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A New Approach to Water Flow Algorithm for Text Line Segmentation

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Abstract: This paper proposes a new approach to water flow algorithm for the text line segmentation. Original method assumes hypothetical water flows under a few specified angles to the document image frame from left to right and vice versa. As a result, unwetted image frames are extracted. These areas are of major importance for text line segmentation. Method modifications mean extension values of water flow angle and unwetted image frames function enlargement. Results are encouraging due to text line segmentation improvement which is the most challenging process stage in document image processing.

Keywords: Document image analysis, Text line segmentation, Morphological operation, Bounding box, Water flow algorithm
Categories: I.4, I.4.1, I.4.3, I.4.6, I.7, I.7.2

1 Introduction

Text line segmentation represents one of the most important steps in document image analysis. It implies a labelling process which assign the same label to spatially aligned units i.e. pixel, connected components or characteristic points [Likforman-Sulem et al., 2007]. Further, based on the obtained labels, text is divided into different areas each one representing text line. After text line segmentation is finished, it provides the essential information for the consecutive documents image steps such as skew detection and correction, text feature extraction and character recognition. Hence, it is prerequisite for the further process of document image analysis. Although some text line detection techniques are successful in printed documents, processing of handwritten documents has remained a key problem in optical character recognition (OCR) [Amin and Wu, 2005]. Most text line segmentation methods are based on the assumptions that distance between neighbouring text lines is significant as well as that text lines are reasonably straight. However, these assumptions are not characterized for handwritten documents. Therefore, text line segmentation is a leading challenge in document image analysis [Likforman-Sulem et al., 2007].

Related work on text line segmentation can be categorized in few directions [Likforman-Sulem et al., 2007]: projection based methods, Hough transform methods, smearing methods, grouping methods, methods for processing overlapping and touching components, stochastic methods, others methods.

Projection base methods have been primarily used for printed document segmentation, but it can be adapted for handwritten documents as well. It uses the vertical projection profile (VPP), which is obtained by summing pixel values along the horizontal axis for each y value. Method is based on identifying valleys in VPP. This is accomplished by finding its maximum and minimum value [Silva et al., 2009]. Because of method drawbacks, short lines will provide low peaks, and very narrow lines. Similarly, text lines including many overlapping components will not produce significant peaks. Hence, method failed to be efficient for multi-skewed text lines.

The Hough transform [Ballard, 1981] is a widespread technique for finding straight lines in the images. Consequently, image is transformed in the Hough domain. Potential alignments are hypothesized in Hough domain and validated in the image domain. Apart from that, projection profile and Hough transform are identical methods in principle. Projection profile shows more variation when the profile is in the direction to the document skew. The direction for the maximum variation is then determined by a cost function. Similarly, the "voting" function in Hough domain determine slope of the straight line [Amin and Fischer, 2000].

In smearing methods the consecutive black pixels along the horizontal direction are smeared [Shi and Govindaraju, 2004]. Consequently, the white space between black pixels is filled with black pixels. It is valid only if their distance is within a predefined threshold. This way, enlarged areas of black pixels around text are formed. It is so-called boundary growing areas. These areas of the smeared image enclose separated text lines. Hence, obtained areas are mandatory for text line segmentation.

Grouping methods is based on building alignments by aggregating them [Likforman-Sulem and Faure, 1994]. The units may be pixels or connected components, blocks or other features such as salient points. These units are joined together to form alignments. The joining scheme is based on both local and global criteria used for checking consistency. If the nearest neighbour belongs to another line, then the nearest-neighbour joining scheme will fail to group complex handwritten units contrary to the printed documents.

Method for overlapping and touching components detects such components during the grouping process when a conflict occurs between two alignments [Zahour et al., 2001]. Further, it applies a set of rules to label overlapping or touching components. These components extend in each alignment region. The rules use as features the density of black pixels of the component in each alignment region, alignment proximity and positions of both alignments around the component. An overlapping component will be assigned to only one alignment. And the separation of a touching component is roughly performed by drawing a horizontal frontier segment. The frontier segment position is decided by analyzing the component VPP. If VPP includes two peaks, the cut will be done in the middle way from them. Otherwise, the component will be cut into two equal parts.

Stochastic method is based on probabilistic algorithm, which accomplished non-linear paths between overlapping text lines. These lines are extracted through hidden Markov modelling (HMM) [Koshinaka et al., 2004]. This way, the image is divided into little cells. Each one them correspond to the state of the HMM. The best segmentation paths are searched from left to right. In the case of touching components, the path of highest probability will cross the touching component at points with as less black pixels as possible. However, the method may fail in the case that contact point contains a lot of black pixels.

Method proposed in [Basu et al., 2006] is classified in smearing methods. This algorithm hypothetically assumed a flow of water in a particular direction across image frame in a way that it faces obstruction from the characters of the text lines. As a result of water flow algorithm, unwetted image frames are extracted. These areas are of major importance for text line segmentation. In our paper, this algorithm adapted in [Brodić and Milivojević, 2010] is further improved, implemented and examined.

The rest of the paper is organized as follows: Section 2 includes general approach to document image processing system. Section 3 incorporates pre-processing stage. Section 4 describes basic and new approach to water flow algorithm. Section 5 defines experiments framework. Section 6 includes test results and its comparative analysis. Section 7 includes conclusions. Section 8 proposes idea for the future work.

