Comparative Study of Low-Light Image Enhancement in Additive Manufacturing

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ABSTRACT

The images captured using the Wire Arc Additive Manufacturing (WAAM) process may exhibit problems such as bright arc glare, sensor noise, and non-uniform illumination of the image which can hinder the analysis of bead geometry and heat-affected-zone (HAZ) features. In the proposed research to enhance the image quality, five techniques have been tested: CLAHE, Multi-Scale Retinex, LIME-lite, KinD-style Gamma and DCE-lite. The automated enhancement pipeline has been used to evaluate them. The enhanced images are evaluated by PSNR, SSIM, Tenengrad, Shannon entropy and bright-fraction analysis to identify the performance of the proposed image enhancement techniques. Obtained results revealed that the overall assessment increases the contrast, structural preservation, sharpness and detail while reducing the saturation of highlights. This increases visibility of manufacturing features and potential defects, complementing the ability of the WAAM to be monitored with greater confidence while using relatively low computational resources.

KEYWORDS: WAAM, low-light enhancement, Image processing

1. INTRODUCTION

In WAAM the reliable image-based monitoring is still challenging. A small area may be very bright, but the rest of the scene is very dark in or close to a welding arc. Metal reflections, smoke, heat shimmer, and camera noise further degrade image quality and can result in masking of layer boundaries, pores, spatter, undercut and lack of fusion defects. Thus, image enhancement is essential to improve the visibility of the image while retaining important structural information. Some previously proposed methods include LIME for estimation of illumination [1] and Zero-DCE light-weight curve-based enhancement without reference images [2]. To enhance the illumination while retaining the image structure, KinD used the decomposition of the image based on its Retinex [3]. Multi-Scale Retinex [MSR] monitoring also has been shown to be useful for identifying process variations in WAAM [4]. While automatic comparison of several enhancement techniques on WAAM image is still limited. This study analyzed the grayscale images that came from the WAAM process and selected images of welding frames. In this study five methods used are CLAHE [5], MSR, KinD, LIME-lite and DCE lite. Graphical abstract of the study is given in figure 1.

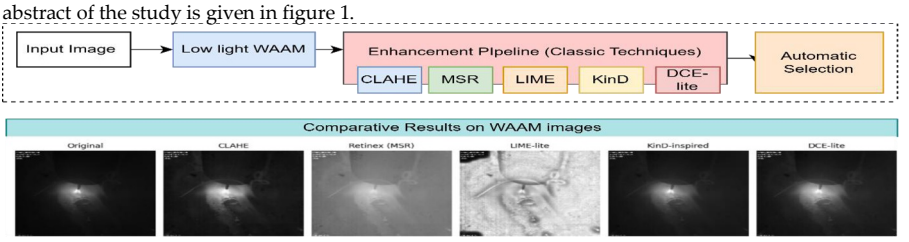


Figure 1. Graphical abstract of study

2. MATERIAL & METHODS

The proposed framework evaluates five image-enhancement techniques CLAHE, Multi-Scale Retinex (MSR), KinD, LIME-lite, and DCE-lite for improving the visibility of grayscale welding images. Before

© The Author(s) 2026
D. Nikam et al. (eds.), *Proceedings of the Global Symposium on Adaptive Manufacturing (GSAM 2026)*, Advances in Engineering Research 308,
https://doi.org/10.2991/978-94-6239-813-9_24

enhancement, each frame is converted to grayscale and normalized to the range [0,1]. Lightweight image diagnostics, including bright-fraction, dark-fraction, Tenengrad sharpness, and Shannon entropy, are calculated to characterize the illumination and detail content of each frame.

CLAHE improves local contrast by dividing the image into tiles, applying histogram equalization with contrast limiting, and combining the enhanced regions to reduce artifacts. An 8×8 tile grid and clip limit of approximately 2.0 are used as the initial settings. MSR models the image as illumination and reflectance and reduces uneven lighting by subtracting blurred versions of the image at multiple scales. Three Gaussian scales (σ = 15, 80, and 250) are employed with a mild percentile stretch. KinD provides a Retinex-based curve enhancement that increases mid-tone visibility while preserving structural details and limiting highlight saturation. LIME-lite estimates a smoothed illumination map and enhances darker regions through illumination compensation with the limited gain. DCE-lite applies a small, bounded enhancement curve iteratively to increase mid-tone exposure while monitoring glare.

3. RESULTS

All experiments were performed on intel core i5 with python 3.8 and essential libraries. All images were small 256×256 grayscale copies. Each image check with SSIM and PSNR with data range 1.0. also used roughly "60% Tenengrad + 40% entropy − 70% bright- fraction for performance analysis as shown in figure 2.

Algorithm	PSNR	SSIM	Teng	Entr	Bright
KinD- Insp	28.199	0.9078	2800.0	4.370	0.002
DCE-Lite	23.005	0.8549	3253.6	4.366	0.002
CLAHE	24.860	0.7264	3122.9	4.824	0.002
LIME LITE	6.720	0.3114	12061.7	5.188	0.020
Retinex(MSR)	9.456	0.2776	2935.0	5.885	0.001

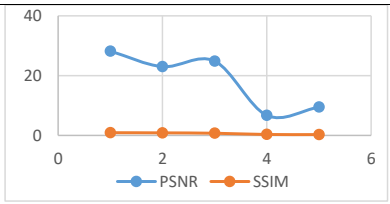


FIGURE 2. Performance with analysis of all methods a) performance measure b) visual representation

4. DISCUSSION

The results indicate that the set of parameters for KinD-gamma provides the best overall improvement in terms of visibility of dark regions, preservation of important WAAM structures, and a limited glare contribution. CLAHE and MSR are good at handling local contrast and uneven illumination, while LIME-lite and DCE-lite will work well on brightness, but may add noise or change highlights. In summary, preservation of the bead's geometry and HAZ is best for KinD-gamma, rendering it the ideal solution for useable low-light AM inspection application.

5. CONCLUSION

The proposed framework shows that adaptive enhancement can significantly enhance the interpretable content of low-light WAAM images. The most balanced performance was obtained with KinD-Inspired as it improved the mid-tone features, retained structural information, and reduced the glare created by the arcs. These results are useful for more accurate and confident visual monitoring in WAAM.

REFERENCES

1.V. Supraja, S.et.al., "LIME: Low-light image enhancement via illumination map estimation," International Journal of Scientific Research in Science, Engineering and Technology,9(2),376–382,2022.

2.C. Li, C. Guo, and C. C. Loy, "Learning to enhance low- light image via zero-reference deep curve estimation," IEEE TPAMI, early access,2021.

3.Y. Zhang, J. Zhang, and X. Guo, "Kindling the darkness: A practical low-light image enhancer," in ACM MM,2019, pp.1632–1640.

4. D. J. Jobson, Z. Rahman, and G. A. Woodell, "A multiscale retinex for bridging the gap between color images and the human observation of scenes," IEEE Trans. Image Processing,6(7), 965-976,1997.

5. A. M. Reza, "Realization of the contrast limited adaptive histogram equalization (CLAHE) for real-time image enhancement," Journal of VLSI Signal Processing, 38,35–44, 2004

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