

ORIGINAL ARTICLE

ENHANCING CORONARY ANGIOGRAPHY IMAGES: A NOVEL HYBRID APPROACH MEAN TOTAL VARIATION FILTER FOR NOISE REDUCTION AND EDGE PRESERVATION

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ABSTRACT

Background: Angiography is a medical imaging technique that uses X-ray imaging to visualize blood vessels in the body, aiding in the diagnosis of vascular conditions. Coronary angiography is a vital medical procedure that provides detailed images of a patient's coronary arteries and helps diagnose heart-related conditions. Challenges in coronary angiography involve image noise, which can reduce image quality and make it difficult to identify vascular structures. Additionally, variations in contrast and the presence of artifacts can impact the accuracy of diagnoses. To improve the image quality and enhance the image visibility needed to address the above challenges, this article proposed a novel hybrid approach called the Mean Total Variation Filter (MTVF).

Materials & Methods: The study used an experimental design to assess how well the Mean Total Variation Filter (MTVF) improves the quality of coronary angiography images. The medical images were obtained in a controlled lab setting, where the research was carried out and the subsequent analysis was performed. The study spanned approximately six months, covering the phases of developing the algorithm, acquiring images, and evaluating performance. To select images, a purposive sampling method was employed, focusing on coronary angiography images with various levels of noise and artifacts. This method ensures that the selected images represent common challenges found in clinical practice. Preliminary studies suggested a minimum of 30 images were needed to achieve statistically significant results, ensuring enough test cases to accurately evaluate the proposed algorithm's performance. The effectiveness of the MTVF approach was measured using several quantitative metrics: Correlation Coefficient (CoC), Peak Signal-to-Noise Ratio (PSNR), Mean Square Error (MSE), and Root Mean Square Error (RMSE). These metrics were chosen to thoroughly assess the algorithm's capability in reducing noise and enhancing image quality.

Results: The performance of the proposed algorithm was assessed using various parameters for test image 1. The evaluation results indicate a high CoC of 0.9997, an impressive PSNR of 51.01, a low MSE of 1.3020, and a minimal RMSE of 0.0133. These metrics collectively highlight the algorithm's ability to produce excellent results in enhancing the quality of test image 1, making it a promising technique for noise reduction and image enhancement.

Conclusion: The analysis highlights the outstanding performance of the proposed hybrid MTVF method in removing noise, outperforming current techniques.

KEY WORDS: Medical imaging; De-noise; Image Quality; Mean Filter; Total Variation.

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INTRODUCTION

Angiography, also known as angiogram and arteriography is a medical imaging procedure that has transformed our ability to visualize the blood vessels in all parts of the human body. An angiography procedure that uses X-ray technology and a specific contrast agent to produce detailed images of veins and arteries. These images help in the diagnosis of various vascular problems by physicians.¹ This

non-invasive technique, which provides a window into the circulatory system and permits fast interventions, has become an essential tool in the disciplines of cardiology, neurology, and other medicine.²

An important procedure for identifying and assessing coronary artery problems, coronary angiography offers significant details about the condition of a patient’s heart and blood vessels.³ However, there can be different variations in the quality of angiography images because of factors like patient characteristics and variations in imaging conditions. Healthcare professionals may find it challenging to diagnose patients effectively as a result of these variations, which might include issues with contrast, brightness, and overall image quality. To address these issues, more modern approaches can improve the contrast, and visibility of coronary blood vessels and complex

vascular structures, ultimately enhancing the diagnostic procedure.⁴

Digital image processing has had an increasing influence on the field of medical imaging over the past decade or so. It is a useful tool for improving the quality of medical imaging, which eventually results in more precise medical evaluations and diagnoses. Among the availability of a large number of techniques, de-noising has received a lot of attention. This is primarily due to the capacity to improve visual information and make images more apparent.⁵

Noise issues with coronary angiography images are common and include artifacts, background noise, and low-quality vascular structures. To address these issues, proposed a novel hybrid technique called Mean Total Variation Filter (MTVF). This technique has been designed specifically to improve

