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Image De-noising Based on WMF Technique for Electrical Trees Structure in High Voltage Cable Insulation

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ABSTRACT

Electrical treeing is a common problem during the pre-breakdown phenomenon in solid insulations due to the damage caused by Partial Discharge (PD) that progresses through stressed insulation via chemical degradation, which resembles the shape of a tree root. This resulted in a decrease in performance through degrading the insulation, which became a serious problem while dealing with electrical equipment. Hence, a deep understanding of electrical tree structure is vital to improving the quality of solid insulations. Ergo, optical microscopy is primarily used to examine tree structures, shapes, and fractal dimensions to reconstruct electrical tree structures for morphological study. However, optical microscopy images are frequently degraded by noise from readout procedures or image data acquisition systems, noise caused by occlusion, illumination, non-uniform intensity, destroying potential tree pixels, and a critical loss of information about the electrical tree structures. Therefore, this research proposed the Wiener Median Fusion (WMF) filter for electrical tree study. The performance of the WMF de-noising technique improves the image quality for the precise portrayal of the electrical tree structure based on thresholding segmentation algorithm analysis in terms of accuracy, sensitivity, and false positive rate. Based on the analysis of the thresholding segmentation algorithm, Otsu's thresholding exhibits the highest result compared to Niblack. The Otsu's overall percentage in terms of accuracy is 80.2934%, the sensitivity is 99.1513%, and the false positive rate is 82.6265%.

1. Introduction

Partial Discharge (PD) is an incomplete bridging between electrodes within an electrical insulation system under high field stress. PD is a good sign that warns of electrical insulation faults within the

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power system [1-3]. It can develop into electrical trees and surface tracking, leading to a breakdown between phase and earth or between phases of a 3-phase system. Moreover, studies are being made to understand the propagation of electrical treeing, which can be divided into three stages: inception, propagation, and completion [4]. In addition, treeing in solid insulation is an expression of electrical deterioration, and it appears to resemble a tree-like path channeling through the insulation wall. Electrical treeing creates a tree-like structure of gas-filled channels that grow from the stress concentration, slowing aging and jeopardizing human safety [5,6].

Electrical tree characteristics can be divided into several forms, such as a branch-like tree, pine-like tree, bush-like tree, and some minority tree formation that rarely occurs during the experiment process [7-9]. Even though the tree is rare, it is still possible for those types of trees to pop out during breakdown. Hence, previous research had conducted several tests to properly study the formation of the electrical tree, which helped future research to improve the founding subject. Electrical trees are usually grown in the laboratory using a pin-plane electrode system, and then the images are collected for research purposes.

The growing electrical tree then forms during the breakdown process from the tips of the electrode needle. The whole process is monitored through a personal computer using a charge-coupled device (CCD) camera from the microscope placed above the sample. However, the image collected can still be corrupted by various noise sources. In [10-12], the research team stated that the image quality was affected by CCD camera resolution. Furthermore, the lower resolution of the CCD camera provides blurred images of electrical treeing, which is also considered a noisy image. Meanwhile, the temperature of the room or surrounding area can also corrupt the image data. Hence, image de-noising in pre-processing is a usual method to eliminate the noise.

However, the traditional image de-noising technique from previous research suggests that it is impossible to eliminate the noise in corrupted image data based on medical images widely used to research image processing. Hence, a proposed fusion filter method is studied on these electrical treeing images. Image fusion encompasses all data analysis strategies to combine information from multiple images obtained using the same or different spectroscopic platforms. Additionally, image fusion can refer to either creating a single multi-set or multi-way structure with all the images involved or connecting the related individual images using regression models. In any case, data analysis performed on structures of fused images always outperforms individual image analysis results.

