Automatic Parameters Estimation for Document Binarization

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Abstract

Most of the document binarization techniques have many parameters that can initially be specified. Usually, subjective document binarization evaluation, employs human observers for estimation of the proper set of parameters for each one of the binarization techniques. Thus, the selection of the proper values for these parameters is crucial for the final binarization result. However, there is not any set of parameters that guarantees the best binarization result for all document images. It is important, the estimation of the proper values to be adaptive for each one of the processing images. Thus, this paper proposes a new technique which permits the estimation of the proper parameter values for each one of the document binarization techniques. The proposed approach is based on a statistical performance analysis of a set of binarization results obtained by the application of a binarization technique using different parameter values. Furthermore, using the statistical performance analysis, the best document binarization result of a set of document binarization techniques can also be estimated. In this way, document binarization techniques can be compared and evaluated using, for each one of them, the proper parameter values for every document image. Several experimental and comparative results, exhibiting the performance of the proposed technique, are presented.

Keywords: Binarization, Thresholding, Document Processing, Segmentation, Evaluation, Detection.
1. Introduction

Document binarization is an active area in image processing. Many binarization techniques for gray-scale, and recently, for color document images have been proposed. Most of these techniques have parameters, the proper values of which must initially be defined. It is obvious that the proper values of the parameter set (PS) are appropriate to the processing image and possibly to similar images. However, the estimation of the proper PS values should be applied again for dissimilar images. Although, the estimation of the proper PS values is a crucial stage, it is usually missed or heuristic estimated because there is no automatic parameter estimation process exists for document binarization techniques, until now. This paper proposes a new technique which can be used for the automatic estimation of the proper PS values for document binarization techniques.

In general, global [1-5] and local [6-14] binarization techniques can be applied for document binarization. In global techniques a global threshold value is used for all pixels while in local techniques different local threshold values are estimated and applied for each one of the pixels. The global binarization techniques are suitable for converting any gray-scale image into a binary form but are inappropriate for complex document images, and even more, for degraded document images. In cases of complex and degraded documents, the application of a local binarization technique gives better binarization results. In this category belong the techniques of Bernsen [6], Chow and Kaneko [7], Eikvil [8], Mardia and Hainsworth [9], Niblack [10], Taxt [11], Yanowitz and Bruckstein [12], and Sauvola and Pietikainen [13-14]. In another category, can be classified binarization techniques that are based on general clustering approaches such as the Fuzzy C-means (FCM) [19] algorithm and the Kohonen based techniques proposed by Papamarkos et al. [20-23]. Especially for document binarization, probably, the most powerful techniques are those that take into account not only the image gray-scale values, but also the structural characteristics of the characters. In this category belong methods that are based on stroke analysis, such as the stroke width (SW) and characters’ geometry properties. The ALLT and its improvement versions [15-16], [29] and IIFA [17-18], [29] are two of the most powerful techniques in this category.
Most of the binarization techniques, especially those coming from the category of local thresholding algorithms, have PS values that must be defined before their application to a document image. It is obvious that different values of the PS lead to different binarization results which mean that there is not a set of proper PS values for all types of document images. This has already proved by many evaluations that have been made so far (Trier and Taxt [24], Trier and Jain [25], Leedham et al. [26], Sezgin and Sankur [27]). Therefore, for every technique, in order to achieve the best binarization results the proper PS values must initially be estimated.

In this paper, a Parameter Estimation Algorithm (PEA), which can be used to detect the proper PS values of every document binarization technique, is proposed. The estimation is based on the analysis of the correspondence between the different document binarization results obtained by the application of a specific binarization technique to a document image, using different PS values. The proposed method is based on the work of Yitzhaky and Peli [28] which is used for edge detection evaluation. In their approach, a specific range and a specific step for each one of the parameters is initially defined. The proper values for the PS are then estimated by comparing the results obtained by all possible combinations of the PS values. The proper PS values are estimated using a Receiver Operating Characteristics (ROC) analysis and a Chi-square test. In order to improve this algorithm, we use a wide initial range for every parameter and in order to estimate the proper parameter value an adaptive convergence procedure is applied. Specifically, in each iteration of the adaptive procedure, the parameters’ ranges are redefined according to the estimation of the best and second best binarization result obtained. The adaptive procedure terminates when the ranges of the parameters values cannot be further reduced and the proper PS values are those obtained from the last iteration.

