A BINARIZATION ALGORITHM FOR HISTORICAL MANUSCRIPTS

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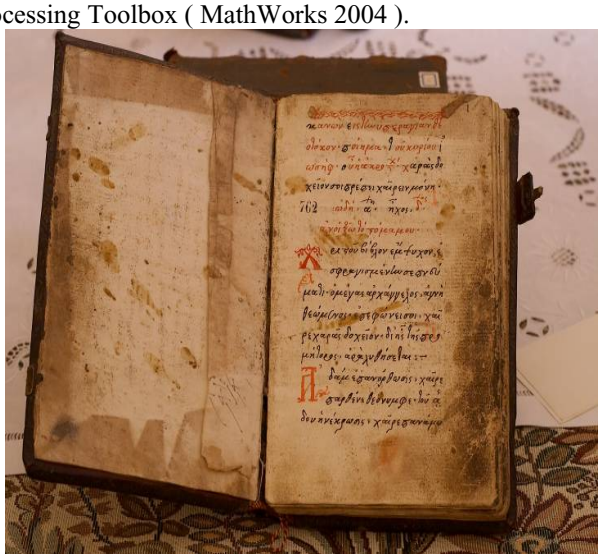
Abstract: Binarization methods are applied to document images for discriminating the text from the background based on pure thresholding and filtering combined with image processing algorithms. The proposed binarization procedure consists of five discrete steps in image processing, for different classes of document images. A refinement technique enhances further the image quality. Results on Byzantine historical manuscripts are discussed and potential applications and further research are proposed. The main contribution of this paper is to propose a simple and robust binarization procedure for pre-filtered historical manuscripts images, and simulation results are also presented.

Keywords: Image processing, document, binarization, denoising, global, local, thresholding.

Introduction: Academic libraries, institutions and historical museums pile-up or preserve documents in storage areas. Our work in this paper contributes to documents safe and efficient preservation in its original state through out the years and their unconditional exploitation to researchers, a major issue for historical documents collections that are poorly preserved and are prone to degradation processes, see fig. 1. Documents digitalization, allows access to wider public, while cultural institutions and heritage organizations create local or national digital libraries accessed through the internet. Our work concentrates on basic techniques used for image enhancement and restoration, denoising and binarization. The entire system is implemented in visual environment using Matlab programming and MathWorks Inc, Image Processing Toolbox (MathWorks 2004).



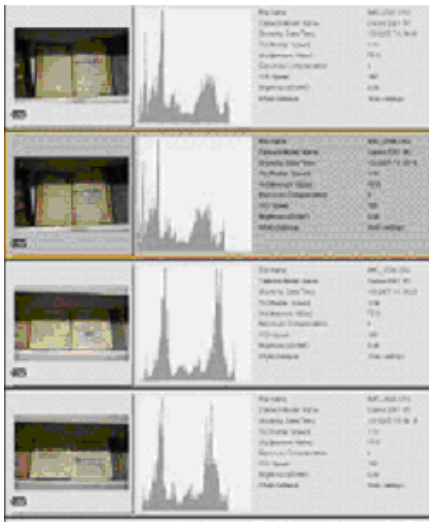


Figure 1: Byzantine Manuscript; taking photos of Byzantine manuscript. Digital photo and Intensity Histograms

Denoising refers to the removal of noise on the image (Sonka et al, 2008) and binarization refers to the conversion of a grayscale image to binary. Both techniques are basic stages in our image processing of Byzantine historical manuscripts. Denoising are filtering methods that eliminate the noise, enhance the quality of text characters and make the background texture uniform (Gonzalez et al, (2002), Papamarkos, (2001)). Binarization (thresholding) converts the grayscale document image to binary, by changing the foreground pixels (text characters) to black and background pixels to white. The paper presents the need for degraded historical manuscripts images preservation by binarization implemented by a procedure based on image preparation, type classification and refinement of pre-filtered images in spatial (mean, median and Wiener filter) and frequency (Butterworth and Gaussian low pass filter) domain. The work concentrates on text image enhancement and

restoration, denoising and binarization using Matlab. Binarization is obtained by global (Otsu) and local (Niblack, Sauvola and Bernsen method) thresholding. The method consists of image acquisition, preparation, denoising, thresholding and final refinement steps. Filtering, thresholding and final binarization results on poor quality text images with various but systematically classified degradation problems enables us to compare our methodology to existing binarization techniques.

Denoising - Filtering: Denoising methods are divided in filtering in spatial and frequency domain (Motwani et al, 2004). In our work we implemented three filters in spatial domain (mean, median and Wiener filters) with various windows sizes and two filters in frequency domain (Butterworth and Gaussian).

