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A Comparative Evaluation of CLAHE-Enhanced Local Otsu Thresholding for Degraded Document Binarization under Non-uniform Illumination

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Abstract:

Document image binarization under non-uniform illumination remains difficult because shadows, stains, paper texture, and spatial intensity variation weaken the separation between the textual foreground and background. This study presents a controlled comparative and ablation evaluation of a fixed-parameter configuration in which contrast-limited adaptive histogram equalization (CLAHE) precedes Local Otsu thresholding. The configuration was compared with Global Otsu, CLAHE-enhanced Global Otsu, Local Otsu, Niblack, and Sauvola using ten degraded document images and corresponding ground truth masks. Performance was measured using intersection over union (IoU), Dice score, accuracy, precision, recall, specificity, balanced accuracy, and processing time. Sauvola achieved the strongest overall result, with mean IoU and Dice values of 0.4845 and 0.6443, respectively. CLAHE-enhanced Local Otsu obtained mean IoU and

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Dice values of 0.2941 and 0.4481, respectively, together with high recall (0.9600) but low precision (0.2988). Friedman testing confirmed significant differences among the six methods for IoU and Dice ($\chi^2(5) = 31.943$, $p<0.001$, Kendall's $W = 0.639$). Holm-corrected Wilcoxon comparisons showed that Sauvola significantly outperformed every other method (adjusted $p = 0.0293$), whereas CLAHE-enhanced Local Otsu did not differ significantly from plain Local Otsu (adjusted $p = 0.4199$ for IoU and 0.4219 for Dice). The findings therefore indicate that CLAHE recovered weak foreground strokes but also amplified background degradation and did not provide a statistically validated overlap improvement. Because the experiment used only ten images and no independent validation subset, the conclusions remain preliminary and dataset-specific.

Keywords: document image binarization; non-uniform illumination; CLAHE; Local Otsu; adaptive thresholding; ground-truth evaluation.

تقييم مقارن لعتبة أوتسو المحلية المعززة بتحسين التباين المحدود المتكيف للمدرج التكراري لثنائية صور الوثائق المتدهورة تحت الإضاءة غير المتجانسة

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الملخص:

تظل عملية تحويل صور الوثائق إلى صور ثنائية تحت الإضاءة غير المتجانسة تحدياً بسبب الظلال والبقع وملمس الورق والتغير المكاني في شدة الإضاءة. تقدم هذه الدراسة تقييماً مقارناً وتحليلاً تفكيكياً مضبوطاً لإعداد ثابت المعلمات يطبق تحسين التباين المحدود المتكيف للمدرج التكراري (CLAHE) قبل طريقة أوتسو المحلية. قورنت الطريقة مع أوتسو العامة، وأوتسو العامة بعد CLAHE، وأوتسو المحلية، وNiblack، وSauvola باستخدام عشر صور وثائق متدهورة مع أقنعة حقيقة مرجعية. تم التقييم بمقاييس IoU وDice والدقة والإحكام والاستدعاء والنوعية والدقة المتوازنة وزمن التنفيذ. حققت Sauvola أفضل أداء إجمالي بمتوسط IoU بلغ 0.4845 ومتوسط Dice بلغ

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0.6443، بينما حققت أوتسو المحلية المعززة بـCLAHE متوسط IoU قدره 0.2941 ومتوسط Dice قدره 0.4481 مع استدعاء مرتفع 0.9600 وإحكام منخفض 0.2988. أكد اختبار Friedman وجود فروق دالة إحصائياً بين الطرق الست في IoU وDice، إذ بلغت قيمة كاي تربيع 31.943 بدرجات حرية 5، وكانت القيمة الاحتمالية أقل من 0.001، وبلغ Kendall's W مقدار 0.639. وأظهرت مقارنات Wilcoxon المصححة بطريقة Holm تفوق Sauvola دالاً إحصائياً على جميع الطرق الأخرى بقيمة احتمالية مصححة مقدارها 0.0293، في حين لم يكن الفرق بين أوتسو المحلية وأوتسو المحلية المعززة بـCLAHE دالاً إحصائياً، حيث بلغت القيمة المصححة 0.4199 لـIoU و0.4219 لـDice. وتشير النتائج إلى أن CLAHE حسنت استرجاع النصوص الضعيفة لكنها ضاعفت تفاصيل الخلفية ولم تحقق تحسناً إحصائياً موثوقاً في التداخل. ونظراً لاعتماد التجربة على عشر صور فقط دون مجموعة تحقق مستقلة، تظل الاستنتاجات أولية ومحدودة بالمجموعة المستخدمة.

