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Digital Restoration by Denoising and Binarization of Historical Manuscripts Images

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1. Introduction

This chapter deals with digital restoration, preservation, and data base storage of historical manuscripts images. It focuses on restoration techniques and binarization methods combined with image processing applied on document images for text - background enhancement and discrimination. Sequential image processing procedures are applied for image refinement and enhancement on quality class categorized images. Research results on historical (i.e. Byzantine, old newspapers, etc) manuscripts are presented.

The historical documents images acquisition types / formats are raw data files or JPG, video, i.e. frames at a speed, storage / transfer types / format e.g. lossless / lossy compressed files, standard print formats, reduced by calibration with a flat-field image. Rarely different areas of a large image are shot with overlapping in order to create a panorama; image alignment/stitching include key point detection feature matching , geometric registration and global registration.

Among libraries, and museums, there are old documents preserved in storage areas. Many of these documents are considered as quite important for national heritage, see fig. 1. Their efficient preservation and unconditional exploitation to wider public even through the internet is a trend in modern archaeology.

In image acquisition by digital cameras, see fig. 1, no flash lights are used, since the light could permanently degrade the documents colours and results in poor quality images.

Our work concentrates on two basic techniques used for image enhancement and restoration, denoising and binarization. Denoising refers to the removal of noise on the image and binarization refers to the conversion of a grayscale image to binary. Binarization by thresholding converts the grayscale document image to binary, by changing the foreground pixels (text characters) to black and background pixels to white. Image thresholding obtains a resulting binary image in black and white, easily stored in computer, while retaining all the basic characteristics of the original image.

All algorithms and ideas in this chapter are applied and tested to old pages photographically acquired from historical books and manuscripts called "Codices", from the Holy Monastery of Dousiko, Pylh, near Meteora, Trikala, see Fig. 1.

Fig. 1. Taking photos of Byzantine manuscript from Dousiko Byzantine Holy Monastery, Pylh, Greece

2. Document image acquisition

Document raw image acquisition (sharpness, resolution and transfer function curves) by camera, video or scanner highly depends on machine vision systems (Boyle 1988, Davies, 1990) and the combined effects of viewing distance / angle from the eye, depth of field, optimum aperture, lens sharpness. camera misalignment, aperture, lens characteristics, polarizing filters, diffraction, light and illumination types, focus, zoom, scaling and sharpness control, long exposure noise reduction, optimal intelligence and minimally processing sensors (Adams, 1995).

We acquire old documents images by a digital field camera (a CMOS technology SLR "CANON 1.8II" with a 50 mm lens) with high resolution ratio (4,368 x 2,904 pixels a total of 12,684,672 recorded pixels (12 Mbytes storage space), and stored in computer and compressed for storage minimization and sensors size 24 mm x 36mm (Canon 2007).

Raw images usually have 12 bits colour information per pixel. Image editing software uses 8 bits, or 16 bits. The 12 bits per pixel data from a RAW file is more accurate than the 8 bit format of a .jpg, but the .jpg 8 bits contain various corrections. For textual images published on the web site, enlarged and printed to larger dimensions than 10″ x 8″ compression may provide inadequate quality. Raw format allows us to correct defects (under/over exposure, colour balance, etc). Raw/.jpg images differ in that we make the adjustment before/after non-linear corrections (γ- correction) i.e. before/after saving it as a .JPG, TIFF, PSD files.
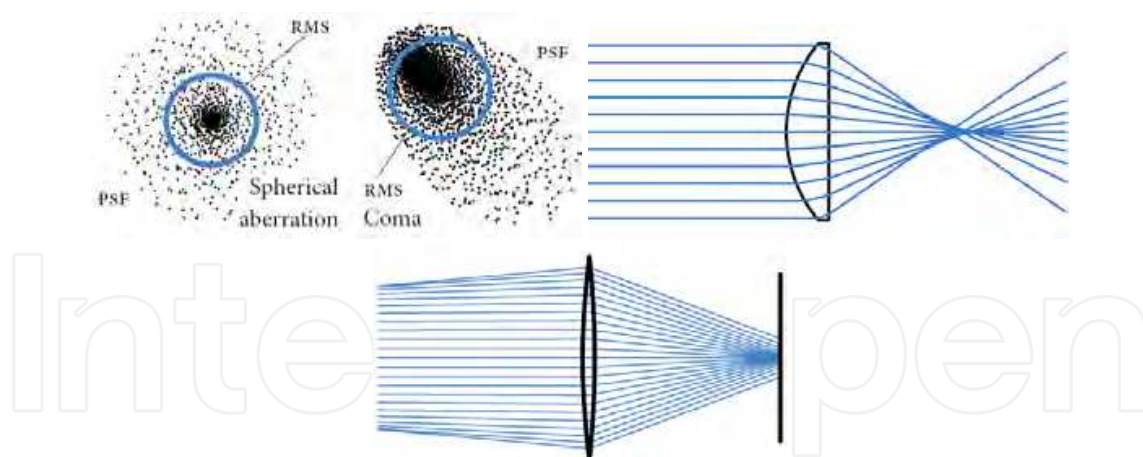
Fig. 2a. Spherical error (lens chromatic aberrations), i.e. optical imperfections (different bending of light at different wavelengths), the inability of spherical surfaces to provide clear images over large fields of view, changes in focus for light rays that don't pass through the center of the lens, etc (Ren, 2006).
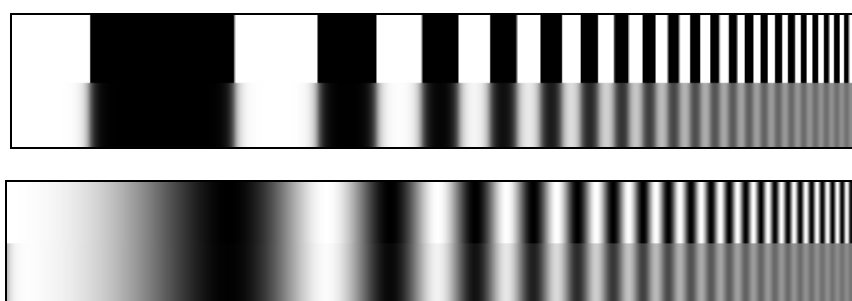

Fig. 2b. Lenses inaccuracies - Sine pattern with lens degradation and low to high spatial frequencies variations. Sharpness boundaries between zones of different tones or colors.

Signal processing varies with image content (feature contrast) and a camera's ability to render fine detail (texture), i.e., low contrast, high spatial frequency image content. Spatial frequency response is related to total image quality resolution and tonal response. Log f-contrast is sensitive to noise. Sensitivity to sharpening decreases and sensitivity to noise reduction increases from top (most contrast) to bottom (least contrast). Tone photos and correct radial exposure and brightness should be calibrated. SQF (subjective quality factor) is a measure of perceived print sharpness that incorporates the contrast sensitivity function (CSF) of the human eye (Legge, 1985). Retouche software filters, focus and control sharpness without edge lines or artifacts, while color correction software, master exposure compensation, white balance corrector that correct miscoloration in photos caused by any light source (Papamarkos, 2001).

Dynamic or exposure range of cameras and scanners is the range of tones over which a camera responds and over which noise remains under a specified level; log exposure is proportional to optical density. Digital cameras output may not follow an exact gamma (exponential) curve (confusion factor), a tone reproduction curve ("S" curve) is superposed on the gamma curve to boost visual contrast without sacrificing dynamic range in middle tones while reducing it in highlights and shadows. Resolution is the ability to resolve fine detail (ppi or dpi).

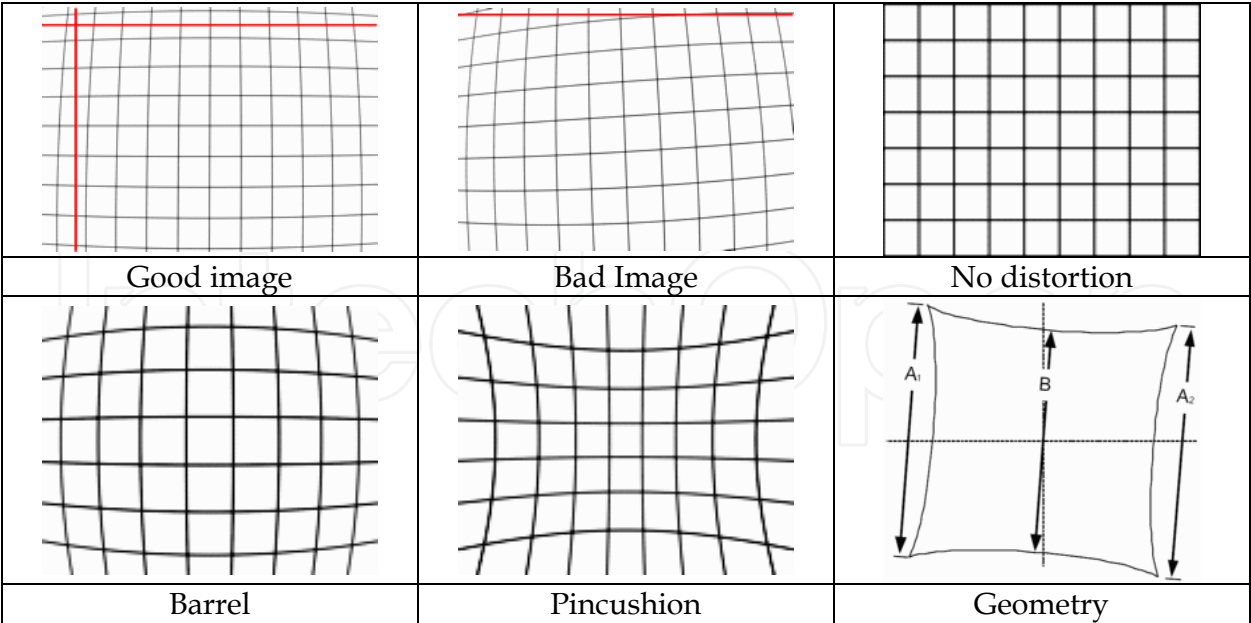| Good image	Bad Image	No distortion
Barrel	Pincushion	Geometry

Fig. 3. Geometric errors of lenses or images displays

Aberrations are chromatic (longitudinal / lateral), coma, astigmatism and curvature of field degrade lens performance and cause focus on different image planes, color fringing due magnification differences with wavelength, see fig. 2. Geometric or perspective (radial lens) distortion have two forms, barrel and pincushion, see fig. 3. Distortion can detect vertical and horizontal lines in extreme wide angle, telephoto and zoom lenses. Highly distorted images are a special case.

The ability of the eye to resolve detail is known as visual acuity. The normal human eye can distinguish patterns of alternating black and white lines with a feature size as small as one minute of an arc (1/60 degree or $\pi/(60*180) = 0.000291$ radians). A pattern of higher spatial frequency in larger prints, would appear pure gray, low contrast patterns at the maximum spatial frequency will also appear gray. The human eye and brain have a limited ability to discern tonal values, and to analyze large numbers of images simultaneously; it is more qualitative than quantitative. Wavelength (color) psychophysics influences text vision, especially in low-vision conditions. Photopic / scotopic conditions, photoreceptor disorders, characters near the acuity limit, lower luminance, wavelength effects, spectral sensitivities, light scatter or absorption result in depressed / optimal performance in the red, blue / green, gray regions. Eyes differentiate in vertical and horizontal banding. Eyes are wired to recognize differences in vertical and horizontal banding, while the recorded images appear arranged in diagonal arrays. Noise tends to be most visible at medium spatial (actually angular) frequencies where the eye's Contrast Sensitivity Function is large.

3. Image background - foreground

In foreground / background analysis, the goal is objects separation and cleaning. Poor contrast between foreground and background characters exists in transparent texts.