For document binarization, it is important to lead to the best binarization result comparing the binary images obtained by a set of independent binarization techniques. For this purpose, we introduce a new technique that, using the PEA, leads to the evaluation of the best binarization result obtained by a set of independent binarization techniques. Specifically, for every independent binarization technique the proper PS values are first estimated using the PEA. Next, the best document binarization results obtained in the previous stage are compared using the Yitzhaky and Peli method and the final best binarization result is achieved.
The proposed technique was extensively tested using a variety of documents most of which come from the old Greek Parliamentary Proceedings and from the University of Washington database [30]. Characteristic examples and comparative results are presented to confirm the effectiveness of the proposed method. The entire system has been implemented in a visual environment using Dephi 7.

2. Obtaining the best Binarization Result

When we binarize a document image, we do not know initially which is the optimum or the ideal result that we must obtain. This is a major problem in comparative evaluation tests. In order to have comparative results, it is important to estimate a ground truth image. By estimating the ground truth image we can compare the different results obtained, and therefore, we can estimate the best of it. This ground truth image, known as Estimated Ground Truth (EGT) image, can be selected from a list of Potential Ground Truth (PGT) images as proposed by Yitzhaky and Peli [28] for edge detection evaluation.

Consider \( N \) document binary images \( D_j \) \((j = 1, \ldots, N)\) obtained by the application of one or more document binarization techniques to a gray-scale document image of size \( K \times L \). In order to get the best binary image it is necessary to obtain first the EGT image. After this, the independent binarization results are compared with the EGT image using the Chi-square test.

The entire procedure is described in the following where with “0” and “1” are considered the background and foreground pixels, respectively.

**Stage 1** For every pixel, it is calculated how many binary images consider this as foreground pixel. The results are stored to a matrix \( C(x, y), x = 0, \ldots, K - 1 \) and \( y = 0, \ldots, L - 1 \). It is obvious that the values of this matrix will be between 0 and \( N \).

**Stage 2** \( N \) \( PGT_i, i = 1, \ldots, N \) binary images are produced using the matrix \( C(x, y) \).

Every \( PGT_i \) image is defined as the image that has as foreground pixels all the pixels with \( C(x, y) \geq i \).

**Stage 3** For each \( PGT_i \) image, four probabilities are defined:
• Probability that a pixel is a foreground pixel in both $PGT_i$ and $D_j$ images:

$$TP_{PGT_i,D_j} = \frac{1}{K \cdot L} \sum_{k=1}^{K} \sum_{l=1}^{L} PGT_i \cap D_j$$

(1)

• Probability that a pixel is a foreground pixel in $PGT_i$ image and background pixel in $D_j$ image:

$$FP_{PGT_i,D_j} = \frac{1}{K \cdot L} \sum_{k=1}^{K} \sum_{l=1}^{L} PGT_i \cap D_j$$

(2)

• Probability that a pixel is a background pixel in both $PGT_i$ and $D_j$ images:

$$TN_{PGT_i,D_j} = \frac{1}{K \cdot L} \sum_{k=1}^{K} \sum_{l=1}^{L} PGT_i \cap D_j$$

(3)

• Probability that a pixel is a background pixel in $PGT_i$ image and foreground pixel in $D_j$ image:

$$FN_{PGT_i,D_j} = \frac{1}{K \cdot L} \sum_{k=1}^{K} \sum_{l=1}^{L} PGT_i \cap D_j$$

(4)

$PGT_i$ and $PGT_j$ represent the background and foreground pixels in $PGT_i$ image, while $D_h$ and $D_j$ represent the background and foreground pixels in $D_j$ image. According to the above definitions, for each $PGT_i$ the average value of the four probabilities resulting from its match with each of the individual binarization results $D_j$, is calculated:

$$TP_{PGT} = \frac{1}{N} \sum_{j=1}^{N} TP_{PGT_i,D_j}$$

(5)

$$FP_{PGT} = \frac{1}{N} \sum_{j=1}^{N} FP_{PGT_i,D_j}$$

(6)
\[ TN_{PGT_i} = \frac{1}{N} \sum_{j=1}^{N} TN_{PGT_i,D_j} \]  
\[ FN_{PGT_i} = \frac{1}{N} \sum_{j=1}^{N} FN_{PGT_i,D_j} \]