The image fusion concept is also present in super-resolution algorithms, which is achieved by combining information from images collected on the same sample and shifted by a sub-pixel motion step or from image frames collected in short time lapses in single-molecule fluorescence imaging [13,14]. Note that the fundamental process of fusion de-noising is the same as the fusion image. The process combines information from two different filters to eliminate noise in digital images using a superimposed technique. Moreover, the fusion de-noising can refer to either creating a single multi-set or multi-way structure with all the filters involved. In any case, data analysis performed on structures of fusion de-noising always outperforms individual de-noising processes [15,16].

In [17], the illumination correction of the study's retinal images fused two filters, superimposed low passed and Gaussian filtering. In this paper, each filter overlapped on each other; a low pass filter, also known as a smoothing filter, was used to remove random and periodic noises and reveal a background pattern. Since each pixel generates its own independent noise, noise in non-uniform retinal images always changes rapidly from pixel to pixel.

Furthermore, in [18-20], the performance of median filter-supported window sizes was evaluated to eliminate salt and pepper noise in gray and Red, Green and Blue (RGB) photos. The primary goal of this paper is to assess the performance of a median filter-supported window size and its ability to eliminate completely different noise densities in gray and colored photos. Moreover, the experimental results reveal that the window sizes of the median filter provide a degree of result on noise removal in photos, with low-level window size providing higher performance in low noise densities as associate example 3x3. Here, a pair of cascaded median filters outperforms a single median filter.

The writer proposes a hybrid filtering-based fusion approach in [21] for infrared and visible images. A Gaussian filter was applied to perform two-scale decomposition on the source image. Additionally, the detail and base layers are fused using a weighted averaging method of the improved co-occurrence filter and guided filter, respectively, and the fusion result is obtained by superimposition. For two-scale decomposition, the mean and Gaussian filters are commonly used. Other than that, the decomposition of the Gaussian filter is sharper, and the edge information obtained by the Gaussian filtering is more significant. As a result, the Gaussian filter is applied to our fusion framework to obtain a base layer with a large amount of background information. Therefore, the proposed fusion method was effective compared to the existing one.

Based on a research study in [22], a new hybrid filtering approach named Mean-Median-Gaussian (MMG) is proposed to smooth the images and determine the boundary lines. The MMG hybrid filter was created by calculating the resultant vectors of the results obtained from mean median and Gaussian filters. Moreover, to convert the created image to a 1-byte unsigned integer (uint8) format, normalization was performed by dividing it by the maximum pixel value in the image and multiplying it by 255. The result of MMG hybrid filtering revealed more success than the MMG based on the research paper regarding edge detection. Indeed, the findings of this research suggest that the proposed technique marks its superiority in terms of preserving contours.

Therefore, the proposed Wiener Median Fusion (WMF) filter is created to eliminate the unwanted noise that forms on the image data by superimposing different filters and creating a multi-way-based fusion filter. The idea of superimposing a normalized image is based on previous research's successful findings in preserving contours. Hence, this paper studies different fusion techniques that are able to eliminate the noise and increase the value of parameters based on accuracy, sensitivity, and false positive rate.

Consequently, to analyze the findings of this paper, the thresholding segmentation methods, Otsu and Niblack, are applied to detect a tree growth (length and width) for treeing image reconstruction in terms of accuracy, sensitivity, and false positive rate. The global variance was used to derive the threshold value as well as between-class variation. The Otsu thresholding is determined as follows:

$$k = \frac{\sigma^2 B}{\sigma^2 G}, \tag{1}$$

Where k is a threshold value, σ2B is a global variance of the entire image, and σ2G is a between-class variance.

Note that the Niblack method is the most widely used methodology in the segmentation area [16]. The fundamental concept behind this strategy is to utilize the local mean and standard deviation as the major parameters to obtain the best threshold value. The Niblack technique equation is as follows:

$$T(x, y) = m(x, y) + k\delta(x, y), \tag{2}$$

Where m(x,y) is the local mean, while δ(x,y) represents the standard deviation of the pixels inside the local window, and k is a bias.

However, if the object's size fluctuates and the image has a variation in intensity, this technique will fail to work [23-25]. Eventually, this paper focuses on image processing and analyzing different de-noising techniques in terms of accuracy and sensitivity. It compares existing pre-processing techniques and develops a fusion de-noising technique to improve accuracy, sensitivity, and false positive rate.