A text or object within an image viewed dark in color and placed on a light background, exhibits histogram with a good bi-modal distribution, see fig. 4, 5. One peak represents the

object pixels, one represents the background (Kapur, 1985) , see fig. 5. Significant incident illumination gradient across the image blurs out the histogram information. The histogram is altered by many image enhancement operators, mainly the contrast stretching and histogram equalization. Contrast stretching improves contrast. High peaks at the end of the histogram, suggest high intensity and contrast colors. Image statistics calculate histogram, mean color values, standard deviation, median, histogram shape matching, histogram based image segmentation, histogram equalization, etc for each color channel in RGB, HSL, YCbCr color space. Vertical - Horizontal Intensity statistics provide information about vertical - horizontal distribution of pixel intensities and is used to locate objects, centers, etc. Picture segmentation maximizes the separability of resultant classes (Yanowitz, 1989).
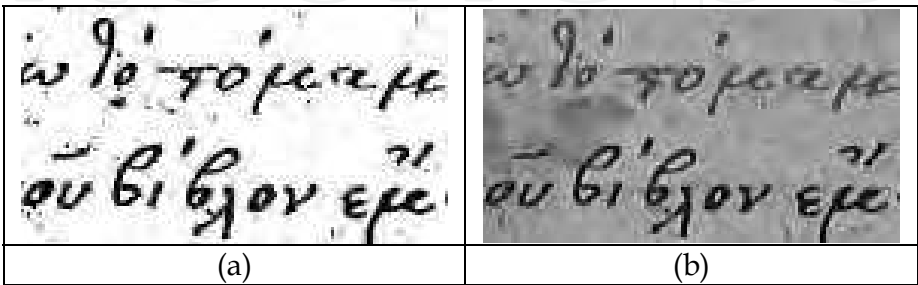

| (a) | (b) |

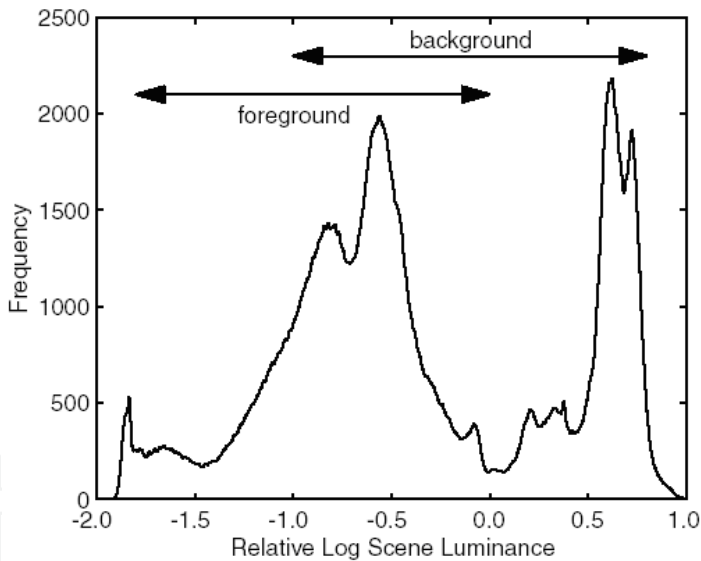Fig. 4. Foreground / background analysis

Fig. 5. Histogram of relative log scene luminance range

Because the dynamic range of the original scene is substantially larger than this, a subset of the image data must be selected. Different results are obtained depending on whether the foreground or background region of the image is selected. Background could be complex and inhomogeneous, while segmentation, ratio foreground / background contrast comparison, classification of large background regions optimize results, see fig. 6.

Very low-contrast texts are detrimental to readability and identifiability, because the background may show large variations in luminance (Knoblauch, 1991). While backgrounds (culture, wave, plain) are uniform, the text is not. A common text area contains 23% of text pixels.

Fig. 6. Various quality old paper background textures in old documents, see App. 1.

4. Histogram analysis

Image statistics parameters and transformation include character features, font information, size, mean-square error, position, dimension and shape, area, gravity point, number of work pieces, correlation, clustering, connection characteristics, ROI, min/max, average/deviation/skewness, column / row location, rms pixel values, etc, see fig. 7, 8, 9, 10, 11. Image color spaces offer flexibility on image processing, i.e. the HLS space has advantages since saturation is low for black/white pixels, brightness is independent of the saturation and freedom of choice to brightness, luminance or lightness function; saturation values are easily compared
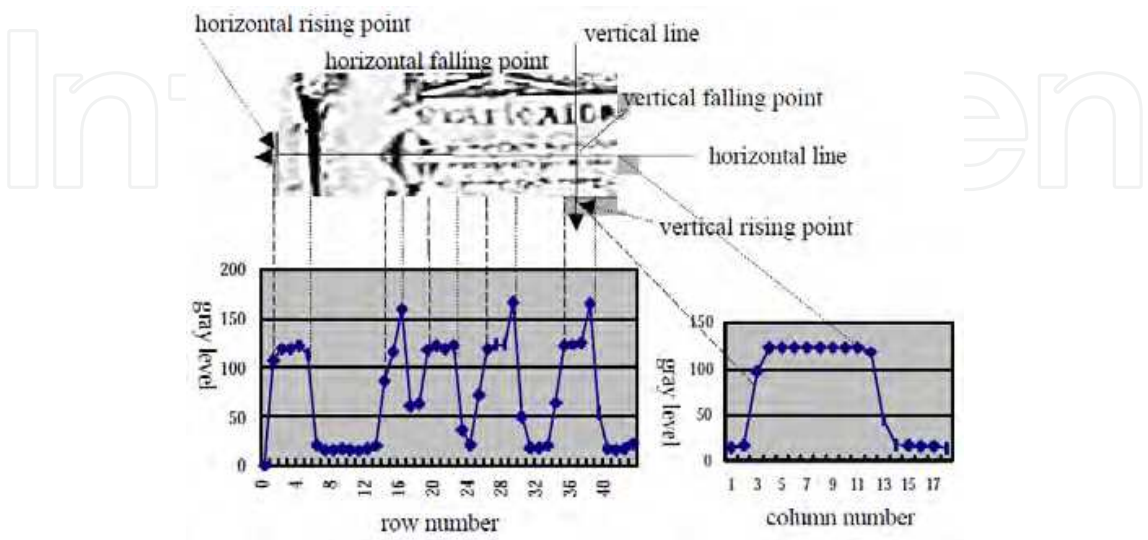

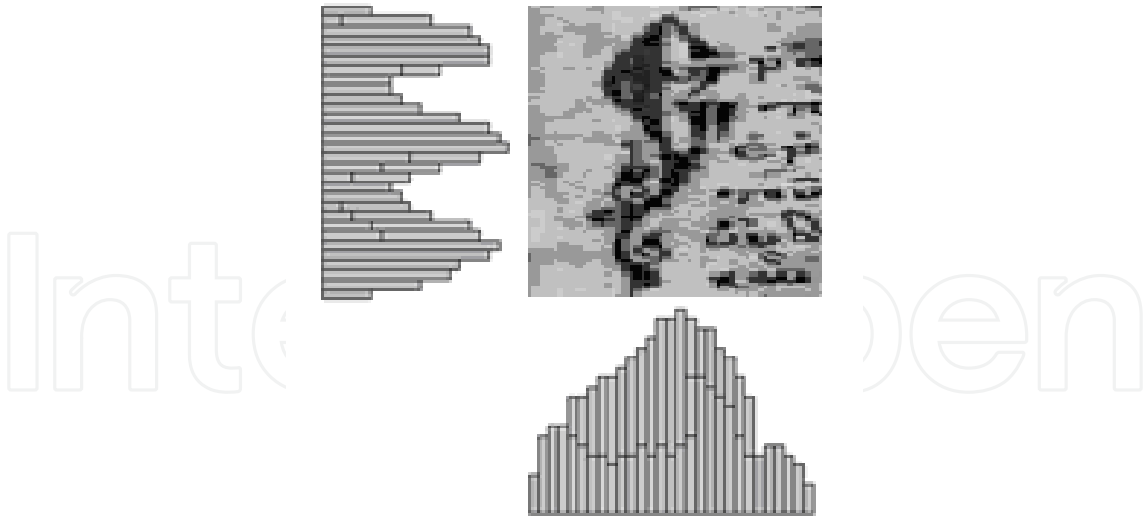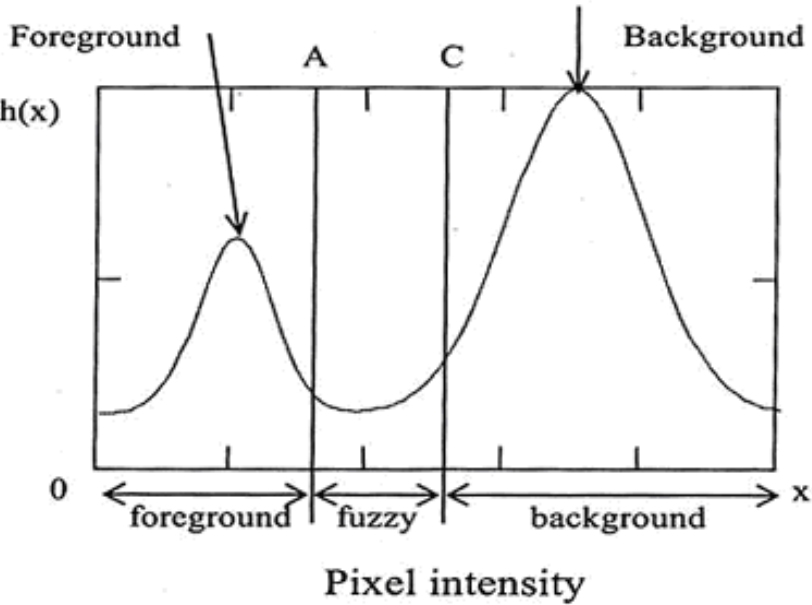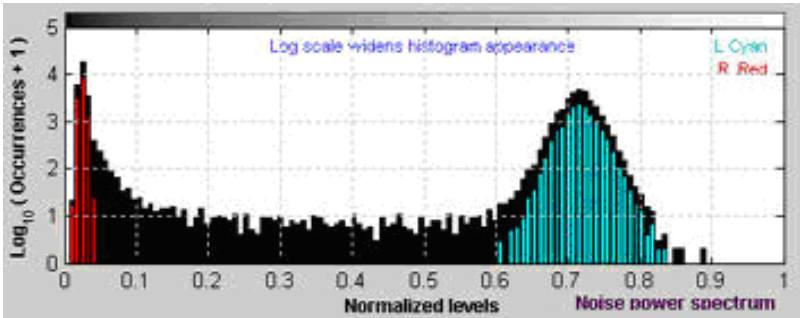Fig. 7. Horizontal/vertical cross intensities

Fig. 8. Horizontal/vertical histogram projections

Histograms and noise analysis: The black (background) histogram contains pixel levels for the entire ROI. Sharpening may cause extra bumps to appear in the black histogram. Histogram logarithmic scale improve analysis

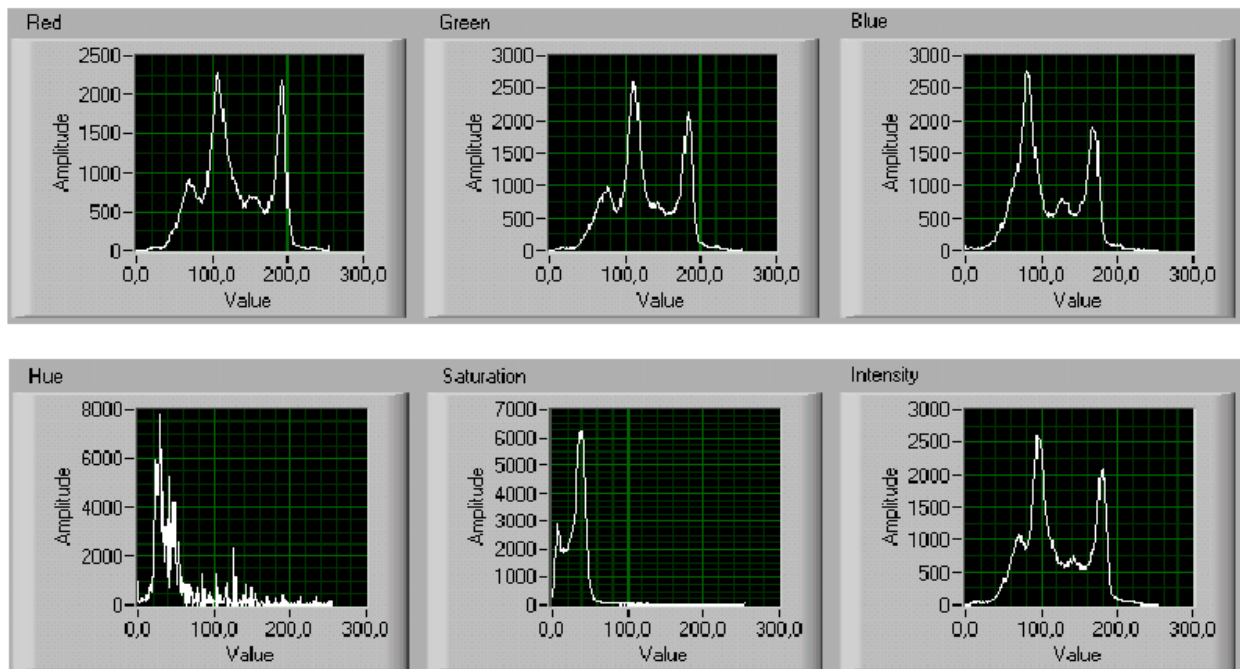Fig. 9. Intensity Histogram with 3 classes of pixels