Table 1: The summary of the related work

Work	Type	Techniques	Descriptions	Performance metrics	Results
Aslam et al. ⁶	MRI Image	Hybrid Approach Median Filters + Wiener Filters	The framework combines morphological operations, a customized version of Median Filters, and Wiener Filters. Morphological operations are employed to extract the image’s boundary and shape.	PSNR SNR RMSE MSE	32.91 11.23 5.78 33.47
Balagam et al. ⁷	MRI Image	Switched Mode Fuzzy Median Filter (SMFMF)	Identifying and extracting noisy pixels is the objective of the SMFMF. The noisy pixel is then to be replaced with the value of the median pixel.	PSNR NC	49.0021 0.9970
Kesari et al. ⁸	MRI Image	Adaptive Median filter	While the median filter effectively eliminates noise, it tends to inadvertently remove edges, which are crucial image features, in the process of noise reduction.	PSNR SNR	23.9323 14.4522
Ning et al. ⁹	CT, MRI images	Adaptive Median, Median Filter	Eliminating salt-and-pepper noise from medical images is highly important, especially in the initial stages of preparing virtual endoscope systems.	PSNR	12.5896 19.4984
Priya et al. ¹⁰	MRI Images	Circular Adaptive Median Filter	Denosing technique tailored for MRI images afflicted by salt and pepper noise of diverse noise densities.	PSNR	28.7718
Arulpandy et al. ¹¹	MRI Image, General Images	Modified Mean Filter	Speckle noise refers to a type of multiplicative noise that influences individual pixels within a grayscale image.	PSNR MSE	11.5127 0.1263
Kalaiyarasi et al. ¹²	Breast Ultrasound Image	Median Filter-Based Multistage Neural Network	While noise reduction methods work effectively, they often struggle to retain the sharpness of image edges.	PSNR SSIM EPI	53.80 98.54 0.74
Devanand et al. ¹³	Ultrasound Images	Hybrid Bilateral & Median Modified Wiener Filter	These images are employed in medical diagnostics to detect anomalies or illnesses within the human body.	PSNR RMSE	31.9823 40.3942
Radhika et al. ¹⁴	MRI Images	Optimum Weighted Mean Filter	The two-step filtering approach is designed to eliminate noise in MRI images. This approach seeks to retain essential structural elements of the images, including borders and textures.	PSNR NAE MSE SSIM	0.65 0.18 0.24 0.98

the quality of blood vessels in images of coronary angiography. This hybrid technique is very effective at mitigating different types of noise since the Mean Filter is effective at decreasing high-frequency noise and the Total Variation regularisation serves to make the image smooth. This hybrid technique significant objective is to effectively remove both external and internal noise from the images, which will improve the accuracy and dependability of subsequent analysis and processing in the field of coronary angiography. Highlights of the main contribution are:

- To Propose the novel hybrid approach known as the Mean Total Variation Filter (MTVF) to eliminate noise from medical images.
- Eliminating noise is essential for mitigating issues like motion artifacts, beam hardening artifacts, and ring artifacts, which can influence the accuracy of the results.
- Assess the outcomes of the new technique on diverse datasets using both qualitative and quantitative measures.

Related Work

Recently, medical image processing (MIP) has gained considerable attention and is a notably pertinent field of study for researchers. To thoroughly assess medical images, it's imperative to have enhanced and high-quality images at hand. Achieving this level of image enhancement and quality necessitates overcoming certain challenges, including low-quality vascular structures, background noise, and various artifacts. Tackling these challenges involves employing noise removal techniques, and Table 1 provides a concise summary of prior work in this domain.

MATERIALS & METHODS

The study used an experimental design to assess how well the Mean Total Variation Filter (MTVF) improves the quality of coronary angiography images. The medical images were obtained in a controlled lab setting, where the research was carried out and the subsequent analysis was performed. The study spanned approximately six months, covering the phases of developing the algorithm, acquiring images, and evaluating performance.

The objective of the proposed hybrid approach is to enhance the visual quality and suitability of the input angiograms by improving the visibility and clarity of the blood vessels and relevant structures. The proposed hybrid de-noising technique effectively reduced the effects of artifacts, background noise, and poor vascular structure in the images by considering these limitations. The novel hybrid technique is described in the following.

Mean Total Variation Filter

The proposed hybrid approach, which fused a Mean Filter (MF) with Total Variation (TV), is an

intriguing and beneficial way to minimize the noise (de-noising). The basic yet efficient spatial filter that is well-known for its ability to reduce noise is the Mean Filter.¹⁵ It works by decreasing high-frequency noise components and smoothing the image. This is particularly beneficial in situations when noise is distorting the image and our objective is to obtain a cleaner version of the image. On the contrary, Total Variation (TV) regularisation preserves edges while enhancing visual smoothness.¹⁶ It accomplishes this by reducing pixel intensity variations or discontinuities. The edge preservation is significant for retaining the structural characteristics in an image.