2. Methodology

The experimental setup consists of a 50 Hz 240/ 100kV high voltage (HV) transformer, a 10 MΩ limiting resistor, and a 1000: 1 capacitive divider. The complete sample was placed into an acrylic test chamber, where the needle is then connected to the HV source, and the other end of the sample will be connected to the grounding potential. To prevent external discharge and flashover during the experiment processes, the test chamber was filled with mineral oil. The test chamber was placed under the microscope to observe the initiation of the electrical tree.

First, electrical stress is applied to the cable sample until the sample's electrical Tree Inception Voltage (TIV) is reached. Subsequently, the applied voltage is fixed at TIV for each cable sample to investigate the characteristics of electrical tree growth after initiation. The CCD camera and a personal computer are utilized to record the treeing images that are transferred from the real-time microscope digital imaging system from time to time. Figure 1 illustrates the experiment setup for treeing image data acquisition.

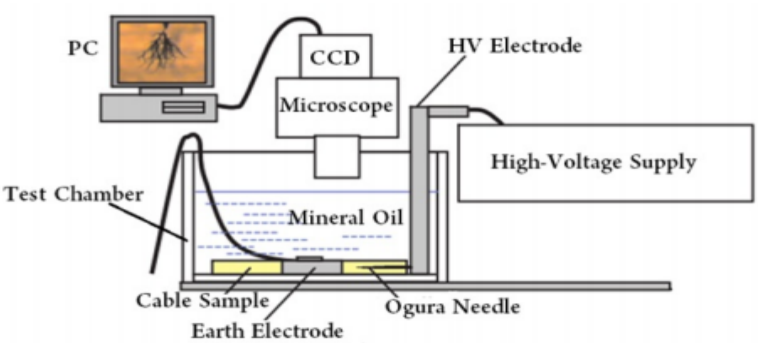


Fig. 1. Experiment setup for treeing image data acquisition

2.1 Sample Development and Data Acquisition

A CCD camera is a solid-state electrical device that converts light into an electronic signal. It refers to the coupling of the electrical potentials within the chemical structure of the silicon material that makes up the chip's layer. Utilizing a CCD camera and magnifying instrument, a microscope with computerized recording helps to observe and record the treeing process clearly in real time without interruption of applied voltage stress. In addition, the 2D images of electrical tree growth are sampled directly from the original video recording to retain as much information of the treeing structure pixels resulting from the experiment.

Thus, images from the sample made using an Ogura® tungsten needle with a radius size of 5 µm that had been captured using a CCD camera are being enhanced by adding noise. The original images collected are divided into each sample of Ogura® tungsten needle with different radii. Figure 2 displays original images captured from previous laboratory experiments. Consequently, color images were turned into grayscale images since it is less complex to work with them than color images.

A grayscale image is one in which the only colors are grayscale shades. Such images differ from other color images since less information is required for each pixel, simplifying the algorithm. Besides, it is a single-layer image ranging from 0 to 255, whereas RGB has three different layer images. Furthermore, the solution that works on grayscale images with noise is similar to full-color images. Other than that, computer vision is usually performed on grayscale images. Hence, it is common to test against grayscale images.