الكلمات المفتاحية: ثنائية صور الوثائق، الإضاءة غير المتجانسة، CLAHE، أوتسو المحلية، العتبة المتكيفة، الحقيقة المرجعية.

1. Introduction

Document image binarization separates the textual foreground from the paper background and is an essential preprocessing stage for optical character recognition, archival digitization, layout analysis, and document restoration. Global thresholding remains attractive because it is simple and deterministic; however, a single threshold becomes unreliable when a page contains shadows, illumination gradients, stains, faded text, folds, and textured paper. In such cases, pixels belonging to the same character may have different intensities, whereas dark background regions may resemble foreground text.

Otsu thresholding selects a global gray-level threshold by maximizing the between-class variance (Otsu, 1979). Local methods improve spatial adaptation by estimating the thresholds from neighborhoods. Niblack uses the local mean and standard deviation (Niblack, 1986), whereas Sauvola modifies this rule to suppress low-variance document backgrounds more effectively (Sauvola and Pietikäinen, 2000). CLAHE enhances the local contrast by processing contextual regions and limiting histogram amplification (Pizer et al., 1987; Zuiderveld, 1994). Although

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CLAHE can reveal faint strokes, it can also strengthen stains, borders, and paper fibers, and shadow transitions.

The scientific contribution of this study is empirical rather than algorithmic. CLAHE and Local Otsu are established techniques; therefore, their combination is not a new or universally robust algorithm. Instead, this study isolates the effect of CLAHE through controlled ablation comparisons and examines whether increased foreground sensitivity compensates for the amplified background degradation. This framing and the revised title directly address the distinction between comparative evaluation and novelty.

The objectives were to (1) evaluate six thresholding configurations under an identical protocol, (2) quantify overlap, foreground detection, background rejection, and runtime, (3) explain the effect of CLAHE by comparing each Otsu variant with and without enhancement, and (4) identify representative success and failure patterns. The reported conclusions were intentionally limited to the ten evaluated image-ground-truth pairs.

2. Related Work and Research Gap

Classical document binarization ranges from global histogram-based methods to local statistical methods and hybrid pre-processing pipelines. Otsu is effective for approximately bimodal histograms but is sensitive to nonuniform illumination. Niblack preserves weak strokes but often produces background noise, whereas Sauvola generally improves the balance between text preservation and background suppression. Public document binarization contests and surveys have emphasized the continuing effects of degradation, uneven illumination, bleed-through, and acquisition artifacts (Gatos et al., 2009; Sulaiman et al., 2019; Yang et al., 2024).

Recent studies have explored various techniques, including robust local statistics, texture-aware methods, hybrid preprocessing, and learning-based approaches (Su et al., 2013; Bloechle et al., 2023; Bernardino et al., 2024). However, there is no single thresholding rule that always works for every document, regardless of the condition. Nevertheless, classic methods are still useful. They are especially useful when you need something transparent, do not have much computing power, or cannot find training data.

The gap examined here is the controlled isolation of the fixed-parameter CLAHE before Local Otsu. Enhancement and local

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thresholding have often been studied separately or embedded within larger pipelines, making it difficult to determine whether the observed behavior is attributable to CLAHE, local threshold estimation, or post-processing. The present design uses identical images, masks, polarity, cleanup settings, metric definitions, and runtime protocol for all methods. Global Otsu and Local Otsu provide direct non-CLAHE baselines, whereas their CLAHE-enhanced counterparts isolate the enhancement effect.

3. Materials and Methods

3.1 Dataset and Evaluation Protocol

The experiment used ten degraded document images (real_01 to real_10) and ten corresponding binary ground-truth masks. The images contained dark handwritten or printed foreground on relatively bright paper and exhibited non-uniform illumination, shadows, fading, stains, texture, and spatially varying backgrounds. The ground truth foreground was encoded in black and converted internally to logical one, the and background was converted to zero. When the dimensions differed, the reference mask was resized with nearest-neighbor interpolation to preserve the binary labels.