<table>
<tr><td colspan="3">Spatial Domain filters</td></tr>
<tr><td colspan="3">Linear filtering in spatial domain is performed by applying a filter with a weighted sum of neighbouring pixels. The weight is defined by the filter. Filtering is achieved by convolution and convolution kernel is the correlation kernel rotated by 180^o (Gonzalez et al, 2002).</td></tr>
<tr><td>Mean filter</td><td>Median Filter</td><td>Wiener filter</td></tr>
<tr><td>The simplest linear filter is the mean filter. The intensity of every pixel in the image is replaced with the averaged value of intensity of its neighbour pixels. The new value of intensity of a pixel (i, j) of an image I is given by:</td><td>Median filter is a non linear filter. For $A\{a1, a2, a3, ...an\}$, and $a1 \le a2 \le a3 \le ..... \le an \in R$ the new value of intensity of a pixel (i, j) of an image I is given by:</td><td rowspan="3">Wiener filter, known as “minimum mean square error filter”, is an adaptive linear filter, applied to an image locally, by taking into account the local image variance. When the variance in an image is large the Wiener filter results in light local smoothing, while when the variance is small, it gives an improved local smoothing (MathWorks, 2004).</td></tr>
<tr><td>$$I(i,j) = \frac{1}{M} \sum_{(x,y) \in N} I(x,y)$$</td><td rowspan="2">$$median(A) = \begin{cases} a_{\frac{n+1}{2}}, \text{if n is odd} \\ \frac{1}{2}\left(a_{\frac{n}{2}} + a_{\frac{n}{\frac{n}{2}+1}} \right), \text{if n is even} \end{cases}$$</td></tr>
<tr><td>where M represents the number of pixels in the neighbourhood N.</td></tr>
</table>

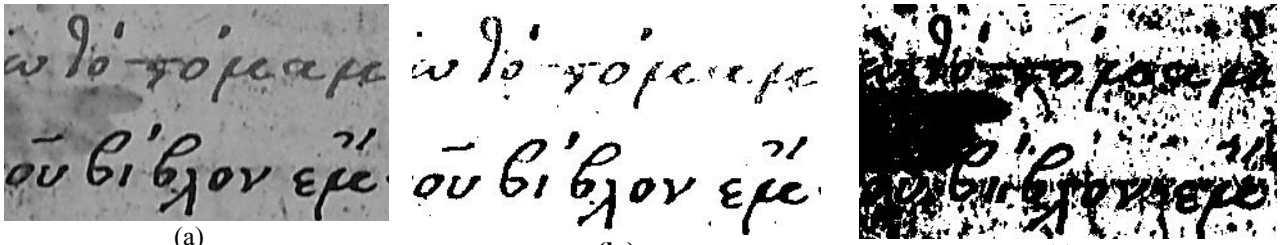
<table>
<tr><td colspan="2">Frequency Domain Filters</td></tr>
<tr><td colspan="2">Spatial frequency filtering is implemented by low pass filters which perform Fourier transform. These are smoothing frequency filters, since they smooth edges and sharp transitions in an icon, such as noise. Low frequencies in the Fourier transform of an image are responsible for the grey level appearance over the smoothed areas. On the other hand, high frequencies are responsible for the presence of details, edges (Ventzas, 1994) and noise in the image. There are two types of low pass filters that are described here: Butterworth and Gaussian.</td></tr>
<tr><td>Butterworth Low Pass Filter</td><td>Gaussian Low Pass Filter</td></tr>
<tr><td>Butterworth filter is a low pass filter with transfer function:</td><td>Gaussian low pass filter removes effectively the noise but blurs the image. The mathematical form for two-dimensional Gaussian filter is given by</td></tr>
<tr><td>$$H(u,v) = \frac{1}{1 + [D(u,v)/D_0]^{2n}}$$</td><td>$$H(u,v) = e^{-D^2(u,v)/2\sigma^2}$$</td></tr>
<tr><td>where D_0 is a specific non negative quantity, and D(u,v) it the distance from point (u,v) to the centre of the frequency rectangle [Gonzalez et al, 2002].</td><td>where D(u,v) it the distance from the origin of the Fourier transform (Gonzalez et al, 2002).</td></tr>
</table>

Binarization - Thresholding: Robust binarization gives the possibility of a correct extraction of the sketched line drawing or text from its background. For the binarization of images many algorithms have been implemented. Thresholding is a sufficiently accurate and high processing speed segmentation approach to monochrome image. This paper describes a modified logical thresholding method for binarization of seriously degraded and very poor quality gray-scale document images. This method can deal with complex signal-dependent noise and variable background intensity caused by non uniform illumination, shadow, smear or smudge and very low contrast images. The outcome binary image has no obvious loss of useful information. Firstly, we analyse the clustering and connection characteristics of the character stroke from the run-length histogram for selected image regions and various inhomogeneous gray-scale backgrounds. Then, we propose a modified logical thresholding method to extract the binary image adaptively from the degraded gray-scale document image with complex and inhomogeneous background. It can adjust the size of the local area and logical thresholding level adaptively according to the local run-length histogram and the local gray-scale inhomogeneity. Our method can threshold various poor quality gray-scale document images without the need of any prior knowledge of the document image and without manual parameter fine-tuning and without taking into account character geometric features. It keeps useful information more

accurately without over connected and broken strokes of the characters, and thus, has a wider range of applications compared with other methods.