To propose a hybrid approach for image de-noising, the idea involves combining the Mean Filter with Total Variation regularization. This hybrid technique is particularly designed to capitalize on the features of each technique to yield enhanced results in terms of noise reduction and image quality.

Applying the Mean Filter for a pixel in the noisy image:

$$I_{\text{mean}}(x,y) = \sum(I(x+i,y+j))/k1^2 \tag{1}$$

For all in the neighborhood.

The TV regularisation term reduces the overall fluctuation of the image's pixel intensities, which is:

$$TV(I) = \sum(|\nabla I(x,y)|) \tag{2}$$

For all (x, y) in the image.

The TV regularization update aims to minimize the following energy functional:

$$E(I) = \sum(|\nabla I(x,y)|) + W_{tv} * \sum|I(x,y) - I_{\text{mean}}(x,y)|^2 \tag{3}$$

The eq. (3) presented the objective or energy function, denoted as E(I), which is regularly used in image processing for tasks like image enhancement and de-noising. Let's break down its elements:

E(I) This is the total energy of the image I. It evaluates how well the image fulfills certain criteria, such as smoothness and similarity to a mean image.

$\sum(|\nabla I(x,y)|)$ this part of the equation calculates the sum of the absolute gradients of the image I. In simpler terms, it measures the rate of change of pixel intensities across the image. Gradients are used to find edges and other image features. So, this term encourages the image I to have a smooth or low-contrast appearance. W_{tv} This is a weight parameter associated with the Total Variation (TV) term. It allows you to control the influence of the TV term on the overall energy function. If you increase, the TV term has a stronger impact on the solution.

$\sum|I(x,y) - I_{\text{mean}}(x,y)|^2$ this term calculates the addition of squared differences among each pixel $I(x,y)$ and the corresponding pixel in the mean image $(I_{\text{mean}}(x,y))$. The mean image can be thought of as a reference image. This term encourages the image I to be close to the mean image in terms of pixel values. In

summary, the Eq. (3) represents a trade-off between two objectives:

The first term encourages the image to be smooth (low gradients), which is often desirable in tasks like denoising. The pseudocode is elaborated in Algorithm 1.

The second term encourages the image to be similar to a mean image, which could help in reducing noise or artifacts present in the original image.

This hybrid technique effectively combines the noise-reduction capabilities of the Mean Filter with the edge-preserving characteristics of Total Variation regularization, resulting in a denoised image that retains important image details while reducing noise. The process iteratively refines the image through TV regularization, further enhancing its quality. The hybrid Mean Total Variation Filter technique excels in noise reduction while simultaneously maintaining image features, offering superior image quality, and facilitating more accurate medical diagnoses.

Algorithm 1: Proposed Algorithm Mean Total Variation Filter (MTVF)

Input: Image A^{IP}

Mean Filter Kernel Size: $k1$

TV Weight: w_{tv}

Number of TV Iterations: $iters$

Initialize an output image I_{mean}

//This is a for loop

For Loop pixel in the image:

 //Compute the local mean within a neighborhood of size $k1$ around the pixel $I_{mean}(x,y)$ using Eq.(1)

 Set the corresponding pixel in $I_{mean}(x,y)$

End For Loop

Initialize an output image $I_{denoised}$ as a copy of I_{mean}

//This is a for loop

For Loop i in range $iters$

 Compute the gradient of $I_{denoised}$

 Apply the TV regularization using Eq. (2)

$I_{denoised} = \text{argmin}(I, w_{tv} * TV(I))$

Where $TV(I)$ is the total variation of image I .

Repeat

 TV regularization minimizes energy functional for $iter$ using Eq. (3)

End For Loop

Output: The final denoised image is $I_{denoised}$

Performance measures

In medical image processing commonly used evaluation metrics, which measure the effectiveness of the noise removal approaches include CoC, RMSE, PSNR, and MSE. These metrics offer the quantitative means of assessing and comparing the quality of an enhanced image against the true image. The metrics are discussed as follows:

Mean Squared Error It quantifies the overall quality of a denoised image by measuring the average squared difference between corresponding pixels in the noisy image, and the cleaned image.¹⁷ MSE is calculated using the following equation:

$$MSE = (1/X*Y) * \sum [(I(r,s) - D(r,s))^2] \quad (5)$$

where the image's width and height are represented by X and Y, the original image's pixel value at coordinates (r, s) is represented by $I(r, s)$, and the denoised image's pixel value at the same coordinates is represented by $D(r, s)$.