Fig. 10. A CMYK color space is smaller than the monitor RGB color space. Physical display limitations reduce CMYK colors displayed
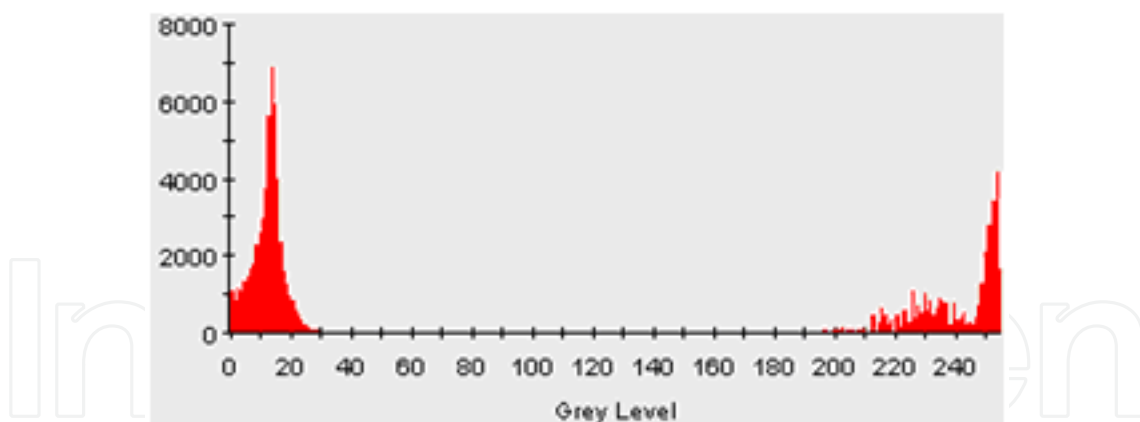

Fig. 11. Hue histogram. The reds and violets are separated by a large discontinuity

5. Color processing

When raw RGB data are used without color balance compensation we get incorrect color result, see fig. 12, 13. Soft proofing process minimizes visible color differences, while PDF/X-4 standard provides a framework that enables colored elements can be reproduced well on different output devices and media. Color (miscoloration) correction software and white balance corrector includes scalar or vectorial processes. The color ratios (R/G) can be especially useful for diagnosing uneven color response.

Original Image	Lightness adjustment
Hue (red = -180)	Saturation
Color balance	Contrast
Changing lower Threshold limit	Changing upper Threshold limit

Level		Curve software	Desaturation
RGB Equalize	RGB decomposition	White Balance	Stretch Contrast

Fig. 12. Signal processing filters

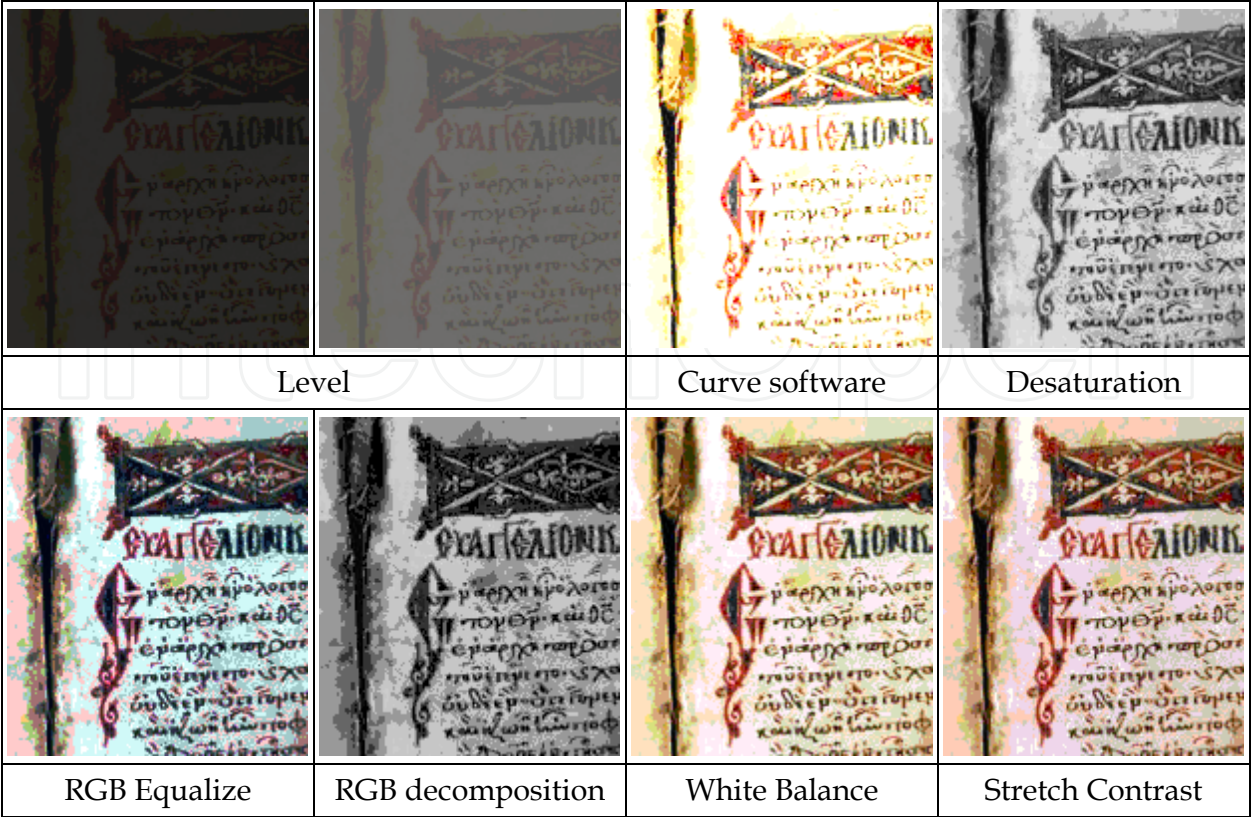|		
Brightness 0%	raw image	100 % saturation
Colour (RGB / YMC) 0%	raw image	100 %

| Raw | Y | G | Red |

Fig. 13. Saturation enhancement - Text in different color spaces (Hunt, 2001)

All achieved image deformations are artificial but they are used in understanding or inversion restoration of distorted images, e.g. scanned thick bound documents (Zhang, 2001), see fig. 14. Warp occurs in words, location, shape, shade and orientation.

Defocus filter applies a Gaussian blur to the image, making it less clear. Other filters reproduce the effect of aging in old, traditional black-and-white photographs, toned with shades of brown, see fig. 15. To achieve this effect, the filter desaturates the image, reduces brightness and contrast, modifies the color balance and marks the image with spots, see fig. 14.

| Blinds filter | Curve bend filter | Emboss filter |
| Erase Every Other row | Engrave filter | Lens Distortion filter |

Newsprint filter	Page curl filter	Shift filter
Ripple filter	Value Propagate Filter	Video filter
Filter waves filter	Whirl and Pinch filter	Wind filter

Fig. 14. Distorted images – Distortion

Old photo filter gives an old photo, blurred with brown shade, spots, jagged border	Coffee stain filter adds / subtracts realistic looking stains randomly spread out

Fig. 15. Maturing old images or stains on images

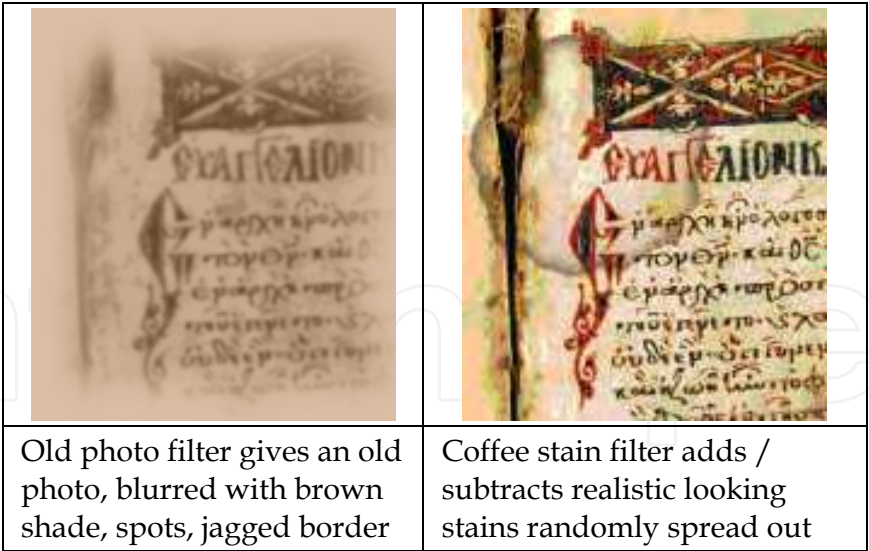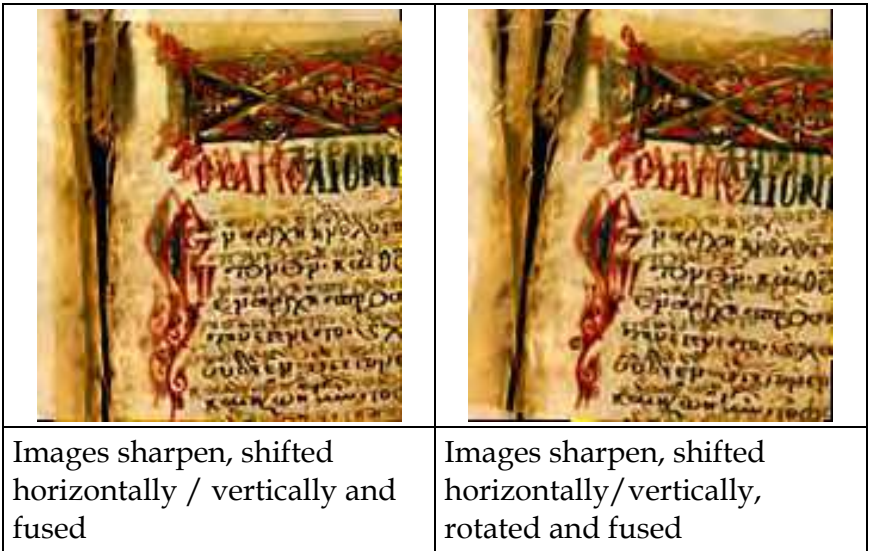|	
Images sharpen, shifted horizontally / vertically and fused	Images sharpen, shifted horizontally/vertically, rotated and fused

Fig. 16. Images fusion techniques

The apply canvas and the weave filter applies an artist's canvas-like or weave effect with parameters direction, light source, apparent depth. Clothify filter adds a cloth-like texture with parameters azimuth, elevation, depth). Impressionist and Oilify filter include cubism and gives image the look of a painting with parameters overlay, scale, texture, graininess of the texture, relief, brush, luminosity, gamma correction, mid tones brightens/darkens, aspect ratio, directions, color noise, background. The cartoon filter is similar to a black felt pen drawing subsequently shaded with color. This is achieved by darkening areas that are already distinctly darker than their neighbourhood with parameters lines thinner or thicker, darker and sharper. The predator filter effect makes the image/selection look something like a thermogram. This will reduce the image to edges in a few basic (red, green, blue and gray) colors on a dark background. Photocopy filter makes the image like a black and white photocopy. Soft glow filter applied lights the image with a soft glow diffuse effect, see fig. 17.

6. Layers fusion

Certain data fusion techniques of complementary spatial and spectral resolution characteristics produce enhanced observations, see fig. 16. Dual image point processing maps two pixel brightnesses, one from each image, to an output image by the overlay or the composite operation that merges unrelated objects from two images; this is done on a per band basis. The images are identical scenes, but acquired at different times and spectral filters. An alpha channel represents the transparency of the image (D'Zmura, 1997). The Threshold Alpha command converts semi-transparent areas of the active layer into completely transparent or completely opaque areas. It only works on layers of RGB images which have an alpha channel. The transparency transition is abrupt. Composition refers to the merging of two or more distinct objects into a new compound object with new functionality. A single object image is processed to extract object features, modify some of the features, and then merge the modified object back. Image processing techniques include skewed documents correction (Kavallieratou, 1999).

