doi.org/10.52866/esj.2025.01.25.18

Quantifying the Effectiveness of Two Contrast Enhancement Techniques in Infrared Images

Basaad Hadi Hamza
Department of Physics, College of Science, Mustansiriyah University, Baghdad, Iraq;
E-mail: bassaadhadi@uomustansiriyah.edu.iq.

Abstract:

Owing to its temperature range, the images captured by the thermal cameras usually characterized by a white hue in addition to the lack in contrast, overexposed, and underexposed areas which make the conventional contrast enhancement methods inadequate. The current search presents an algorithm for enhancing the quality of infrared images based on the Contrast Limited Adaptive Histogram Equalization (CLAHE). The main contribution of this work focuses on evaluating the effectiveness of contrast enhancement methods of infrared images to make the latter adequate in different applications. The enhancing results suggest that CLAHE is more effective than Histogram Equalization (HE) in enhancing infrared images through its role in enhancing the visual details in addition to occupy high rate values for both Peak Signal to Noise Ratio (PSNR) and Root Mean Square Error (RMSE). Hence, CLAHE has the ability at final to improve the efficiency of infrared images in different potential applications, such as recognizing the defects in metals as an example.

Keywords: Infrared image, Infrared Sensor, Gaussian Blurring, Peak Signal to Noise Ratio, Mean Square Error, Contrast Limited Adaptive Histogram Equalization.

المقياس الكمي لفعالية أثنين من تقنيات تحسين التباين في صور الأشعة تحت الحمراء

د. بسعاد هادي حمزة
الجامعة المستنصرية / كلية العلوم - قسم الفيزياء

مستخلص:

بالنظر الى مدى نطاق درجات الحرارة، فإن الصور الملتقطة بواسطة الكاميرات الحرارية تتميز عادةً بوجود اللون الأبيض بالإضافة إلى قلة التباين لهذا النوع كذلك المساحات المتعرضة المنخفضة والعالية التعرض للاشعاع الحراري يجعل طرق تحسين التباين التقليدية لهذا النوع من الصورغير كافية. يقدم البحث الحالي خوارزمية لتحسين جودة صور الأشعة تحت الحمراء بناءً على استخدام طريقة معادلة الرسم البياني التكيفي المحدود للتباين.(CLAHE) . تركز المساهمة الرئيسية لهذا العمل على تقييم فعالية طرق تحسين التباين لصور الأشعة تحت الحمراء لجعل هذه الأخيرة كافية في التطبيقات المختلفة. تشير النتائج المعززة إلى أن استخدام تقنية (CLAHE) أكثر فعالية من معادلة الرسم البياني (HE) في تحسين صور الأشعة تحت الحمراء من خلال دورها في تعزيز التفاصيل المرئية بالإضافة إلى احتلال قيم معدل عالية لكل من نسبة ذروة الإشارة إلى الضوضاء (PSNR) وجذر متوسط مربع الخطأ (RMSE). ومن ثم، فإن CLAHE لديه القدرة أخيرًا على تحسين كفاءة صور الأشعة تحت الحمراء في التطبيقات المحتملة المختلفة، مثل كشف العيوب في المعادن.

1. Introduction

The basic concept for evaluating any infrared system is based on infrared signature derived from images of the infrared target and the background. Such images transferred then into range of intensity gray levels which indicate the temperature of the IR target and scene background [1-2]. The ability of the IR sensor model consisting of the adjustment procedure to measure performance with real-time simulations in the infrared spectrum part. Such model can be utilized in different practical applications like health assessment, threat detection, thermal imaging,…etc. The imaging model can be used as a computation tool for single and multi-band color images [3].

RadThermIR, and MuSES are commercial software programs designed to simulate IR signatures which permit for realistic replication of an infrared environment [4]. Over the traditional analytical techniques, the infrared and optical sensors gave several advantages, like the property to detect various compounds immediately without coast [5]. The thermal IR cameras often used in the surveillance scenarios because of its ability in capturing images through the day time, night and maintain the anonymity of the objects being monitored [6-7].

Each pixel in the thermal IR image represents a thermal spot which is display on the image. The infrared camera can also detects radiation from other environments while measuring a specific target like the nearby and surrounding objects [8-9]. IR images considered as widely used application in various fields. Nevertheless and due to the nature of infrared detectors in addition to atmospheric conditions which affects upon the quality for IR images and yielded lower values for both contrast, and Signal-to-Noise Ratio (SNR).

In image processing field, image quality enhancement is a critical need and the segmentation effectiveness in addition to object recognition depend upon the ability to enhance the contrast of the infrared images [10]. The Common used algorithms in improving image contrast include Histogram Equalization (HE), histogram matching, gray level transformation, and un-sharp mask methods. However, these methods often amplify the noise in the image while improving contrast

[11]. To enhance the visual quality of IR images, a robust contrast-enhancing algorithm based on Contrast Limited Adaptive Histogram Equalization (CLAHE) has been developed. This de-noising algorithm directly reduces noise at higher resolution levels while enhancing contrast [12].