**Stage 4** In this stage, the sensitivity \( TPR_{PGT_i} \) and specificity \( 1 - FPR_{PGT_i} \) values are calculated according to the relations:

\[ TPR_{PGT_i} = \frac{TP_{PGT_i}}{P} \]  
\[ FPR_{PGT_i} = \frac{FP_{PGT_i}}{1-P} \]

where \( P = TP_{PGT_i} + FN_{PGT_i}, \forall i \)

**Stage 5** This stage is used to obtain the EGT image. The EGT image is selected to be one of the \( PGT_i \) images.

For each \( PGT_i \), the \( X^2_{PGT_i} \) value is calculated, according to the relation:

\[ X^2_{PGT_i} = \frac{(sensitivity - Q_{PGT_i}) \cdot (specificity - (1-Q_{PGT_i}))}{(1-Q_{PGT_i}) \cdot Q_{PGT_i}} \]

where \( Q_{PGT_i} = TP_{PGT_i} + FP_{PGT_i} \). A histogram from the values of \( X^2_{PGT_i} \) is constructed (CT-Chi-square histogram). The best CT will be the value of \( i \) that maximizes \( X^2_{PGT_i} \). The \( PGT_i \) image in this CT level will be then considered as the EGT image. An example of a CT Chi-square histogram is shown in Figure 1 for \( N = 9 \). The detected CT level in this example is the fifth.

**Stage 6** For each image \( D_j \), four probabilities are defined:

- Probability that a pixel is a foreground pixel in both \( D_j \) and EGT images:

\[ TP_{D_j,EGT} = \frac{1}{K \cdot L} \sum_{k=1}^{K} \sum_{l=1}^{L} D_{j,k,l} \cap EGT_i \]
• Probability that a pixel is a foreground pixel in $D_j$ image and background pixel in EGT image:

$$FP_{D_j,\text{EGT}} = \frac{1}{K \cdot L} \sum_{k=1}^{K} \sum_{l=1}^{L} D_{ji} \cap \text{EGT}_i$$

(13)

• Probability that a pixel is a background pixel in both $D_j$ and EGT images:

$$TN_{D_j,\text{EGT}} = \frac{1}{K \cdot L} \sum_{k=1}^{K} \sum_{l=1}^{L} D_{ji} \cap \text{EGT}_i$$

(14)

• Probability that a pixel is a background pixel in $D_j$ image and foreground pixel in EGT image:

$$FN_{D_j,\text{EGT}} = \frac{1}{K \cdot L} \sum_{k=1}^{K} \sum_{l=1}^{L} D_{ji} \cap \text{EGT}_i$$

(15)

Stage 7 Stages 4 and 5 are repeated to compare each binary image $D_j$ with the EGT image, using the relations (12)-(15) rather than the relations (5)-(8) which calculated in Stage 3. According to the Chi-square test, the maximum value of $X^2_{D_j,\text{EGT}}$ indicates the $D_j$ image which is the estimated best document binarization result. Sorting the values of the Chi-square histogram, the binarization results are sorted according to their quality.

3. Parameter Estimation Algorithm

In the first stage of the proposed evaluation system it is necessary to estimate the proper PS values for the application to the processing image of each one of the independent document binarization techniques. This estimation is based on the method of Yitzhaky and Peli [28] proposed for edge detection evaluation. However, in order to increase the accuracy of the estimated proper PS values we improve this algorithm by using a wide initial range for every parameter and an adaptive convergence procedure. That is, the parameters’ ranges are redefined according to the estimation of the best and second best binarization result obtained in each iteration of the adaptive procedure. This procedure terminates when the ranges of the parameters values cannot be further reduced and the proper PS values are those obtained from
the last iteration. It is important to notice that this is an adaptive procedure because it is applied to every processing document image.

The stages of the proposed parameter estimation algorithm, for two parameters \((P_1, P_2)\), are as follows:

**Stage 1** Define the initial range of the PS values. Consider as \([s_1, e_1]\) the range for the first parameter and \([s_2, e_2]\) the range for the second one.