All image-mask pairs were evaluated with six deterministic configurations: Global Otsu, CLAHE + Global Otsu, Local Otsu, Niblack, Sauvola, and CLAHE + Local Otsu. The same dark-foreground polarity, full-image evaluation region, morphological cleanup, metric definitions, and CPU-based MATLAB environment were used. Because the image source and usage permissions were not documented as a public benchmark, the collection is described as a project dataset and the conclusions are limited accordingly.

3.2 Processing Framework

Figure 1 illustrates the overall experimental processing framework used in this study, from image preprocessing through thresholding, post-processing, and performance evaluation.

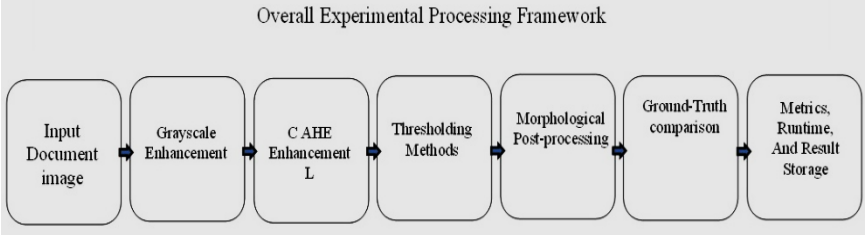

Fig. 1: Overall experimental processing framework.

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Each image was converted to grayscale and 8-bit intensity. A CLAHE-enhanced image was generated once and reused by the two CLAHE-based configurations. Following thresholding, connected foreground components smaller than 10 pixels were removed, and a radius-one morphological cleanup was applied identically to all methods. The predicted masks were compared with the ground truth, and the metrics and runtime were stored automatically

3.3 CLAHE and Local Otsu Implementation

CLAHE used a clip limit of 0.005 and a nominal tile size of 64 pixels. The low clip limit was selected to restrict aggressive amplification, whereas the larger contextual scale produced a smoother adaptation across document backgrounds. These values were applied to all images and were not adjusted for each sample.

Local Otsu used a 49-pixel window and 0.50 overlap. Within each window, the Otsu threshold maximized the between-class variance. Border windows were clipped to the available image extent. Thresholds from overlapping windows were averaged to form a spatial threshold map, after which pixels at or below the local threshold were classified as dark foreground. The following pseudocode makes the traversal, boundary handling, and merging procedures explicit.

```
step = round(window_size * (1 - overlap_ratio))
accum_T = zeros(H, W); weight = zeros(H, W)
for y0 = 1 : step : H
  for x0 = 1 : step : W
    y1 = min(y0 + window_size - 1, H)
    x1 = min(x0 + window_size - 1, W)
    win = image(y0:y1, x0:x1)
    t_local = graythresh(win) * 255
    accum_T(y0:y1, x0:x1) += t_local
    weight(y0:y1, x0:x1) += 1
T_map = accum_T ./ max(weight, 1)
B = (image<= T_map)
```

3.4 Parameter Configuration

Table 1 lists the fixed settings. These were guided by preliminary visual inspection and commonly used ranges rather than an independent validation set or systematic sensitivity sweep. This introduces a risk of dataset-specific tuning; consequently, the values are not claimed to be optimal. A future validation subset should be used to select the clip limit, tile scale, window size, overlap, and cleanup parameters before final testing.

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Table 1: Summary of the fixed parameter settings used for all evaluated thresholding methods and their respective roles in the experimental framework.

Parameter	Value	Role
CLAHE clip limit	0.005	Limits local histogram amplification
Nominal CLAHE tile size	64 pixels	Controls enhancement scale
Local threshold window	49 pixels	Defines the local neighborhood
Window overlap	0.50	Smooths adjacent threshold estimates
Niblack coefficient k	-0.10	Offsets the local mean
Sauvola coefficient k	0.20	Controls local-contrast sensitivity
Sauvola dynamic range R	0.50	Normalizes local standard deviation
Minimum component area	10 pixels	Removes isolated foreground noise
Morphological radius	1 pixel	Limits modification of thin strokes

3.5 Evaluation Measures

For each predicted mask, true positives (TP), true negatives (TN), false positives (FP), and false negatives (FN) were counted. The following measures were calculated: IoU = TP/(TP+FP+FN); Dice = 2TP/(2TP+FP+FN); accuracy = (TP+TN)/(TP+TN+FP+FN); precision = TP/(TP+FP); recall = TP/(TP+FN); specificity = TN/(TN+FP); and balanced accuracy = (recall+specificity)/2. Runtime was measured using MATLAB tic and toc. Because document backgrounds occupied more pixels than foreground text, accuracy was interpreted together with IoU, Dice, precision, recall, specificity, and balanced accuracy.