2. Related Work

Contrast enhancement has been widely used by numerous researchers for improving the quality of infrared images. S. Christian in [13] determined that homomorphic filtering and histogram equalization techniques outperformed the other techniques by noting that all the implemented techniques are global contrast enhancement methods. B. Wang et al. [14] designed a new algorithm by utilizing the characteristics of the HP memristor, which resulted in improving the performance. To improve the visual quality of IR images, C. Liu et al. presented an optimized contrast enhancement technique by combining global and local enhancement techniques. The proposed method outperforms block-based methods in enhancing the quality of IR images.

The authors in [16] presented data recorded with both types of cameras in dim light environments and estimated the results of applying image enhancement techniques; noise reduction, super-reconstruction, and local adaptive contrast enhancement. The authors found in the comparison results from both cameras that an image identifier performed well in the case of dim environment, otherwise, the Electro-Magnified Camera (EMCCD) performed better in bright cases. To enhance the contrast of CT and MRI T1 images, L. Chandrashekar, and A. S. Asundi used CLAHE technique. The proposed technique improved the visual quality at the final such that the tumors can be segmented and classified efficiently. Their results showed that the enhancement in contrast and entropy for Laplacian Pyramid fused image and CLAHE-Particle Swarm Optimization enhanced image was executed by 2.55 % and 5.18% respectively.

Based on adaptive histogram correction and equalization, W. Deng et al. in [18] proposed a contrast enhancement method by combining an adaptive histogram correction and histogram equalization to reduce artifacts and insufficient local detail enhancement.

Their results showed that the adopted enhancement method was better, especially in dark areas.

In this research, an algorithm is introduced to enhance the quality of infrared images acquired by IR sensors. The algorithm is centered on the Contrast Limited Adaptive Histogram Equilibrium (CLAHE) method, which emphasizes the enhancement of contrast in infrared images. The key contribution of this study is the assessment of the efficacy of contrast enhancement techniques for infrared images to test their applicability in various domains.

3. Proposed Scheme

The following models can be used in the current research.

3.1 Infrared Sensor performance model

To analyze the performance of an IR sensor, it is better to start with Planck's equation for blackbody radiation. Thermal surveillance equipment is needed to obtain thermal images of the various wavelength bands. A "black body" at a specific wavelength (λ) and temperature (T) can be represented by the following Eq. [19],[20] :

$$R(\lambda, T) = \frac{\varepsilon(\lambda)\ c_1}{\lambda^5\ \left(\exp\left(\frac{c_2}{\lambda\ Tmax}\right)-1\right)}\ [W/(cm^2 \mu m\ sr)] \qquad (1)$$

Where C_1=1.191 x 10^4 ($W\mu^4/cm^4$ sr) and C_2=1.428 x 10^4 (μmK) are the radiation constants, and ε(λ) is the spectral emissivity of an object. If the object is a gray body, then ε(λ)<1. The radiance of an object between wavelengths (λ1 and λ2) can be calculated using Eq. 2:

$$R(T) = \int_{\lambda 1}^{\lambda 2} \frac{c_1}{\lambda^5\ \left(\exp\left(\frac{c_2}{\lambda\ Tmax}\right)-1\right)} d\lambda \qquad (2)$$

and the voltage of the detector can be determined using Eq. 3:

$$V = A\, \Omega\, L(T) \int_{\lambda 1}^{\lambda 2} (\tau_{amb}(\lambda).\ \tau_{opt}(\lambda).S(\lambda))\ d\lambda \qquad (3)$$

In such an equation, A represents the lens area and Ω is the solid angle of the detector, with a constant value and τ_{amb} and τ_{opt} denote the spectral transmittance of the atmosphere and detector optics, respectively. S(λ) is the spectral responsivity, expressed in units of (V/W), and the integral of the wavelength-bandwidth will have constant values if the systems are time-invariant. The detector's output is proportional to the radiance R(T), depending on the temperature. This implies that the gray levels of an IR image are proportional to the radiance of a specific wavelength bandwidth concerning an object's temperature [21]. In previous results found in [22], the authors used a conversion technique to convert images from one wavelength band to another.

3.2 Contrast Limited Adaptive Histogram Equalization (CLAHE)

Infrared images typically have reduced contrast and contain overexposed and underexposed regions, making conventional contrast enhancement techniques unsatisfactory [23]. An adaptive version of the adaptive histogram approach is commonly used to solve this issue. Contrast enhancement methods alter image intensities to increase the difference in color or intensity between two objects. Analytical histogram equalization is such a method, but adaptive histogram equalization (AHE) is a more effective approach as it enhances the contrast of small data segments (tiles) rather than the entire image. The contrast Limited Adaptive Histogram Equalization (CLAHE) is the result of combining AHE with a limited contrast method [24]. CLAHE segments the image into equally sized, non-overlapping areas, calculates each area's histogram and determines a clip limit for contrast expansion. The clip limit is calculated using the next Eq. [25]:

$$\beta = \frac{MN}{L}\left(1 + \frac{\alpha}{100}(S_{max} - 1)\right) \qquad (4)$$