A review of the recent research on binarization is given here. Otsu (1979) suggested a nonparametric automatic optimal threshold selection for picture segmentation in order to maximize the separability of the resultant classes in gray levels. Kapur et al (1985) and Niblack (1986) introduced a maximum entropy algorithm that divides the histogram of the image into two probability distributions, one representing the objects and one representing the background. Yanowitz, D.L. and A.M. Bruckstein (1989) presented a method for finding a threshold surface, by a gradient map of the image, to point at well-defined object boundaries for local thresholds. Solihin, Y. and C.G. Leedham (1999) proposed a new class of histogram based global thresholding techniques based on a two stage thresholding approach of foreground, background, and a fuzzy area. Wu et al (1999) automatically detected and extracted text in images from different sources, including video, newspapers, advertisements, stock certificates, photographs, using multiscale texture segmentation and spatial cohesion constraints, by a histogram-based binarization algorithm. Yang and Yan (2000) presented a logical adaptive thresholding method to binarize seriously degraded and very poor quality gray-scale document image with complex signal-dependent noise. Sauvola et al (2000) presented a new method for adaptive document image binarization, where the page is considered as a collection of subcomponents such as text, background and picture. Zhang et al (2001) described problems of distorted images of scanned thick, bound documents, to remove shade and adjust the warped words, with location, shape and orientation. Randolph et al (2001) suggested a binary domain approach that enhances fax documents by directional filter bank enabling edges and contours in the text letters to be smoothed appropriately. Leedham, et al (2003) proposed new thresholding techniques and compared against existing algorithms. Wu et al (2003) experimented with a multi-stage global thresholding approach followed by a local spatial thresholding, which works well for simple and complex images of postal envelopes. Fan et al (2003), proposed spatial correlations of wavelet coefficients by replacing the thresholding process with a diffusion process for highly corrupted document images. Bartolo et al (2004) introduced accurate binarization of a low-level digital image without user-defined parameters restrictions on Bernsen's algorithm that classifies correctly image of poor quality, with inhomogeneous paper background, suitable for text shadow boundaries removal. Gatos et al (2004) proposed a digital image binarization scheme for low quality historical documents by five distinct steps: a pre-processing low-pass Wiener filter, a rough estimation of foreground regions using Niblack's approach, a background surface calculation by interpolating neighbouring background intensities, a thresholding by combining the calculated background surface with the original image and finally a post-processing quality and connectivity step. Sezgin et al (2004) compared and categorized most image thresholding methods, such as histogram shape, measurement space clustering, entropy, object attributes, spatial correlation and local gray-level surface for NDT and document images, based on the combined performance measures. Bieniecki et al (2005) compared between multi-pass algorithms of global and local threshold by Bernsen method for proper pixel neighbourhood window size that fits the size of image objects. Chen et al (2005) compared global or local thresholding techniques for degraded historical documents images and introduced a local feature thresholding decompose algorithm or document sub regions using quad-tree decomposition. Gatos et al (2005) investigated closed cavity regions in the characters and proposed a segmentation-free recognition procedure for old handwritten manuscript. J. He at al (2005) compared alternative binarization algorithms for historical archive documents recognition performance in a commercial OCR engine. Kitadai et al (2005) studied text on stained, damaged, and degraded wood, to extract characters from badly blurred or missing ink by binarization discriminant analysis. Kavallieratou (2005) and Kavallieratou et al (2005) presented a binarization method of document images and photos. The method uses the fact that the pixels that compose the text in a document do not exceed the 10% of its size. Ashley et al (2007) studied binarisation algorithms of greyscale images in optical music recognition by pre-processing, that differ significantly from non-music documents. Badekas et al (2007) suggested a system for the binarization of normal and degraded documents for visualisation and recognition of text characters by a Kohonen adaptive neural network. Badekas et al (2007) presented a technique for the binarization of text blocks in colour document images that contain text and graphics highly mixed with the background, based on a colour reduction. Konidaris et al (2007) searched for keywords in historical printed documents combining synthetic data and user feedback by synthetic image words creation and word segmentation.

Global thresholding	Otsu's method
The simplest implementation of thresholding is to choose an intensity value as a threshold level and the values below this threshold become 0 (black) and the values above this threshold become 1 (white). If T is the global threshold of image f(x,y) and the g(x,y) is the thresholding image, then: $g(x,y)=\begin{cases}1, & if \quad f(x,y)\geq T\\ 0, & otherwise\end{cases}$	Among the global techniques the most efficient is Otsu's technique [7]. Otsu's method applies clustering analysis to the grayscale data of input image and models two clusters of Gaussian distribution of pixels of the image. The optimal threshold minimizes the class variance of the two classes of pixels.