2 Document Image Processing System

Although document conversion system incorporates scanning, binarization, region segmentation, text recognition and document analysis, its procedure can be divided into three main stages: pre-processing, processing and post-processing, such as shown in Figure 1.

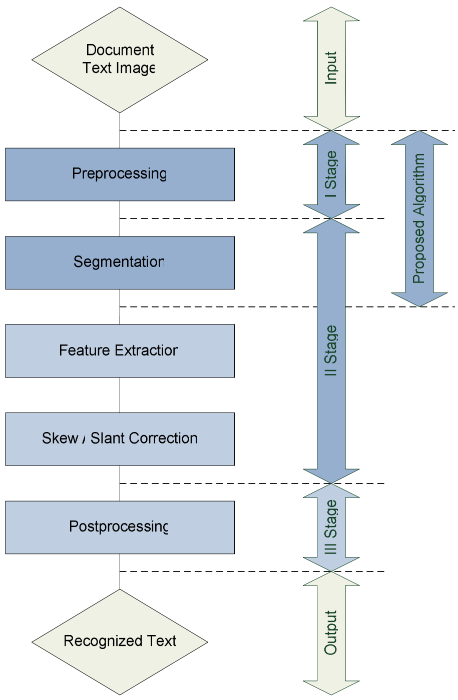


Figure 1: Document text image identification procedure

In the first stage, algorithms for document text image binarization and normalization are applied. After pre-processing stage, text is prepared for segmentation, feature extraction and character recognition. During the second stage, algorithm for text segmentation, skew rate and reference text line identification is enforced. Also, reference text based on skew and stroke angle, is straightened and repaired. Finally, in third stage character recognition process is applied.

3 Pre-processing

As a result of scanning process, document text image is obtained. It is an input of text grayscale image described by following intensity matrix [Gonzales and Woods, 2002]:

$$D(i, j) \in [0, \ldots, 255] \quad , \tag{1}$$

where $i \in [1, M]$ and $j \in [1, N]$.

After applying intensity segmentation with binarization, intensity function is converted into binary form given by:

$$X(i, j) = \begin{cases} 1 & for \quad D(i, j) \geq D_{th} \\ 0 & for \quad D(i, j) < D_{th} \end{cases} \quad , \tag{2}$$

where D_{th} is given by Otsu algorithm [Otsu, 1979]. It represents the threshold sensitivity decision value. Similar methods for binarization proposed in [Sauvola and Pietikainen, 2000], [Bukhari et al., 2009] and [Khashman and Sekeroglu, 2008] can be used instead the above method.

Document text image is black and white image represented by matrix **X**. Each character or word consists of the only black pixels. Hence, every point $X(i, j)$ i.e. $X_{i,j}$ is represented by number of coordinate pairs (0, 1), where $i = 1, \ldots, M$, $j = 1, \ldots, N$ of matrix **X** [Gonzales and Woods, 2002]. It is represented by document text image fragment as in Figure 2.

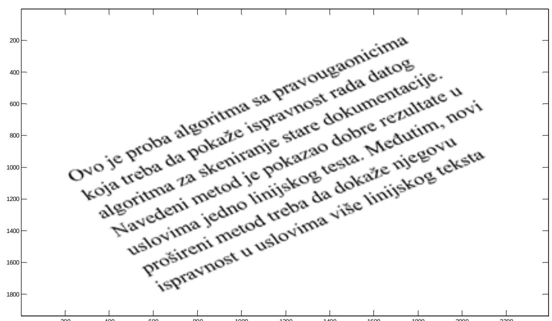


*Figure 2: Document text image fragment represented by matrix **X***

3.1 Morphological Pre-processing

Further, morphological preprocessing is performed to make document text image “noiseless”. The morphological preprocessing was defined in [Brodić and Dokić, 2010] by following steps:

1. Erosion of the document image:

$$\mathbf{X}_{\mathrm{e}} = \mathbf{X} \ominus \mathbf{S}_1, \tag{3}$$

2. Dilatation of the eroded document image, i.e. opening of the document image:

$$\mathbf{X}_{\mathrm{o}} = \mathbf{X} \circ \mathbf{S}_1 = \mathbf{X}_{\mathrm{e}} \oplus \mathbf{S}_1 = (\mathbf{X} \ominus \mathbf{S}_1) \oplus \mathbf{S}_1, \tag{4}$$

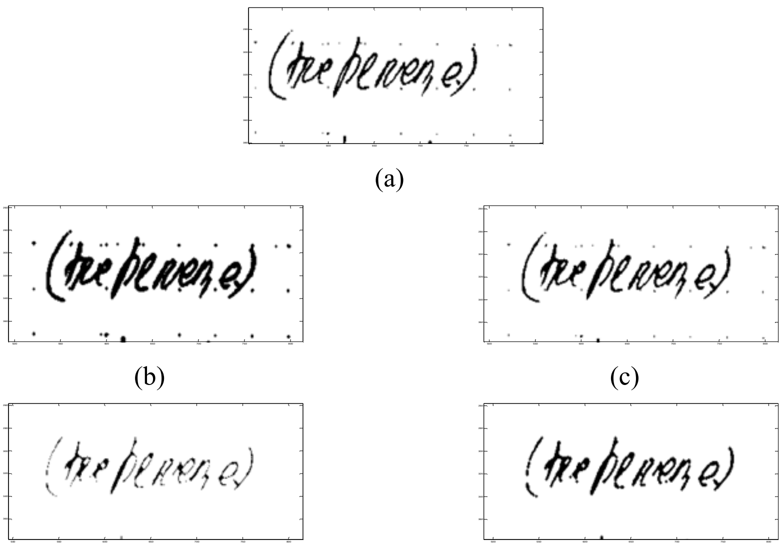
3. Dilatation of the opened document image, i.e. double dilatation of the eroded document image:

$$\mathbf{X}_{\mathrm{do}} = (\mathbf{X} \circ \mathbf{S}_1) \oplus \mathbf{S}_1 = \mathbf{X}_{\mathrm{o}} \oplus \mathbf{S}_1 = ((\mathbf{X} \ominus \mathbf{S}_1) \oplus \mathbf{S}_1) \oplus \mathbf{S}_1, \tag{5}$$