For grayscale mapping with contrast-limiting histograms, the cumulative distribution functions (CDF) are calculated using a dip factor, region size M and N, and a maximum clip limit of 100. A clip factor of 0 results in a clip limit of MN/L, while a clip limit of 100 permits a maximum slope of S_{max}. Median and Gaussian filters are used to reduce noise in captured images. Both quantitative and graphical analyses were used to assess the quality of the enhancement results, with mean square error (MSE) used as the foundation for evaluation. MSE is calculated as the squared difference between the original IR image and the enhanced image, divided by the product of M and N. A lower MSE indicates better image enhancement performance [26], [27].

$$MSE = \sum_{i=1}^{M} \sum_{j=1}^{N} \frac{[F(i,j)-F\_1\,(i,j)]^2}{M \times N} \quad (5)$$

Root mean square error (RMSE) is the square root of MSE and measures the standard deviation of residuals. Peak signal-to-noise ratio (PSNR) is defined as the ratio of peak signal energy to mean standard deviation (MSE) and is computed after performing a linear fitting of processed image pixels to match the original image pixels [28]. This removes contrast and brightness correction errors before calculating PSNR, with peak signal energy expected to be 2552 and MSE summed over the selected region of interest of the processed sequence [29].

$$PSNR = 10 \log \left(\frac{{F_{max}}^2}{MSE}\right) \quad (6)$$

4. Tools and Methodology

The IR camera model 'Ti10 Fluke' captured the IR images of various metals; an iron target in stick form with a temperature of 58.4ºC, a circular iron target with 193.8ºC, and a cylindrical steel target with 91.3ºC with different conductivities, as displayed in Fig. 1a, respectively. The camera had an image range of 20.6°C to 140.1°C and a lens description of 20mm. Table 1 displays the properties of the used metals, sourced from the Ministry of Science and Technology/Department of Renewable Energies/Baghdad/ Iraq.

5. Results and Discussion

The author's findings in [22] indicate, that the design of an infrared (IR) lens is typically focused on two specific spectral bands; mid-wave infrared (MWIR) ranging from 3-5 μm and long-wave infrared (LWIR) ranging from 8-12 μm. In general, the 3-5 μm wave band is preferred for hot and humid environments with very long ranges, while the 8-12 μm wave band is preferred for cold and dusty environments. Based on these considerations, Figs. 1b, and c depict the application of Eqs. 2 and 3 to estimate the radiance and detector voltage for the band 3-5 μm respectively.