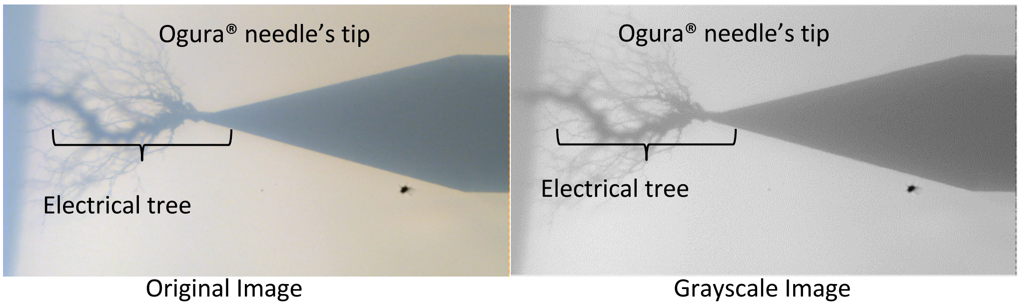


Fig. 2. Sample of original and grayscale images

2.2 Fusion De-noising Method

In this paper, an image de-noising based on a fusion technique is proposed to eliminate the noise in the images. The suggested method is illustrated in Figure 3.

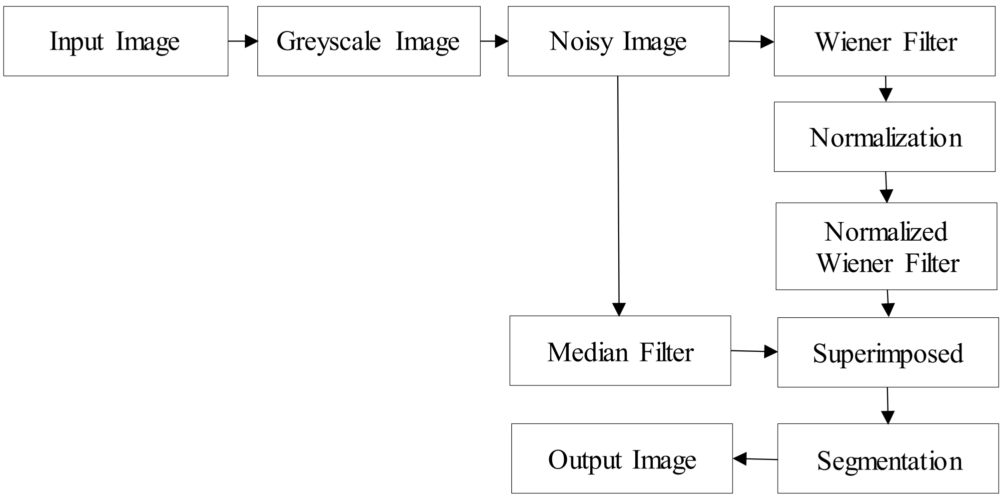


Fig. 3. Block diagram of fusion de-noising technique

First, the color input image was called and turned into a grayscale. For digital image processing, color image (RGB) needs to be converted into grayscale, considering that grayscale simplifies the algorithm and reduces computational requirements. Furthermore, the color image provides extraneous information that may increase the quantity of training data required to attain high performance. Noise is necessarily added to test the robustness and performance of the proposed filter in the presence of a known amount of noise. Hence, a method with a certain window size is critical for preserving the information on the image.

The window size chosen is dependent on the application. Therefore, the Wiener was created using a 3x3 window size in this research. Since 5x5 implies larger chunks taken and generalized due to the batch size increased by virtue of the fact of averaging out of Kernels data points' simulation with weights. However, having an additional layer and two layers of 3x3 does not necessarily increase the gap in the de-noising performance due to fringe case loss since averaging out occurred twice. Nevertheless, it does add a small number of precisions in terms of having an additional layer. Finally, the image underwent a normalization process. Note that normalization is the process that changes the range of pixel values [26,27].

2.3 Thresholding Algorithm Image Segmentation

Figure 4 depicts a flowchart of the thresholding technique. The input image first went through a pre-processing stage, where an efficient local brightness normalization is used. This method estimates the luminosity and contrast variability in the image's background and compensates for this variability in the entire image.