Fig. 17. Artistic effects assist to optimal presentation or understanding of wear and image degradation

7. Image text degradation by noise

Digital camera images with excessive noise reduction will have an unusually rapid falloff of the noise spectrum. The pixel noise is highly visible; it wouldn't be suitable for portraits and other high quality work, but it would be acceptable when a grainy look is tolerated. Temporal noise is the random difference between otherwise identical images: $N_{temporal} =$ Noise($Image_1$-$Image_2$) / $\sqrt{2}$; dividing by the square root of 2 scales temporal noise to be the same as noise measured in an individual image. Noise will be worse for higher contrast cameras, affected by the gamma encoding. Gradual illumination nonuniformities should be removed from the noise results. Noise is largest in the dark areas because of gamma encoding. Noise corrupts the images as additive /multiplicative Gaussian, uniform, speckle noise and complex signal dependent noise, salt and pepper with standard deviations ($\sigma=15.0 \div \sigma =2.5$); filters reduce them to $\sigma=2.0$ $\sigma=0.5$ respectively). Combinations of noise type, amount, etc corrupt images totally, partially or locally.

The documents images are classified into six distinct image categories / conditions, see fig. 18:

1. Acceptable images that are in good condition of camera acquisition and paper
2. Images that present spots, stains, smears, scratches, damages or smudges
3. Images with shadows and wrinkles (Blinn, 1978) caused by:

      3.1   High humidity over the years, fragile paper or
      3.2   Bad / non uniform illumination and background
      3.3   Aging paper colours deterioration and brightness degradation
4.   Transparent or oily page or ink wet, seeking / visible from the other side
5.   Thin / thick / consistent stroke pen width texts, multiple touching characters
6.   Badly blurred or missing ink broken characters with holes or light handwriting
7.   Characters with different colours (e.g. red) ink, poor quality of ink

Documents with poor quality paper, fragile, etc.	The brightness of the aging paper has deteriorated colours over the years.	Poor contrast between foreground and background characters.	Documents condition, poor quality of ink, broken characters, characters with holes or light handwriting.
Ink wet paper with characters visible both sides of paper.	Dirty documents with various sizes or colours of spots, stains, smears or smudges.	High humidity over the years cause wrinkles to the paper.	Image acquisition problems illumination, types of light, non uniformity, low contrast, etc.

Fig. 18. Description of problems appeared and examined on Byzantine documents

7.1 Noise on images

Randomization (%) represents the percentage of noise affected pixels. A normal distribution of noise means, that only slight noise is added to the most pixels in the affected area, while less pixels are affected by more extreme values. Noise may be additive (uncorrelated) or multiplicative (correlated - also known as speckle noise), repetitive. For wide band and high-pass noise the summation is quite linear while for low-pass noise no summation needed. Hue noise changes the color (strong /weak hue variation) of the pixels in a random pattern; noise varies by saturation or brightness of scattered pixels.
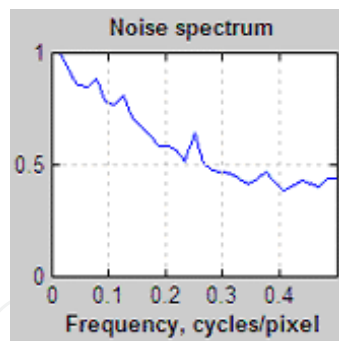
Fig. 19. Noise spectrum
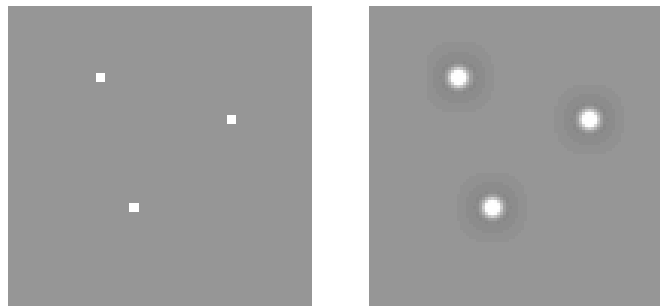

Fig. 20. Antialiased images

Fig. 21. Sharpened images

Artifacts, noise contamination, see fig. 19, edges, sharp transitions, edge blurring, saturation effect on bright / dark text scenes, high corruption, etc. appear for signal above the Nyquist frequency in the digital sensor. Color aliasing and Moire fringing is a type of aliasing, see fig. 20. Noise in digital sensors tends to have the greatest impact in dark regions. The larger the image (the greater the magnification), the more important noise becomes. Color quantization error cause false colours and contours.

Analog-to-digital image conversion and image sample / capture rate limitations suggest the highest spatial frequency, Nyquist frequency $f_N = 1/(2 *$ pixel spacing); the design of anti-aliasing (lowpass) filters always involves a trade off that compromises sharpness. Antialias filter reduces or reverses alias effects, jaggies. Antialiasing produces smoother curves by adjusting the boundary between the background and the pixel region that is being antialiased; pixel intensities or opacities are changed for a smoother transition to the background. Lateral Chromatic Aberration (LCA), or color fringing, is visible on tangential edge boundaries.
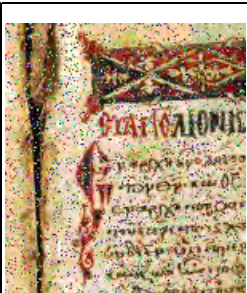
| The HSV Noise filter creates noise in the HSV active layer | The Hurl filter changes each affected pixel to a random color | The RGB Noise filter adds noise to a layer normal-ly distributed | Slur Filter effect melts the image downwards | The spread filter swaps each pixel with randomly chosen pixel |

Fig. 22. Color spaces filters

Out-of-focus photographs and most digitized images often need a sharpness correction. To prevent color distortion while sharpening, we decompose our image to HSV and work only on value, see fig. 22. So we protect areas of smooth tonal transition from sharpening, see fig. 23, 24. In an image with some blur we sharpen by applying some more blur: the intensity variation will be more gradual. We subtract the blurredness intensity from the intensity of the image and get the red curve, which is more abrupt: contrast and sharpness are increased. If blurring is important, this dip is very deep; the result of the subtraction can be negative, and a complementary color stripe will appear along the contrast, or a black halo around a star on the light background of a nebula (black eye effect) , see fig. 21.

| Despeckle removes small isolated defects | Red Eye Removal filter | Sharpen | Unsharp mask filter |

Fig. 23. Edges on Images (Ventzas, 1994)

Physical vs image contours are often very different. A physical edge of the image might yield practically no contour, while a shadow casts a clear image virtual contour where there in fact is no physical edge.
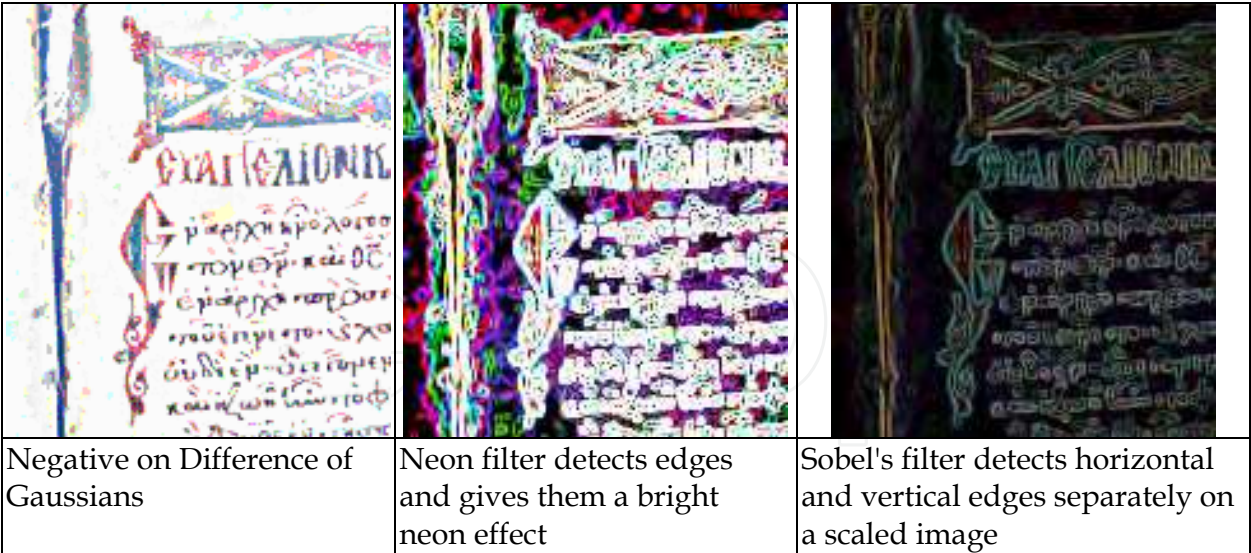
Negative on Difference of Gaussians	Neon filter detects edges and gives them a bright neon effect	Sobel's filter detects horizontal and vertical edges separately on a scaled image

Fig. 24. Grayscale edge detection and preserving algorithms create contours around objects

8. Denoising

Denoising filtering methods are in spatial or in frequency domain (Motwani, 2004). Filters are also subdivided to linear and non-linear filters. Many types of filters exist. We concentrate in three filters in spatial domain (mean, median and wiener) with various windows sizes and two filters in frequency domain (Butterworth and Gaussian), see fig. 28.

8.1 Time domain processing

Mean filter: The intensity of every pixel in the image is replaced with the averaged value of intensity of its neighbour pixels.

$$I(i,j) = \frac{1}{M} \sum_{(x,y) \in N} I(x,y)$$

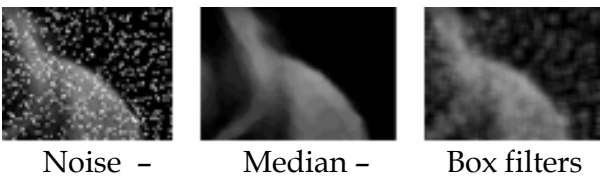where M the number of pixels in the neighbourhood N.

Median Filter: This is a non linear filter.

If $A\{a1, a2, a3, \ldots an\}$

and $a1 \leq a2 \leq a3 \leq \ldots \leq an \in R$

$$median(A) = \begin{cases} a_{\frac{n+1}{2}}, \text{if n is odd} \\ \frac{1}{2}\left(a_{\frac{n}{2}} + a_{\frac{n}{2}+1}\right), \text{if n is even} \end{cases}$$

Median is a lower rms error filter and remove impulse noise spikes.

Noise –   Median –   Box filters

Wiener filter: 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.

Linear filtering in spatial domain is performed by applying a filter with a weighted sum of neighbouring pixels. Filtering is achieved by convolution or correlation kernel rotated by 180°.