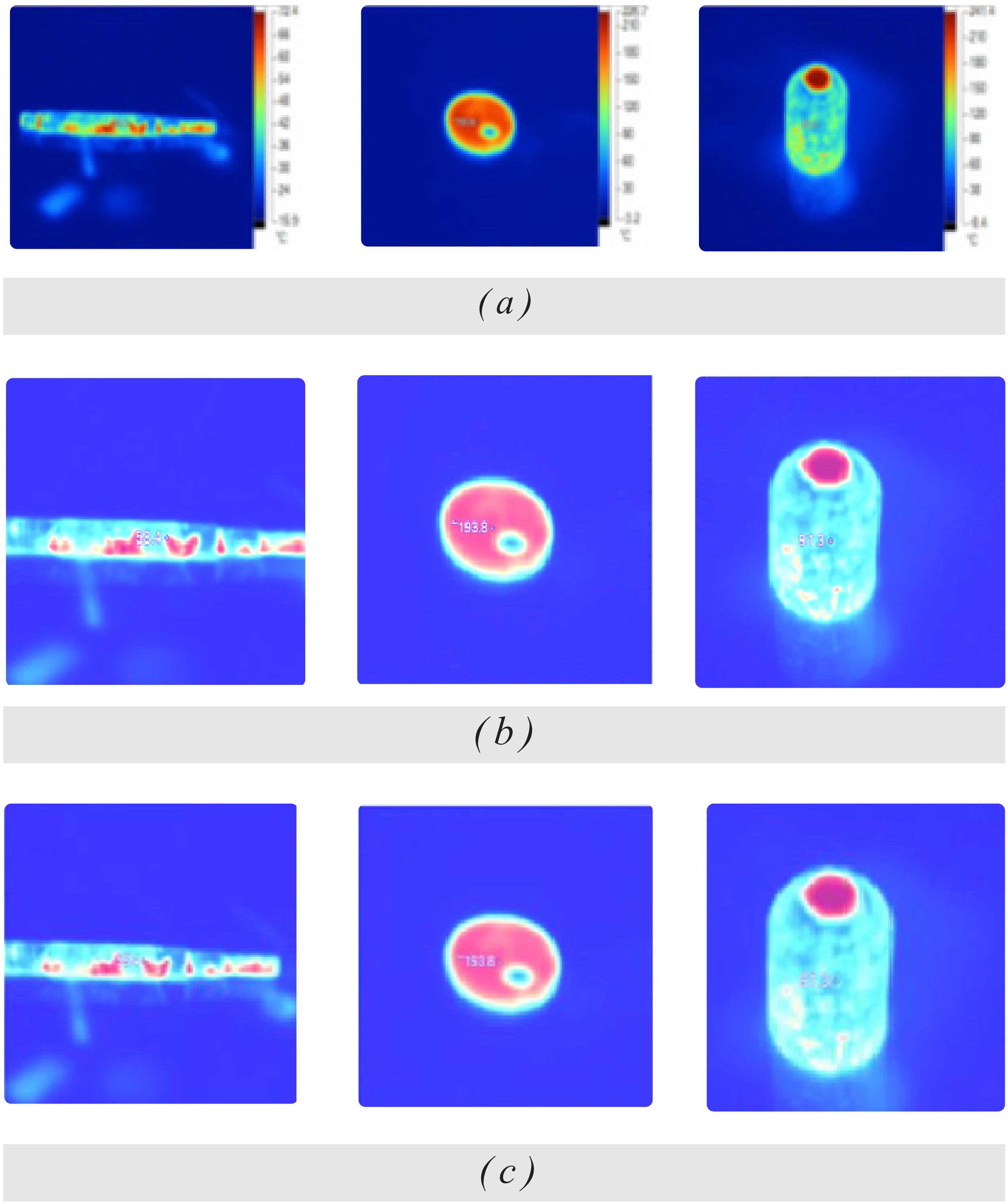

Fig. 1 –The radiance and detector voltage application upon the original image. (a) Original image; (b) The application of radiance equation; (c) The detector voltage estimation.

High radiation areas show that the images of metal's temperature is comparatively high, meaning that more heat energy is received or released by these regions. Small or uneven surface regions like these could be signs of a flaw like corrosion or a crack that is allowing heat to accumulate in that area. However, regions of low radiation can suggest that this portion of the metal is experiencing inhomogeneous cooling. This could be because of a fault that affects thermal conductivity in that region.

The proposed system uses CLAHE for image enhancement, and the performance can be measured by the statistical estimators mentioned above; PSNR and RMSE. The whole procedure can be shown in Fig. 2, while Fig. 3 shows the results for the proposed technique upon the original IR images. Experimental results show that the new algorithm increases the contrast in IR images effectively and produces an enhanced image with the better visual quality compared to the standard Histogram Equalization (HE) method as shown in Fig. 4.

Table 1:- *The properties of the used three metals*

Type of Metal	Emissivity	Temperature (°C)	Conductivity (W/m K)	Calibration Range
IRON	0.28	Tmin= -8.4 Tmax=241.4	69.4	-25.0°C to 125.0 °C
IRON CIRCLE	0.96	Tmin= -3.2 Tmax=226	33.8	-25.0°C to 125.0 °C
STEEL	0.22	Tmin= 15.9 Tmax=72.4	14.4	-25.0°C to 125.0 °C