Root Mean Squared Error is commonly used to quantify the overall quality of a denoised image by

measuring the square root of the average of the squared differences between corresponding pixels in the noisy image, and cleaned image.^{18,19} The RMSE is determined by applying the subsequent formula:

$$RMSE = \text{sqrt}(MSE) \quad (6)$$

Peak Signal-to-Noise Ratio assesses the quality of an image by measuring the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of the image. $PSNR = 10 * \log_{10}((MAX^2/MSE))$ (4)

where MAX is the maximum possible pixel value in the image.^{17,20}

Correlation Coefficient measures the linear relationship between the pixel values of the true and improved images.²¹ The CoC is determined by applying the subsequent formula:

$$CoC = \text{cov}(I, D) / (\sigma_I * \sigma_D) \quad (7)$$

where $\text{cov}(I, D)$ represents the covariance between the pixel values of the original and denoised images, and σ_I and σ_D represent the standard deviations of the original and denoised images, respectively where I and D stand for the original and denoised images' standard deviations, respectively, and $\text{cov}(I, D)$ denotes the covariance between the pixel values of the two images.^{22,23}

Experimentation

The article primarily focuses on enhancing the quality of coronary angiography medical images by applying de-noising approaches. It evaluates several techniques, which include Gaussian Filter (GF), Total Variation (TV), Mean Filter (MEF), Median Filter (MF), Bilateral Filter (BF), KNN, Wiener filter (WF), Modified Wiener Filter (MWF), Adaptive Median Filter (AMF), Anisotropic Diffusion Filter (ADF), and the proposed hybrid approach Mean Total Variation Filter (MTVF). The study aims to evaluate how effective the proposed approach is in enhancing images for further analysis. This section of the article is divided into three subsections: setting up the simulations, visual analysis, and statistical analysis.

Simulation Setup

The Windows 10 Pro operating system was used to conduct this medical image processing simulation. We used a PC with an Intel(R) Core(TM) i5-6300U CPU running at 2.40 GHz and 2.50 GHz with 8GB of RAM to assess the computation time and also used the Jupiter Lab development environment, an open-source interactive web-based IDE for scientific computing, for these studies. To access Jupiter Lab, we applied an Anaconda emulator, with Python and R distribution tailored for research areas such as data science, machine learning, and scientific computing.

Dataset Description: This study employed a dataset comprising invasive coronary angiograms sourced from a couple of well-known hospitals in Peshawar, Pakistan: "The Teaching Hospital Khyber Peshawar

and the Cardiology Centre of Complex Hospital Hayatabad". Each coronary angiogram in the image set measures 512×512 pixels. Although the dataset encompasses data from numerous patients, our study focused on specific cases. Cardiologists supervised and guided the collection of these angiographic images.

RESULTS

In this section, the results of the novel hybrid approach demonstrate superior performance in comparison to various advanced noise removal techniques. We

assessed the quality and enhancement of denoised images through human observation and perception, evaluating the efficiency of both our hybrid method and existing techniques. We conducted a detailed examination of the novel technique versatility and effectiveness in image quality when compared to well-established approaches on three different testing images of coronary angiography. Figures 2, 3, and 4 illustrate the performance comparison between our novel technique and other existing techniques.

Figures 1, 2, and 3 display the experimental results of the "coronary angiography test image", along with