4. Closing of the opened document image, i.e. erosion of the double dilatation of the eroded document image:

$$\mathbf{X} = (\mathbf{X} \circ \mathbf{S}_1) \bullet \mathbf{S}_1 = \mathbf{X}_{\mathrm{do}} \ominus \mathbf{S}_1 = (((\mathbf{X} \ominus \mathbf{S}_1) \oplus \mathbf{S}_1) \oplus \mathbf{S}_1) \ominus \mathbf{S}_1. \tag{6}$$

For the above operations, structuring element $\mathbf{S}_1$ dimension 3x3 is used [Gonzales and Woods, 2002]. Morphological pre-processing functionality is shown in Figure 3.



(a) (b) (c) (d) (e)

Figure 3: Morphological pre-processing steps: (a) noisy document image fragment, (b) erosion, (c) opening, (d) dilatation of the opening, (e) closing of the opening

3.2 Bounding Box

Next prerequisite is the extraction of the bounding box over the text objects. Special case of the bounding box is a rectangular region whose edges are parallel to the coordinate axes. It is defined by its endpoints: x_{min}, y_{min}, x_{max}, y_{max}. Hence, each pixel X(i, j) that belongs to the box is given by [Preparata and Shamos, 1985]:

$$X(i, j) \,\big|\, (x_{\min} \le i \le x_{\max}) \wedge (y_{\min} \le j \le y_{\max}) \ . \tag{7}$$

Inclusion of the point X(i, j) in a bounding box is tested by verifying above four inequalities. If any one of them fails, then the point is not inside it. Bounding box definition is shown in Figure 4.

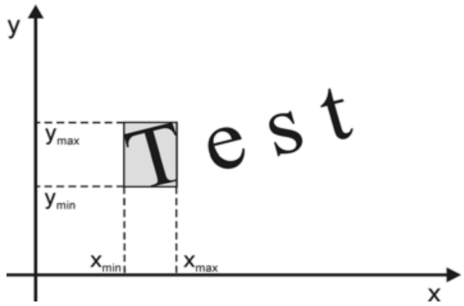


Figure 4: Bounding box definition

All separated text elements like letters, part of words or words are surrounded by bounding boxes [Wang et al., 1997]. Bounding box example over sample text is shown in Figure 5.

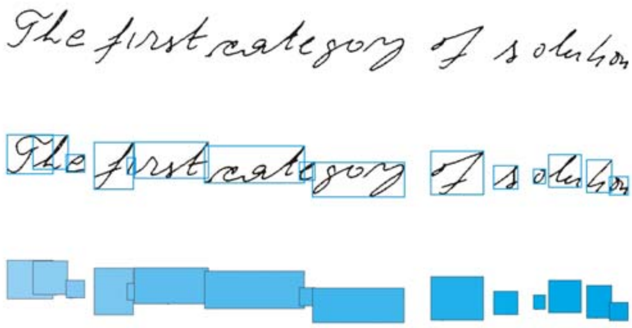


Figure 5: Bounding boxes over the text objects

Each of them represents the distinct control area where water flow algorithm will be activated. It is valid only for object corresponding to the text in that area. Thereby, obtained bounding boxes represent control areas authorized for the water flow algorithm criteria application. Hence, they are prerequisite for the new approach to water flow algorithm.

3.3 Basic Water Flow Algorithm

Original water flow algorithm proposed in [Basu et al., 2006] assumes hypothetical water flows under a few angles of the document image frame from left to right and vice versa. In this hypothetically assumed situation, water is flowing across the image frame. For the water flows from left to right, the situation is shown in Figure 6.

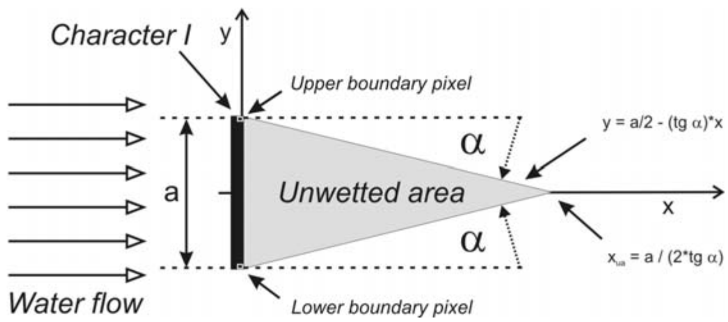


Figure 6: Unwetted area definition

Areas that are not wetted form unwetted ones. The stripes of unwetted areas are labelled for the extraction of text lines. Further, this hypothetical water flow is expected to fill up the gaps between consecutive text lines. Hence, unwetted areas left on the image frame lies under the text lines. Once the labelling is completed, the image is divided into two different types of stripes. First one contains text lines. The other one contains line spacing.

