Enhancing Manuscript Readability Using Advanced Image Processing Techniques

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Abstract. This paper explores AI-based image processing techniques to enhance the readability of 12th-century palimpsests from the Bulgarian National Library. Combining UV/IR imaging with methods like denoising, CLAHE, and sharpening, the study demonstrates significant improvements in recovering obscured texts for research and educational purposes.

Keywords: Palimpsest, Cultural Heritage, Image processing, Enhancement, Learning.

1 Background Theory

In 2024 several research projects were conducted on some of the palimpsests in the National Library of St. Cyril and Methodius, which are known to contain Glagolitic text. The Glagolitic alphabet was created by the Byzantine clerics Cyril and Methodius between 855 and 862. Intended for the translation of liturgical literature for the Christian Church in Greater Moravia, it also became the first alphabet specifically adapted for writing in Slavic languages. The Glagolitic alphabet was used for the first translations of ecclesiastical literature. St. Cyril and St. Methodius and their disciples spread Christianity in Great Moravia and Pannonia in the 9th century. Currently, 39 manuscripts in Glagolitic are known throughout the world, most of which are in the form of palimpsests. A palimpsest (from Ancient Greek πάλιν, "again", "again", and ψάειν, "rub") is an ancient manuscript whose original text was removed by rubbing or washing, and then the page - or pages - were used for another, new text (Rasheva-Yordanova et al., 2024).

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2 Main Part

2.1 Description of the Research

This paper is based on a research project aimed at digitizing medieval manuscripts and enhancing their readability through advanced image processing techniques. In the first project year, several palimpsests were photographed, including the 12th-century Dragothian Minae (NBCM no. 880), which contains both Cyrillic and Glagolitic layers. Imaging was carried out using a Hamamatsu C9300 IR CCD camera (330–1000 nm) and a Canon 2000D, supported by a filter wheel with UV and VIS-NIR filters (see Table 1).

Table 1. Hamamatsu camera filters.

No.	Filter type	Illumination
1	SP400	UV
2	LP400	UV
3	LP400	Visible-Near-Infrared
4	BP 450	Visible-Near-Infrared
5	BP 550	Visible-Near-Infrared
6	BP 650	Visible-Near-Infrared
7	BP 780	Visible-Near-Infrared
8	LP800	IR

The Canon 2000D photographs were taken while illuminating the manuscripts with infrared and ultraviolet light. Thus, each page was photographed a total of 10 times, 8 times with the Hamamatsu C9300 and 2 times with the Canon 2000D.
The pipeline **of** processing images showing in Fig. 1.

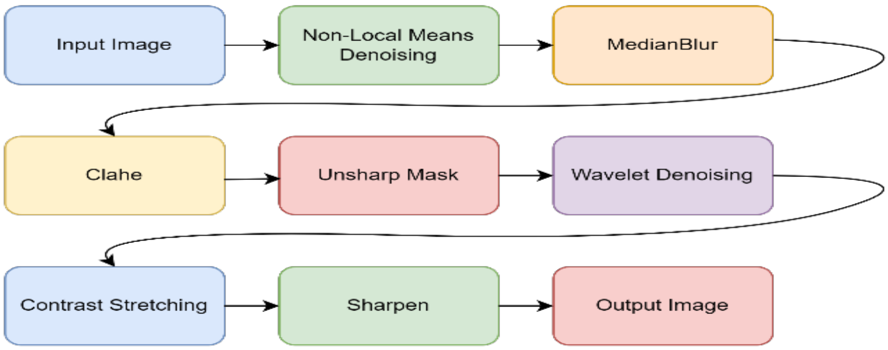

Fig. 1. Pipeline of processing images.

