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Full Paper

Detection of nanoparticles in images supported by hybrid edge detection method

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Abstract: In recent years significant advancements have been made in the field of edge detection in digital images through the integration of various techniques, resulting in the emergence of a novel methodology known as multimodal edge detection. This research paper presents an innovative solution for the identification and localisation of nanoparticles in digital images by leveraging different aspects of digital image processing. The effectiveness of the proposed approach is evaluated by analysing a large number of samples using spatial and amplitude resolution frameworks. Matlab software is used to provide the necessary mathematical support for this study. The results demonstrate notable advancements in the components of edge detection, and the proposed method consistently performs well across different detection scenarios. The findings of this investigation have potential implications for the advancement of edge detection techniques in various application domains.

Keywords: algorithm, digital image processing, edge detection, hybrid method, nanoparticles, level of detail

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INTRODUCTION

Edge detection is a rapidly evolving research area and holds significant importance in the field of digital image processing. Edge detection algorithms find applications in robotics, video compression for modern video formats, industrial processes, night vision devices, object recognition algorithms, and various other domains. While spatial domain-based algorithms utilising a 2D gradient with differently defined sub-matrices (such as 2x2 or 3x3 pixels) prevail, there is no universal solution. It may seem that spatial domain algorithms yield the best results.

However, for specific requirements in medical imaging, higher-quality results are obtained with a Pyramidal edge detection algorithm based on analog resolution [1]. When higher processing speed and analog signal processing are required, the Fuzzy algorithm based on frequency image processing is employed. The Sobel operator is commonly used as a reference operator for edge detection in all algorithms. It employs a 3x3 sub-matrix and cumulative gradient for the x and y directions, providing high-quality results for images of varying sizes and levels of detail (LoD) [2].

To cater to the needs of multi-channel images, filters have been developed, such as the Frei-Chen algorithm for edge detection using nine convolutional masks of size 3x3 [3], and the Prewitt algorithm based on a 5x5 matrix [4]. For higher sensitivity and treatment of images with low detail, the Robert function based on a 2x2 convolution matrix is employed [5]. The Gauss-Laplace operator, characterised by the lowest threshold, is suitable for edge detection [6]. In the case of images with a medium LoD, the extended version of the Robert's function utilising three 3x3 convolution matrices, known as the Robinson operator, can be used [7]. The Kirsch operator is recommended for edge detection in high-resolution images [8, 9]. The Saar and Canny edge detection operators are based on the Sobel detection and are known for their high complexity [10, 11]. Canny, in particular, is recommended for detecting edges in images with low to medium LoD.

Despite the availability of various operators, they are fixed and applied under specific conditions of digital image processing. A major drawback is that users determine the suitability of an operator based on personal judgment or specific situation descriptions in paper, without the ability to define algorithm parameters. Another limitation of these algorithms is their lack of consideration for image noise, which can reach up to 12% depending on the optical sensor used [12, 13]. Illumination presents a third challenge, where images captured under different brightness levels have a significantly reduced detail level [14]. Consequently, the potential of edge detection algorithms is diminished and they cannot fully showcase their capabilities [15]. These three limitations formed the basis for the proposed solution, which includes:

1. User-defined detection threshold;
2. Filtering as a preparatory step for edge detection;
3. Considering the image's illumination level and performing edge detection accordingly.

METHODS

Weighted Filter

There are several variations of the median filter [16], based on the approximation of matrix pixels [17]. The most widely used ones include the median value filter (average filter) and the weighted filter. The distinction between these filters lies in the differently defined sub-matrix and the pre-multiplier associated with the sub-matrix. A more comprehensive discussion on the definition of submatrices and the submatrices themselves can be found in the literature [18].

Regarding the weighted filter:

$$wt = \frac{1}{4}\begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix}. \tag{1}$$

An important characteristic of this filter, as demonstrated in the previous research [19], is its ability to effectively handle image noise levels of up to 5%.

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Histogram Equalisation

Histogram equalisation is one of the commonly employed modifications of pixel values per shade of grey. It aims to equalise the number of pixels per shade of grey based on the cumulative histogram. In practice this implies that each shade of grey within the range of 0-255 (in 8-bit colour spectrum) should have an equal or approximately equal number of pixels per shade of grey [20]. To achieve this, the analysis software first calculates the histogram of the image and then determines the function of cumulative distribution (*fcd*). Based on the fundamental formula for histogram calculation, new values are obtained [21]. The formula is given by:

$$HE(i) = round\left(\frac{fcd(I) - fcd_{min}}{MxN - fcd_{min}}(L-1)\right), \quad (2)$$

where *HE* is histogram equalisation, fcd_{min} represents the minimum value of the function of cumulative distribution, *MxN* denotes the number of columns and rows in the image matrix, and *L* represents the number of grey levels (typically 256 in most cases) [22].

Negative

The concept of ‘negative’, once popular in traditional camera technology, holds limited significance in digital image processing today [20]. In the context of digital images, the negative refers to the opposite colour value of pixels within the observed colour range. The negative pixel value (*npv*) can be calculated by subtracting the original pixel value (*opv*) from the full 8-bit range value:

$$npv(m,n) = 255 - opv. \quad (3)$$

While simple colour inversion has become less prevalent for processing modern digital images, selectively incorporating negative transforms in specific steps of a multi-stage workflow can enrich the feature diversity for subsequent extraction. This allows negative pixel patches to augment edge detection in a targeted manner when judiciously integrated. Hence the inclusion of image negatives within the proposed hybrid method serves not as a stand-alone technique but rather as a supplemental data source to enhance the versatility of edge features identified across multiple domains. The fusion of results from conventional and inverted processing expands the scope of detectable edges.