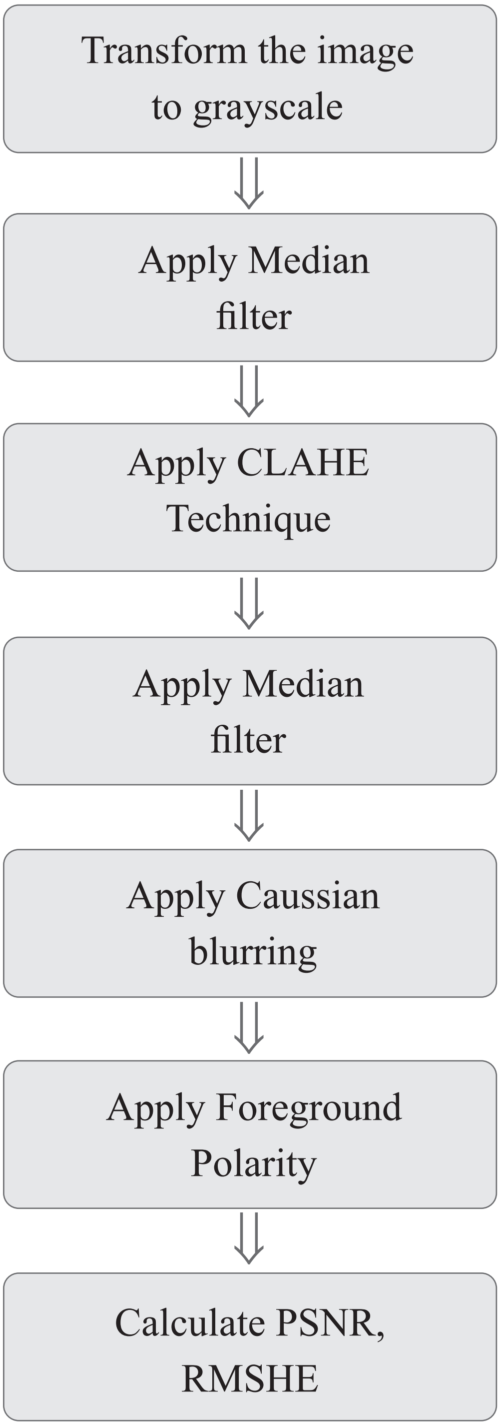

Fig. 2 –*Block Diagram for the proposed system*

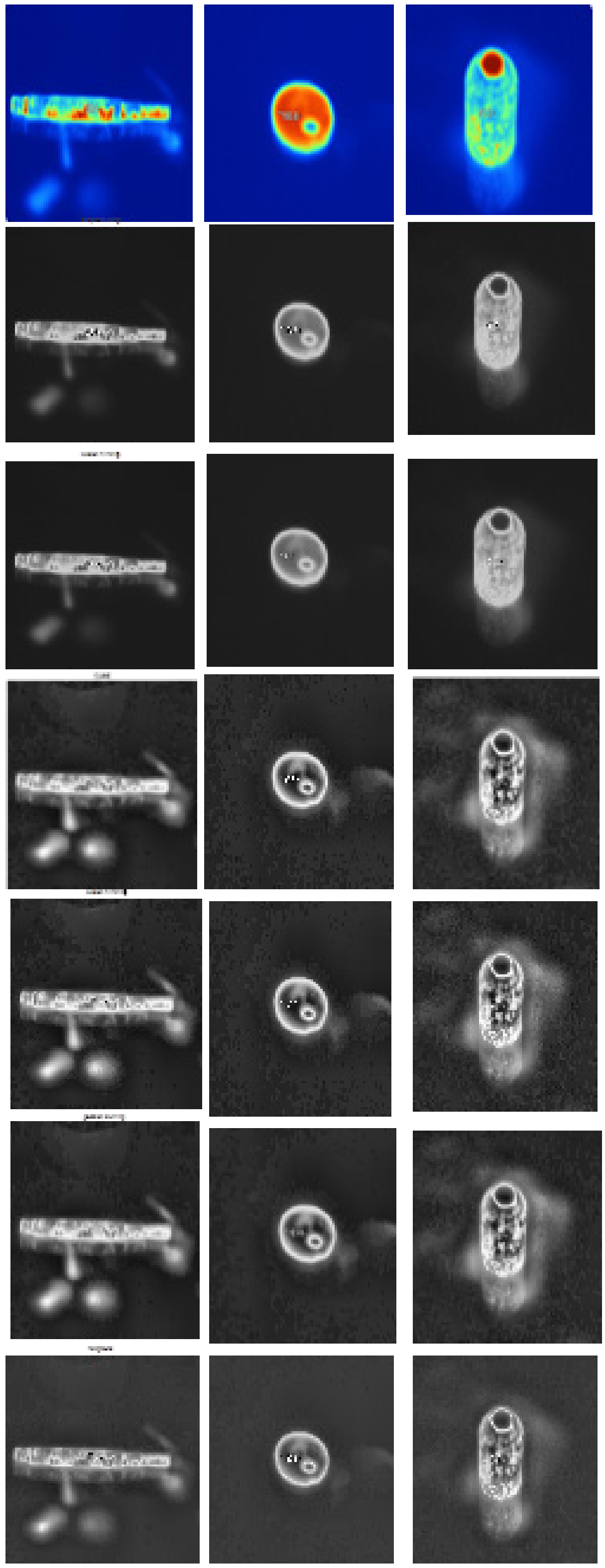

Fig. 3 –*The results for the proposed technique on the original images*

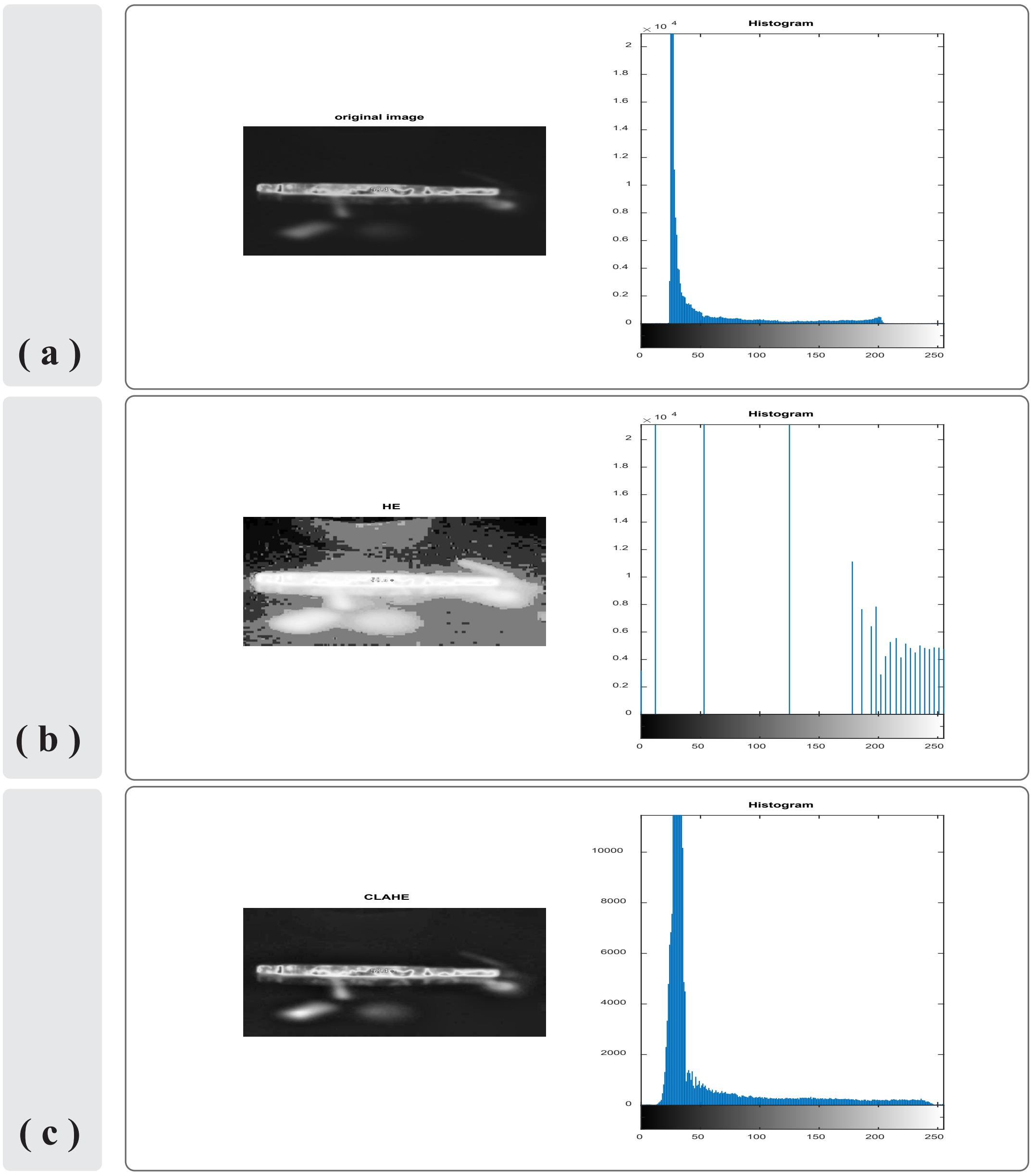

Fig. 4 –*Visual quality results upon histograms;*
(a) Original image; (b) HE; (c) CLAHE techniques

The results shown in Fig. 5 indicate that the proposed technique is more effective in enhancing IR images than HE, in terms of visual quality and evaluation used metrics. It is evident from the evaluation of IR images that the CLAHE method outperforms HE in enhancing image contrast. Additionally, the use of RMSE proves to be a better metric than PSNR for measuring the performance of these two approaches.