Furthermore, flow angle α as a referent parameter (see Figure 5) is introduced in [Basu et al., 2006]. It is measured between two lines which intersect each other at the endpoint of an obstacle. It is formed by labelling original document image using spatial filter mask. These masks, with the size of 3 x *P*, where *P* = {2, …, 5}, are used in [Basu et al., 2006]. This way, algorithm simply creates unwetted areas under fixed flow angles α of: 14°, 18°, 26.6° and 45°. For the water flows from left to right, the situation is shown in Figure 7.

●	○
●	●
●	○

(a)

●	○	○
●	●	●
●	○	○

(b)

●	○	○	○
●	●	●	●
●	○	○	○

(c)

●	○	○	○	○
●	●	●	●	●
●	○	○	○	○

(d)

Figure 7: Filter mask defined by flow angle α: (a) 45°, (b) 26.6°, (c) 18°, (d) 14°

Using of the spatial filter masks is defined by the position of the text black pixels. They represent prospective seed points. If the pixel represents lower or upper boundary one, then the spatial filter mask will be exploited. Thus, it activates the algorithm process. As the result, unwetted stripes bounded text. This circumstance is shown in Figure 8.

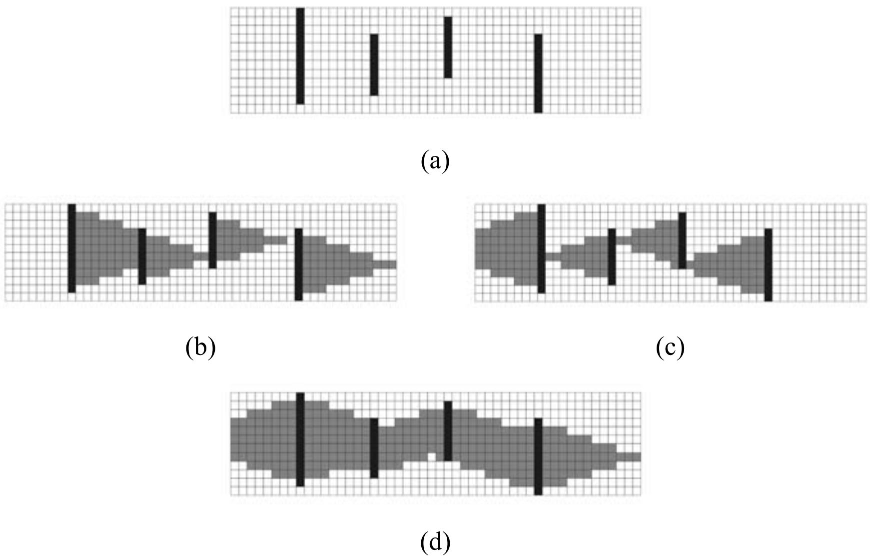


Figure 8: Water flow algorithm involving water flow angle α of 18°: (a) initial text containing four I letters, (b) unwetted areas made by water flow from left to right, (c) unwetted areas made by water flow from right to left, (d) united unwetted areas

3.4 A New Approach to the Water Flow Algorithm

Apart from original algorithm procedure, unwetted areas could be determined by lines. Each line is defined as:

$$y = kx + b, \tag{8}$$

where slope k = tan(α). Two lines defined by angle ±α make connection in specific pixel creating closed unwetted area (see Figure 6, parameter b = 0) [Brodić and Milivojević, 2010].

Modification made on water flow algorithm is in its formulation. It forms the water flow function which determines the water flow angle value. Still, making straight lines from boundary pixel type and connecting each others in specified point makes unweted region as well. Hence, modified water flow algorithm is free to choose different flow angle α from 0º to 90º. In addition, different decision-making process on boundary text pixels is made. Figure 9 illustrates these circumstances [Brodić and Milivojević, 2010].

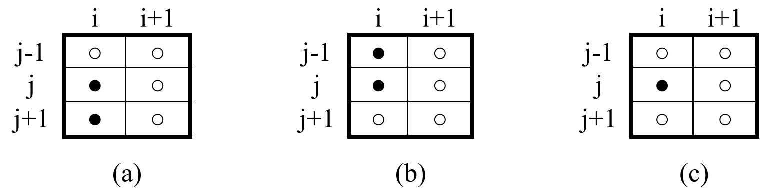


Figure 9: Pixel type determination: (a) upper boundary pixel, (b) lower boundary pixel, (c) boundary pixel for additional investigation

Due to pixel type, i.e. upper or lower, slope is $-\alpha$ or $+\alpha$, respectively. However, pixel without complete location has been additionally investigated. It depends on neighbor area of pixels. Apart from [Gonzales and Woods, 2002], enlarged window composed of *R* x *S* pixels, defined as a basis. In [Brodić and Milivojević, 2009] $R = 5$ and $S = 7$ is proposed. It is shown in Figure 10.