2.2 Non-Local Means Denoising

Non-Local Means (NLM) Denoising is a popular and effective method for denoising images. Unlike traditional methods like Gaussian blur or median filtering, NLM denoising doesn't just rely on local pixels but uses similarity across the entire image to better preserve the details while removing noise. However, due to the high computational cost, it's more efficient to average pixels within a smaller region. We refer to the pixel to be denoised as i and the neighboring pixels as j, which are used to denoise pixel i. The estimated value for a pixel i is calculated using a weighted average of the surrounding neighborhood pixels j (Wang et al., 2016). Below is the equation of non-local means denoising.

$$I(i) = \sum_{j \in N_i^s} w_{ij} I(j) \tag{1}$$

2.3 Median Blur (Median Filtering)

The median filter is a nonlinear signal processing method based on statistical principles. It replaces a noisy pixel with the median value from its neighborhood, determined by sorting pixel intensities within a mask (Zhu & Huang, 2012). This approach is particularly effective for removing salt-and-pepper noise while preserving edges and high-frequency details. Owing to these advantages, median filtering has become widely used in image restoration tasks (Raju et al., 2012). An illustration of the filtering process is shown in the figure below.

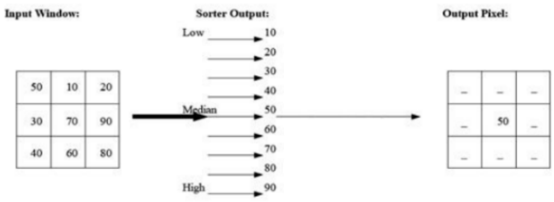

Fig. 2. An example of median filter operation, source- Boateng, Kwame Osei et al. "Improving the Effectiveness of the Median Filter." (2012).

2.4 CLAHE (Contrast Limited Adaptive Histogram Equalization)

CLAHE is a local contrast enhancement technique used to improve the visibility of details in images, especially in areas with poor contrast. Unlike traditional histogram equalization, CLAHE operates in smaller, localized regions of an image, providing a more natural enhancement without over-amplifying noise. CLAHE can overcome the problem of excessive contrast enhancement by setting a boundary value on the histogram (Rasheva-Yordanova et al., 2024). The method for calculating the clip limit of a histogram is defined by the Equation (2) below:

$$\beta = \frac{M}{N}\left(1 + \frac{\alpha}{100}(S_{max} - 1)\right)$$

The variable M denotes the region size, N represents the grayscale value (256), and α is the clip factor that determines the amount of histogram enhancement, ranging from 0 to 100. The CLAHE process starts by setting the region size and clip limit, followed by generating the histogram for each region. The histogram is then clipped according to the specified clip limit, and any excess values are redistributed.

2.5 Unsharp Mask

The unsharp mask filter has gained considerable attention from researchers over the past decade due to its straightforward application across different types of images. The unsharp mask filter is a widely used sharpening technique designed to enhance blurry images and restore acceptable quality. However, it often causes an overshoot effect, an unwanted artifact that creates visible white halos around the edges of the recovered image (Al-Ameen et al., 2019).

2.6 Wavelet Denoising

Wavelet denoising is an advanced technique used to reduce noise in images while preserving important details such as edges and textures. n wavelet denoising, the thresholding algorithm is typically applied in orthogonal decompositions, such as multi-resolution analysis and wavelet packet transformation. However, wavelet thresholding presents several challenges, including choosing between hard and soft thresholding, as well as deciding whether to use a fixed or level-dependent threshold. Making appropriate selections for these factors is crucial to achieving more accurate estimations (Luo & Zhang, 2012).

2.7 Contrast Stretching

Contrast stretching is a simple image enhancement technique used to improve the contrast in an image by expanding the range of pixel intensity values across the entire image. Linear contrast stretching is a transformation technique in which the values of the original image are uniformly expanded to occupy the entire range of the output device. In this context, DN represents the Digital Number of a pixel, $DNst$ is the corresponding Digital Number in the enhanced output image, and $DNmax$ and $DNmin$ are the maximum and minimum Digital Number values in the original image, respectively (https://dspmuranchi.ac.in/pdf/Blog/Contrast%20Enhancement.pdf). Fig. 3 below shows linear contrast stretching.

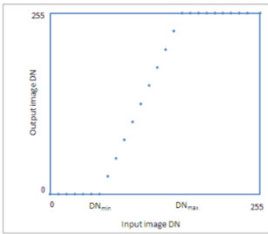

Fig. 3. Linear contrast stretching function.