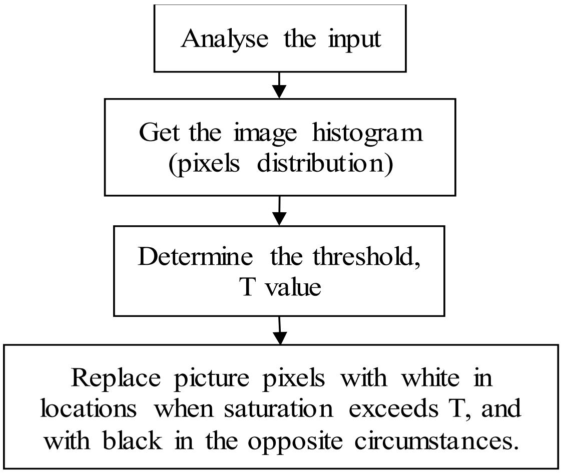


Fig. 4. Thresholding flow in image processing

An image may be defined as a two-dimensional function f (x, y), where x and y are spatial (plane) coordinates, and the amplitude of "f" at any pair of coordinates (x, y) is known as the image's intensity or gray level at that location. At the same time, histogram equalization is a method for increasing contrast by altering picture intensities [28]. The intensities on the histogram can be better distributed with this change. This allows locations with low local contrast to produce stronger contrast. Other than that, histogram equalization does this by extending the most persistent intensity values effectively. The strategy works well in images with both bright and dark backgrounds and foregrounds.

The Otsu's and Niblack thresholding method is used in image processing for automated binarization level determination depending on the structure of the histogram [17]. The method assumes that the picture is divided into two categories: foreground and background. Consequently, the best threshold value is calculated by minimizing the weighted within-class variances of these two classes. The image intensity threshold is set manually at a specific value or by default based on the application. Meanwhile, the T values from this experiment were a default value according to its application. The T value is set to be 1; an increase or decrease in the T value causes a change in the intensity of images.

Next, iterating over all the believable threshold values and enumerating a measure of spread for the pixel levels on each side of the threshold. The goal is to identify the value at which the total of foreground and background escalates at its smallest. In general, the most basic feature shared by pixels in a certain location is intensity. The thresholding technique is commonly employed to separate bright and dark zones. Hence, a grayscale image is transformed into a binary image by setting all pixels below a specified threshold value to '0' and all pixels above that value to '1'. Finally, the fusion de-noising technique is compared based on the thresholding segmentation algorithm in terms of accuracy, sensitivity, and false positive rate.

3. Results and Discussion

In digital image processing, image augmentation refers to image manipulations used to create different versions of similar content to expose the model to a broader range of data sets. For example, randomly changing the rotation, brightness, deconstruction, or scale of an input image necessitates that a model considers how an image subject appears in various situations. Besides, a transformation of an image that could be augmented in some cases may be better served as a pre-processing step in others.

Furthermore, image restoration aims to "rewind" or "undo" defects that degrade an image. Degradation manifests itself in various ways, including noise and technical issues. In cases such as technical issues, it may occur due to camera miss-focus and camera angle. In cases where noise has corrupted the image, it is best to compensate for the degradation it has caused. In this research, the original image was deconstructed with noise, and then the filter or de-noising technique was introduced and implemented on several image data.

3.1 Comparison between Selected De-noising Methods

The images were corrupted by applying noise, such as Salt and Pepper. All the image datasets were in grayscale form, and the size of each image is 1920×1080 pixels and 24-bit depth. Apart from that, all the function was written and run in MATLAB   software.

Figures 5 until 7 contain the parameter values for peak-signal-noise ratio (PSNR), signal-noise ratio (SNR), and mean-square error (MSE) of the Salt and Pepper noise based on Median, Wiener, and Gaussian.