Hybrid Method of Edge Detection

This model enables precise control of the detection threshold by the user, facilitating the extraction of edges from digital images. The output image obtained through the processing of the hybrid method of edge detection [23] encompasses the complete processing result over the original image, the negative of the original image, and the weighted filter with a detection threshold of 12. The detection threshold, set at 5% of the rock skive's greyscale, is defined to account for edge detection. In the case of 5% detection, the edge detection characteristics closely resemble those of the Sobel operator. However, in nanoparticle images, there is an inherent presence of increased noise that necessitates elimination prior to edge detection. Consequently, the hybrid model serves as an excellent solution for nanoparticle detection. The hybrid method already incorporates a weighted filter designed to reduce noise levels by up to 5%, and with the control over the detection threshold, the detection process can be further fine-tuned.

Figure 1 illustrates the block diagram of the hybrid method of edge detection. The execution process of the code is denoted by the numbers 1, 2 and 3. Number 1 signifies the loading of the

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image and the definition of the detection threshold. Number 2 corresponds to the segments of the code where edge detection is performed. Finally, in the section of the code marked with the number 3, the intermediate results of edge detection over the original image, the negative of the original image, and the weighted filter are combined using a detection threshold of 15.

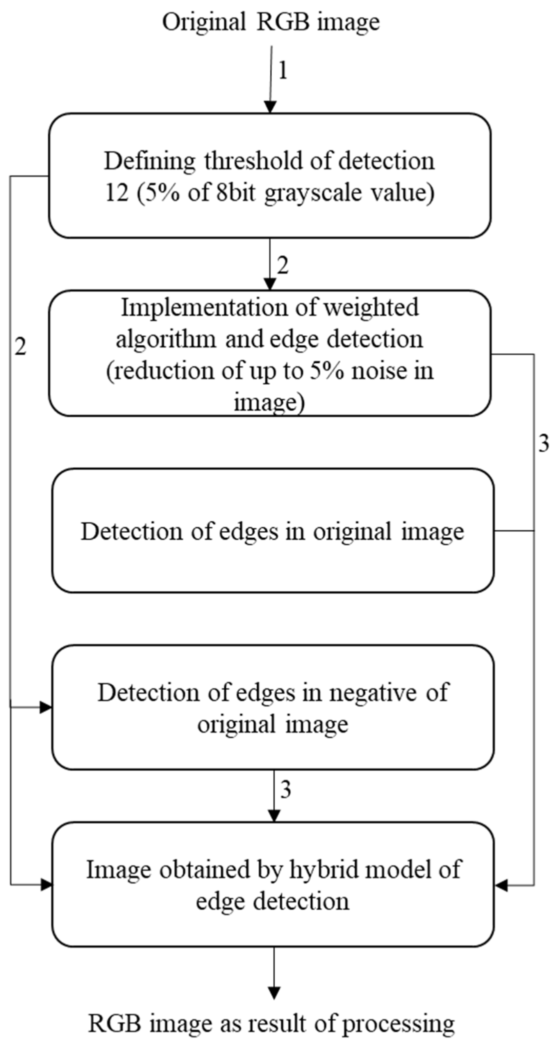

Figure 1. Block diagram of hybrid method of edge detection

RESULTS AND DISCUSSION

As this is a newly defined method of detection, the obtained results are compared with those obtained from other detection methods, with particular emphasis on comparison with the Sobel operator, which serves as a reference in the field of edge detection. Such result comparisons will provide a comprehensive understanding of the positioning of the new detection method in relation to existing ones. The evaluation is conducted at three different levels:

1. Spatial resolution: emphasis is placed on images with low, medium and high LoD;
2. Amplitude resolution: evaluation is performed on medical images;
3. Structural Dissimilarity Index Model (DSSIM): the difference between the added signal and the original is assessed.

The survey was conducted on a sample of over 70 images using the Matlab package software. The images had different resolutions and were in square and rectangular formats. All the

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images in the manuscript were created in the TIFF format to eliminate any negative effects of compression on the final results. The selected digital images were meticulously categorised based on their LoD. Images with LoD less than 2 were classified as low LoD; those with LoD ranging from 2.01 to 3.9 were deemed to be of medium LoD, and images with LoD exceeding 3.91 were categorised as high LoD [24]. A quantitative analysis was conducted using ten different edge detection algorithms. Figure 2 provides typical examples of images with low, medium and high LoD, representative of the field of digital image processing.

Due to structural differences between the obtained images containing detected edges and the original images, parameters such as peak signal-to-noise ratio (PSNR), signal-to-noise ratio (SNR), mean squared error (MSE), and structural similarity index measure (SSIM) could not be included in the analysis. Instead, the evaluation was performed through LoD, entropy and DSSIM, combining both quantitative and qualitative methods of analysis. Figure 3 presents an overview of mean values of the results obtained after applying the evaluated algorithms.

Images with low entropy values have limited potential for further post-processing. On the other hand, images processed with edge detection algorithms require different treatment [25, 26]. It is important to note that this holds true for all edge detection algorithms except the hybrid method. In the hybrid method, the user defines the detection threshold before initiating the image processing and has control over the entire process.