2.8 Sharpening

A common operation in the digital imaging process is digital image sharpening. The most frequent application of sharpening occurs during image editing (Williams & Burns, 2008). Image sharpening enhances edges and details by amplifying high-frequency components. Additionally, sharpening boosts MTF50 and MTF50P, which are indicators of perceived sharpness, although it also amplifies noise, which can be problematic in noisy systems (https://www.imatest.com/docs/sharpening/). The Fig. 4 below shows sharpening on a line and edge.

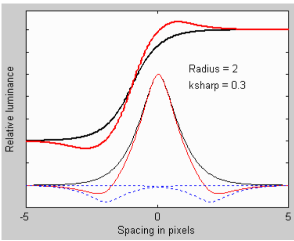

Fig. 4. Sharpening on a line and edge. Source - https://www.imatest.com/docs/sharpening/.

For the purpose of our study, we have used the 26th page of the Dragotin Minae, shown in Fig. 5. There are 10 pictures on this page with different filters.

Fig. 5. Page 26 - Dragotin Minae.

We selected 4 images (shown in Fig. 6) on the above page by palimpsest, taken in different conditions - IR, UV, taken with Canon 2000D and 2 in VIS-NIR (**Visible and**

Near-Infrared regions of the electromagnetic spectrum) range - 450nm and 550nm, respectively with Hamamatsu C9300 IR CCD. We cropped one section of each image measuring 500x400 pixels. The cropped images have the same coordinates, allowing us to track and compare the results effectively.

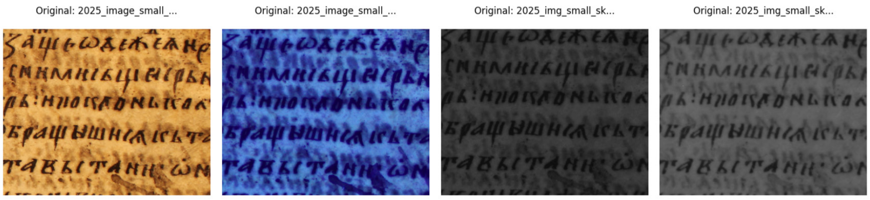

Fig. 6. Selected original images.

3 Results of the Experiment

The first technique we employed was Non-Local Means Denoising (Fig. 7), which effectively reduced random noise when applied to an IR photo. This technique preserved fine details and edges, which is important for enhancing the legibility of text or patterns in palimpsests.

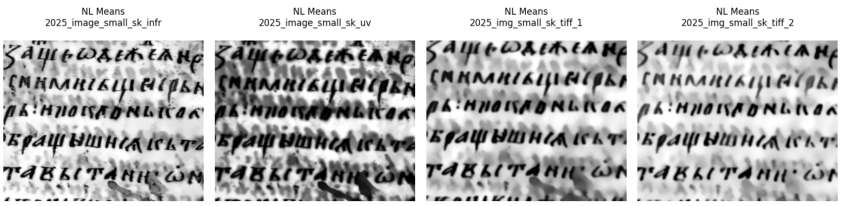

Fig. 7. Result after Non-Local Means Denoising.

On the other hand, the technique maintains texture details, which can help in distinguishing faded or overwritten text. We can see that the underlying text has become more visible in the UV photo. The visible light photograph, taken with a Canon 2000D, blurred and faded the background text, especially in low-contrast areas. The VIS-NIR range photo captured with the Hamamatsu C9300 clearly displayed the front text. However, the underlying text became significantly more blurred and almost indistinguishable.

The Median Blur (Median Filtering) technique preserved edges and the visibility of the front text but caused blurring of fine details in the background text, as we can observe in Fig. 8.

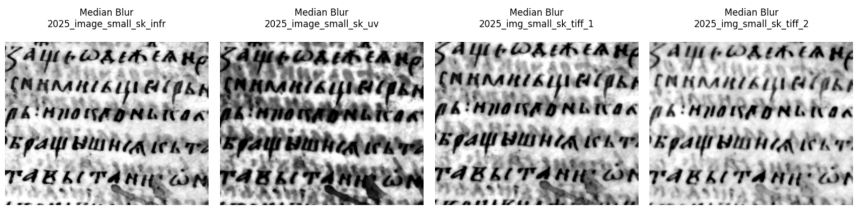

Fig. 8. Result after Median Blur.