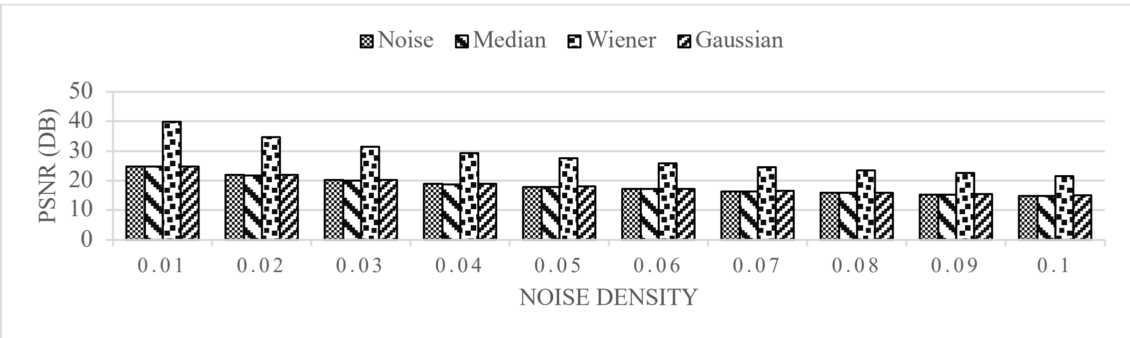


Fig. 5. Filters comparison of PSNR values for Salt and Pepper noise

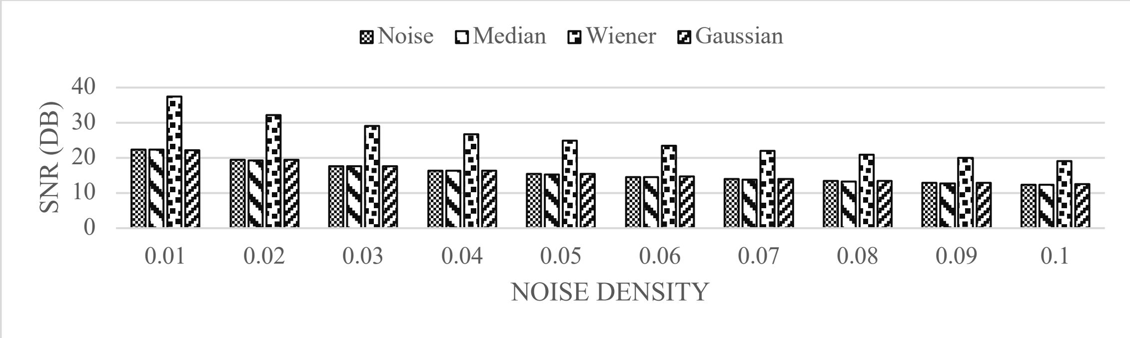


Fig. 6. Filters comparison of SNR values for Salt and Pepper noise

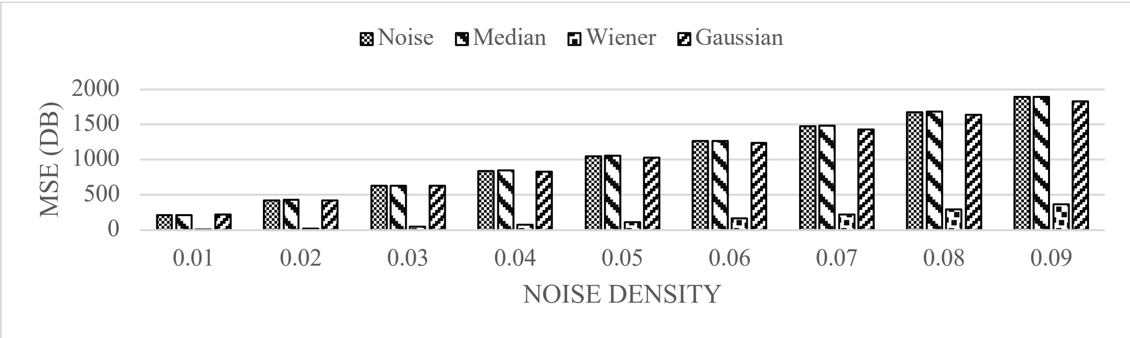


Fig. 7. Filters comparison of MSE values for Salt and Pepper noise

In the comparison based on the Figures for each noise, the best filter choice is Wiener, and parameters such as PSNR, SNR, and MSE are considered. The Wiener filter performs better than the Median and Gaussian filters. Other than that, Wiener's PSNR and SNR value is the highest from all three filters assessed, even higher than the noise value. However, the MSE of Wiener is lower than the noise MSE value, representing high performance with a lower error value. Based on the graph presented, the Wiener filter seems to outperform the other filters concerning image quality and preservation of crucial data.