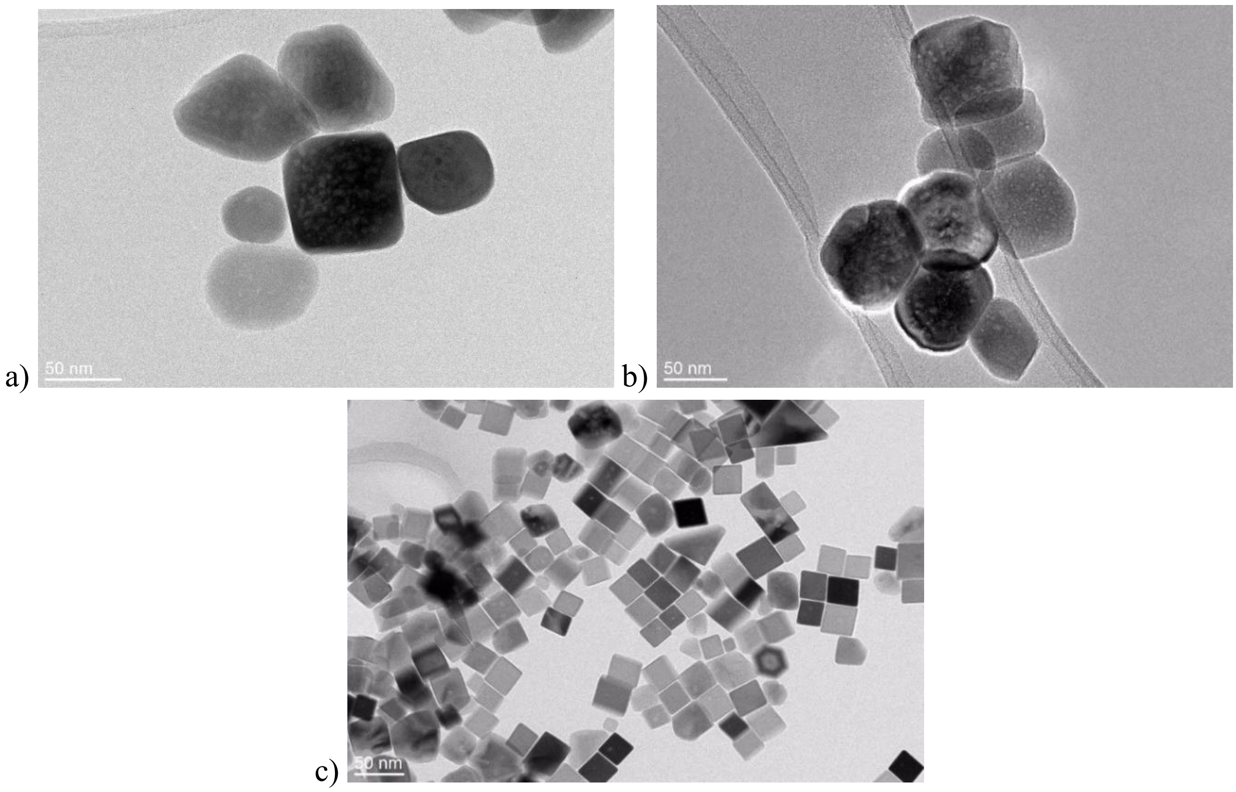

Figure 2. Examples of images with a) low LoD), b) medium LoD, c) high LoD

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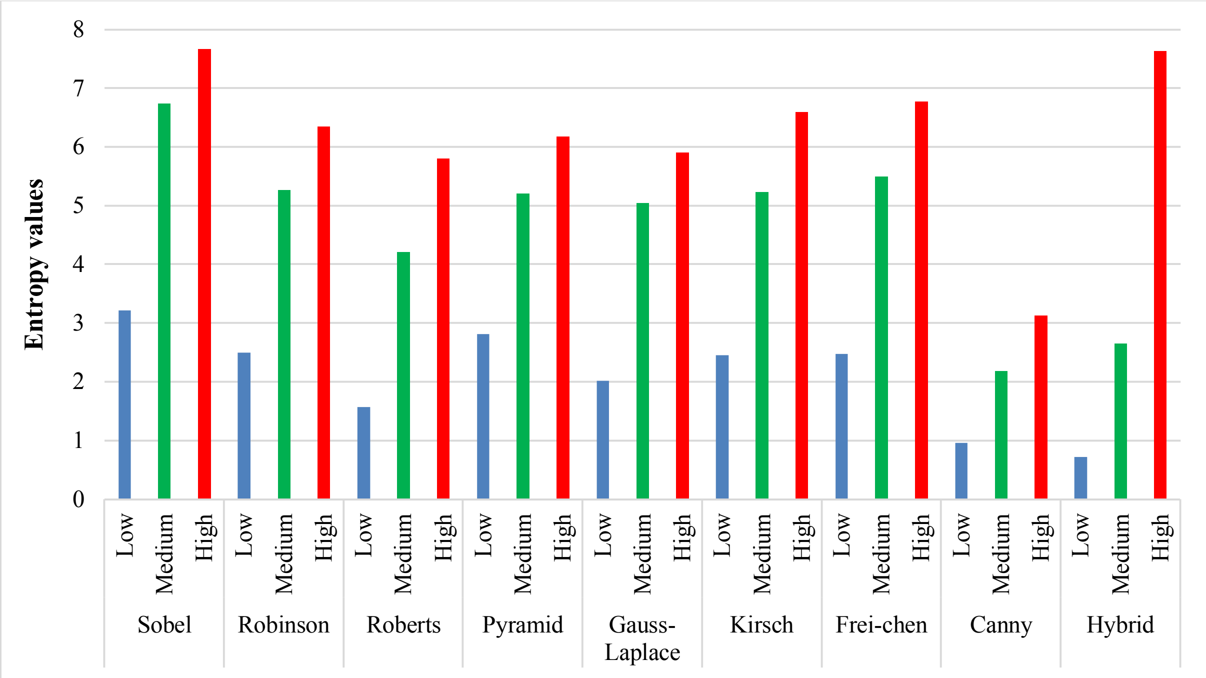