3.6 Statistical Analysis

Because all six methods were evaluated on the same ten document images, the observations were treated as repeated measures. Separate non-parametric Friedman tests were applied to the two primary overlap measures, IoU and Dice. Kendall's W was reported as the overall effect-size measure. When the omnibus test was

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significant, the 15 pairwise method comparisons were evaluated using the Wilcoxon signed-rank test, and the Holm correction was applied to control the family-wise error rate. Statistical significance was defined at an adjusted p-value of<0.05. The complete per-image metric matrix used in the analysis was exported by the experimental pipeline in detailed_results.csv and detailed_results.xlsx and should accompany the resubmission as supplementary data.

4. Results and Discussion

4.1 Quantitative Comparison

Table 2 reports mean ± standard deviation across the ten image-ground-truth pairs. Sauvola achieved the highest mean IoU, Dice, accuracy, precision, specificity, and balanced accuracy. Niblack achieved the highest recall. CLAHE + Local Otsu produced high recall but substantially lower precision, showing that weak text was recovered together with many false foreground pixels.

Table 2: Quantitative performance of the six evaluated methods reported as mean ± standard deviation across the ten test images.

Method	IoU	Dice	Precision	Recall	Specificity	Bal. Acc.	Time (s)
Global Otsu	0.234 ± 0.109	0.368 ± 0.149	0.250 ± 0.123	0.882 ± 0.108	0.653 ± 0.239	0.768 ± 0.075	0.047 ± 0.022
CLAHE + Global Otsu	0.277 ± 0.126	0.419 ± 0.169	0.281 ± 0.129	0.971 ± 0.021	0.696 ± 0.189	0.833 ± 0.085	0.191 ± 0.107
Local Otsu	0.313 ± 0.103	0.467 ± 0.128	0.330 ± 0.115	0.887 ± 0.042	0.812 ± 0.082	0.850 ± 0.028	0.696 ± 0.506
Niblack	0.278 ± 0.102	0.426 ± 0.130	0.281 ± 0.105	0.976 ± 0.013	0.744 ± 0.081	0.860 ± 0.039	0.157 ± 0.089
Sauvola	0.485 ± 0.120	0.644 ± 0.117	0.549 ± 0.144	0.809 ± 0.113	0.937 ± 0.022	0.873 ± 0.053	0.122 ± 0.071
CLAHE + Local Otsu	0.294 ± 0.085	0.448 ± 0.108	0.299 ± 0.089	0.960 ± 0.021	0.775 ± 0.068	0.868 ± 0.034	0.845 ± 0.649

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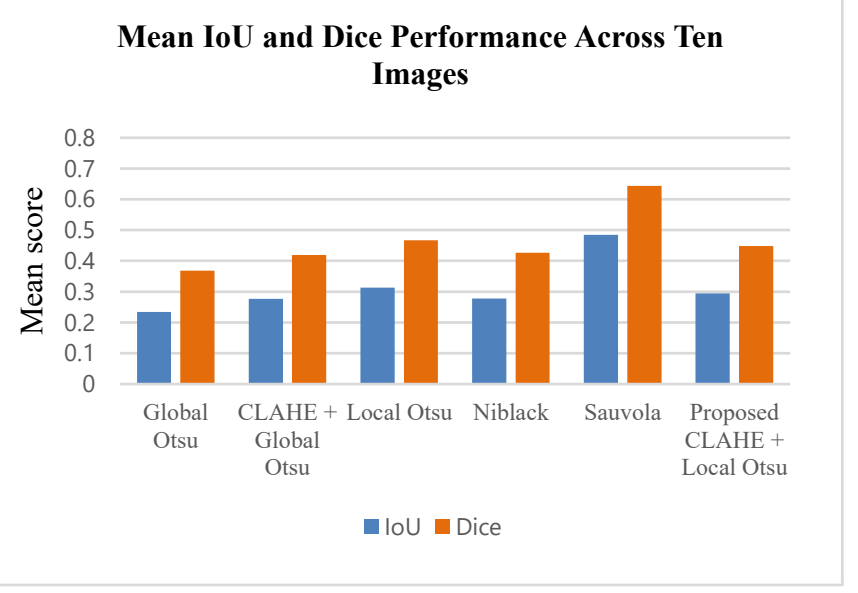

Fig. 2: Mean IoU and Dice scores; error bars show one standard deviation.