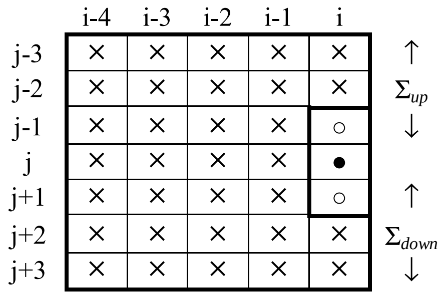


Figure 10: Enlarged window for the investigation of the boundary pixel

Position of window is backwards from investigated pixel candidate. Relation between Σ_{up} and Σ_{down} defines pixel attitude. Firstly, Σ_{up} or Σ_{down} represents sum of the black pixel in upper or lower marked region. Hence, the following is valid [Brodić and Milivojević, 2009]: it is lower boundary pixel if $\Sigma_{up} > \Sigma_{down}$, upper boundary pixel if $\Sigma_{up} < \Sigma_{down}$, or else no boundary pixel.

In proposed approach defined in (4), algorithm can choose different water flow angle α from the set $\{0° \div 90°\}$. Unfortunately, whole range of α isn't applicable due to impossibility of joining words to form text line regions.

4 Experiments

Algorithm quality examination consists of few text experiments representing test procedure. Basic and new approach to water flow algorithm is evaluated by combined text experiments framework. Due to the algorithm nature, only text line segmentation quality is examined. It is based on the following tests:

- Multi-line text segmentation test,
- Multi-line waved text segmentation test,

- Multi-line fractured text segmentation test,
- Handwritten text segmentation test.

Its schematic diagram of the test procedure is shown in Figure 11.

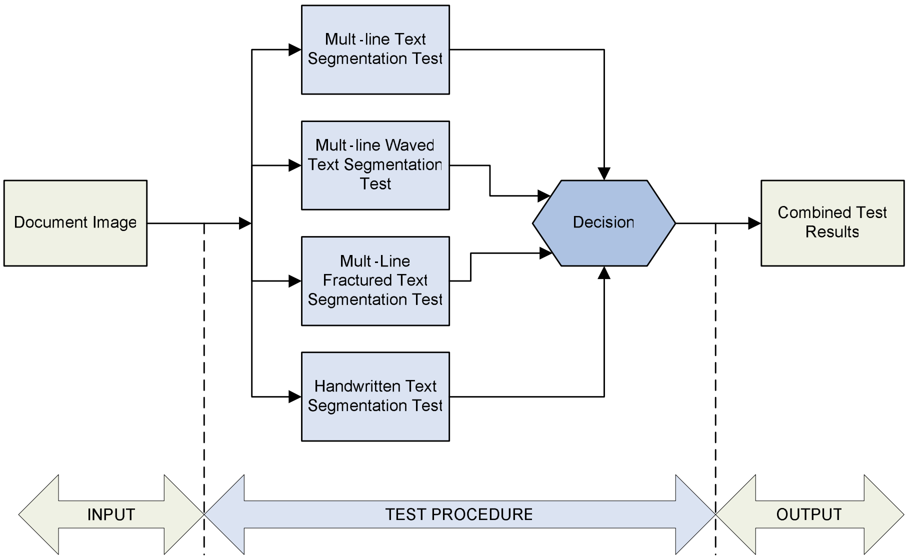
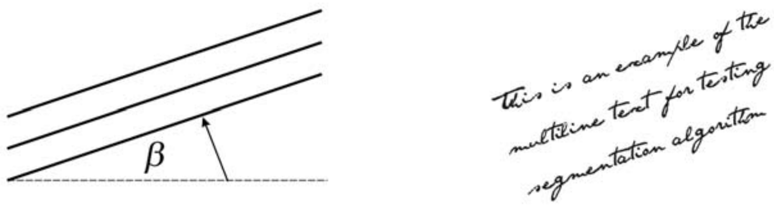


Figure 11: Schematic diagram of test procedure

4.1 Multi-line Text Segmentation Test

The first experiment in combined text experiments framework is multi-line straight text sample. This multi-line text sample is shown in Figure 12.



(a) (b)

Figure 12: Multi-line straight text: (a) definition, (b) sample text

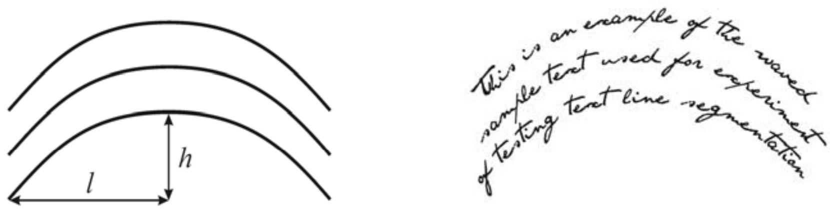
Consequently, the number of existing text objects in multi-line text image relate to text segmentation quality success. Hence, the less objects the better segmentation process, except the number may not be less than text lines number. As a quality measure, the root mean square error $RMSE_{seg}$ has been used. It is calculated as [Bolstad, 2004] [Brodić at al., 2010] [Brodić, 2010]:

$$RMSE_{seg} = \sqrt{\frac{1}{P}\sum_{k=1}^{P}(O_{k,ref} - O_{k,est})^2} \quad , \tag{9}$$

where $k = 1, \ldots, P$ is the number of examined text samples, $O_{k,ref}$ is the number of referent objects in text i.e. number of text lines, and $O_{k,est}$ is the number of obtained objects in text by the applied algorithm.

4.2 Multi-line Waved Text Segmentation Test

The second text line segmentation experiment is based on multi-line waved text. Sample text is formed as a group of text lines using the waved referent line as a basis. Referent line is defined by the parameter $\varepsilon = h/l$. Typically, ε is used from the set {1/8, 1/6, 1/4, 1/3, …} [Brodić at al., 2010] [Brodić, 2010]. Multi-line waved text sample for this experiment is shown in Figure 13.