**Stage 2** Define the number of steps that will be used in each iteration. For the two parameters case, let \(St_1\) and \(St_2\) be the numbers of steps for the ranges \([s_1, e_1]\) and \([s_2, e_2]\), respectively. In most cases \(St_1 = St_2 = 3\).

**Stage 3** Calculate the lengths \(L_1\) and \(L_2\) of each step, according to the following relations:

\[
L_1 = \frac{e_1 - s_1}{St_1 - 1}, \quad L_2 = \frac{e_2 - s_2}{St_2 - 1}
\]

**Stage 4** In each step, the values of parameters \(P_1, P_2\) are updated according to the relations:

\[
P_1(i) = s_1 + i \cdot L_1, \quad (i = 0, \ldots, St_1 - 1)
\]

\[
P_2(i) = s_2 + i \cdot L_2, \quad (i = 0, \ldots, St_2 - 1)
\]

**Stage 5** Apply the binarization technique to the processed document image using all the possible combinations of \((P_1, P_2)\). Thus, \(N\) binary images \(D_j, j = 1, \ldots, N\) are produced, where \(N\) is equal to \(N = St_1 \cdot St_2\).

**Stage 6** Examine the \(N\) binary document results, using the algorithm described in Section 2, to estimate the best and the second best document binarization results. Let \((P_{1b}, P_{2b})\) and \((P_{1s}, P_{2s})\) be the parameters’ values obtained from the best and the second best binarization results, respectively.

**Stage 7** Redefine the ranges for the two parameters as \([s_1', e_1']\) and \([s_2', e_2']\) that will be used during the next iteration of the method, according to the relations:
Stage 8 Redefine the steps $St'_1, St'_2$ for the ranges that will be used in the next iteration according to the relations:

$$[s'_1, e'_1] = \begin{cases} 
  \text{If } P_{1b} \neq P_{1s} \text{ then } & \begin{cases} 
    \text{If } P_{1b} > P_{1s} \text{ then } [s'_1, e'_1] = [P_{1s}, P_{1b}] \\
    \text{If } P_{1b} < P_{1s} \text{ then } [s'_1, e'_1] = [P_{1b}, P_{1s}] 
  \end{cases} \\
  \text{If } P_{1b} = P_{1s} = A \text{ then } [s'_1, e'_1] = \left[ \frac{s_1 + A}{2}, \frac{e_1 + A}{2} \right] 
\end{cases}$$  \hspace{1cm} (19)

$$[s'_2, e'_2] = \begin{cases} 
  \text{If } P_{2b} \neq P_{2s} \text{ then } & \begin{cases} 
    \text{If } P_{2b} > P_{2s} \text{ then } [s'_2, e'_2] = [P_{2s}, P_{2b}] \\
    \text{If } P_{2b} < P_{2s} \text{ then } [s'_2, e'_2] = [P_{2b}, P_{2s}] 
  \end{cases} \\
  \text{If } P_{2b} = P_{2s} = A \text{ then } [s'_2, e'_2] = \left[ \frac{s_2 + A}{2}, \frac{e_2 + A}{2} \right] 
\end{cases}$$  \hspace{1cm} (20)

Stage 9 If $St'_1 \cdot St'_2 > 3$ go to Stage 3 and repeat all the stages. The iterations terminate when the calculated new steps for the next iteration have a product less or equal to 3 ($St'_1 \cdot St'_2 \leq 3$). The proper PS values are those estimated during the Stage 6 of the last iteration.

4. Comparing the results of different binarization techniques

The proposed evaluation technique can be extended to estimate the best binarization results by comparing the binary images obtained by independent techniques. The algorithm described in Section 2 can be used to compare the binarization results obtained by the application of independent document binarization techniques. Specifically, the best document binarization results obtained from the independent techniques using the proper PS values are compared through the procedure described in Section 2. That is, the final best document binarization result is obtained as follows:

Stage 1 Estimate the proper PS values for each document binarization technique, using the PEA described in Section 3.
**Stage 2** Obtain the document binarization results from each one of the independent binarization techniques by using their proper PS values.

**Stage 3** Compare the binary images obtained in Stage 2 and estimate the final best document binarization result by using the algorithm described in Section 2.