Figure 2 illustrates the mean IoU and Dice scores of the six evaluated methods, while the error bars represent one standard deviation across the ten test images.

CLAHE + Local Otsu achieved mean IoU and Dice values of 0.2941 and 0.4481. These values exceeded Global Otsu (0.2344 and 0.3680) but remained below Local Otsu without CLAHE (0.3126 and 0.4673) and Sauvola (0.4845 and 0.6443). Thus, localized Otsu improved upon a single global threshold, but the fixed CLAHE stage did not improve overlap relative to plain Local Otsu.

4.2 Effect of CLAHE

For Global Otsu, CLAHE increased mean IoU from 0.2344 to 0.2769, Dice from 0.3680 to 0.4187, and recall from 0.8823 to 0.9706. For Local Otsu, CLAHE increased recall from 0.8868 to 0.9600 but decreased IoU, Dice, precision, and specificity. This contrast demonstrates that enhancement strengthened weak foreground information while simultaneously amplifying background texture. Therefore, the benefit depended on the

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thresholding stage and the relative amount of text and degradation in each local region.

The low precision of 0.2988 is particularly important because it reveals substantial over-segmentation that is not apparent from recall alone. This result prevents any claim that CLAHE + Local Otsu was superior or robust under the evaluated conditions. Its balanced accuracy was high because recall was high, but IoU and Dice correctly penalized the large false-positive foreground area.

4.3 Computational Cost

Global Otsu was the fastest method at 0.0470 s. Sauvola required 0.1222 s, while Local Otsu and CLAHE + Local Otsu required 0.6960 s and 0.8450 s. The overlapping-window implementation repeated histogram analysis across many regions; adding CLAHE further increased the total cost. Sauvola therefore provided the strongest quality-runtime trade-off in this experiment.

4.4 Qualitative Analysis

Visual inspection focused on text preservation, background suppression, shadow sensitivity, stains, borders, and paper texture. Global Otsu was strongly affected by dark background regions. CLAHE + Global Otsu recovered more faint content but retained amplified background. Niblack preserved weak strokes but produced dense noise. Local Otsu adapted to illumination more effectively than Global Otsu, while Sauvola produced the cleanest balance in the representative example. CLAHE + Local Otsu retained weak text but also classified enhanced background structures as foreground.

Figure 3 presents a qualitative visual comparison of the segmentation results obtained by the evaluated methods on a representative degraded document image.

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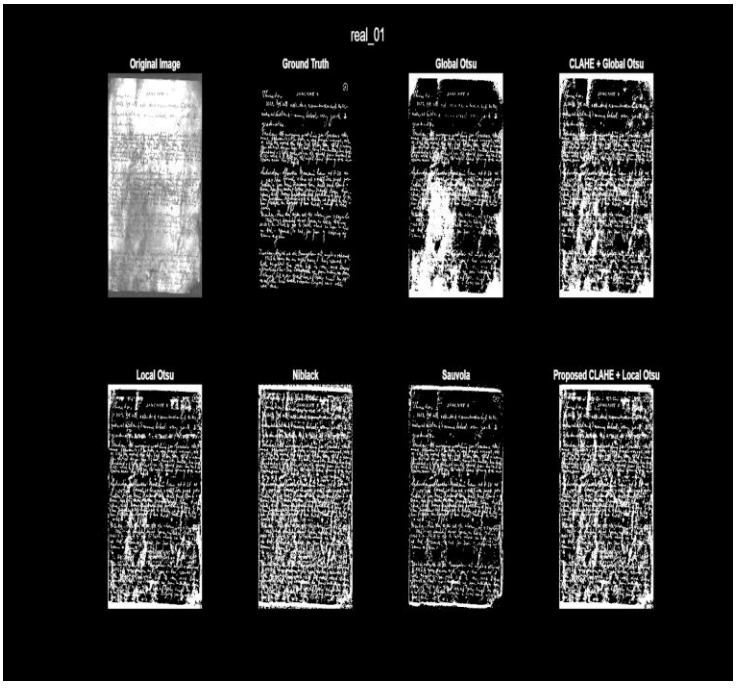

Fig. 3: Qualitative comparison for real_01. White pixels denote detected foreground and black pixels denote background.