(a) **(b)** (c)

Figure 2: Global threshold (a) grayscale image (b) *T*=80 (c) *T*=150

Common problem in document images are changes in illumination, or local shadows that are difficult to give a global threshold, i.e. for the whole image, see fig. 2. Background Surface Thresholding (BST) computes a surface of background intensities at every point in the image and performs adaptive thresholding based on this result. The surface is estimated by identifying regions of low resolution text and interpolating neighbouring background intensities into these regions. The final threshold is a combination of this surface and a global offset. According to our evaluation BST produces considerably fewer OCR errors than Niblack's local average method while it is more runtime efficient. For small windows noisy background regions and for larger windows inconsistent stroke width were produced, i.e. the method is related to neighbouring features and it is less susceptible to misclassification of large homogeneous regions.

Local thresholding		
Niblack's method	Sauvola's method	Bernsen's Method
Niblack's method is based on the calculation of the local mean and of local standard deviation (Niblack, 1986). The threshold in the pixel (x,y) is decided by the expression:	Sauvola's method is an adaptive threshold method (Sauvola et al, 2000). The computation of local threshold (i.e., for each pixel separately) is based on estimation of local mean and local standard deviation. The threshold value T(x,y) at the pixel (x,y) is defined by the relation:	Bernsen's method calculates the local threshold value based in the mean value of the minimum and maximum intensities of pixels within a window (Papamarkos (2001)). If the window is centred at the pixel (x,y) the threshold for I(x,y) is defined by:
T(x,y)=m(x,y)+k*s(x,y)		$T(x,y)=\frac{Z_{\max}+Z_{\min}}{2}$
where m(x,y) and s(x,y) are the average and the standard deviation of a local area respectively. The size of the window must be large enough to suppress the noise in the image, but also small enough to preserve local details of the image. A window size 15-by-15 works efficiently. The value of k is used to adjust the percentage of total pixels that belong to foreground object especially in the boundaries of the object. A value of k = -0.2	$T(x,y)=m(x,y)\left[1+k\left(1-\frac{s(x,y)}{R}\right)\right]$ where k and R are constants with usual values k = 0.1 and R = 128.	where Z_{max} and Z_{min} are the maximum and minimum intensity of the window. This threshold works properly only when the contrast is large. The contrast is defined as $C(x,y)=Z_{\max}-Z_{\min}$. If the contrast is less that a specific value k the pixels within the window may be set to background or to foreground according to the class that most suitably describes the

produces objects separated well enough from background.		window. This algorithm is dependent on k value and also on the size n of window N-by-N.

METHOD APPLICATION AND RESULTS:

Historical manuscripts present information distortions that are visible in the form of poor quality, shadows, non uniform illumination, low contrast, large signal dependent noise, smear and strain spurious point noise and ragged edges. Since documents images vary in characteristics compared with common images we classify the documents image types and the applied methods. There is not a single suitable method that can be applied to all types of images, or an image type to suppress the output image artifacts. Before image processing stages the 'difficult' document images have been grouped to six distinct categories, i.e. image conditions:

IMAGE CONDITION	TECHNICAL COMMENTS
GOOD	Paper acceptable without spots, stains, smears, aging, brightness degradation
SPOTS and STAINS	Images with spots, stains, smears or smudges, with less or more background noise.
SHADOWS or WRINKLES	High humidity and illumination variation caused wrinkles effects and shadows
TRANSPARENT PAGE	ink seeking from the other side of page and oily page
THIN STROKES of PEN:	Images with thin strokes of pen, i.e. stroke width analysis
BROKEN CHARACTERS	Broken
COLOURED CHARACTERS	Characters with red ink

The below described discrete stages were applied to pages acquired from historical books and manuscripts called "Codices", from the Holy Monastery of Dousiko near Meteora, Trikala, see Table 1. The proposed binarization method was tested on numerous low quality digitized historical manuscripts and digital text images. The proposed method is robust to many source type-related degradations illumination variations and produces images with very little noise and consistent stroke width, with minimal prior knowledge of the document image.

Historical manuscripts digital processing algorithm

The method applied consists of five stages that are described schematically as in fig. 3. These stages are described analytically as follows:

Stage 1: Image acquisition

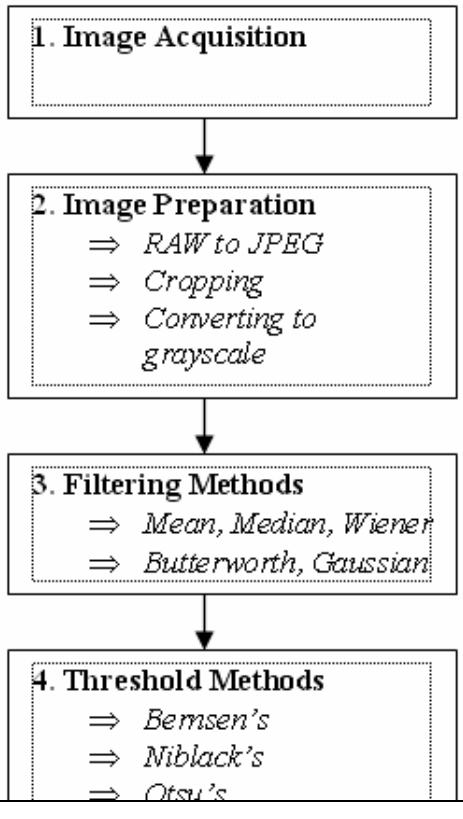
The images are acquired by a digital camera with high resolution ratio, stored in computer and converted to compressed file formats with low storage requirements. The digital camera used is a CMOS technology SLR "CANON 1.8II" [Canon, 2007] with a 50mm lens. The resolution of the camera was the in the range of 4,368 by 2,904 pixels. The sensors size is 24 mm by 36mm. JPEG files were used due to lower size and computation time, especially for old books reproduction, since RAW or TIFF files are memory and CPU time consuming. "MATLAB IP Toolbox" [2004] supports all these format. We worked with a sufficient number of document images and applied various filters, extended to many types, sizes, windows, etc, in order to explore denoising procedures.