8.2 Blur filter

The motion blur filter creates a movement blur, the simple blur filter produces an out of focus camera effect, the IIR and selective Gaussian blur sets its value to the average of a radius; the blur can be set to act in one direction or above a difference threshold, so contrasts are preserved (blur a background and not foreground) and add depth, see fig. 27. The blur tool is used to soften tile seams in images used in tiled backgrounds. Convolution filtering reduces the effects of noise in images or sharpens the detail in blurred images. The selection of the weights determines the nature of the filtering action (high-pass, low-pass). There are several blurring filter kernel:
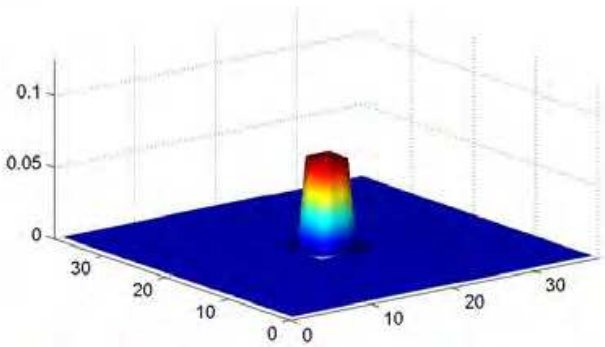

Fig. 25. The Box filter
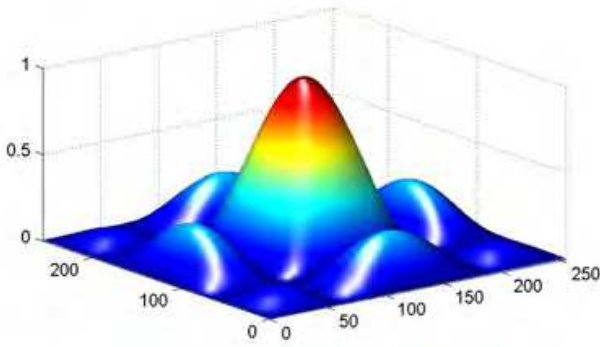
Fig. 26. Bartlett filter

The Box filter is simple, but Bartlett and Gaussian filters produce better blurring, see fig. 25. Bartlett filter pixels to the center are weighted more heavily than pixels away, see fig. 26.

original	motion blur	IIR Gauss blur	Fractal filter	Rippling filter
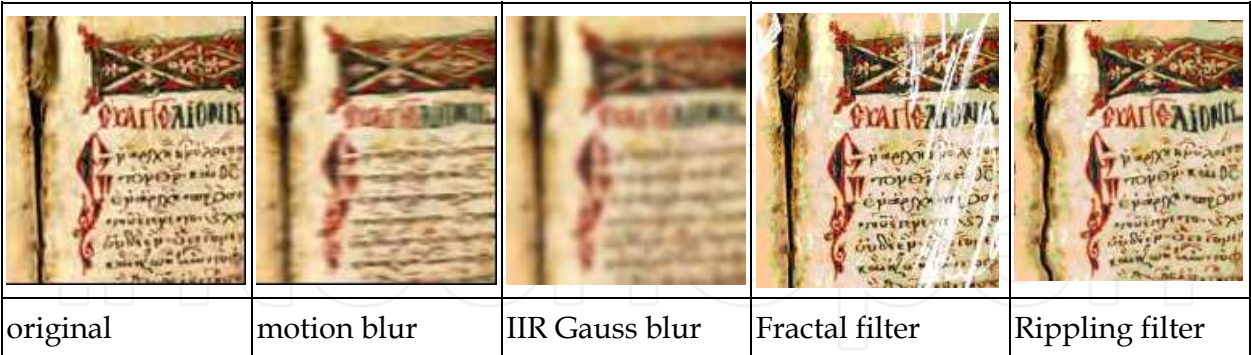
Fig. 27. Blur filters

8.3 Frequency domain processing

Image spatial frequency is measured horizontally, vertically or at any diagonal. DCT/IDCT is better at compactly representing very small images (Gonzalez, 2002, Sonka, 1998).

Butterworth Low Pass Filter

$$H(u,v) = \frac{1}{1 + [D(u,v)/D_0]^{2n}}$$

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, see fig. 28.

Gaussian Low Pass Filter (bell curved kernel).

$$H(u,v) = e^{-D^2(u,v)/2\sigma^2}$$

where $D(u,v)$ it the distance from the origin of the Fourier transform

Fig. 28. Ideal, Butterworth and Gaussian low pass filters and corresponding image effects

The Gaussian filter is separable, and can be split into horizontal /vertical passes. We can filter bright portions, downsample, horizontal and vertical blur and accumulate. By skipping the high-pass filter, we soften the entire image (anti-aliasing).

8.4 Non linear filtering

Filters are linear or nonlinear. The linear takes into consideration only the relative position in kernel, and remains constant throughout the whole image filtering. No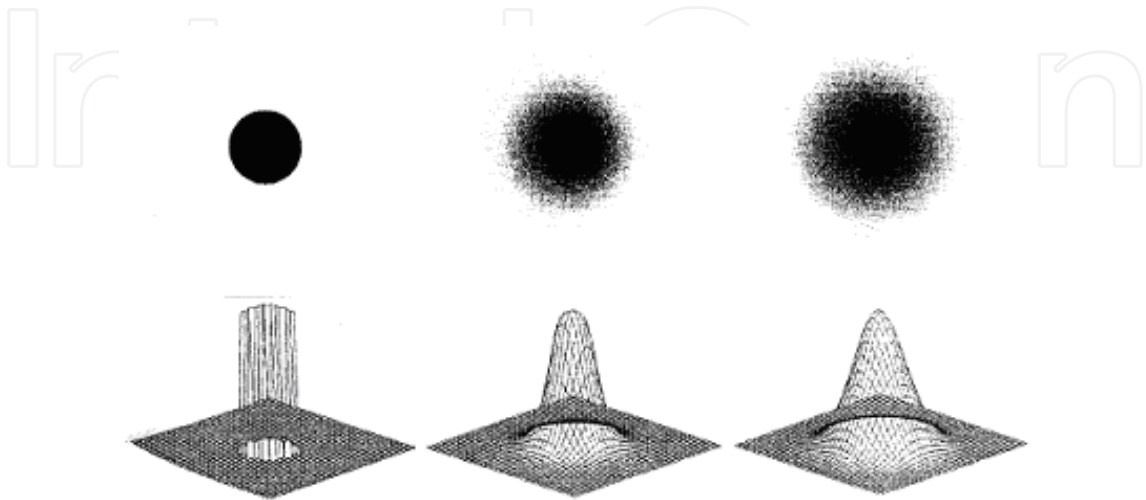nlinear filters are relative to the target pixel and the coefficients are calculated as a function of local variations of the signal. In the linear filter class, average and Gaussian filters are often used. Among the nonlinear filters, the median filter is popular. A selective blurring filter is often used, which emphases the pixels with similar intensity to the target pixel. A bilateral filter is an edge preserving technique being widely used in image processing. Comparing it to the selective blurring filter, it takes into account intensity and spatial similarity with a uniform or Gaussian kernel.
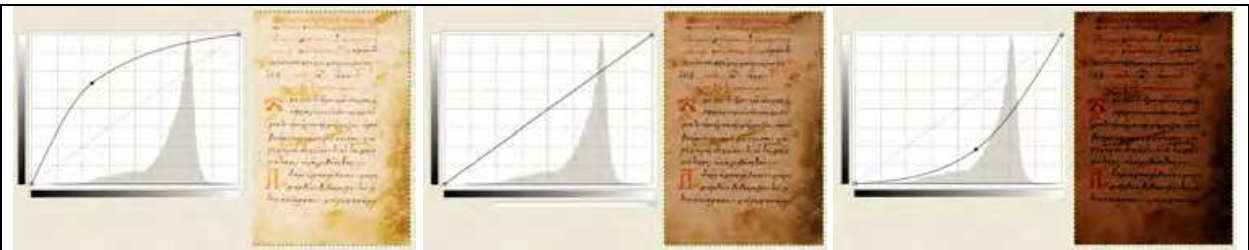
Fig. 29. The image is linearized, the pixel levels are adjusted to remove the camera gamma encoding

Linear image processing assumes linear luminance. Images are frequently gamma encoded, in the sRGB color space, so luminance is not linear. To apply a linear filter, we must gamma decode the values, and if resampling, we must gamma decode, resample, then gamma encode, see fig. 29. The magnitude squared is an enhancement operation, the Phase operation is phase enhancement, quantizing an image on logarithmic rather than linear scale (human eye has a logarithmic intensity response) results in logarithmic enhancement.

| Noisy image | Gaussian | Median | Midrange | Filtered | Ideal filter |

Fig. 30. Filters responses

In low level image processing, for shape and edge detection we differentiate filters performance in cases of high noise compared to small noise conditions, see fig. 30. Nonnegative filters do not introduce overshoot or ringing artifacts. Other temporal/spatial/ frequency averaging filters are the non-liner diffusion, the shock, the inverse scale space

filter, reconstruction filter, Brickwall, Tent, BSpline filters. Resampling, decimation, interpolation decreases/increases the sampling rate. In photography, a variety of interpolation 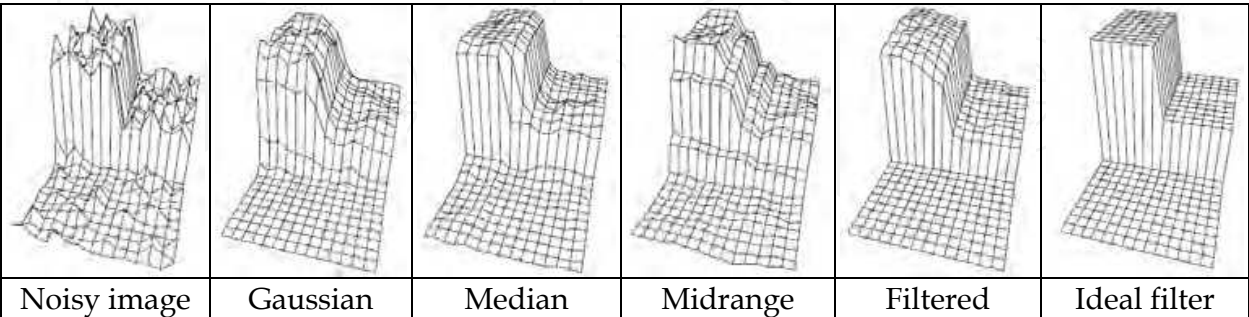filters exist, such as nearest neighbour averaging, bilinear, bicubic interpolation for higher resampling ratios. Reconstruction filters reconstruct an image from a collection of wavelet coefficients.
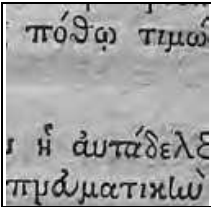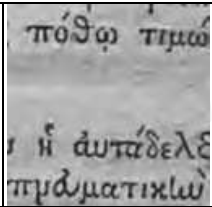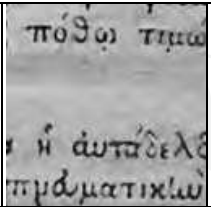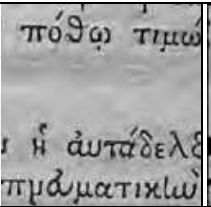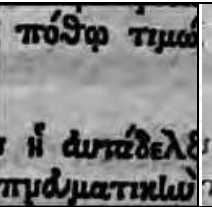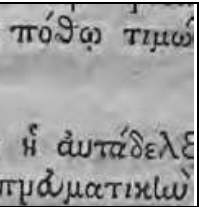
original image grayscale	after mean filter 5-by-5	after median filter 7-by-7	after max filter 5-by-5	after min filter 5-by-5	after wiener filter 7-by-7

Table 1. Filtering on Byzantine documents

9. Denoising results

a.   Filtering improves the image quality, and prepares it for binarization
b.   Spatial domain filtering uses Mean, Median and Wiener filters
c.   Frequency domain filtering uses the Butterworth and Gaussian low pass filters
d.   The paper condition and lighting conditions is an important factor

Type of filter	Performance	High Noise	Small Noise
Gaussian	*poor*	*same*	
Median	*good*	*bad*	*good*
		very good and same with Salt & Pepper	
Midrange	*bad*	*bad*	*bad*
Gradient inverse weighed	*good*	*very bad with Salt & Pepper noise*	
K-nearest neighbor	*bad*	*bad*	*bad*

Table 2. Filters performance

Researchers investigated the combined effects of high and low pass filtering on both letters and noise (noise filtered but letters unfiltered, etc). Averaged thresholds showed that for a given noise, unfiltered letters (the sum of the high- and low-pass letters) led to better recognition than either component filtered letter alone. High-pass letters led to better performance than unfiltered letters in low-pass noise.

Cleaning up scanned text pages from old manuscripts is achieved through Dilation Erosion, Opening and Closing techniques of raw or negative images. We look on how to clean up isolated noise dots without removing dots that are part of characters, by using bwareaopen, bwlabel and regionprops to highlight the pixels that were removed and logical operators (logical AND of the dilated characters with the pixels removed or logical OR) to restore the removed pixels. We suggest the use of morphological reconstruction to get all the pixels connected to the overlapping pixels. Thinning and cropping could lead to segmented characters that include parts (remains) of other neighboring print objects, while skeletonization displaces junctions, and short false branches occur. Thinning of thick binary

images reduces shape outlines, while different thinning rules optimize edge noise, remove, add or move spurious noise and edges, see fig. 31.