4.5 Statistical Analysis and Failure Patterns

The Friedman test revealed clear, statistically significant differences between the six methods for both IoU and Dice— the same result in both cases: $\chi^2(5) = 31.943$, $p<0.001$, Kendall's $W = 0.639$. This effect size indicates that the methods were ranked consistently across all ten images. As expected, IoU and Dice yielded identical rankings, as Dice is a monotonic transformation of IoU.

Sauvola obtained the highest mean rank (6.0), followed by Local Otsu (4.1), CLAHE + Global Otsu and CLAHE + Local Otsu (3.3 each), Niblack (2.8), and Global Otsu (1.5). Holm-corrected Wilcoxon tests showed that Sauvola significantly outperformed each of the other five methods for both IoU and Dice (adjusted $p = 0.0293$ in every comparison). No other pairwise difference remained significant after correction. In particular, Local Otsu and CLAHE +

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Local Otsu did not differ significantly for IoU (adjusted p = 0.4199) or Dice (adjusted p = 0.4219), providing no statistical evidence that fixed-parameter CLAHE improved Local Otsu overlap performance.

Table 3: Results of the Friedman test for the IoU and Dice performance metrics across the evaluated thresholding methods.

Metric	χ^2	df	p-value	Kendall's W
IoU	31.943	5	<0.001	0.639
Dice	31.943	5	<0.001	0.639

Table 4: Mean ranks of the evaluated methods and Holm-adjusted pairwise comparison results

Method	**Mean rank**	**Adj. p vs Sauvola (IoU)**	**Adj. p vs Sauvola (Dice)**
Global Otsu	1.5	0.0293	0.0293
CLAHE + Global Otsu	3.3	0.0293	0.0293
Local Otsu	4.1	0.0293	0.0293
Niblack	2.8	0.0293	0.0293
Sauvola	6.0	—	—
CLAHE + Local Otsu	3.3	0.0293	0.0293

The main failure pattern was the enhancement of non-textual structures that formed connected components larger than the cleanup threshold. Fixed parameters also responded unevenly to different text scales, resolutions, and degradation severities. Border clipping produced smaller windows at image edges, and the same parameter set could not adapt optimally to both relatively clean and severely degraded documents.

5. Limitations

The evaluation was limited to ten project images and did not include a separate validation set, independent test set, or verified public benchmark. Dataset provenance, acquisition devices, languages, resolutions, and usage permissions were not sufficiently documented to support broad external generalization. The fixed parameters were guided by preliminary inspection rather than a

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systematic sweep, which creates a risk of mild overfitting to the evaluated images.

The experiment assumed dark text on bright backgrounds and did not test inverted or mixed-polarity documents. Morphological cleanup relied on component area and a small fixed radius; therefore, large connected stains and borders could remain. The comparison was limited to classical thresholding methods and did not include recent learning-based systems. The runtime was measured using one CPU-based MATLAB implementation. Although Friedman and corrected pairwise tests were completed, only ten paired images were available; consequently, statistical power, effect-size stability, and external generalizability remain limited.
Accordingly, the results should be interpreted as an initial dataset-specific comparative evaluation rather than as evidence of universal superiority or robustness.

6. Conclusions and Future Work

This study compared six document-binarization configurations under non-uniform illumination. Sauvola achieved the strongest overall quality, with mean IoU and Dice scores of 0.4845 and 0.6443, and significantly outperformed all other methods in both measures after Holm correction (adjusted $p = 0.0293$). CLAHE + Local Otsu achieved high recall (0.9600) but low precision (0.2988), mean IoU of 0.2941, and mean Dice of 0.4481. It recovered weak text but amplified background degradation and required the highest mean runtime. Plain Local Otsu achieved slightly better overlap, and the differences between the two Local Otsu configurations were not statistically significant. Therefore, the evaluated evidence does not support fixed-parameter CLAHE as a reliable improvement to Local Otsu under these conditions.
Future work should evaluate recognized public benchmarks, document image provenance, and separate validation and test subsets. Parameter sensitivity should be measured systematically for the CLAHE clip limit and tile scale, local Otsu window and overlap, and post-processing settings. Statistical conclusions should be

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replicated on substantially larger datasets with confidence intervals and independently selected parameters. Background normalization, polarity detection, noise-aware enhancement, text-structure-based cleanup, optimized local histograms, and comparisons with modern learning-based methods should also be investigated.