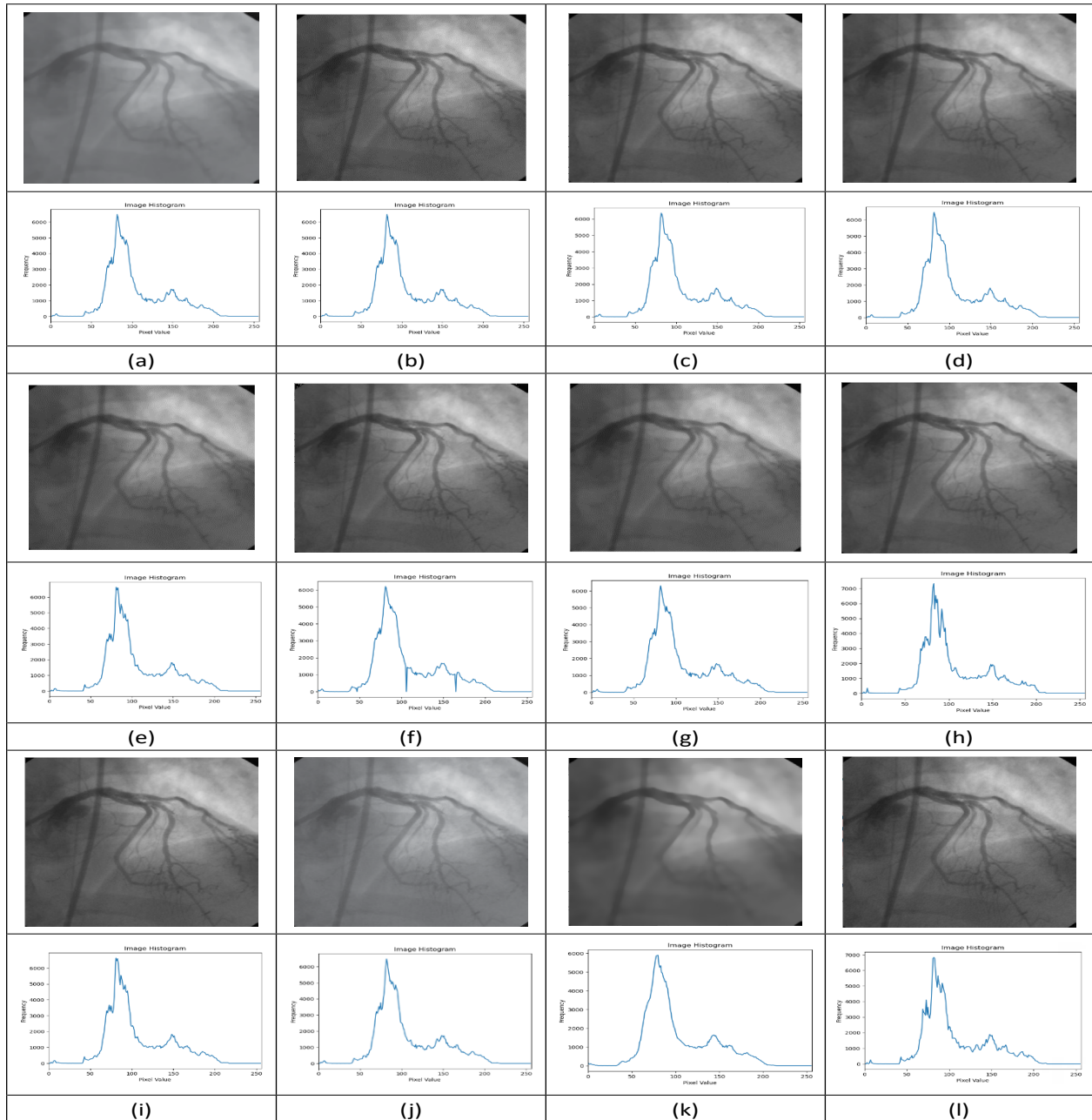


Figure 1: Test Input Image 1 and its Corresponding De-noise Images (a) Input image,(b) MF, (c) TV, (d) MEF, (e) GF,(f) BF (g) MWF,(h) KNN, (l) WF, (j) AMF, (k) ADF, (l) MTVF

its corresponding histogram. Image (a) serves as the input image, characterized by noise, blurriness, and artifacts. Images (b) to (l) represent denoised versions generated by various de-noising techniques. While the resulting images exhibit noticeable improvements compared to the input image, it is evident that the proposed hybrid method outperforms all others in terms of image quality across all three sets of images. Through an in-depth review of the

histogram plot, it becomes evident that the novel MTVF approach adeptly mitigates insignificant contrast enhancement challenges, by curtailing undesirable segments within the histogram. Additionally, the method improves image details by dispersing intensity occurrence levels uniformly throughout the dynamic range. Together, these procedures improve the angiogram image overall and make it more consistent with visual expectations.