	Dilate filter	Erode noise
Convolution kernel (5x5 or 3x3) (sharpen, blur, edge, enhance, detect, emboss, etc)		
Emboss filter	Displacement filter	Illusion Filter
Fractal trace filter	Seamless filter	Warp filter
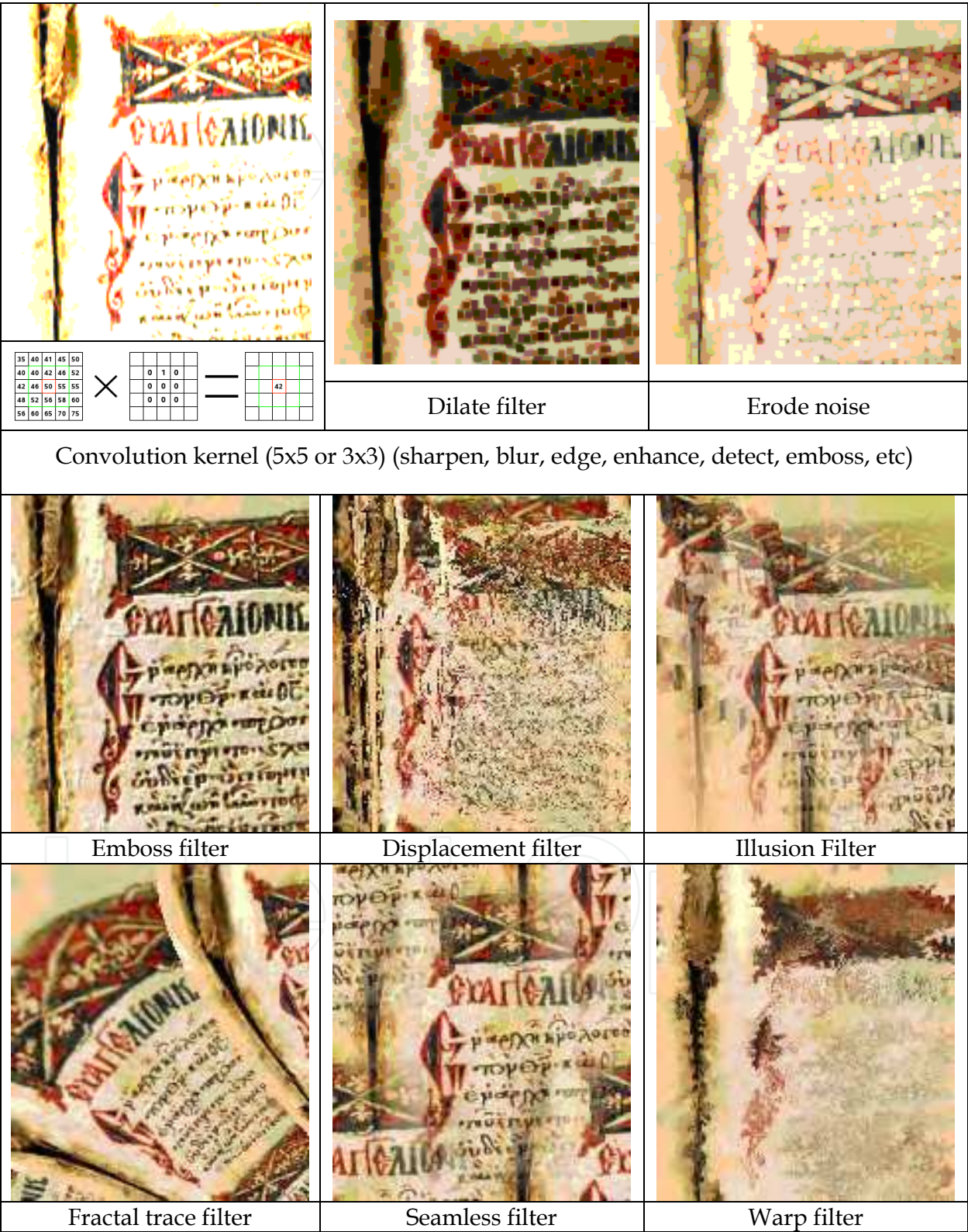
Fig. 31. Convolution filters / Erosion / Dilation on Images

Warp filter masks an image to protect / wrap / unwrap it against filter action (steps, smears, blackens, displaces, dithers, swirls, scatters, etc), see fig. 31.
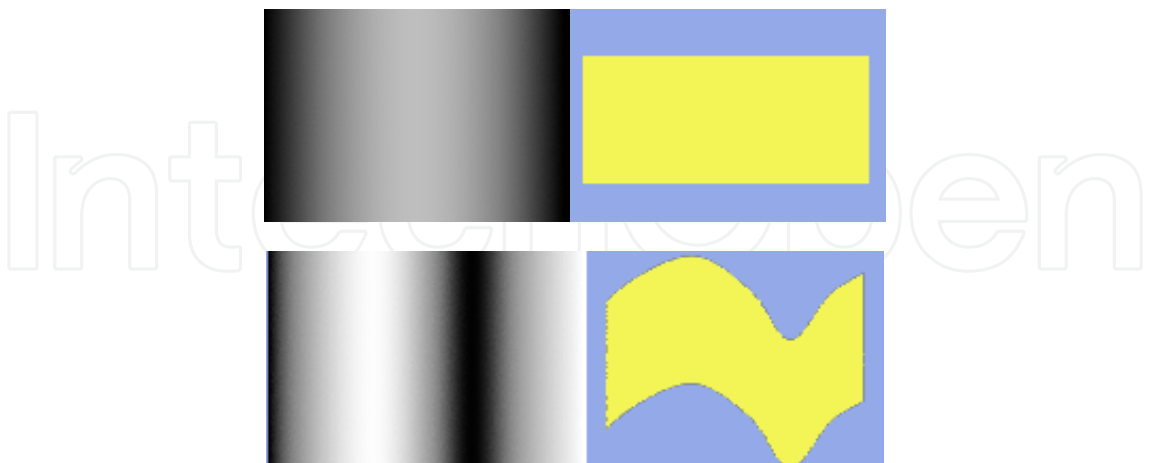
Fig. 32. Whirl: Using gradient to bend / unbend a text
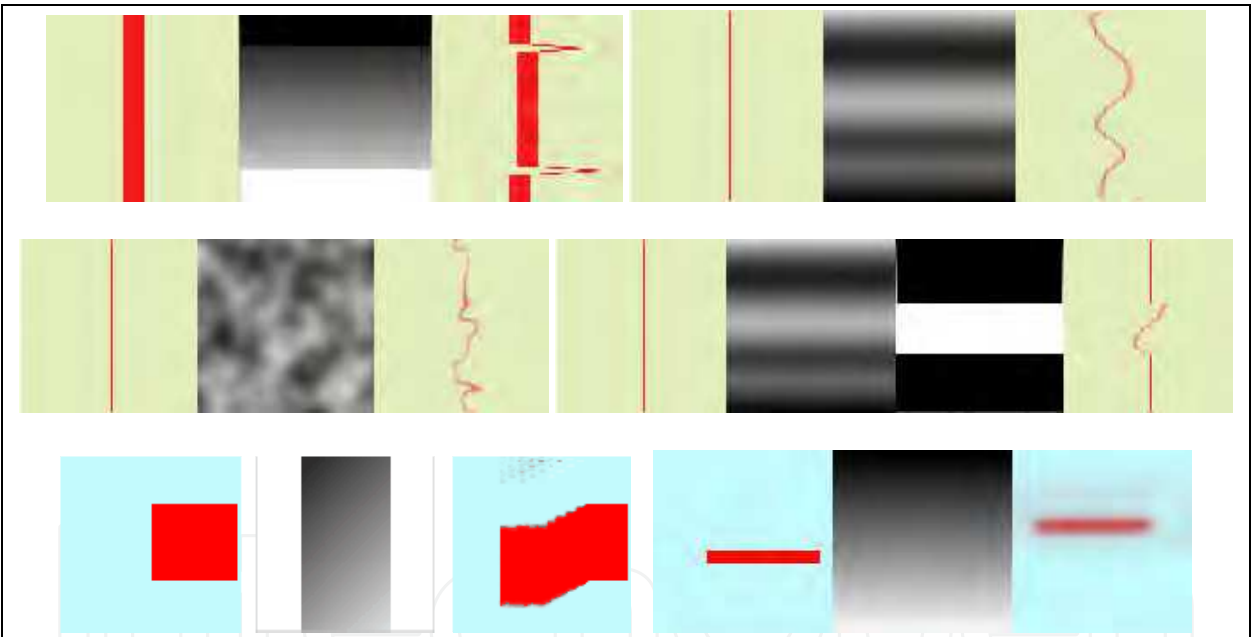
Fig. 33. Convolution filters

9.1 Image enhancement

Image Enhancement of degraded text includes add borders, crop an image, rescale amplitude, equalize / match histogram, modify / apply multi-band (RGB), or color-cube / generic lookup table, dithering, offsets, pixel point processing (pixel inverting), thresholding (binary contrast enhancement), segmentation with / without a priori font information, retouche light, radial exposure and brightness, handwritten characters clarification (Gatos, 2004), texture unsharp masking, edge enhancement, etc (Gupta, 2007) , see fig. 34. Retouching filters, controls focus and sharpness without artifacts, with color correction, exposure compensation, white balance corrector for miscoloration caused by light source,

master transparency like GIFs with transparent backgrounds, master contrast, saturation, correct camera lens distortions, master noise filtering, photos tone, etc. Historical manuscripts image processing consists of the following five stages:

```
┌─────────────────────────────────┐
│ 1. Image Acquisition            │
└─────────────────────────────────┘
              ↓
┌─────────────────────────────────┐
│ 2. Image Preparation            │
│   ⇒ RAW to JPEG                 │
│   ⇒ Cropping                    │
│   ⇒ Converting to               │
│     grayscale                   │
└─────────────────────────────────┘
              ↓
┌─────────────────────────────────┐
│ 3. Filtering Methods            │
│   ⇒ Mean, Median, Wiener        │
│   ⇒ Butterworth, Gaussian       │
└─────────────────────────────────┘
              ↓
┌─────────────────────────────────┐
│ 4. Threshold Methods            │
│   ⇒ Bernsen's                   │
│   ⇒ Niblack's                   │
│   ⇒ Otsu's                      │
│   ⇒ Sauvola's                   │
└─────────────────────────────────┘
              ↓
┌─────────────────────────────────┐
│ 5. Image refinement             │
│   ⇒ Filling small holes         │
│   ⇒ Removing noisy pixels       │
└─────────────────────────────────┘
```
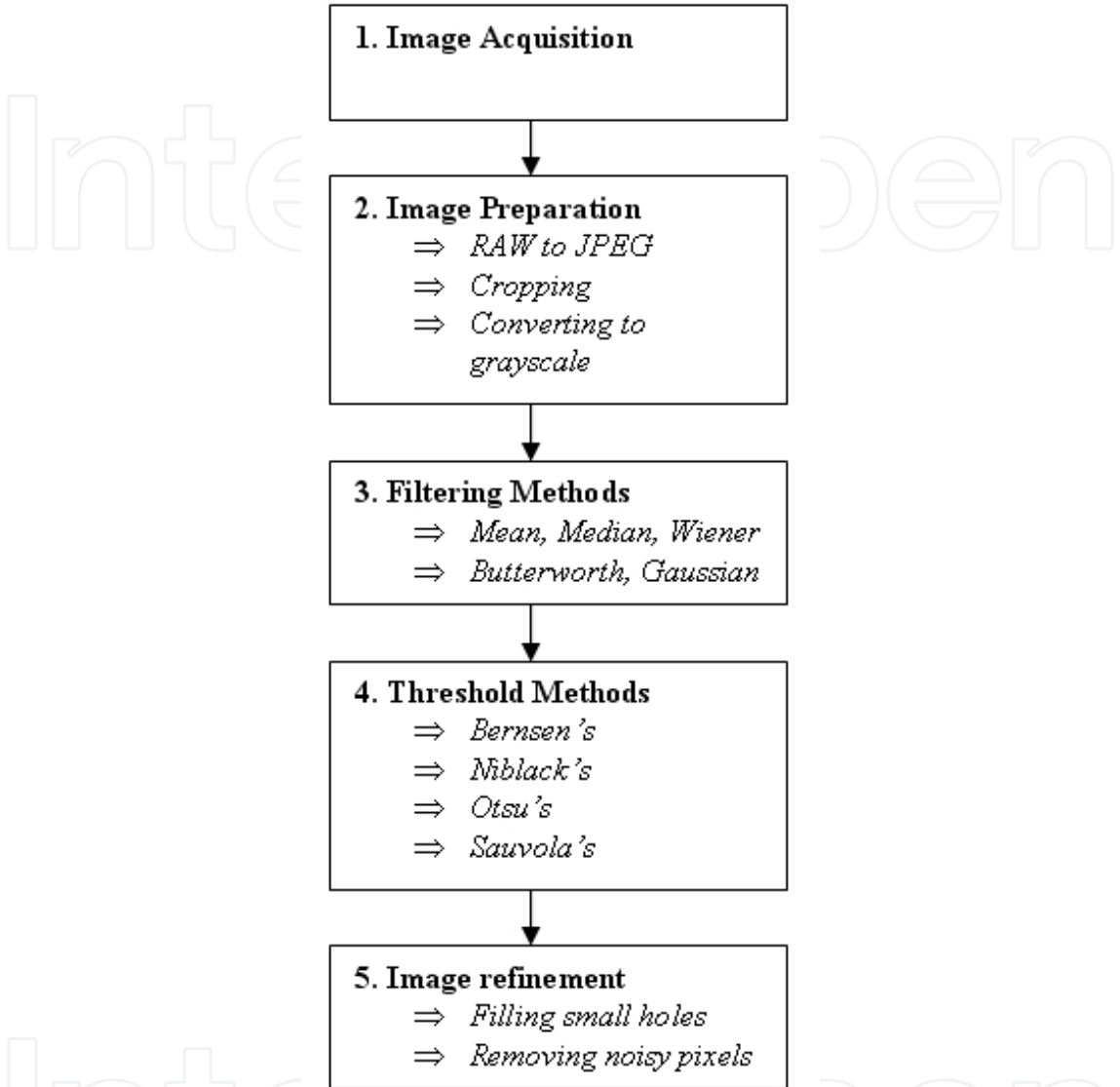
Image acquisition by a digital camera offers inherent advantages, i.e. produces less noise, with high resolution and image prepared for binarization.