### 5. The binarization techniques included in the evaluation system

In order to achieve satisfactory document binarization results a number of powerful binarization techniques are included in the proposed evaluation system. Two of them are global binarization techniques, three belong to the category of local binarization techniques and two are document binarization techniques that are based on structural characteristics of the characters. Specifically, the binarization techniques that were implemented and included in the proposed evaluation system are:

1. Otsu’s technique [1]
2. Fuzzy C-Mean (FCM) [19]
3. Niblack’s technique [10]
4. Sauvola and Pietikainen’s technique [13-14]
5. Bernsen’s technique [6]
6. Adaptive Logical Level Technique (ALLT) [15-16], [29]
7. Improvement of Integrated Function Algorithm (IIFA) [17-18], [29]

The Otsu’s technique [1] is a global binarization method while FCM [19] performs global binarization by using fuzzy logic. In the category of local binarization techniques belong the techniques of Bernsen [6], Niblack [10] and Sauvola and Pietikainen [13-14]. Each one of these techniques uses two parameters to calculate a local threshold value for each pixel. Then, this threshold value is used locally in order to decide if a pixel is considered as foreground or background pixel. The relations that give the local threshold values $T(x, y)$ for each one of these techniques are:

1. **Bernsen’s technique**

\[
T(x, y) = \begin{cases} 
\frac{P_{low} + P_{high}}{2}, & \text{if } P_{high} - P_{low} \geq L \\
GT, & \text{if } P_{high} - P_{low} < L 
\end{cases}
\]

(23)
where $P_{low}$ and $P_{high}$ are the lowest and the highest gray-level value in a $N \times N$ window centered in the pixel $(x, y)$, respectively and $GT$ a global threshold value (for example a threshold value that is calculated from the application of the method of Otsu to the entire image). The window size $N$ and the parameter $L$ are the two independent parameters of this technique.

2. Niblack’s technique

$$T(x, y) = m(x, y) + k \cdot s(x, y)$$

(24)

where $m(x, y)$ and $s(x, y)$ are the local mean and standard deviation values in a $N \times N$ window centered in the pixel $(x, y)$, respectively. The window size $N$ and the constant $k$ are the two independent parameters of this technique. It should be noticed that in our experiments the Niblack’s technique is used without any post-processing step.

3. Sauvola and Pietikainen’s technique

$$T(x, y) = m(x, y) \left[ 1 + k \left( 1 - \frac{s(x, y)}{R} \right) \right]$$

(25)

where $m(x, y)$ and $s(x, y)$ are the same as in the previous technique and $R$ is equal to 128 in most cases. The window size $N$ and the constant $k$ are the two independent parameters of this technique.

The ALLT [15-16] and the IIFA [17-18] belong to the category of document binarization techniques that are based on structural text characteristics such as the characters’ stroke width. In order to improve further the document binarization results, obtained by these techniques, significant improvements are proposed by Badekas and Papamarkos [29] and these versions of techniques are included in the proposed evaluations system. Our experiments show that these techniques are very stable when they are applied to different types of document images. However, ALLT is more sensitive in the definition of its parameter $a$ comparing to the definition of the IIFA’s parameter $T_p$. 


6. Experimental Results

Three experiments that use the proposed evaluation technique were performed and described in this section. Because there is not available the ground through binary images a psycho-visual experiment is also included in which the binarization results obtained are compared by individual people. The specific experiment proves the effectiveness of the proposed automatic evaluation procedure.

Experiment 1

In this experiment the proposed evaluation technique is used to compare and estimate the best document binarization result produced by the seven independent binarization techniques described in Section 5. The local document binarization techniques are very sensitive to the definition of their parameters, in spite of ALLT and IIFA which seem to be more stable. The Otsu’s technique has no parameters to define and FCM is used with a value of fuzzyfier \( m \) equal to 1.5.

Figure 2 shows the original document image used in this experiment which is coming from the old Greek Parliamentary Proceedings. The proper PS values obtained and the initial range for each parameter are given in Table 1. The proper PS values are obtained using five iterations. Table 2 gives all the PS values obtained during the five iterations and also the best and second best binarization results that are estimated in each iteration. As it is described in the PEA, the best and the second best binarization results in every iteration define the parameters ranges for the next iteration. The proper PS values of the independent document binarization techniques obtained after the five iterations, correspond to the binary document images shown in Figures 3-7. Furthermore, the document binary images obtained by the application of the Otsu and FCM are shown in Figures 8-9.