In the UV photo, median filtering led to a loss of fine details and sharpness, reducing text readability. While it preserved edges well, it blurred intricate elements in the Canon 2000D image. In the final image, edges remained intact, but contrast and clarity of faint underlying text were diminished.

CLAHE improved brightness and contrast, particularly in areas with uneven lighting. In the UV image, it enhanced faded text but also introduced noticeable noise, resulting in a grainy appearance. In other cases, CLAHE clarified dull regions and improved layer separation between front and background texts, revealing details in shadowed or low-contrast areas (Fig. 9).

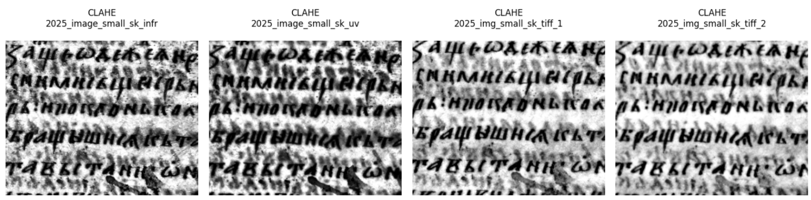

Fig. 9. Result after CLAHE.

When we applied an unsharp mask in the IR photo, we found that it enhanced the sharpness of the front text, but sharpening led to distorted details in some areas. On the other hand, in the UV picture, the technique increased the brightness and the contrast which improved the readability of the faint text (Fig. 10).

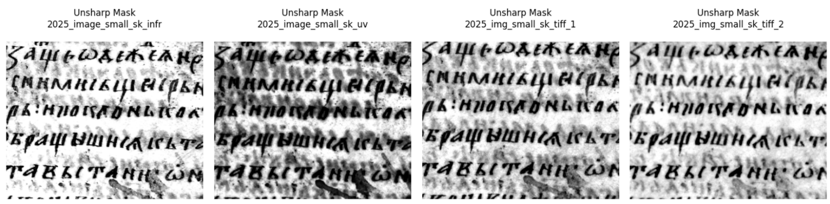

Fig. 10. Result after Unsharp mask.

The mask improved the crispness of text and fine details in the visible light photo. The technique provided better edge contrast and enhanced fine spectral details in the picture taken with Hamamatsu C9300.

We observed that the wavelet denoising preserved edges and fine details, but it was computationally intensive compared to the other techniques when applied in the IR photo (Fig. 11).

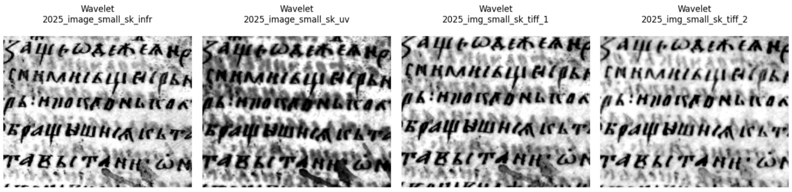

Fig. 11. Result after Wavelet denoising.

In the UV picture, the technique made some text features smooth, which reduced their sharpness. In the photo taken with Canon 2000D, the wavelet denoising kept the sharpness of visible areas, while at the same time did not distort fine details. We observed that the approach maintained the integrity of text and edge features in the last photo captured with Hamamatsu C9300.

When we applied contrast stretching, we found that contrast stretching increased contrast but caused loss of subtle tonal variations and amplified noise in the IR photo. Regarding the UV picture, the technique enhanced the brightness but exaggerated speckle noise and resulted in loss of detail in underexposed regions. In terms of the visible light photo, the contrast stretching improved the overall image contrast, making dull areas look more vivid (Fig. 12).

Fig. 12. Result after Contrast processing.

When the technique was applied in the fourth picture, the visibility of spectral differences was enhanced, but subtle differences between the layers became less distinct.

As we applied sharpening in the IR photo, we discovered that the visibility of edges was improved but the noise was amplified, and the underlying text appeared distorted. In the UV photo the technique made texture details more prominent, but caused loss of smooth gradients, giving a harsh look (Fig. 13).