(a) (b)

Figure 13: Multi-line waved text: (a) definition, (b) sample text

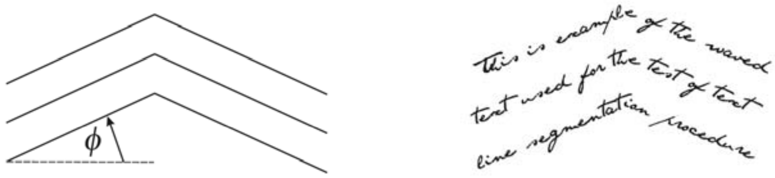
Similarly, as in the previous test, the number of existing text objects after applied algorithm relate to the text segmentation quality success. Again, for the quality measure, the root mean square error $RMSE_{seg,wav}$ has been used. It is calculated as [Bolstad, 2004] [Brodić at al., 2010] [Brodić, 2010]:

$$RMSE_{seg,wav} = \sqrt{\frac{1}{R}\sum_{l=1}^{R}(O_{l,ref} - O_{l,est})^2} \quad , \tag{10}$$

where $l = 1, \ldots, R$ is the number of examined text samples, $O_{l,ref}$ is the number of referent objects in text i.e. number of text lines, and $O_{l,est}$ is the number of obtained objects in text by the applied algorithm.

4.3 Multi-line Fractured Text Segmentation Test

The third text line segmentation experiment is based on multi-line fractured text. This text is formed by using the fractured referent line as a basis. Fractured text referent line is defined by the slope angle ϕ, as a parameter. Typically, ϕ is used from the set {5°, 10°, 15°, 20°} [Brodić at al., 2010] [Brodić, 2010]. Multi-line fractured text sample for the last segmentation experiment is shown in Figure 14.



(a) (b)

Figure 14: Multi-line fractured text: (a) definition, (b) sample text

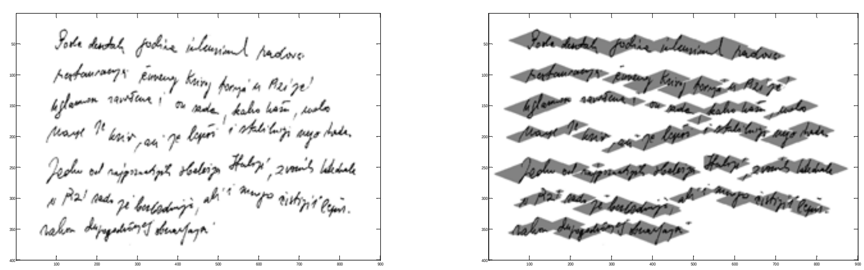
Again, the number of existing text objects relate to the text segmentation quality success. Root mean square error $RMSE_{seg,frac}$ has been used as a quality measure. It is calculated as [Bolstad, 2004] [Brodić at al., 2010] [Brodić, 2010]:

$$RMSE_{seg,frac} = \sqrt{\frac{1}{Q}\sum_{m=1}^{Q}(O_{m,ref} - O_{m,est})^2} \quad , \tag{11}$$

where m = 1, …, Q is the number of examined text samples, $O_{m,ref}$ is the number of referent objects in text i.e. number of text lines, and $O_{m,est}$ is the number of obtained objects in text by the applied algorithm.

4.4 Handwritten Text Segmentation Test

The last experiment is based on text line segmentation for the custom handwritten documents. They are written in English as well as in Serbian Latin and Cyrillic letters. The total number of analyzed handwritten text lines was 234. For the sake of conformity, documents body is the only considered in the analysis of the text line segmentation. One of the handwritten documents samples is shown in Figure 15.



(a) (b)

Figure 15: Multi-line handwritten text: (a) sample text, (b) text after segmentation

Currently, the number of correctly segmented text lines and theirs segmented errors are investigated. Errors are divided in 3 groups [Sanchez at al., 2008]:

- Split lines error,
- Joined lines error,
- Lines including outlier words.

Split lines error represents the text lines which are wrongly divided by algorithm in two or more components [Sanchez at al., 2008]. Joined lines error corresponds to the situation where the sequence of *n* consecutive lines is considered by the algorithm as a unique line. In this situation *n* - 1 line represent the group of the erroneous [Sanchez at al., 2008]. Lines including outlier words correspond to lines containing words that are incorrectly assigned to two adjacent lines [Sanchez at al., 2008].

5 Test Results and Comparative Analysis

It should be noticed that new approach to water flow algorithm can choose freely the water flow angle α from 0º to 90º by almost any increment value. For the purpose of testing algorithm, the water flow angle α is used from the following value set {10°, 12°, 14°, 15°, 18°, 20°, 25°, 26.6°, 30°, 45°}. Full set of these values is reserved only for the new approach of the water flow algorithm. By contrast, the subset values {14°, 18°, 26.6°, 45°} are used for the basic water flow algorithm. After applying water flow algorithm, typical resulting images of the text line segmentation experiments are shown in Figure 16.