Stage 2: Image preparation

The preparation of the image before filtering and binarization consists of:
a. conversion from RAW to TIFF / JPEG
b. cropping
c. conversion to gray scale.

Stage 3: Denoising

The best denoising filter is derived after comparison of various types of filters and more specifically the: Mean, Median and Wiener filters in spatial domain and Gaussian and Butterworth filters in the frequency domain.



Stage 4: Thresholding	
Thresholding are applied by global (Otsu's) and local (Niblack, Sauvola, Bernsen) thresholding techniques on previous stage resulting filtered images.	
Stage 5: Refinement	
A refinement procedure, based on erosion and dilation, is applied on the binarized image, such that the obtained image has its characteristics further clarified in the texture and foreground compared with the background area.	

Figure 3: Proposed method stages

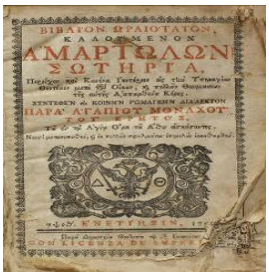
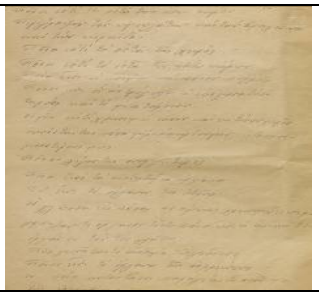
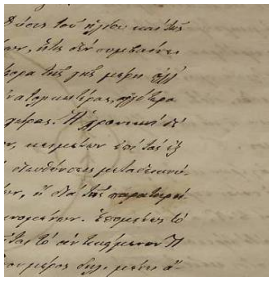
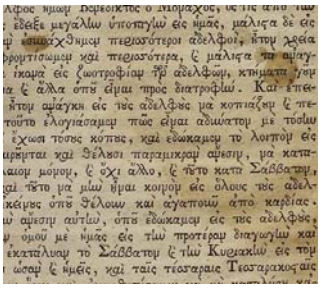
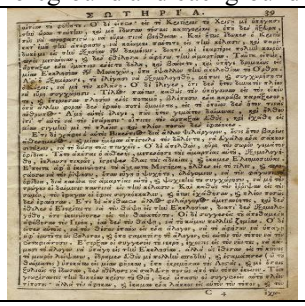
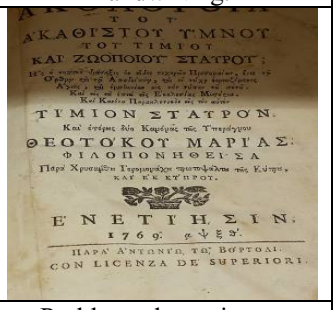
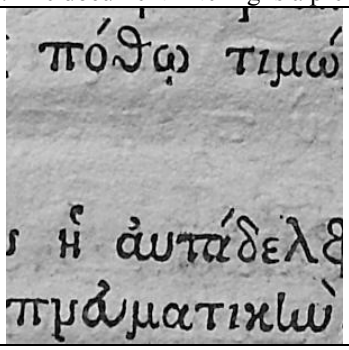
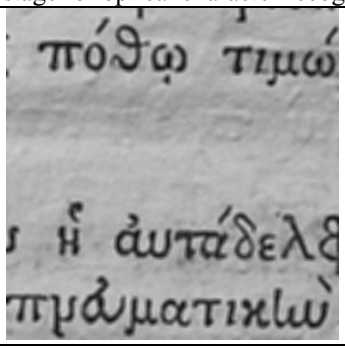
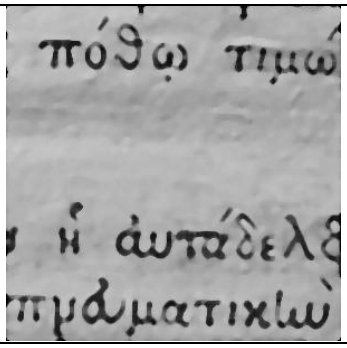
			
Documents with poor quality paper	The brightness of the aging paper colours	Poor contrast between foreground and background	Broken characters, light handwriting.
			