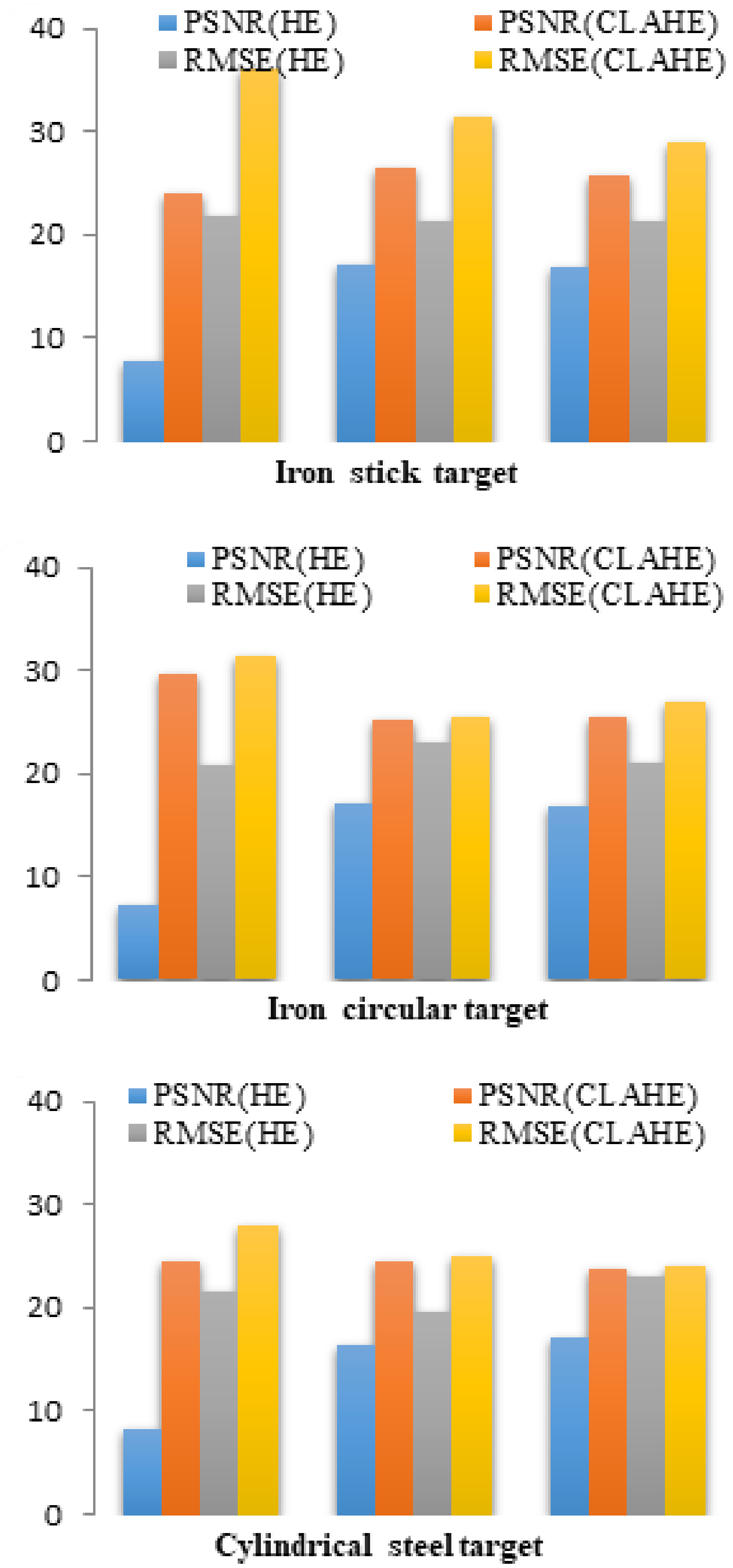

Fig. 5 –*PSNR and RMSE for both techniques upon the three IR images*

6. Conclusion

In conclusion, this study focused on enhancing contrast while suppressing noise in IR images. The proposed Contrast Limited Adaptive Histogram Equalization (CLAHE) algorithm was compared to the traditional Histogram Equalization (HE) algorithm through experimental examination, and it was found that the CLAHE algorithm outperforms HE in terms of producing enhanced visual details with higher values of the statistical used metrics; PSNR and RMSE. The proposed method can be used to obtain significantly clearer images with more accurate details than the original input IR images. This method could be best suited for use in industrial and commercial infrared imaging applications, and one potential application could be in detecting defects in metals.

Overall, the proposed algorithm is a promising technique for enhancing the quality of IR images, and it has the potential to improve the accuracy and effectiveness of infrared imaging in various applications.

7. References

[1]T. W. Bae, Y. C. Kim and S. H. Ahn, "IR Composite Image Generation by Wavelength Band Based on Temperature Synthesis Estimated from IR Target Signature and Background Scene," Journal of Sensors, Hindawi, vol. 2019, pp. 1-17, 2019, https://doi.org/10.1155/2019/9423976.

[2] H. Zhu, Y. Guan , L. Deng, Y. Li and Y. Li, "Infrared moving point target detection based on an anisotropic spatial-temporal fourth-order diffusion filter," Computers & Electrical Engineering, vol. 68, pp. 550-556, 2018, https://doi.org/10.1016/j.compeleceng.2018.05.009.

[3] W. Wan, "Passive IR sensor performance analysis using Mathcad modeling," in Infrared Imaging Systems: Design, Analysis, Modeling, and Testing XX, Orlando, Florida, United States, 2009, https://doi: 10.1117/12.815238.

[4] N. Claes, H. Patrik, W. Thomas and S. Stefan, "Benchmarking and Validation of IR Signature Programs: SensorVision, CAMEO-SIM and

RadThermIR," Deffence Technical Information Center, Brussels, Belgium, 2005, https://apps.dtic.mil/sti/citations/ADA457113.

[5] G. Gauglitz, "Direct optical sensors: principles and selected applications," Anal Bioanal Chem, vol. 381, no. 1, pp. 141-155, 2005, https://doi.org/10.1007/s00216-004-2895-4.

[6] Y. W. K. Zoetgnandea, A. J. Fougères, G. Cormierc and J. L. Dillensegera, "Robust low resolution thermal stereo camera calibration," in Eleventh International Conference on Machine Vision (ICMV 2018), Munich, Germany, 2019, https://doi.org/10.1117/12.2523440.

[7] A. Berg, Detection and Tracking in Thermal Infrared Imagery, Sweden: Linköping studies in science and technology, 2016.

[8] Q. H. Tran, H. Dongyeob, C. Kang, A. Haldar and J. Huh, "Effects of Ambient Temperature and Relative Humidity on Subsurface Defect Detection in Concrete Structures by Active Thermal Imaging," Sensors, vol. 17, no. 8, 2017, https://doi.org/10.3390/s17081718.

[9] Q. Fang, B. D. Nguyen, C. I. Castanedo, Y. Duan and X. Maldague II, "Automatic defect detection in infrared thermography by deep learning algorithm," in Proc. SPIE 11409, Thermosense: Thermal Infrared Applications XLII, 114090T, 2020, https://doi.org/10.1117/12.2555553.

[10] F. W. Panella, A. Pirinu and V. Dattoma , "A Brief Review and Advances of Thermographic Image - Processing Methods for IRT Inspection: a Case of Study on GFRP Plate," Exp Tech, vol. 45, pp. 429-443, 2021, https://doi.org/10.1007/s40799-020-00414-4.

[11] S. C. F. Lin, C. Y. Wong, M. A. Rahman, G. Jiang , S. Liu, N. Kwok, H. Shi, Y.-H. Yu and T. W. Wu, "Image enhancement using the averaging histogram equalization (AVHEQ) approach for contrast improvement and brightness preservation," Computers & Electrical Engineering, vol. 46, pp. 356-370, 2015, https://doi.org/10.1016/j.compeleceng.2015.06.001.