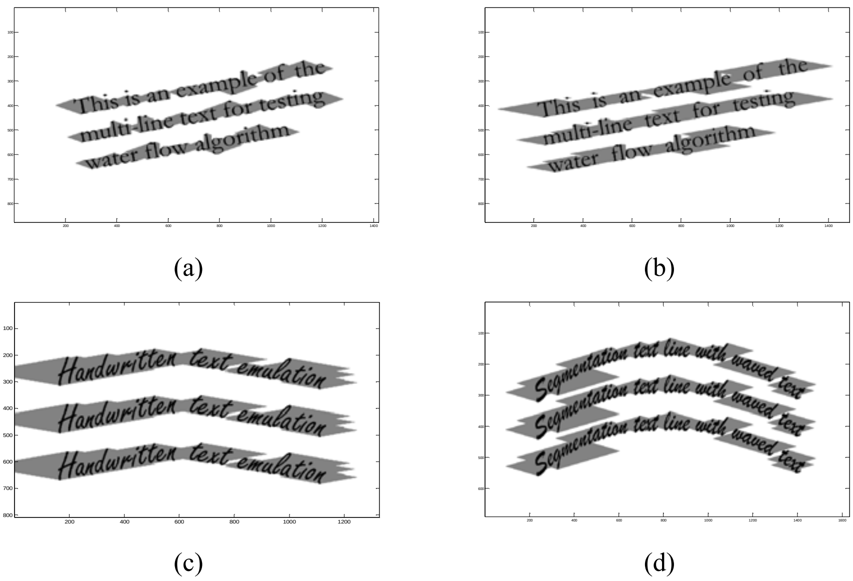


Figure 16: Text line segmentation experiments: (a) multi-line text segmentation test, (b) multi-line text segmentation test with extended inter word spacing, (c) multi-line fractured text segmentation test, (d) multi-line waved text segmentation test

First experiment results are divided in two groups. In the first group, multi-line straight text segmentation test with normal inter word spacing is used. Second one used extended inter word spacing. Obtained results are evaluated by *RMSE* method. These results are shown in Figures 17-18, respectively.

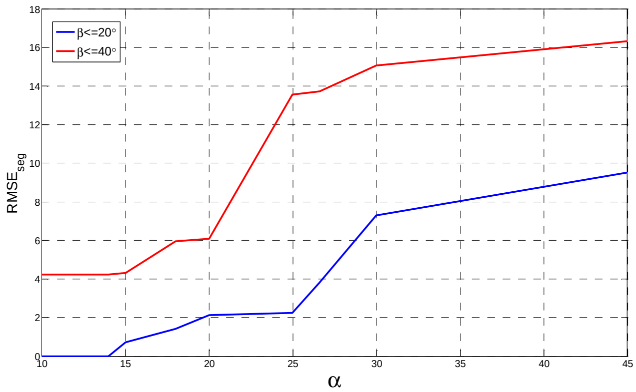


Figure 17: $RMSE_{seg}$ for multi-line straight text with normal inter word spacing

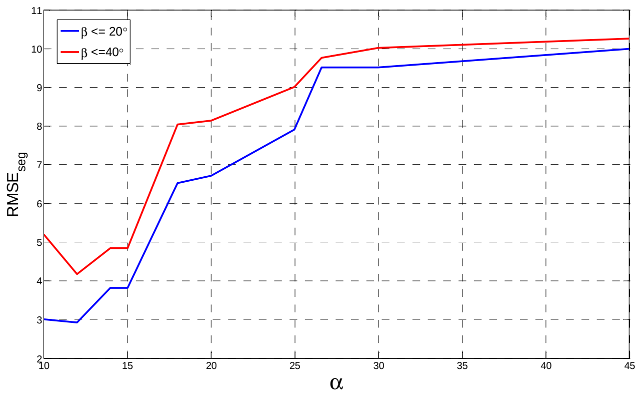


Figure 18: $RMSE_{seg}$ for multi-line straight text with extended inter word spacing

In multi-line straight text, skew parameter β is used. Its values are selected from the set {10°, 20°, 30°, 40°} [Brodić at al., 2010] [Brodić, 2010]. Obviously, smaller water flow angles lead to better segmentation results. Also, “the flow of hypothetical water” better follows text with smaller skewing. Hence, smaller *RMSE* is obtained for $\beta \leq 20°$ than for $\beta \leq 40°$. Besides, suitable water flow angles α are up to 20°.

Further, curvilinear waved text defined by parameter ε is used. Its values are chosen from the set {1/8, 1/4, 1/3} [Brodić at al., 2010] [Brodić, 2010]. Obtained results is given by $RMSE_{seg,wav}$. It is shown in Figure 19.

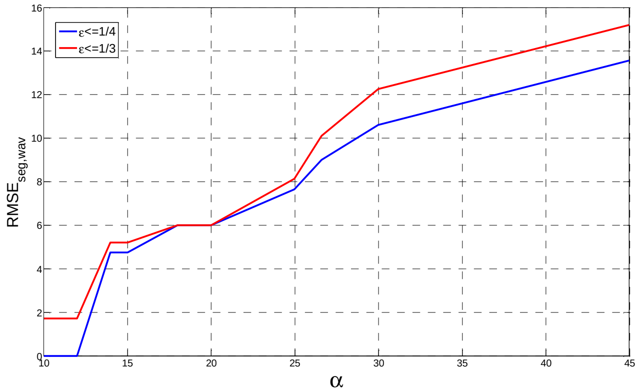


Figure 19: $RMSE_{seg,wav}$ for multi-line waved text

The best results are obtained for very small water flow angles. These values are out of the reach from the basic algorithm. Still, usable water flow angles are up to 20°.