Ink wet characters visible both sides	Dirty documents with spots, stains, smears or smudges.	High humidity cause wrinkles to the paper	Problems due to image acquisition, illumination,

Table 1: Documents problems classification

Denoising results

The filters applied are Mean, Median, Wiener, Gaussian and Butterworth ones. The application of each filter with variable sizes of window, explored all possible denoising results:

a. Filtering improved the quality of the image, thus preparing it for binarization, see Table 2.
b. Spatial domain filtering using the Mean, Median and especially Wiener filters.
c. Frequency domain filtering using the Butterworth and Gaussian low pass filters.
d. The paper condition is an unexpected factor.
e. The document filtering is a preliminary stage for optical character recognition.

		
original grayscale image	after mean filter 5-by-5	after median filter 7-by-7

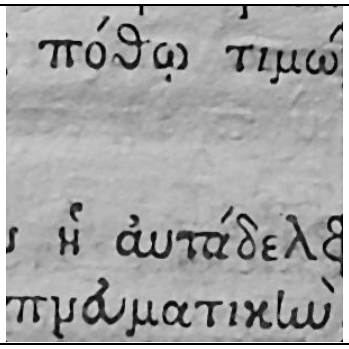
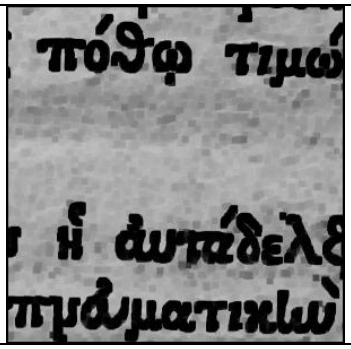
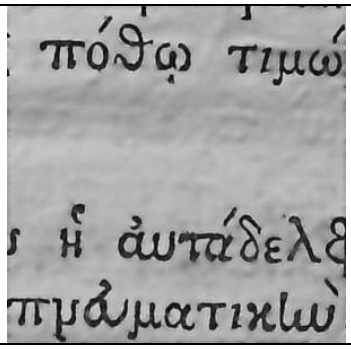
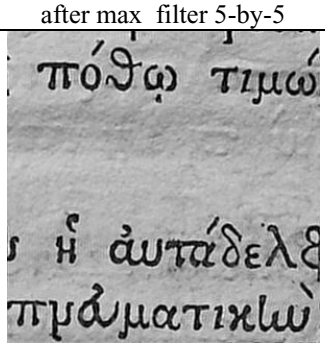
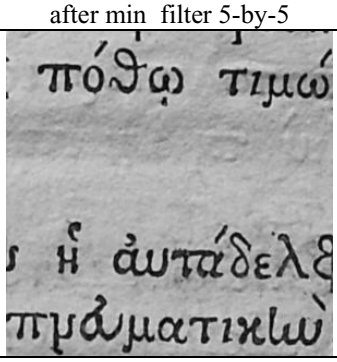
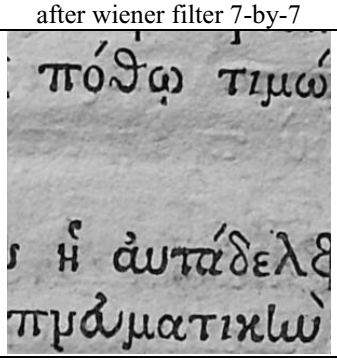
		
after max filter 5-by-5	after min filter 5-by-5	after wiener filter 7-by-7
		
ideal filter, radius value of 100	Butterworth filter, radius value of 100	Gaussian filter, radius value of 100

Table 2: Filtering on documents

Documents Image Category / Binarization	Bernsen	Niblack	Otsu	Sauvola
GOOD CONDITION	*BEST*	*BEST*	*BEST*	*BEST*
SPOTS and STAINS	*BAD*	*GOOD*	*BAD*	*BEST*
SHADOWS or WRINKLES	*BAD*	*BEST*	*BAD*	*BEST*
INK SEEKING from other SIDE	*BAD*	*GOOD*	*BAD*	*BEST*
THIN STROKES of PEN	*BAD*	*BAD*	*GOOD*	*BAD*
RED coloured CHARACTERS	*BEST*	*GOOD*	*GOOD*	*GOOD*

Table 3: Results from combination of Wiener filter 5-by-5 with binarization methods for each image category

Document Image Thresholding:

Binarization is applied to all document image categories. Image focusing, sharpness and clarification on the handwritten characters, and texture was compared with the original ones, see Table 3. The binarization, based on adaptive global / local thresholding, is an efficient step in image digitalisation and works best on high resolution images. The JPEG produced file formats needed the least computational effort to be processed. Previous research classifies threshold methods in two categories, global or local (adaptive) threshold to separate foreground from background objects. We have chosen four binarization methods (Otsu's, Niblack's, Sauvola's and Bernsen's) and looked into the results of each one in a range of document images taken from the Holy Monastery of Dousiko at Meteora - Trikala, Thessaly, Greece. Thresholding techniques applied to non-similar types of documents images revealed the hidden capabilities of combined filtering and binarization of the categorized types of images. The conclusions of the suitable methods for each type of document image are given in Table 3. The application of Wiener filtering with a window size of 5-by-5 has produced the best results to almost all of the specified image categories, see Table 3. Eikvil's and Parker's binarization methods were not included into our comparison, but thresholding techniques review indicated bad text detection recall ranking.