Figure 3. Entropy values after treatment with various edge detection operators at different LoD

For images with lower LoD, the detected edges do not have a significant presence in the observed image, as indicated in certain cases where it accounts for 5-7% [27]. It is reasonable to assert that images with low and medium LoD do not necessarily require a high degree of entropy. In contrast, for images with a high LoD, the LoD is five times or more greater than in the previous two categories of images. Consequently, it is logical to observe the results in this manner. As can be noticed from Figure 3, at low and medium LoD, the hybrid model, with the current detection threshold of 13 (equivalent to ~5% of the 8-bit scale), performs similarly to the Canny edge detection operator. The Canny operator is recommended for edge detection in these cases as Sobel detection yields exceptionally high values for low-level details. The hybrid model of edge detection fulfills the described expectations, producing results on par with the most complex operator of edge detection, the Canny operator, at low and medium LoD. Moreover, it yields similar results to the reference model, Sobel, at high LoD.

Figure 4 presents the standard deviation of entropy values for each algorithm, providing an indication of the stability of each algorithm at similar levels of entropy. This ratio offers insights into the reliability of each algorithm. A lower standard deviation value indicates higher algorithm stability. From the results, it can be observed that the Canny operator exhibits the greatest stability, followed by the hybrid method and the Sobel algorithm for edge detection. Comparative visual results are depicted in Figure 5.

It is evident that the hybrid method yields significantly superior results compared to other algorithms. In Figure 6 images of nanoparticles that undergo processing through Canny operator, Gauss-Laplacian operator and Sobel operator can be observed. On the other hand, Figure 5 showcases images processed using the hybrid method. It is evident that this approach yields markedly superior results in terms of visual processing quality. The hybrid method appears to outperform the individual operators in enhancing the nanoparticle images.

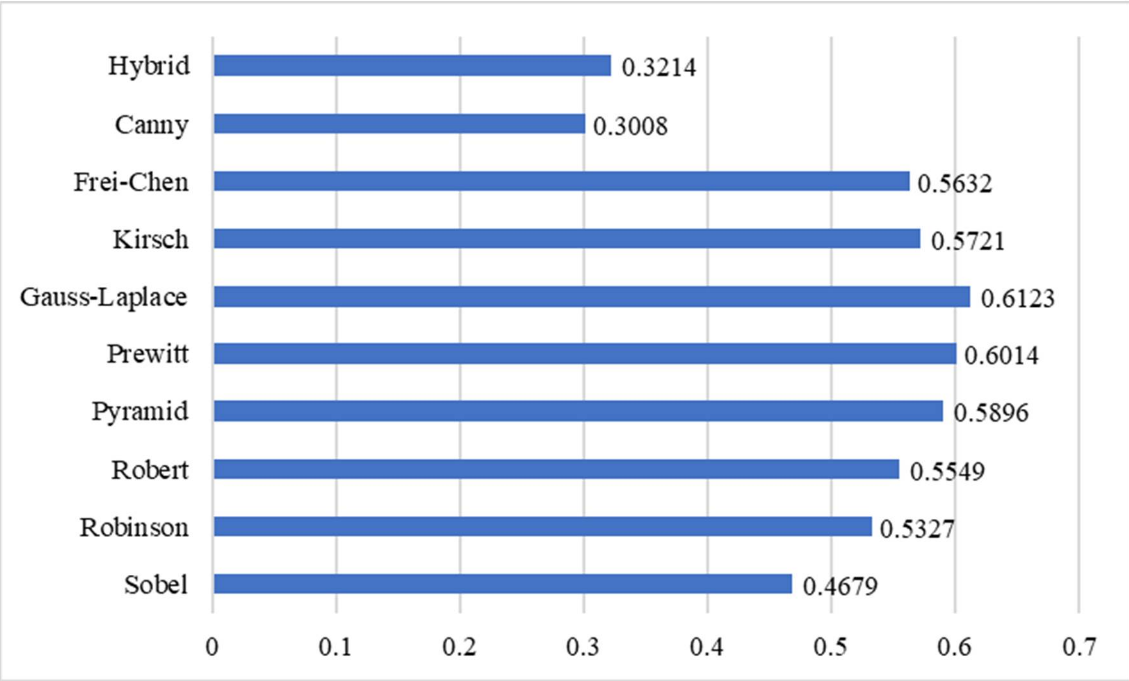

Figure 4. Values of standard deviation for values of entropy

a) b) c)