In the third test experiment, parameter ϕ representing skew angle of the fractured text is used. Its values are selected from the set {5°, 10°, 15°, 20°} [Brodić at al., 2010] [Brodić, 2010]. Obtained results represented by $RMSE_{seg,frac}$ are shown in Figure 20.

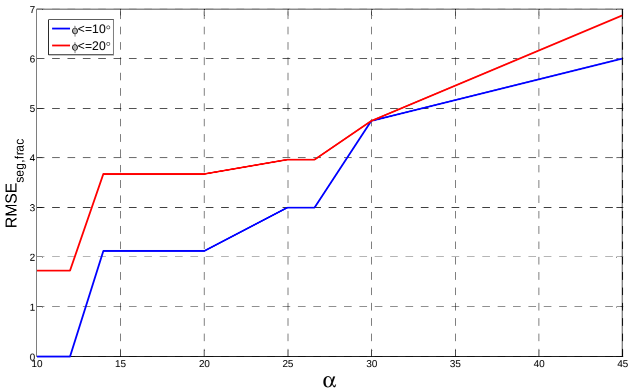


Figure 20: $RMSE_{seg,frac}$ for multi-line fractured text

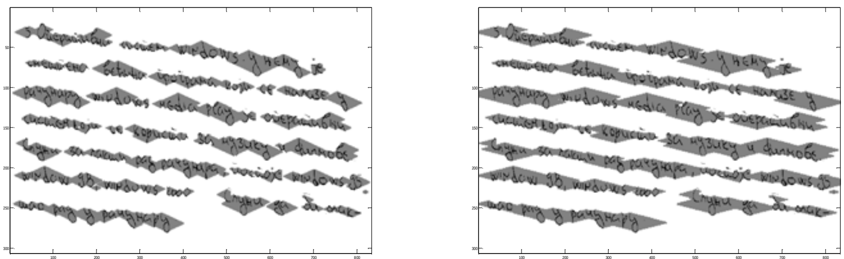
Again, the best results are obtained for the small water flow angles.

In the last experiment handwritten documents are tested. Table 1 presents the number of correctly segmented text lines as well as different types of text segmentation errors for these documents.

Water flow angle	14º		12º		10º	
	#	%	#	%	#	%
Correctly segmented	90	38.46%	102	43.59%	150	64.10%
Split lines error	140	59.84%	124	52.99%	76	32.48%
Joined lines error	2	0.85%	4	1.71%	4	1.71%
Lines including outlier words	2	0.85%	4	1.71%	4	1.71%
Sum	234	100%	234	100%	234	100%

Table 1: Text lines segmentation results produced by basic method with α = 14º [Basu et al., 2006] and new approach with α from the set {10º, 12º}.

Visual presentation of the segmentation results for the handwritten documents by water flow algorithm with different angles α is shown in Figure 21.



(a) (b)

Figure 21: Application of the algorithm to the handwritten sample text: (a) basic method with α = 14º, (b) new approach with α = 10º

Comparison of different text segmentation error results is shown in Figure 22.

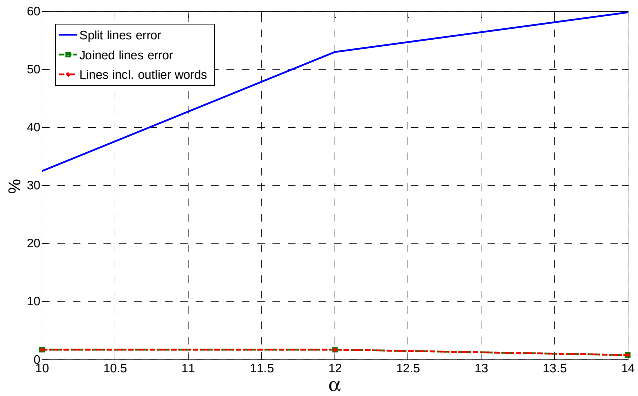


Figure 22: Text segmentation errors (in %) as function of water flow angle α

Because of similar obtained results from the examined tests, process of achieving the decision making is easy. From all obtained results, choosing the small water flow angles below 14° are promising. Especially, water flow angles around 10° gives text line segmentation results improvement. It should be noticed that water flow orientation similar to text skew angle lead to good segmentation results. When characters of different lines touch each others forming the same connected components additional method is required to improve the basic as well as the new approach to algorithm. Hence, algorithm needs some refinements and further improvements. Thereby, additional technique should be incorporated in water flow algorithm extending its functionality and robustness.

6 Conclusions

In this paper, new approach to water flow algorithm for text line segmentation is presented. Water flow algorithm assumes hypothetical water flows under few specified angles of the image frame from left to right and vice versa. As a result of algorithm, unwetted image regions are restored. These unwetted regions are corner stone needed for text line segmentation. They enable the process of joining the jagged and broken text parts that belong to the same text line.

Benefit from the new approach of water flow algorithm is the full control over the water flow angle α. Modified water flow algorithm made water to flow under whole range of different angles up to 90°. Furthermore, it is defined by water flow function $y = kx$ enabling the process of its replacement with some more suitable function.

After examining the water flow algorithm through various tests, its new approach proved better text line segmentation characteristics than the basic one. Also, obtained results showed that water flow algorithm is suitable for text line segmentation of the handwritten text.

7 Future Work

Further improvements of the algorithm should be made by choosing more appropriate water flow function as well as making co-operation with morphological post-processing.

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