Image preparation converts the original raw image format into TIFF /JPEG file format for memory saving and minimal computational effort. Cropping, removing invisible and irrelevant information and converting to grayscale are necessary steps before denoising and binarization.

Denoising is derived by comparing Mean, Median and Wiener filters in spatial domain and Gaussian and Butterworth filters in the frequency domain.

Thresholding is applied by global (Otsu's) and local (Niblack, Sauvola, Bernsen) thresholding techniques to previous stages resulting, filtered images.

Refinement procedure is applied on the binarized image, based on erosion and dilation, such that the obtained image has its characteristics further clarified in the texture and foreground compared with the background area. Cleaning and enhancing stands for visual appearance and beauty while refinement is for reliable, true display.
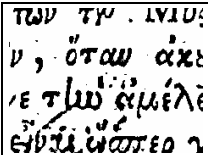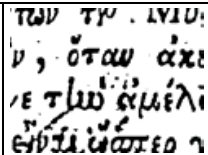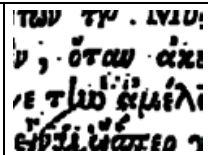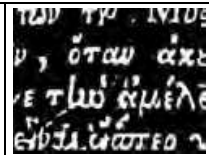
Fig. 34. Enhancement method stages
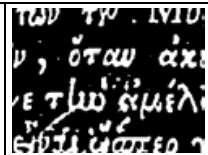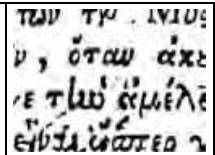
binary	erosion	dilation	negative	opening negative	Final

Table 3. Steps of refinement stage

9.2 Binarization – Thresholding techniques and algorithms

Thresholding, is a binary contrast enhancement technique, that provides a simple means of defining the boundaries of objects that appear on a contrasting background. The threshold range is specified by a low value and a high value (Leedham, 2003, Solihin, 1999) , see fig. 37. For the binarization of images many threshold algorithms, (global, local and adaptive), have been proposed to separate foreground from background objects (Yang, 2000). We have chosen Otsu's (Otsu, 1979), Niblack's (Niblack, 1986), Sauvola's and Bernsen's binarization methods (Sauvola, 2000) are used to compare their results on Byzantine textual images taken from the Holy Monastery of Dousiko, Pylh, near Meteora, Trikala, Thessaly, Greece.

Global thresholding

$$g(x,y) = \begin{cases} 1, & if \quad f(x,y) \geq T \\ 0, & otherwise \end{cases}$$

If T the global threshold of image $f(x,y)$ and the $g(x,y)$ is the thresholding result.

Otsu's optimal threshold method minimizes the class variance of the two classes of pixels.Threshold selection is absolute, conventional, optimal, automatic, adaptive, nonparametric, parametric, etc.

9.3 Lighting conditions

Light text is harder to read than dark text. Responses to light text are slower and less accurate for a given contrast. Letters recognition is based on component features. Optical density is the amount of light reflected or transmitted on a logarithmic scale. Vectorial processing depends on the exposure light conditions. (sun, daylight, lamp, cool white fluorescent lighting, incandescent lamp, flash, candle, etc), illumination, non uniformity, low contrast, degradation, shadows etc. The camera and lighting should be calibrated, each channel is processed separately, stray light reduce the measured dynamic range while lighting should be even, aligned, glare-free with variation less than ±5%, with gray surround and no light behind the camera and stable background intensity to flatten image tones; two lamps at least with incident angle of 20-40° and auto-exposure cameras compensate glare in the dark zones.

Sparkle filter adds sparkles to our image, Lens flare filter gives the impression that sun hit the shot object and creates reflection effect. 3D Effect filter highlights perspective, Drop shadow filter adds a drop-shadow to the image, see fig. 35.

Table 4. Lighting conditions and effects on a Byzantine page

Gradient flare or supernova filter creates random glow, rays, opacity

Lighting effects filter simulates the light up of a spot, with no shadows and details in dark zones, transparency, background, direction, color, intensity, position, reflections by objects.
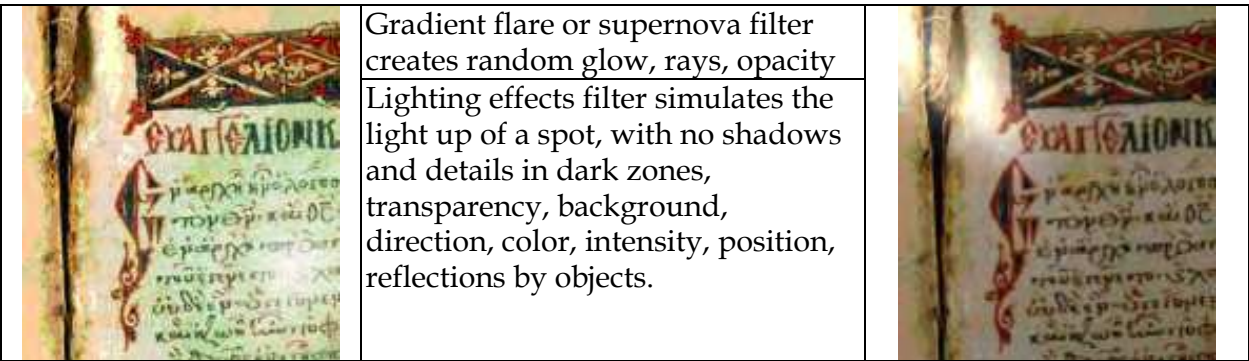
Fig. 35. Lighting effects filter

Changes in illumination, or local shadows do not provide global threshold, see fig. 36.
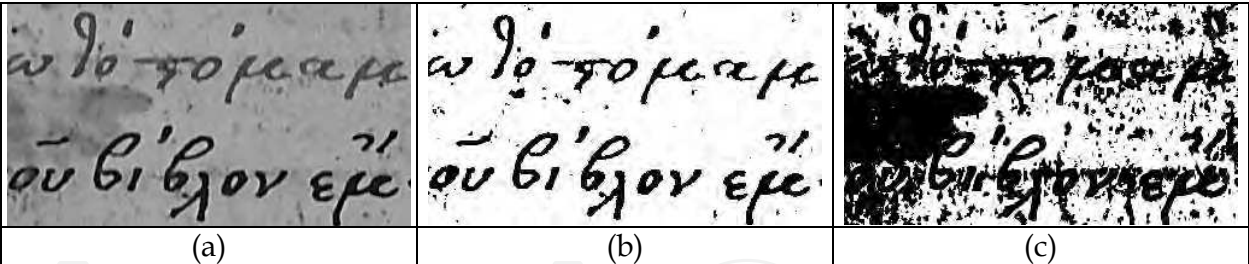

| (a) | (b) | (c) |

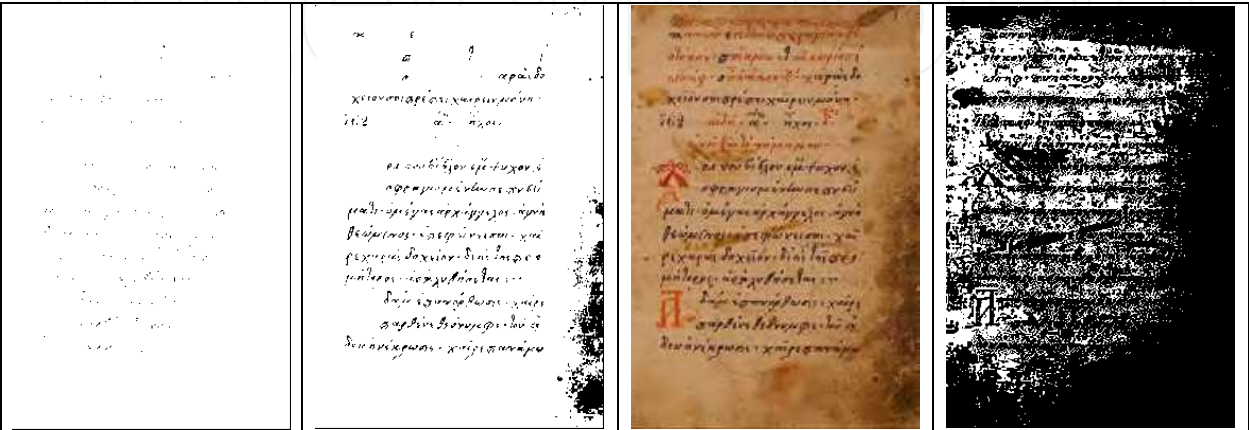Fig. 36. Global threshold (a) grayscale image (b) T=100 (c) T=150

Fig. 37. Levels of thresholding and quality of results

Local thresholding

Niblack's method

$$T(x,y)=m(x,y)+k*s(x,y) \quad k=-0.2$$

where m(x,y) and $s(x,y)$ are the average of a local area and the standard deviation. . A window size 15-by-15 suppresses the noise in the image, but preserves local details

Sauvola's method is an adaptive threshold method, with $k=0.1$ and $R=128$.

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

Bernsen's method where Z_{max} and Z_{min} are maximum/minimum intensity and works in high contrast $C(x,y)$ dependent on k and on the window size n. Threshold produces ghosts.

$$T(x,y) = \frac{Z_{\max} + Z_{\min}}{2}$$

$$C(x,y) = Z_{\max} - Z_{\min}$$

9.4 Thresholding results

Binarization is applied to all document image categories. Image focusing, sharpness and clarification on the handwritten characters (Kavallieratou, 2002), and texture was compared with the original ones, see Table 5. The binarization, based on adaptive global /local thresholding, is efficient in image digitalisation and works best on high resolution images. JPEG file formats need the least computational effort to be processed.

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 5. Results from combination of Wiener filter 5x5 with binarization methods for image category

Thresholding techniques applied to classified byzantine documental images reveal the comparative effect of combined filtering and binarization.