Finally, the best binarization results obtained in the previous stage (Figures 3-9) are compared using the algorithm described in Section 2. Figure 10 shows the CT Chi-square histogram constructed in order to select the EGT image. The detected EGT image is the \( PGT_i \) image that appears the maximum value (IIFA level).

Comparing the EGT image with the independent binarization results, it is concluded that the best document binarization result is the one obtained from the ALLT (Figure 6) while the second best document binarization result is coming from the Sauvola’s
technique (Figure 4). The comparison results obtained using the chi-square test is shown in the histogram of Figure 11.

**Experiment 2**

The proposed technique has been extensively tested with document images from the University of Washington database. This experiment describes the application of the proposed evaluation procedure to the document image shown in Figure 12 which is obtained from the above database. Using the same parameters values and the same initial ranges, as in the previous experiment, we lead to the estimation of the proper PS values for all techniques as they given in Table 3.

The binary images obtained by the seven binarization techniques are depicted in Figures 13-19. The FCM technique (Figure 19) gives the estimated best binarization result. Figure 20 shows the comparison results for the seven binarization techniques.

**Experiment 3**

This final experiment demonstrates the application of the proposed technique to a large number of document images obtained from the old Greek Parliamentary Proceedings. The goal of this experiment is to evaluate the seven independent binarization techniques and to decide which of them gives the best results in the specific database. For each document image, the binarization results obtained, by the application of the independent binarization techniques, are sorted according to the ordering quality results obtained by the proposed evaluation method. The rating value for a document binarization technique can be between 1 (best) and 7 (worst). The mean rating value for each binarization technique is then calculated and the histogram shown in Figure 21 is constructed using these values. It is obvious that the minimum value of this histogram is assigned to the binarization technique which has the best performance for the specific document image database. According to the evaluation results obtained it is concluded that for the specific database the Sauvola and Pietikainen’s technique gives, in most of the cases, the best document binarization results. This conclusion agrees with other evaluation tests such as the test performed by Sezgin and Sankur [27].
Experiment 4

In order to prove the effectiveness of the proposed evaluation technique, a psycho-visual experiment is performed asking a group of people to compare visually the results obtained in Experiment 3 by the independent binarization techniques. These results were printed and given to 20 persons and we asking them to sort the images according to their quality. The mean rating values obtained in this experiment are similar to the values obtained in the previous experiment with a variation of ±0.25. The corresponding histogram constructed in this psycho-visual experiment is shown in Figure 22.
7. Conclusions

This paper proposes a method for the estimation of the proper PS values of a document binarization technique and the best binarization result obtained by a set of independent document binarization techniques. In the case of using one binarization technique, it is important that the proper PS values are adaptively estimated according to the processing document image. The proposed method is extended to produce an evaluation system for independent document binarization techniques. The estimation of the proper PS values is achieved by applying an adaptive convergence procedure starting from a wide initial range for every parameter. The entire system was extensively tested with a variety of document images. Many of them came from standard document databases such as the University of Washington database and the old Greek Parliamentary Proceedings. Several experimental results are presented that confirm the effectiveness of the proposed system. The entire system is implemented in visual environment using Delphi 7.
References


Table 1. Initial ranges and the estimated proper PS values for Experiment 1

<table>
<thead>
<tr>
<th>Technique</th>
<th>Initial ranges</th>
<th>Proper PS values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Niblack</td>
<td>[W \in [3,15], \ k \in [0.2,1.2]]</td>
<td>(W = 14) and (k = 0.67)</td>
</tr>
<tr>
<td>2. Sauvola</td>
<td>(W \in [3,15], \ k \in [0.1,0.6])</td>
<td>(W = 14) and (k = 0.34)</td>
</tr>
<tr>
<td>3. Bernsen</td>
<td>(W \in [3,15], \ L \in [10,90])</td>
<td>(W = 14) and (L = 72)</td>
</tr>
<tr>
<td>4. ALLT</td>
<td>(\alpha \in [0.1,0.4])</td>
<td>(\alpha = 0.10)</td>
</tr>
<tr>
<td>5. IIFA</td>
<td>(T_p \in [10,90])</td>
<td>(T_p = 10)</td>
</tr>
</tbody>
</table>