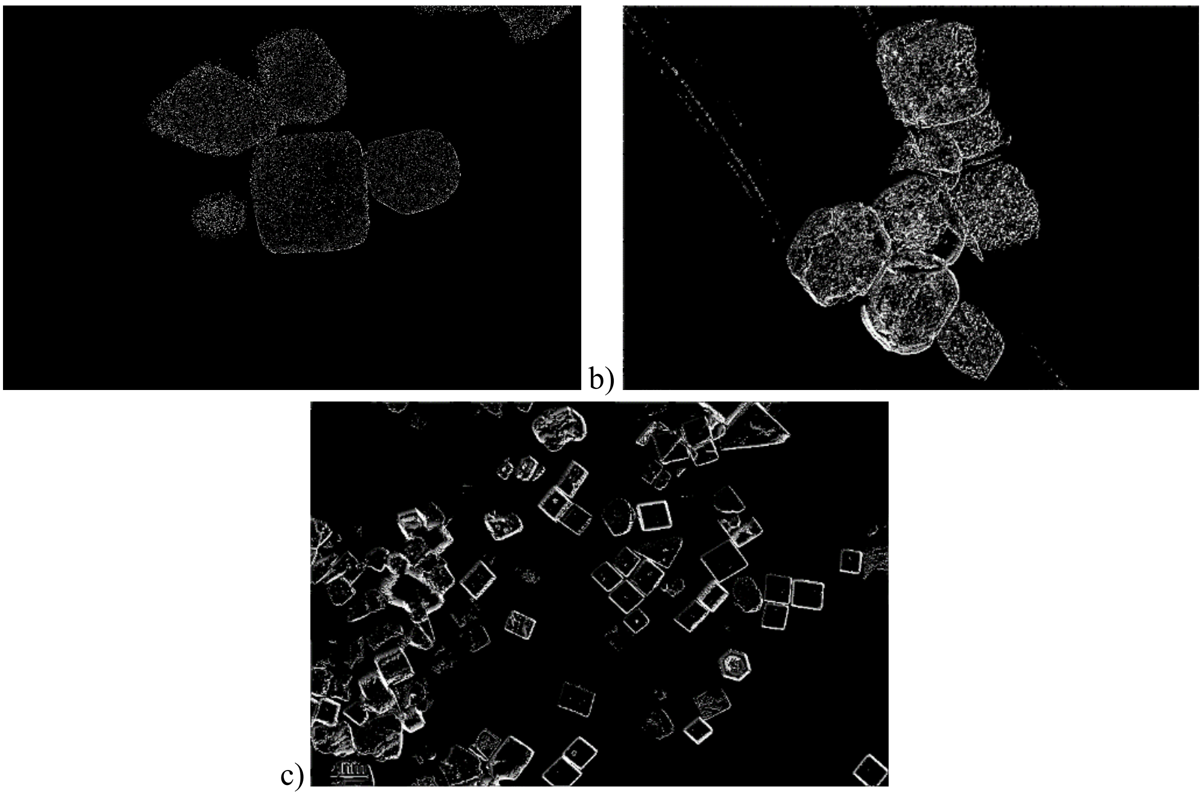

Figure 5. Images of a) low, b) medium and c) high LoD processed by hybrid method

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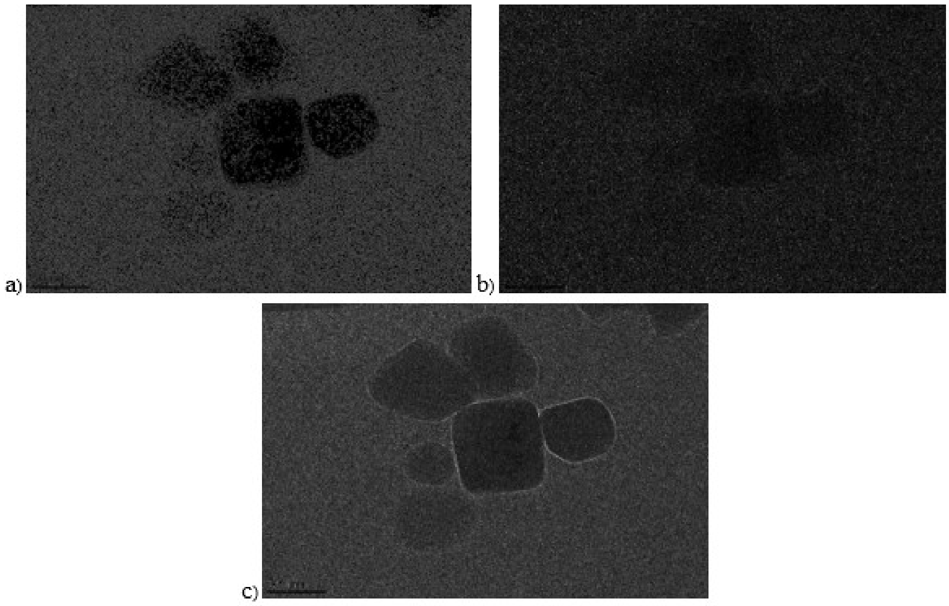

Figure 6. Images with low LoD after processing with a) Canny operator, b) Gauss-Laplacian operator, c) Sobel operator

In terms of amplitude resolution, a 16-bit recording has been utilised to evaluate the quality of the hybrid method (Figure 7). Figure 8 presents the mean entropy values of the processed image using various edge detection operators. It is evident that the Sobel operator yields an exceptionally high value after reconstructing the original image. However, for medical images in amplitude resolution with 16-bit mode recordings, the Pyramidal and Prewitt operator edge detection algorithms outperform other methods.