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 (Niblack, 1993). Bernsen's method produced best results in manuscripts with characters with "spots and stains" and "red coloured characters". Our

post-binarization refinement improves the image quality, the appearance of the binary images and text readability, clarifies the background area, 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, see fig. 38, 39.

original document image with spot	original document image with illumination shadow	with ink seeking from other side, transparent background	binary image with Sauvola's method after 5x5Wiener filter	binary image with Sauvola's method after 5x5Wiener filter	Sauvola method binary image 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 5x5Wiener filter	binary image with Otsu's method after Wiener filter 5x5	image with holes on characters before/after refinement step

Table 6. Document image before and after binarization
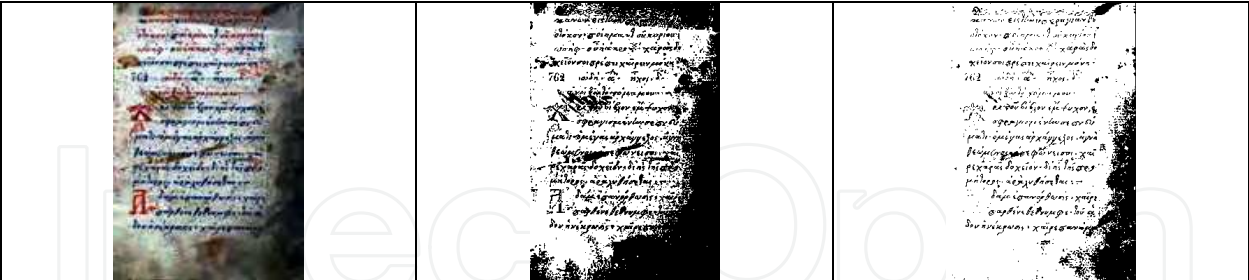
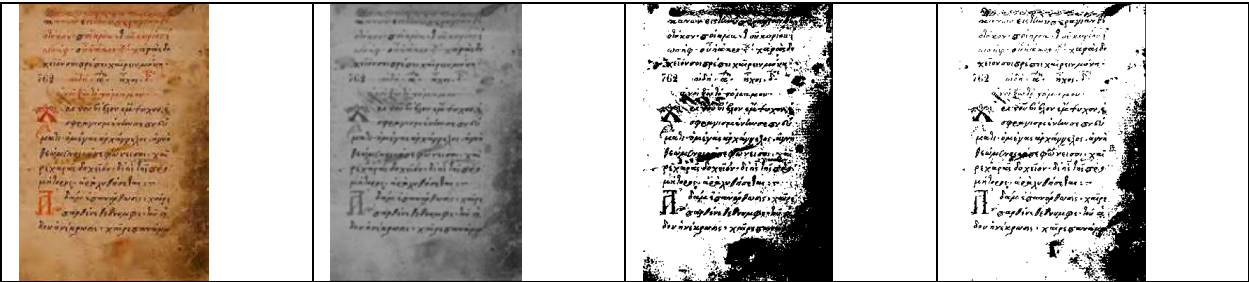Fig. 38. Equalize and Negative or Invert Value and White balance for thresholding

Fig. 39. Colorify / Color enhance and threshold

10. Compression

Byzantine images are saved as RAW file, TIFF, or high quality JPEG. Raw images can be converted to JPEG (maximum quality), TIFF (without LZW compression), or PNG and removes redundancy. TIFF is the standard print industry format. We crop the images to minimize edge effects. RAW to TIFF, JPEG, etc converters perform additional functions such as add gamma curve and an additional tonal response curve, they reduce noise and sharpen the image. Compression tools (lossless and lossy) for images are included, depending on streaming (capture, store, and transfer (via a network) images) vs relative CPU, memory usage, channel demands, and storage requirements. Different compression algorithms are available such as whitespace compression, Run-Length Encoding (RLE), Huffman Encoding, Lempel Ziv-Compression, etc. A special quality of word-based Huffman compressed text is that it does not needs to undergo decompression to be searched by standard searching algorithms, so would lose none of the algorithm searchability. Compression problems include nonlinear quantization, colour channels, etc. JPEGs compress the file or the colour channels in ways that the eye is unable to easily detect, i.e. the structural detail is preserved, but when high levels of compression are applied increasingly fine detail is sacrificed, and some corruption will be detectable at higher magnification. Compression that gives rise to artifacts, corruption of the image, is lossy compression, and once the clarity of your image is lost it cannot be restored.

10.1 Database

Organizing valuable or impossible to access fragile images from Byzantine sources in a database, (Gatos, 2004) is a powerful way to communicate and distribute them on the web by handling a massive quantity of images. Content-Based searching (texture/pattern, shape, color, orientation, and layout or a combination) of Large Image Databases is impractical and time consuming (Date, 2002). The relational database organize and manage such information, create virtual classifications, virtual folders, and interact with images, and metadata. Most frequently requested and computationally intensive jobs should be pre-processed, so that will be quickly hit, while others at the time of request. Utilities and software tools (middleware) facilitate organization for efficient access (searching, browsing, and retrieval), manipulate, enhance, and annotate existing information. Multimedia information contains an enormous amount of embedded information. An abstract function operation is edge detection or thresholding. The semi-compressed domain is convenient since it is an intermediate form that compressed video frames and images must pass through during decompression. A Byzantine manuscript consists of hundreds of pages of high fidelity images where each image is 12÷21 MB or larger; existing tools are not designed to display / search / browse massive digitized documents. Multimedia information is stored at multiple resolutions, and the appropriate level of resolution is selected and transferred automatically based on parameters such as the speed of the link.

It is increasingly difficult to ask a spreadsheet combined questions and we need to normalize the database rows/columns referred to as attributes. Database normalization iteratively divides large tables into smaller, enhances database consistency, reduces redundant data and ensures data dependencies, speeds up server performance with faster sorting and indexing (Date, 1999, Picard, 1993).

	A	B	C	D	E	F	G	H	I	J
						10-90U	10-90C	Over-	Over-	MTF!
1	File	Date/time	PH	Ch	H/V			shoot%	sharp%	LW/F
2						/PH	/PH			
3	canon_eos10d_sfr.jp	3/19/2004 22:21	2048	Y	H	1422	1447	19.5	-0.7	1:
4	canon_g5_sfr.jpg	3/19/2004 22:24	1955	Y	H	1973	1301	48	21.3	1.
5	sigma_sd9_sfr.jpg	3/19/2004 22:27	1504	Y	H	1432	1676	2.4	-7.7	1.
6	sigma_sd10_sfr.jpg	3/19/2004 22:28	1504	Y	H	1563	1628	11.9	-2	1!
7										

Fig. 40. Spreadsheet images acquisition classification scheme

10.1.1 Classification

We classified byzantine images according to their content, i.e. old handwriting, (Greek) manuscript (varying in types, size, color, format and level of noise, capital /lower case letters), document images and photos, byzantine music symbols, etc. Historical documents are high / low contrast, colour / grayscale, totally/partially degraded or damaged, paper image condition, with red ink characters and line gaps or holes, transparent, with transparent objects, transparent background, simple / complex, text / graphics highly mixed, etc (Foley, 1990). Text mining is not information retrieval, extraction, categorization, because they do not generate new information but it involve new discoveries through analysis of a text, i.e. uncover a new relationship. There is always a risk of missing, or misclassifying. We wish to optimize subjective impression and readability perception. Text readability increases by text contrast, background contrast, and relative text contrast (text contrast divided by background contrast). A software classifier can automate processing per document class assisted by a training database for the sorting system composed of images that have distinct differences.

10.2 Suggestions for further work

Documents image restoration, binarization, filtering and processing is an issue of continuous researching. Most of the historical documents images, in libraries and museums, can be acquired and stored dynamically in computers, in digital format for preservation, storage, computation, reproduction, visualization, interpretation and recognition. The proposed technique investigated for optimal methods for every image type, among the existing methods, the image noise and the paper conditions. We investigated for a universally efficient method for all the images categories by focusing on best thresholding value for every pixel area in the image, i.e. a combination of global and local methods structured into processing levels.

Potential application fields include the automation of the combined binarization-filtering procedure and the extension of the method to a wider area of documental and similar or non-documental images.

An image typically goes through a series of transformations that extract information from the image or compute new information based on the image; this sequence can be monitored and automated through an Expert System.

11. Conclusion

Although excellent image processing tools and techniques exist we either do not use them efficiently in application fields, or in an intelligent way (GIMP, 2011, Mathworks, 2011). Errors classification in old documents background, text, stamps and images, image processing by experts or an expert system assisted by image segmentation techniques could reveal lost details.

The purpose of our work on denoising and binarization was to introduce an innovative sequential procedure for digital image acquisition of historical documents including image preparation, image type classification according to their condition and their spatial structure, global and local features or both, including document image data mining.

Image processing pixel alterations, allow one-pass iterations only by near neighborhood of alteration reprocessing algorithms. Algorithm complexity analysis is O(N3), while computational effort and execution time needed is overcome by parallel computational machines. In handwritten documents text orientation, skew, skew detection time and skew reconstruction time are critical parameters.

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. Our work tends to focus mostly on Images Digital Restoration rather than on Binarization. Due to the dynamic research on the field, comparison of methods and techniques is continuous. Method efficiency, universality, versatility, flexibility and robustness is straightforward on any historical document and other cases, but selection or combination of appropriate algorithm (no single algorithm works well for all types of images) is needed. Compared to the image enhancement method, the image classification method is more text / image characteristic-oriented. It highly depends on the images to be processed, or saying in another way, the historical document to be investigated. There is no ideal method working for every case. There is not a single suitable method that can be applied to all types of images.

12. Appendix I. Properties of paper

Property	Comment	Meaning	Range	Standard
Print quality	*appearance properties*	*roughness, gloss, ink absorption, whiteness, brightness*		
Printability	*dot reproduction/gain, print gloss, hue shift and print uniformity*	*true reproduction of original artwork*		
	Good printability, compressibility, absorbency and ink hold out give good printing and hand writing.			
Readability	*ink to paper contrast*			
Basis Weight or Grammage:	*most fundamental property of paper*	*weight of paper per unit area*		*TAPPI T 410, SCAN P6, DIN53104 & ISO: BSENISO536*

Bulk	*(cubic centimetre/g) = Thickness (mm)* Basis Weight (g/m²) * 1000*	*volume or thickness in relation to weigh reciprocal of density*		*TAPPI T 500, SCAN P7 DIN53105, ISO534, BS: ENISO20534*
Decrease in bulk/ increase in density makes the sheet smoother, glossier, less opaque, darker, lower in strength for printing bible				
Caliper or Thickness		*how bulky or dense paper is*	*range from 70 GSM onwards*	*TAPPI T 411*
Curl	*Stresses that are introduced into the sheet during manufacture and use*	*Paper curl is a deviation of a sheet from flat form*		*TAPPI T 466 & T520*
There are three basic types of curl, mechanical, structural and moisture curl; one side of the sheet pick up more moisture				
Dimensional Stability		*dimensional changes cause undesirable cockling and curling*		
	All papers expand with increased moisture content and contract with decreased moisture content, but the rate and extent of changes vary with different papers.			
Moisture			*2 - 12%*	*ISO 287*
	Moisture varies depending on relative humidity, type of pulp used, degree of refining and chemical used. Most properties change as a with moisture content. Very low porosity or coated on one side or wax pick gives resistance to grease and moisture.			
Porosity	*total connecting air voids both vertical and horizontal,*	*ability of fluids, to penetrate the paper structure*	*Paper is highly porous, contains up to 70% air*	
	Porosity is an indication of absorptivity, the ability to accept ink or water			
Smoothness	*roughness, levelness, compressibility, finish, appearance, pattern*	*surface contour of paper*		
Smoothness for writing, ease of travel of the pen over the paper, gives eye appeal as a rough paper is unattractive.				
Permanence	*degree to which paper resists deterioration over time.*			
Optical properties				
Brightness	*for readability and opacity*	*% reflectance of blue light at a wavelength*		*TAPPI/GE and ISO 11475.*
Whiteness	*Balanced white sheets have a yellowish cast but we perceive sheet with a bluish to be whiter*		*Whiter sheets reflect equally red, green, blue light, the visual spectrum*	

Color:	*quality of light, viewed under a different light source*	*hue, saturation, darkness or lightness).*	*aesthetic value*	
Gloss	*Gloss and smoothness*	*diffusely reflected light*		*TAPPI T 480*
Opacity	*sheet light absorbed, both sides printed*	*light not passing through a sheet*		*ISO 2471 and TAPPI T425.*
Sizing / Cobb	*the ability of fluids, , to penetrate the structure of pap*	*the writing ink go into the paper instantly and dry*	*water-repellent materials (rosin, wax, gelatinous)*	
Dirt Content	*visible to the eye such as bark, undigested wood, pitch, rust, plastic, etc*	*dirt specks, unwanted foreign particle*	*change reflected or transmitted light*	
Pin Holes	*Imperfections*	*looking through*		
Other properties are Temperature and Humidity, Conditioning of Paper, Wire side and Felt side, Strength Properties, Surface Strength, Compressibility, Resiliency, Stiffness, etc. Certain properties such as smoothness, texture and ink absorbency differ between wire and felt side.				
Paper types include alkaline paper, antique paper, art paper, Bible paper, General Writing paper, etc.				

13. Acknowledgements

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