The most of the Byzantine manuscripts images taken, belong to the category of images with "spots and stains" and with "red coloured characters". Niblack's and Sauvola's methods produce efficient results in almost all categories except the category of thin strokes of pen in which global Otsu's method has the best results on the produced binary images. In Byzantine manuscripts with characters and drawings with red ink the Bernsen's method produced best results. The proposed algorithms were tested with images including different types of document components and degradations, against well-known thresholding techniques. The results show that the method performs well in each case qualitatively and quantitatively and has superior performance compared to other techniques tested.

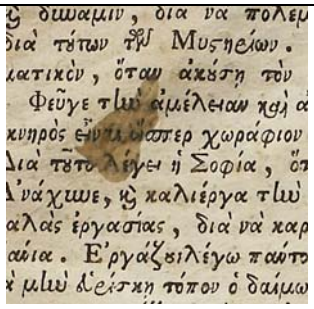
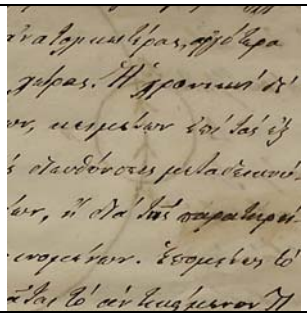
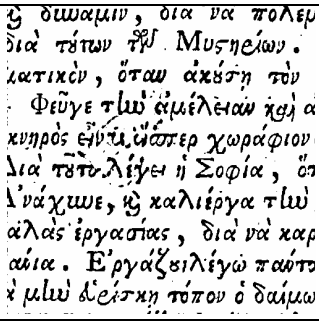
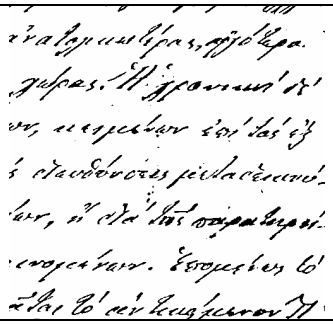
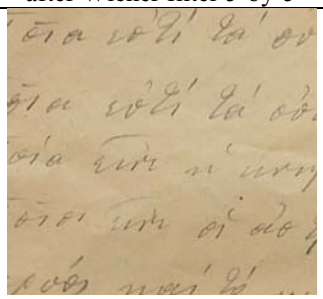
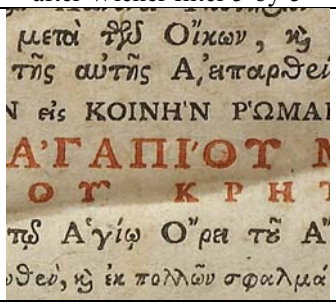
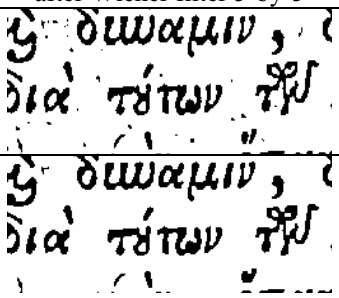
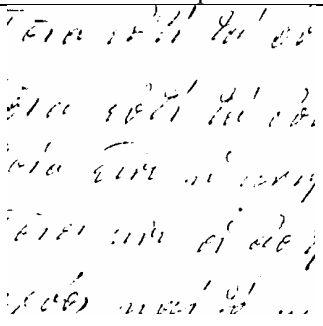
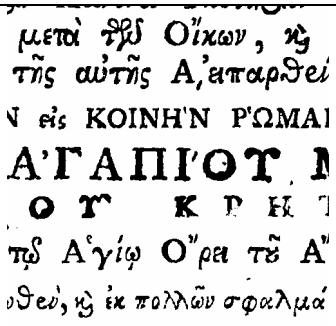
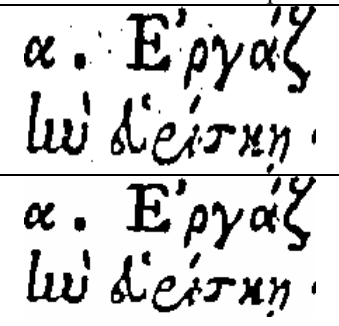
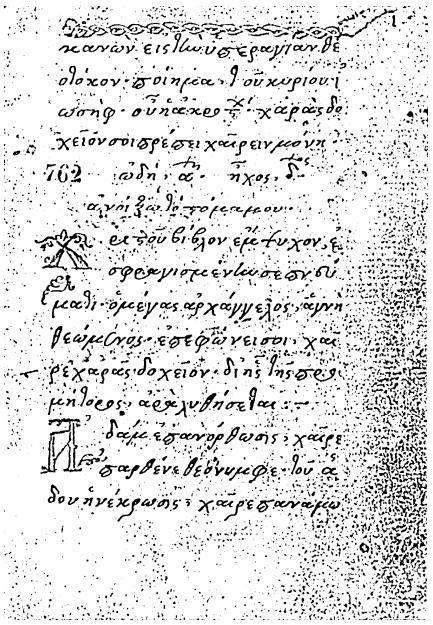
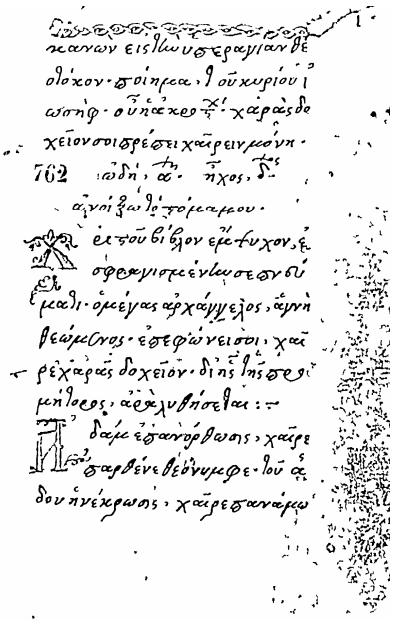
		
