration, the weight of the points the remainder of which surpasses a given pre-fixed iteration value. One of the weighting function methods [8] is:

$$p_{k+1} = p_k \begin{cases} p_k e^{-\left(\frac{|v_k|}{3\sigma}\right)} & \text{if } |v_k| \geq 3\sigma \\ p_k & \text{if } |v_k| < 3\sigma \end{cases} \quad \text{with } \sigma = \sqrt{\frac{\sum_{k=1}^{n} p_k v_k^2}{n-2}}$$

where σ is the standard deviation.

As a rule, the first iteration is performed without weights. In our event, in which handwritten words are processed, a different approach was adopted to increase the efficiency of the method. Such approach consists initially in defining and employing weights since the first iteration. The criterion adopted to define the weights p_k, with $k = 1, ..., n$, is:

$$p_k = \frac{1}{d_k^2} \quad \text{where} \quad d_k = \delta_k / min(\delta_k), \text{with } k = 1, ..., n$$

$$\text{and} \quad \delta_k = (y_k - y_{k-1})^2 + (y_k - y_{k+1})^2$$

Then the weight of the remainders surpassing the standard deviation value is decreased for the first two iterations. For the ensuing iterations, the criterion adopted is to decrease the weight of the remainders surpassing 3σ . Furthermore, better results were achieved using 2σ instead of 3σ in the weighting function exponential denominator.

5. Correction of the handwriting baseline skew

Once the straight line is adjusted by the weighted least squares methods, the global word skew is evaluated and corrected, by rotating the original image utilizing the one-pass implementation [3]. That aims to decrease the losses originating mainly from the pixel fractional addresses, avoiding gaps in the target image.

If necessary, the minima detected in the month of the date are filtered to eliminate the undesirable minima, again utilizing the weighted least squares approach. In the case of figures (day/year), the lowest minimum is preserved.

The use of Hook's transformation [15] to correct the skew of each connected set was eliminated, as opposed to the previous studies [11] [13] [12]. The correction of the ondulation of each connected component is now carried out, if needed, by positioning all the minima belonging to the connected component in the same vertical position of its first minimum, employing El Yacoubi's algorithm [15]. Once the undulation is corrected, the connected components are vertically repositioned so as to be aligned with the first connected component. To ensure a good correction of the undulation using this algorithm, the elimination of the undesirable minima is fundamental.

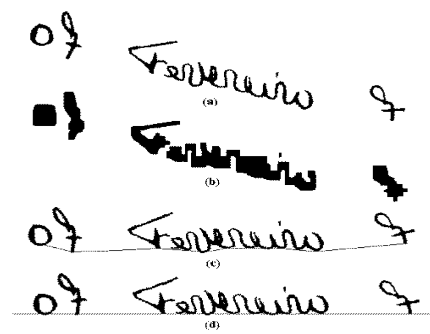

Figure 4. (a) Original image, (b) Pseudo-convex hull image, (c) Connection of the pre-filtered minima segments, (d) Image with the corrected skew.

6 Results Achieved

The tests were applied to 713 images of Brazilian bank checks; 81% were correctly processed (as opposed to 70% in [12]). In Fig. 4, interesting results in a complex image may be observed. In Fig. 5 the enhancement achieved by the use of the weighted least squares instead of least squares is seen. In the word "junho", where few minima are detected by the use of the pseudo-convex hull, only the Weighted Least Squares technique allowed the elimination of the undesirable minimum in "j". Because of word fragmentation, unsolved problems remain, like the one in Fig. 6, where the minimum of the fragmented component "ja" was eliminated, thus adversely affecting the correction. It may be seen that the elimination of only the really undesirable minima is fundamental, so as not to impair the handwriting baseline skew correction.

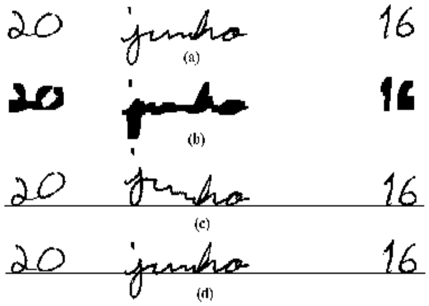

Figure 5. (a) Original image, (b) Pseudo-convex hull image (c) Miscorrected image with the use of the approach in [12], (d) Accurately corrected image.

7. Conclusion

The main goal of this approach was to demonstrate that it is possible to reduce the utilization of empirical thresholds in handwriting baseline skew correction. In this article it was shown that, by associating binary mathematical morphology techniques for the determination of the pseudo-convex hull to the weighted least squares method, the reduction of the empirical thresholds was made possible. In the case of handwritten words, though, the complete elimination of heuristics is still very difficult because of the complexity of handwriting. The utilization of the weighted least squares method allowed the reduction of such problems, leading to better results. Nevertheless, because of word fragmentation and the sometimes small number of minima extracted by the pseudo-convex hull, some problems in the elimination of undesirable minima occur, impairing the handwriting baseline skew correction. The association of this approach to classical techniques such as projection profiles, etc... is envisaged for future works.

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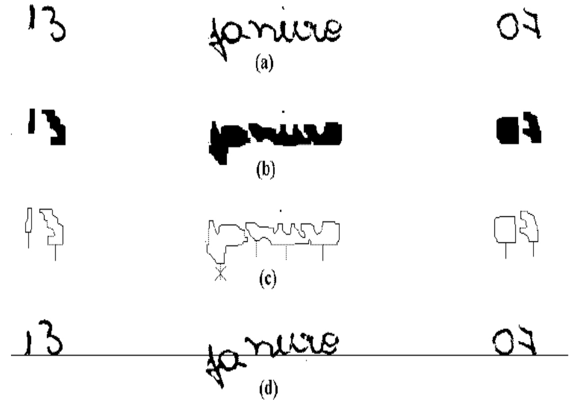

Figure 6. (a) Original image, (b) Pseudo-convex hull image, (c) Pre-filtered minima (d) Inaccurately corrected handwriting baseline skew.

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