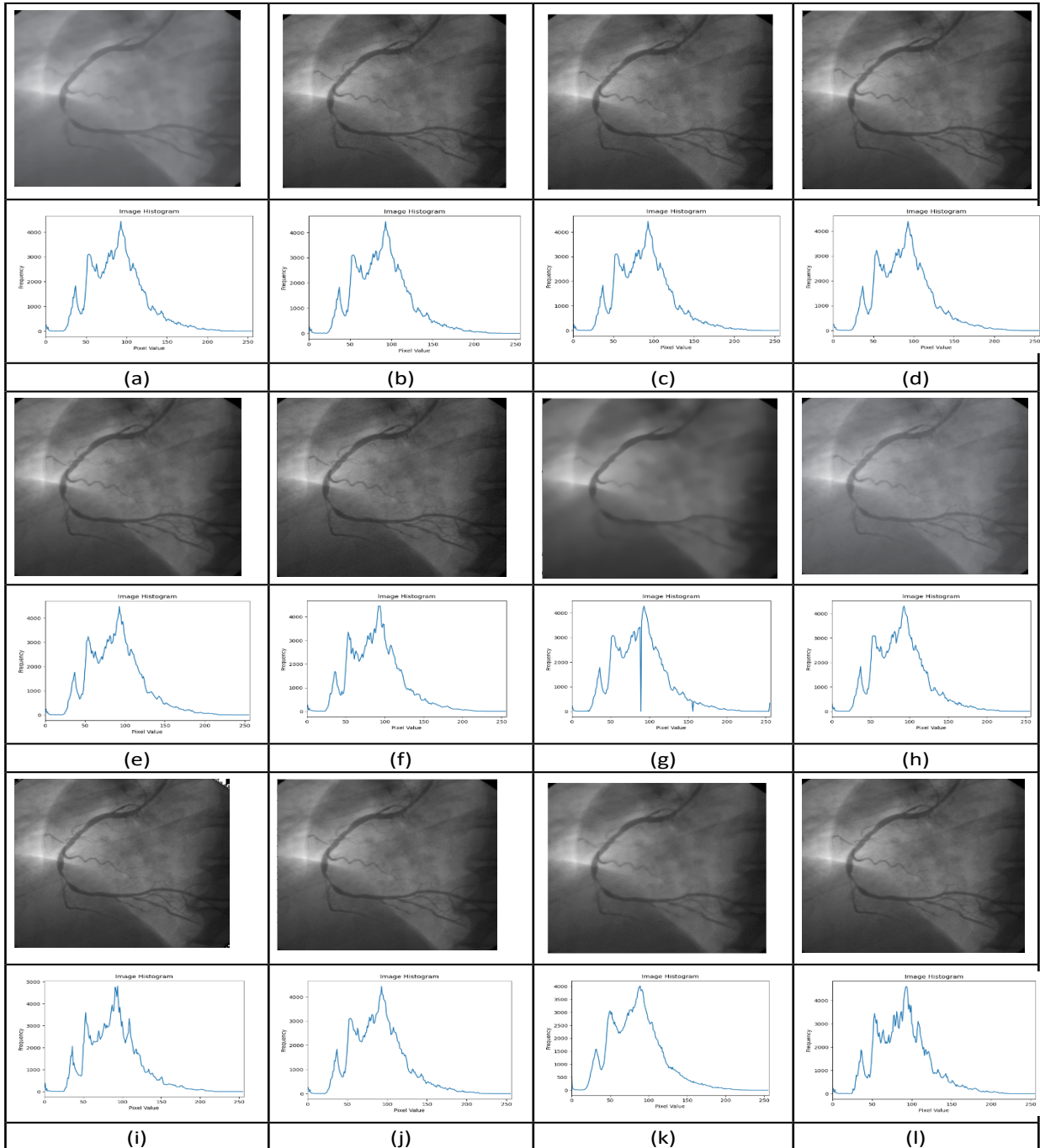


Figure 2: Test Input Image 2 and its Corresponding De-noise Images (a) Input image, (b) MF, (c) TV, (d) MEF, (e) GF, (f) BF (g) MWF,(h) KNN, (i) WF, (j) AMF, (k) ADF, (l) MTVF