original document image with spot	original document image with shadow caused by bad illumination	original image with ink seeking from other side
		
binary image with Sauvola's method after Wiener filter 5-by-5	binary image with Sauvola's method after Wiener filter 5-by-5	binary image with Sauvola's method after Wiener filter 5-by-5
		
original Document image with thin strokes of pen	original Document image with characters with red ink	detail of image with black dots before / after refinement step
		
binary image with Sauvola's method after Wiener filter 5-by-5	binary image with Otsu's method after Wiener filter 5-by-5	detail of image with holes on characters before/after refinement step

Table 4: Document image before and after binarization

Document Image Final refinement
The post-binarization refinement improves the appearance of the binary images and text readability, especially in documents with red ink characters and line gaps or holes. Refinement consists of the successive erosion followed by dilation operation, and opening on the negative image to remove the remaining black pixels that not belong to the text characters/ Results of post-binarization refinement are shown in Tables 4, 5 and 6. The refinement significantly improves the image quality for most of the image types since it clarifies the background area, by clearing up the appearance of the text, especially when it is applied to images after Niblack's and Sauvola's binarization methods.

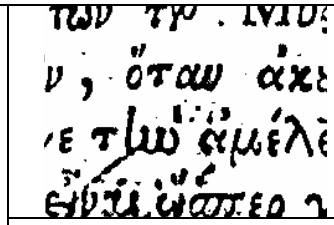


(a)

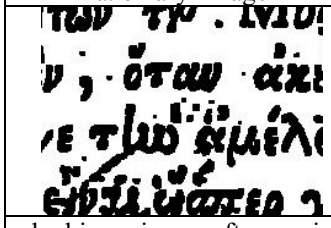


(b)

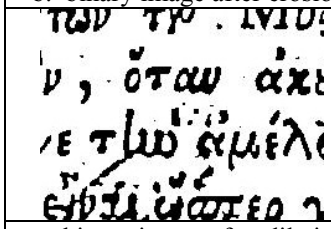
Table 5: Final Refinement (a) binary image (b) Removing 50 connected pixel



a. binary image



b. binary image after erosion



c. binary image after dilation

Table 6: Steps of refinement stage

FUTURE WORK: Potential application fields include the automation of the combined binarization-filtering procedure by a neural network and the extension of the method to a wider area of documental or non-documental images. Parallel computational machines and perceptual optical processing techniques should further increase the method's efficiency. The application of filtering as a preliminary stage for the binarization of the document image promises a great improvement on the quality of the final images. Other filter schemes in the preliminary stage of digital pre-processing can be investigated. By converting historical documents and old newspapers (which have been degraded or partly damaged) to digital formats we preserve them, in the form of the original document, for future reproduction. By digitalization and storing of copies of old books and historical manuscripts, we can store electronically entire libraries to preserve historical manuscripts. Such a text images storage environment and data base is proposed for further research.

CONCLUSION: No algorithm works well for all types of images but some work better than others for particular types of images suggesting that improved performance can be obtained by selection or combination of appropriate algorithm for the type of document image under investigation. We have described algorithms that utilize spatial structure, global and local features or both. Many algorithms require extensive preprocessing steps in order to obtain useful data to work with because document image and data mining classification techniques is still in infancy. The purpose of our work on text image binarization was to introduce an innovative procedure for digital image acquisition of historical documents based on image preparation, image type classification in six categories according to image condition. The estimated results for each class of images and each method are further enhanced by an innovative image refinement technique and a formulation of a class proper method. The potential of the applications of preliminary processing to document images, by adjusting the binarization method according to the category of the image, becomes reasonably estimated taking into account the improvement in the quality of the image as a whole and the increased readability of the texture. The results have shown improved image quality for the six categories of document images which were described by their separate characteristics. It has turned out that our methodology performs better compared to current state-of- the-art adaptive thresholding techniques and it is robust for document images comparing with other thresholding methods based on connectivity and background analysis and might succeed in a wider range of applications.

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