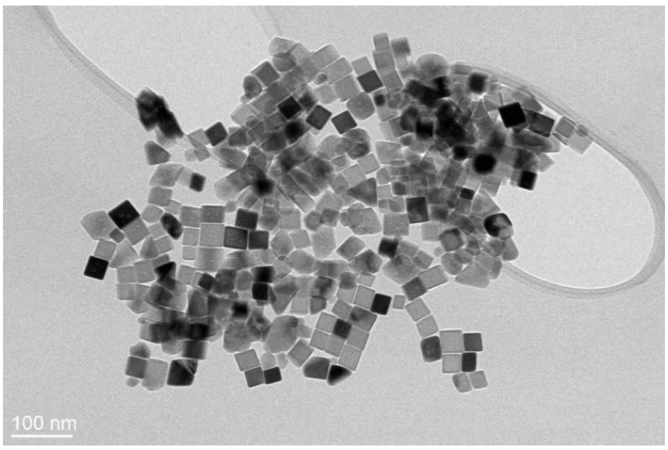

Figure 7. Original image with amplitude resolution

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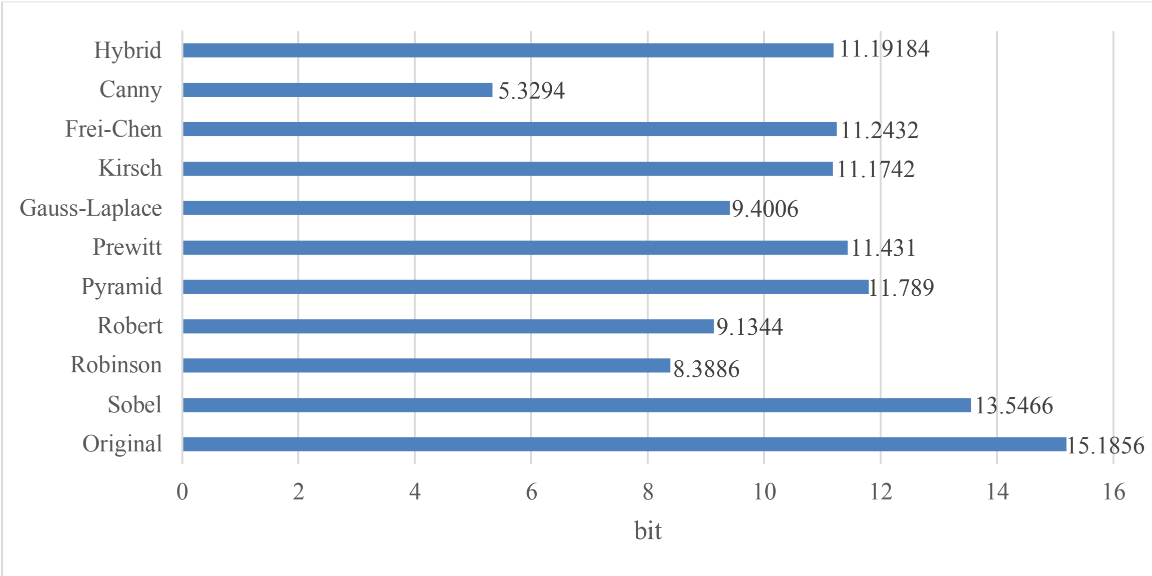

Figure 8. Entropy valuess of observed image processing for amplitude resolution

Observing images in 16-bit format at the bit level provides a different image display compared to standard image recording formats. In RGB mode, where images are recorded, the interpretation of image quality estimates should be approached differently, particularly in relation to spatial resolution. The sensitivity of the optical sensor during the creation of digital images in this recording mode indicates that each bit plane is associated with a specific sensitivity aspect of the sensors (16 in total), and the maximum entropy value in this case is 16 bits. This criterion guides the selection of images for analysis, with each original image having an entropy value exceeding 15 bits. This practically means that each bit plane contains nearly its maximum potential. By applying an edge detection algorithm, the algorithm's ability to detect edges can be evaluated based on how many straight edges it practically contains, and the final result is a cumulative assessment of all detected edges at each level. Hence a higher degree of entropy indicates the algorithm's ability to detect more edges at each bit level.

Among the algorithms, Sobel, Pyramid and Prewitt algorithms perform well in terms of amplitude resolution, followed by the hybrid model, which exhibits minimal loss compared to the first three algorithms. Examples of image processing using different edge detection operators in amplitude resolution are presented in Figure 9. To determine the differences between two images, the most suitable method is the DSSIM, which effectively captures structural differences in digital images. By adding the image with defined edges to the original image and following the explained procedure in the literature [15] and subsequently subtracting the original image, the resulting image can be obtained.

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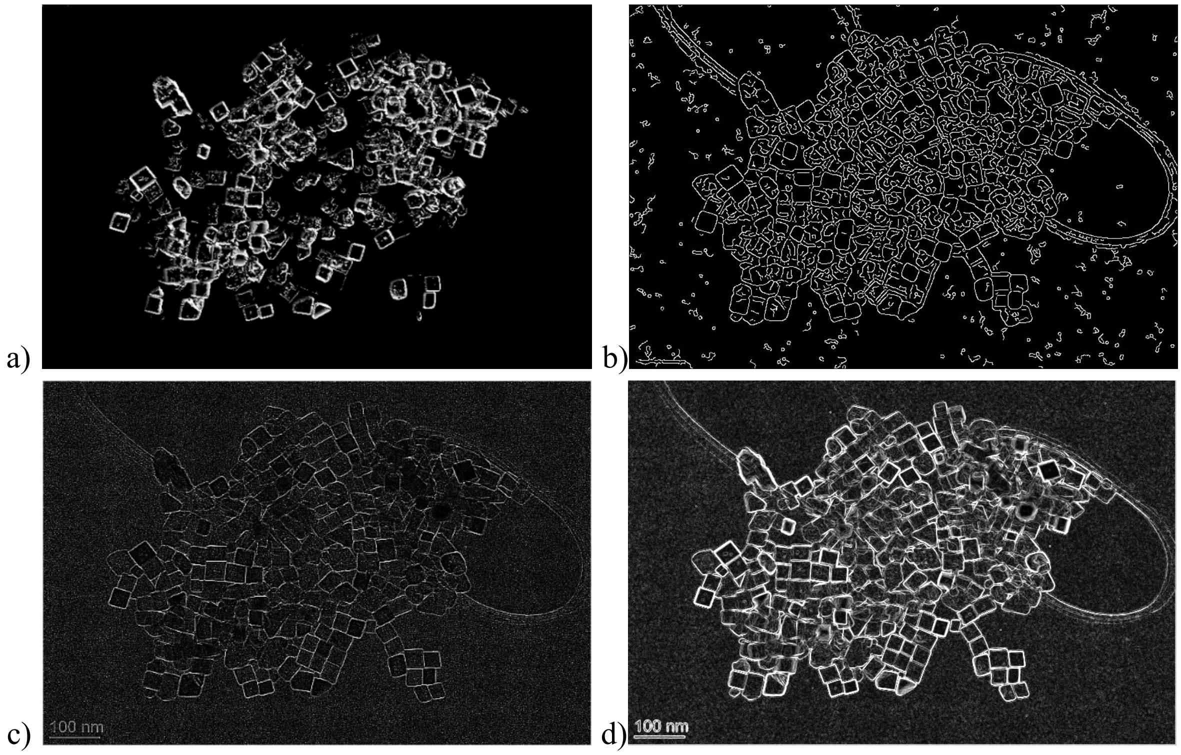