[12] N. M. Kwok, X. Jia, D. Wang, S. Y. Chen, G. Fang and Q. P. Ha, "Visual impact enhancement via

image histogram smoothing and continuous intensity relocation," Computers & Electrical Engineering, vol. 37, no. 5, pp. 681-694, 2011, https://doi.org/10.1016/j.compeleceng.2011.08.002.

[13] S. Christian, Analysis of Contrast Enhancement Methods for Infrared Images, San Luis Obispo: Robert E. Kennedy Library, Cal Poly, 2011, DOI: https://doi.org/10.15368/theses.2011.214.

[14] B. Wang, L. L. Chen and Y. Z. Liu, "New results on contrast enhancement for infrared images," Optik, vol. 178, pp. 1264-1269, 2019, https://doi.org/10.1016/j.ijleo.2018.09.165.

[15] C. Liu, X. Sui, X. Kuang, Y. Liu, G. Gu and Q. Chen, "Optimized Contrast Enhancement for Infrared Images Based on Global and Local Histogram Specification," Remote Sens., vol. 11, no. 7, 2019, https://doi.org/10.3390/rs11070849.

[16] J. Dijk, P. Bijl and A. W. M. M. van Eekeren, "Performance evaluation of image enhancement techniques on night vision imagery," in Proc. SPIE 7662, Infrared Imaging Systems: Design, Analysis, Modeling, and Testing XXI, 2010, https://doi.org/10.1117/12.853396.

[17] L. Chandrashekar and A. S. Asundi, "A Two Stage Multi Objective Enhancement for Fused Magnetic Resonance Image and Computed Tomography Brain Images," Journal of Information Systems and Telecommunication, vol. 8, no. 2, pp. 93-104, 2020, doi:10.29252/jist.8.30.93.

[18] W. Deng, L. Liu, H. Chen and X. Bai, "Infrared image contrast enhancement using adaptive histogram correction framework," Optik, vol. 271, 2022, https://doi.org/10.1016/j.ijleo.2022.170114.

[19] F. Hou, Y. Zhang, Y. Zhou, M. Zhang, B. Lv and J. Wu, "Review on Infrared Imaging Technology," Sustainability, vol. 14, no. 18, 2022, https://doi.org/10.3390/su141811161.

[20] J. Verstockt, S. Verspeek, F. Thiessen, W. A. Tjalma, L. Brochez and G. Steenackers, "Skin Cancer Detection Using Infrared Thermography: Measurement Setup, Procedure and Equipment," Sensors (Basel), vol. 22, no. 9, p. 3327, 2022, doi: 10.3390/s22093327.

[21] M. Lueker, Measurements of Secondary Cosmic Microwave Background Anisotropies with the, Berkeley: University of California, 2010.

[22] B. H. Hamza and H. S. Mahdi, "Improved Detector Performance Rendering in the Optical Spectral Ranges to Provide Accurate Image," Al-Mustansiriyah Journal of Science, vol. 29, no. 4, 2018, DOI: http://doi.org/10.23851/mjs.v29i4.341.

[23] R. Khan, Y. Yang, Q. Liu and Z. H. Qaisar, "A ghostfree contrast enhancement method for multiview images without depth information," Journal of Visual Communication and Image Representation, vol. 78, 2021, https://doi.org/10.1016/j.jvcir.2021.103175.

[24] B. S. Rao, "Dynamic Histogram Equalization for contrast enhancement for digital images," Applied Soft Computing, vol. 89, 2020, https://doi.org/10.1016/j.asoc.2020.106114.

[25] K. Singh, R. Kapoor and S. K. Sinha, "Enhancement of low exposure images via recursive histogram equalization algorithms," Optik, vol. 126, no. 20, pp. 2619-2625, 2015, https://doi.org/10.1016/j.ijleo.2015.06.060.

[26] Q. Fu, Z. Zhang, M. Celenk and A. Wu, "A POSHE-Based Optimum Clip-Limit Contrast Enhancement Method for Ultrasonic Logging Images," Sensors, vol. 18, no. 11, 2018, DOI:10.3390/s18113954.

[27] I. F. H. Al-Shimiry, A. A. D. Al-Zuky and F. E. M. Al-Obaidi, "Geometrical Models for Simulating The Properties of Underwater Bodies Using Digital Image Processing," in AIP conference Proceeding, 2nd International conference On Engineering and Science (ICE2021), 26-27 May, Samawa-Iraq, 2021, https://doi.org/10.1063/5.0068897.

[28] M. Nadipally, "Optimization of Methods for Image-Texture Segmentation Using Ant Colony Optimization," in Intelligent Data-Centric Systems, Intelligent Data Analysis for Biomedical Applications, D. J. Hemanth, D. Gupta and V. E. Balas, Eds., Academic Press, 2019, https://doi.org/10.1016/B978-0-12-815553-0.00002-1, pp. 21-47.

[29]U. Sara, M. Akter and M. S. Uddin, "Image Quality Assessment through FSIM, SSIM, MSE and PSNR—A Comparative Study," Journal of Computer and Communications, vol. 7, no. 3, pp. 8-18, 2019, DOI: 10.4236/jcc.2019.73002.