Table 2. The five iterations that applied in order to detect the proper PS values for each binarization technique in Experiment 1

<table>
<thead>
<tr>
<th>Iteration</th>
<th>Niblack</th>
<th>Sauvola</th>
<th>Bernsen</th>
<th>ALLT</th>
<th>IIFA</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>1. (a=10) (1st)</td>
<td>2. (a=18) (2nd)</td>
<td>3. (a=18)</td>
<td>1. (T_p=10) (2nd)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. (a=18)</td>
<td>3. (a=18)</td>
<td>3. (a=26)</td>
<td>2. (T_p=10) (2nd)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. (a=18)</td>
<td>3. (a=26)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. (a=40)</td>
<td>3. (T_p=50)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. (T_p=90)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second</td>
<td>1. (a=10) (1st)</td>
<td>2. (a=18) (2nd)</td>
<td>3. (a=18)</td>
<td>1. (T_p=10) (2nd)</td>
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<td>3. (a=26)</td>
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<td>3. (a=14)</td>
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<td>Fourth</td>
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<td>3. (a=14)</td>
<td>1. (T_p=10) (1st)</td>
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<td>4. (T_p=20)</td>
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<tr>
<td>Fifth</td>
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Table 3. Initial ranges and the estimated proper PS values for Experiment 2

<table>
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<tr>
<th>Technique</th>
<th>Initial ranges</th>
<th>Proper PS values</th>
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<tbody>
<tr>
<td>1. Niblack</td>
<td>(W \in [3,15], \ k \in [0.2,1.2])</td>
<td>(W = 14) and (k = 0.65)</td>
</tr>
<tr>
<td>2. Sauvola</td>
<td>(W \in [3,15], \ k \in [0.1,0.6])</td>
<td>(W = 11) and (k = 0.34)</td>
</tr>
<tr>
<td>3. Bernsen</td>
<td>(W \in [3,15], \ L \in [10,90])</td>
<td>(W = 8) and (L = 80)</td>
</tr>
<tr>
<td>4. ALLT</td>
<td>(\alpha \in [0.1,0.4])</td>
<td>(\alpha = 0.10)</td>
</tr>
<tr>
<td>5. IIFA</td>
<td>(T_p \in [10,90])</td>
<td>(T_p = 12)</td>
</tr>
</tbody>
</table>
Figure 1. An example of a CT Chi-square histogram. The fifth level is the CT level.

Figure 2. Initial gray-scale document image

Figure 3. Binarization result of Niblack’s technique with $W = 14$ and $k = 0.67$

Figure 4. Binarization result of Sauvola’s technique with $W = 14$ and $k = 0.34$

Figure 5. Binarization result of Bernsen’s technique with $W = 14$ and $L = 72$
Figure 6. Binarization result of ALLT with $a = 0.1$

Figure 7. Binarization result of IIFA with $T_p = 10$

Figure 8. Binarization result of Otsu’s technique

Figure 9. Binarization result of FCM

Figure 10. The CT Chi-square histogram constructed to estimate the $EGT$ image of Figures 2-8
Figure 11. The comparison results in Experiment 1

Figure 12. Original gray-scale document image
Figure 13. Binarization result of Niblack’s technique with $W = 14$ and $k = 0.65$

Figure 14. Binarization result of Sauvola’s technique with $W = 11$ and $k = 0.34$
Figure 15. Binarization result of Bernsen’s technique with $W = 8$ and $L = 80$

Figure 16. Binarization result of ALLT with $a = 0.1$
Figure 17. Binarization result of IIFA with $T_p = 12$

Figure 18. Binarization result of Otsu's technique
Figure 19. Binarization result of FCM

Figure 20. The comparison results in Experiment 2
Figure 21. The histogram constructed by the mean rating values in Experiment 3. Sauvola and Pietikainen’s technique is the binarization technique with the best performance in the examined document image database.

Figure 22. The histogram constructed by the mean rating values in Experiment 4.