Figure 9. Images obtained after filtration using a) Hybrid method, b) Canny operator, c) Pyramidal operator and d) Sobel operator

The DSSIM parameter provides a measure of the difference between two images, as illustrated in Figure 10, by increasing the level of detection of the hybrid filter. While all other algorithms and methods remain fixed, the user has the ability to define the level of detection in this case. For instance, at detection level of 25% of the scale, the DSSIM value reaches nearly 30 according to the DSSIM model. Figure 9 can be taken as an example, where (a) represents the image obtained after applying the hybrid model for edge detection, and (d) represents the image obtained using the Sobel operator for edge detection. At detection level of 7% of the 8-bit scale, the hybrid method closely resembles the Sobel operator in terms of all parameters.

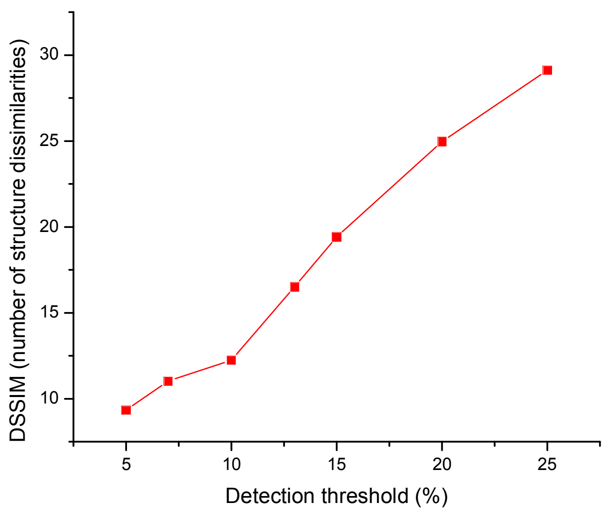

Figure 10. DSSIM in the case of increasing the level of detection threshold

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Qualifications and Considerations

Here we provide a more detailed analysis of the obtained results to furnish readers with deeper comprehension of the advantages of our hybrid methodology. Specifically, we can explicate the performance trends on images of varying detail levels more precisely within the context of the multi-phase approach. For low detail images, adaptive thresholding circumvents false edges that would emerge at lower thresholds, while broader threshold ranges preserve detection sensitivity for more complex images. Such tailored tuning of detection boundaries based on image content is crucial for achieving balanced outcomes. The incorporation of image negatives enriches the input data and enables identification of previously inconspicuous edges. The fusion of multiple intermediate results obtained by processing the originals and negatives contributes to more robust detection. We believe these additions illuminate how specific components of our solution lead to enhanced performance compared to more straightforward gradient techniques.

The proposed technique exhibits strong dependence on parameter tuning that requires customisation for each image type, reducing its versatility and applicability. The multiple processing steps increase computational complexity compared to techniques based solely on gradients. The current implementation is limited to RGB images, while synchronising the approach over video streams and large datasets remains a challenge for the future. Addressing these constraints regarding adaptability and scalability will further augment the technique.

CONCLUSIONS

This study provides an analysis of spatial and amplitude resolution under different predefined conditions, presenting a novel method for edge detection based on relevant parameters for image quality evaluation. A notable feature of the hybrid method is its departure from relying solely on a 2D gradient. The hybrid model demonstrates superior spatial resolution for edge detection, yielding results comparable to the Canny and Sobel operators. Importantly, the combination of the hybrid and Canny operators exhibits the highest reliability, as evidenced by the standard deviation of entropy across different LoD. In the analysis of transmission electron microscopic images of nanoparticles, the hybrid model consistently delivers superior results across various LoD.

Regarding amplitude resolution, the hybrid edge detection method falls within the upper-middle range compared to other algorithms. However, it exhibits remarkable capabilities in accurately delineating edges when processing the images with diverse brightness levels, setting it apart from other algorithms. These findings collectively indicate that the hybrid method should be preferred in scenarios requiring robust edge detection for images generated under varying conditions, particularly in the analysis of transmission electron microscopic images of nanoparticles.

REFERENCES

1. R. Ivkovic, M. Petrovic, B. Gara and M. Milosevic, "Dental image analysis with different edge detection operators", *J. Commun. Technol. Electron.*, **2014**, *59*, 1289-1297.
2. P. P. Acharjya, R. Das and D. Ghoshal, "A study on image edge detection using the gradients", *Int. J. Sci. Res. Publ.*, **2012**, *2*, 1-5.