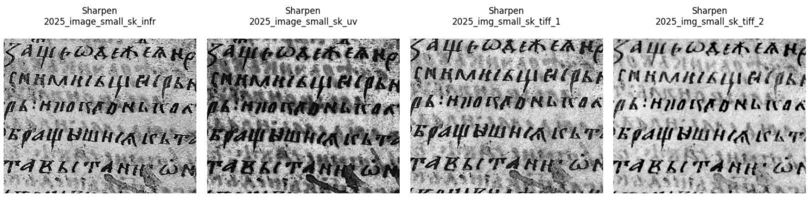

Fig. 13. Result after sharpening images.

When sharpening was applied to the photo taken with Canon 2000D, the text was more readable, and the overall image crispness was enhanced. In the last photo, it can be observed that the technique improved the clarity of text and fine structures and made spectral features more distinct. However, sharpening artifacts may become more visible. Sharpening requires fine-tuning to prevent over-sharpening, which may obscure subtle text details when applied in VIS-NIR Range Photos.

4 Discussion

This study evaluated various image processing techniques applied to palimpsests, highlighting their respective strengths and limitations based on imaging conditions and manuscript characteristics. Non-Local Means Denoising proved effective in IR images but sometimes caused blurring. Median Blur preserved edges but reduced background detail in UV scans. CLAHE enhanced contrast and faded text yet introduced noise. Unsharp Mask improved sharpness but occasionally distorted fine details. Wavelet Denoising maintained clarity but was computationally demanding. Contrast stretching increased visibility but amplified noise, while sharpening improved readability at the risk of artifacts. No single method was universally optimal; effectiveness varied depending on context.

Conclusion

In conclusion, we employed a wide range of advanced techniques designed to uncover valuable historical information. By integrating different image conditions and combining the abovementioned image processing techniques, we tried to find out how and to what extent each technique enhances the readability of ancient palimpsests. We also observed the strengths and weaknesses of each method which enabled us to make a more comprehensive analysis of the manuscripts.

Future work could focus on optimizing the computational efficiency of these methods and developing various approaches that combine their strengths. Integrating machine learning techniques for adaptive parameter selection could further enhance the performance and applicability of these methods in cultural heritage preservation and manuscript analysis.

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References

Al-Ameen, Z., Muttar, A., & Al-Badrani, G. (2019). Improving the sharpness of digital image using an amended unsharp mask filter. *International Journal of Image, Graphics and Signal Processing, 11*(3), 1–9. https://doi.org/10.5815/ijigsp.2019.03.01

DSPMU Ranchi. (n.d.). *Contrast enhancement*. https://dspmuranchi.ac.in/pdf/Blog/Contrast%20Enhancement.pdf

Imatest. (n.d.). *Sharpening*. https://www.imatest.com/docs/sharpening/

Luo, G., & Zhang, D. (2012). Wavelet denoising. In *Advances in wavelet theory and their applications in engineering, physics and technology*. https://doi.org/10.5772/37424

Raju, K. S., Phukan, P., & Baurah, G. (2012). An FPGA implementation of a fast 2-dimensional median filter. In *National Conference on Recent Advances in Communication, Control and Computing Technology (RACCCT)* (pp. 144–147).

Rasheva-Yordanova, K., Dimitrov, G. P., Tsvetkova, P. T., Bankovska, M., & Petrov, P. S. (2024). Improving palimpsest readability via image preprocessing: An investigation into adjustment techniques. *Digital Presentation and Preservation of Cultural and Scientific Heritage, 14*, 107–116. https://doi.org/10.55630/dipp.2024.14.9

scikit-image. (n.d.). *Denoising with wavelets*. https://scikit-image.org/docs/0.23.x/auto_examples/filters/plot_denoise_wavelet.html

Wang, X., Wang, H., Yang, J., & Zhang, Y. (2016). A new method for nonlocal means image denoising using multiple images. *PLOS ONE, 11*(7), e0158664. https://doi.org/10.1371/journal.pone.0158664

Williams, D., & Burns, P. D. (2008). Measuring and managing digital image sharpening. *Archiving Conference, 5*(1), 89–93. https://doi.org/10.2352/issn.2168-3204.2008.5.1.art00018

Zhu, Y., & Huang, C. (2012). An improved median filtering algorithm for image noise reduction. *Physics Procedia, 25*, 609–616. https://doi.org/10.1016/j.phpro.2012.03.133

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