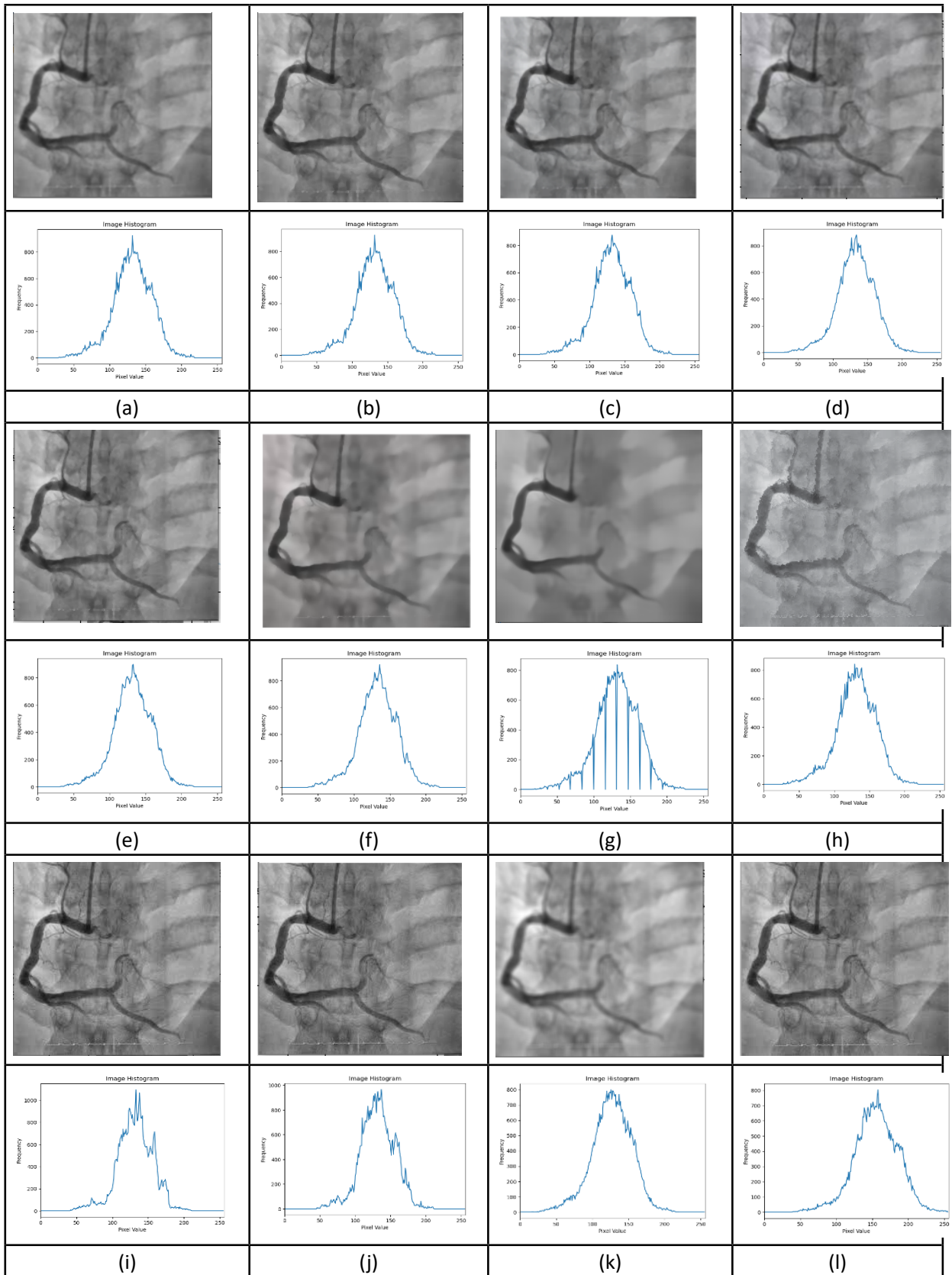


Figure 3: Test Input Image 3 and its Corresponding De-noise Images (a) Input image, (b) MF, (c) TV, (d) MEF, (e) GF, (f) BF, (g) MWF, (h) KNN, (i) WF, (j) AMF, (k) ADF, (l) MTVF

DISCUSSION

A comprehensive statistical performance assessment was conducted to evaluate the proposed hybrid method and existing techniques. This evaluation employed four widely recognized and commonly used metrics for image analysis: PSNR, MSE, RMSE, and CoC.³³

On analyzing Tables 1, 2, and 3, it is clear that the proposed hybrid Mean Total Variation Filter (MTVF) method demonstrates highly promising results. Across all three test images, MTVF stands out with the highest PSNR values, indicating superior image quality, with respective values of 51.01, 50.91, and 39.00. Furthermore, when considering Mean Squared Error and Root Mean Squared Error, both of which measured the average squared differences among pixel values in the true and enhanced imag-

es, MTVF consistently achieves the lowest values among all evaluated techniques. For test image 3, it's worth noting that both Median Filter and MTVF have attained the lowest MSE value, signifying their effectiveness.

Furthermore, the Correlation Coefficient (CoC), a pivotal metric for assessing the quality of enhancement, reveals that the proposed hybrid MTVF method value is close to 1. This signifies positive results, with notable instances in test images 1 and 3, where test image 1 achieved a CoC of 0.9997 with TV and MTVF, and test image 3 obtained a CoC of 0.9897 with MF, TV, and MTVF. In the case of test image 2, Total Variation stands out with the highest CoC result of 0.9996.