3. Y. Feng, J. Zhang and S. Wang, "A new edge detection algorithm based on Canny idea", Proceedings of 2nd International Conference on Materials Science, Resource and Environmental Engineering, **2017**, Hubei Province, China, pp.1-7.
4. J. F. Canny, "A computational approach to edge detection", *IEEE Trans. Pattern Anal. Mach. Intell.*, **1986**, *8*, 679-698.
5. I. K. Ajlan, A. A. D. Al-magsoosi and H. G. Murad, "A comparative study of edge detection techniques in digital images", *J. Mechan. Eng. Res. Develop.*, **2021**, *44*, 109-119.
6. S. Wang, S. Liang and F. Peng, "Image edge detection algorithm based on fuzzy set", *J. Intell. Fuzzy Syst.*, **2020**, *38*, 3557-3566.
7. J. S. J. Lee, R. M. Haralick and L. G. Shapiro, "Morophological edge detection", *IEEE J. Rob. Autonat.*, **1987**, *3*, 142-156.
8. P. Soille, "Morphological Image Analysis: Principles and Applications", Springer-Verlag, Berlin, **2003**, pp.173-179.
9. R. A. Kirsch, "Computer determination of the constituent structure of biological images", *Comput. Biomed. Res.*, **1971**, *4*, 315-328.
10. S. Vijayarani and M. Vinupriya, "Performance analysis of Canny and Sobel edge detection algorithms in image mining", *Int. J. Innovat. Res. Comput. Commun. Eng.*, **2013**, *1*, 1760-1767.
11. L. Zhang, L. Zhang, X. Mou and D. Zhang, "FSIM: A feature similarity index for image quality assessment", *IEEE Trans. Image Process.*, **2011**, *20*, 2378-2386.
12. T. Le, R. Chartrand and T. J. Asaki, "A variational approach to reconstructing images corrupted by Poisson noise", *J. Math. Imag. Vision*, **2007**, *27*, 257-263.
13. F. Luisier, T. Blu and M. Unser, "Image denoising in mixed Poisson–Gaussian noise", *IEEE Trans. Image Process.*, **2011**, *20*, 696-708.
14. R. Ivkovic, B. Jaksic, P. Spalevic, Lj. Lazic and M. Petrovic, "Experimental images analysis with linear change positive and negative degree of brightness", Proceedings of 1st WSEAS International Conference on Image Processing and Pattern Recognition, **2013**, Budapest, Hungary, pp.116-120.
15. B. Jaksic, R. Ivkovic, B. Gara, M. Petrovic and P. Spalevic, "Analysis of different influence of compression algorithm on the image filtered Laplcian, Prewitt and Sobel operator", *Int. J. Darshan Inst. Eng. Res. Emerg. Technol.*, **2013**, *2*, 59-67.
16. R. Ivkovic, I. Milosevic, M. Petrovic and B. Gvozdic, "Timeline of median filter", Proceedings of 2nd International Scientific Conference of IT and Business-Related Research – Synthesis Advanced Engineering Systems, **2015**, Belgrade, Serbia, pp.268-273.
17. D. R. K. Brownrigg, "The weighted median filter", *Commun. ACM*, **1984**, *27*, 807-818.
18. J. Astola, P. Haavisto and Y. Neuvo, "Vector median filters", *Proc. IEEE Image*, **1990**, *78*, 678-689.
19. R. Ivkovic, D. Miljkovic, B. Gara, M. Petrovic and I. Milosevic, "Analysis of quality of nonlinear filters by removing salt and pepper noises", Proceedings of 20th International Scientific Conference YU INFO, **2014**, Kopaonik, Serbia, pp.330-333.
20. R. C. Gonzalez and R. E. Woods, "Digital Image Processing", 2nd Edn., Prentice Hall, Upper Saddle River, **2002**, pp.34-71.
21. E. R. Dougherty, "Random Processes for Image and Signal Processing", Wiley-IEEE Press, New York, **1998**, pp.115-196.
22. E. R. Dougherty, "Random Processes for Image and Signal Processing", 2nd Edn., Wiley- IEEE Press, New York, **2000**, pp.197-306.

Maejo Int. J. Sci. Technol. **2023**, *17*(03), 252-264

23. R. Ivkovic, M. Petrovic, B. Dakovic, B. Jaksic and I. Milosevic, "Segmentation and classification of bi-rads medical images with the imaging biomarkers according to level of detail", *Tech. Gazette*, **2020**, *27*, 527-534.
24. S. Ilic, M. Petrovic, B. Jaksic, P. Spalevic, Lj. Lazic and M. Milosevic, "Experimental analysis of picture quality after compression by different methods", *Przegląd Elektrotech.*, **2013**, *89*, 190-194.
25. P. Upadhyay and J. K. Chhabra, "Kapur's entropy based optimal multilevel image segmentation using crow search algorithm", *Appl. Soft Comput.*, **2020**, *97*, Art.no.105522.
26. S. R. Cloude and E. Pottier, "An entropy based classification scheme for land applications of polarimetric SAR", *IEEE Trans. Geosci. Remote Sens.*, **1997**, *35*, 68-78.
27. R. Ivkovic, I. Milosevic, B. Gara, S. Minic and V. Dakovic, "Algoritam za detekciju ivica slike sa postfiltrom", Proceedings of 13th International Scientific and Professional Conference – Infoteh, **2014**, Jahorina, Bosnia and Hercegovina, pp.652-656.