Declarations

Author Contributions

Farida Hisham Ghariani and Alla Khaled Almuqadimi: conceptualization, methodology, software, investigation, data curation, analysis, visualization, and original draft preparation. Milad Areir: supervision, methodological guidance, review, and editing. All authors reviewed and approved the final manuscript.

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Conflict of Interest

The authors declare that they have no conflict of interest.

Data and Code Availability

The project materials include MATLAB code, parameter settings, image-ground-truth pairs, detailed and summary result tables, threshold maps, binary masks, qualitative figures, and the statistical outputs. The complete per-image table (detailed_results.csv/detailed_results.xlsx), Friedman summaries, mean-rank tables, and Holm-corrected Wilcoxon results should be supplied as supplementary files with the resubmission. Public release of the document images remains subject to verification of their source and usage permissions.

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References

Bernardino, R., Lins, R. D., and Barboza, R. (2024). Texture-based document binarization. In Proceedings of the ACM

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Symposium on Document Engineering (DocEng 2024), San Jose, CA, USA.

Bloechle, J.-L., Hennebert, J., and Gisler, C. (2023). YinYang, a fast and robust adaptive document image binarization for optical character recognition. In Proceedings of the ACM Symposium on Document Engineering (DocEng 2023), Article 19. https://doi.org/10.1145/3573128.3604896

Gatos, B., Ntirogiannis, K., and Pratikakis, I. (2009). ICDAR 2009 Document Image Binarization Contest (DIBCO 2009). In Proceedings of the 10th International Conference on Document Analysis and Recognition, 1375-1382. https://doi.org/10.1109/ICDAR.2009.246

MathWorks. (2026a). adapthisteq: Contrast-limited adaptive histogram equalization (CLAHE). MATLAB Image Processing Toolbox documentation. Accessed July 11, 2026.

MathWorks. (2026b). graythresh: Global image threshold using Otsu's method. MATLAB Image Processing Toolbox documentation. Accessed July 11, 2026.

Niblack, W. (1986). An Introduction to Digital Image Processing. Prentice-Hall International.

Otsu, N. (1979). A threshold selection method from gray-level histograms. IEEE Transactions on Systems, Man, and Cybernetics, 9(1), 62-66. https://doi.org/10.1109/TSMC.1979.4310076

Pizer, S. M., Amburn, E. P., Austin, J. D., Cromartie, R., Geselowitz, A., Greer, T., ter Haar Romeny, B. M., Zimmerman, J. B., and Zuiderveld, K. (1987). Adaptive histogram equalization and its variations. Computer Vision, Graphics, and Image Processing, 39(3), 355-368. https://doi.org/10.1016/S0734-189X(87)80186-X

Sauvola, J., and Pietikäinen, M. (2000). Adaptive document image binarization. Pattern Recognition, 33(2), 225-236. https://doi.org/10.1016/S0031-3203(99)00055-2

Su, B., Lu, S., and Tan, C. L. (2013). Robust document image binarization technique for degraded document images. IEEE

http://www.doi.org/10.62341/istj-vol39-1-fr24

Transactions on Image Processing, 22(4), 1408-1417. https://doi.org/10.1109/TIP.2012.2231089

Sulaiman, A., Omar, K., and Nasrudin, M. F. (2019). Degraded historical document binarization: A review on issues, challenges, techniques, and future directions. Journal of Imaging, 5(4), 48. https://doi.org/10.3390/jimaging5040048

Yang, Z., Zuo, S., Zhou, Y., He, J., and Shi, J. (2024). A review of document binarization: Main techniques, new challenges, and trends. Electronics, 13(7), 1394. https://doi.org/10.3390/electronics13071394

Zuiderveld, K. (1994). Contrast limited adaptive histogram equalization. In P. S. Heckbert (Ed.), Graphics Gems IV (pp. 474-485). Academic Press Professional. https://doi.org/10.1016/B978-0-12-336156-1.50061-6