The computational efficiency of the proposed hybrid algorithms and existing techniques on three test images is shown in Table 5.

Table 2: Evaluation of Noise Reduction Methods Using Four Metrics on Test Image 1

De-noising Approaches	MSE	PSNR	RMSE	CoC
Median Filter	1.9650	49.41	0.0155	0.9991
Total Variation	1.6400	49.90	0.0145	0.9997
Mean Filter	1.9212	48.49	0.0598	0.9996
Gaussian Filter	1.0982	47.72	0.0479	0.9995
Bilateral Filter	3.3086	42.93	1.8189	0.9987
Modified Wiener Filter	113.0909	27.60	10.6344	0.9970
KNN	4.5055	41.59	2.1226	0.9982
Wiener Filter	10.3097	38.00	3.2108	0.9960
Adaptive Median Filter	5.8350	40.47	2.4155	0.9973
Anisotropic Diffusion Filter	34.4518	32.76	5.8695	0.9948
MTVF	1.3020	51.01	0.0133	0.9997

Table 3: Evaluation of Noise Reduction Methods Using Four Metrics on Test Image 2

De-noising Approaches	MSE	PSNR	RMSE	CoC
Median Filter	1.7098	49.60	0.0151	0.9990
Total Variation	1.7004	49.68	0.0150	0.9996
Mean Filter	1.7349	48.42	0.0153	0.9995
Gaussian Filter	1.7354	47.58	0.0153	0.9994
Bilateral Filter	3.5448	42.63	1.8827	0.9983
Modified Wiener Filter	106.0925	27.87	10.3001	0.9945
KNN	4.6829	41.43	2.1640	0.9977
Wiener Filter	10.3148	38.00	3.2116	0.3767
Adaptive Median Filter	6.1142	40.27	2.4727	0.9967
Anisotropic Diffusion Filter	39.5940	32.15	6.2923	0.9937
MTV F	1.6721	50.91	0.0146	0.9995

Table 4: Evaluation of Noise Reduction Methods Using Four Metrics on Test Image 3

De-noising Approaches	MSE	PSNR	RMSE	CoC
Median Filter	11.0993	37.68	3.3315	0.9897
Total Variation	11.2726	37.61	3.3574	0.9897
Mean Filter	11.4026	36.25	3.9246	0.9870
Gaussian Filter	17.1239	35.79	4.1381	0.9857
Bilateral Filter	24.9492	34.16	4.9949	0.9818
Modified Wiener Filter	110.8158	27.68	10.5269	0.9788
KNN	34.3769	32.77	5.8631	0.9514
Wiener Filter	46.8266	31.43	6.8430	0.9536
Adaptive Median Filter	43.2181	31.77	6.5740	0.9329
Anisotropic Diffusion Filter	44.7934	31.62	6.6927	0.9867
MTVF	11.0993	39.00	3.3314	0.9897

Table 5: Presents the Time Complexity (s) of Existing and Proposed De-noising Techniques

Datasets	MF	TV	MF	GF	BF	MWF	KNN	WF	AMD	ADF	MTVF
Test image 1	8.16	0.29	0.02	0.01	0.04	1.23	16.8	0.37	31.69	0.24	9.84
Test image 2	7.60	0.29	0.01	0.99	0.04	1.90	14.26	0.99	36.35	0.24	8.05
Test image 3	1.46	0.17	1.02	0.12	0.57	0.33	2.70	0.13	13.34	0.22	0.25

CONCLUSION

To address the above issues, here proposed a hybrid approach called the Mean Total Variation Filter (MTVF). The analysis emphasizes the exceptional performance of the proposed hybrid MTVF method, particularly in noise removal, surpassing existing techniques. This method leads to the generation of high-quality images while preserving essential information, ultimately assisting medical professionals in achieving more precise diagnoses. Overall, the proposed scheme outperforms existing techniques in terms of visual results, particularly in terms of noise minimizing and image enhancement. The proposed approach is evaluated by four different measures. In the future, we plan to use our novel technique on different kinds of medical images such as CT angiography, MRA, and other applications. We will also use it along with contrast techniques as well.

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CONFLICT OF INTEREST

Authors declare no conflict of interest.

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None declared.

AUTHORS' CONTRIBUTION

The following authors have made substantial contributions to the manuscript as under:

Conception or Design: SSK, AA

Acquisition, Analysis or Interpretation of Data: SSK, AA

Manuscript Writing & Approval: SSK, AA

All the authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.



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