On the other hand, the Median and Gaussian filters perform poorly in filtering the noise. The value of PSNR and SNR was lagging, while Wiener slightly led the rest of the filters. Another assessment was made from MSE parameter values for Median and Gaussian filters. Both filters presented a higher value that can be monitored from the graph presented, compared to Wiener, with a lower MSE value.

Therefore, Wiener is suitable for eliminating or normalizing the noisy images since the Gaussian filter performs poorly in filtering the noise. The value of PSNR and SNR was lagging, while Wiener slightly led the rest of the filters. Next, another assessment was made from MSE parameter values for Median and Gaussian filters. Both filters presented a higher value that can be monitored from the graph presented, compared to Wiener, with a lower MSE value. Therefore, Wiener is suitable to eliminate or normalize noisy images.

3.2 Fusion De-noising Application and Results

The result in the previous subchapter 3.1 suggests that Wiener performs better than the Median and Gaussian filters based on PSNR, SNR, and MSE parameters. However, using only Wiener to eliminate the noise on the corrupted images is not an ideal choice. This is because Weiner filters are the most often utilized de-blurring approach since, they produce the greatest results, although Wiener filters are far more popular in practice. It should also be underlined that Wiener filtering is the basic assumption for restoring other types of blurs, and as a least-mean-squares approach, it has roots in a wide range of other technical applications [29].

Hence, an image fusion de-noising technique is developed to increase the filter performance on electrical tree images. Two types of filters are proposed, which are Wiener and Median filters. Commonly, the Median filter lets a lot of high spatial frequency detail pass while still successfully reducing noise from pictures where fewer than half of the pixels in a smoothing region have been affected [30]. The Wiener filter underwent a normalized process, and then a superimposed technique was applied to lay both filters and create a fusion de-noising technique that improved the filter performance.

This research uses the selected images (Table 1) to examine the proposed fusion de-noising technique. The image segmentation part evaluates the result based on three parameters: accuracy, sensitivity, and false positive rate to determine the effectiveness of the proposed fusion de-noising technique (WMF method). Table 2 entailed the thresholding algorithm segmentation of five (5) selected electrical tree images. Figures 8, 9, and 10 present the results from three different thresholding algorithms, Otsu and Niblack.

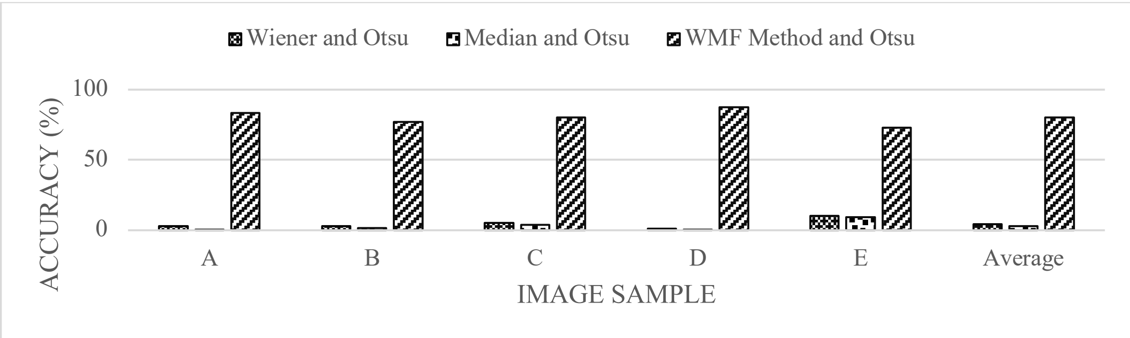


Fig. 8. Comparison between Wiener, Median, and WMF Methods with Otsu's thresholding application based on accuracy (%)

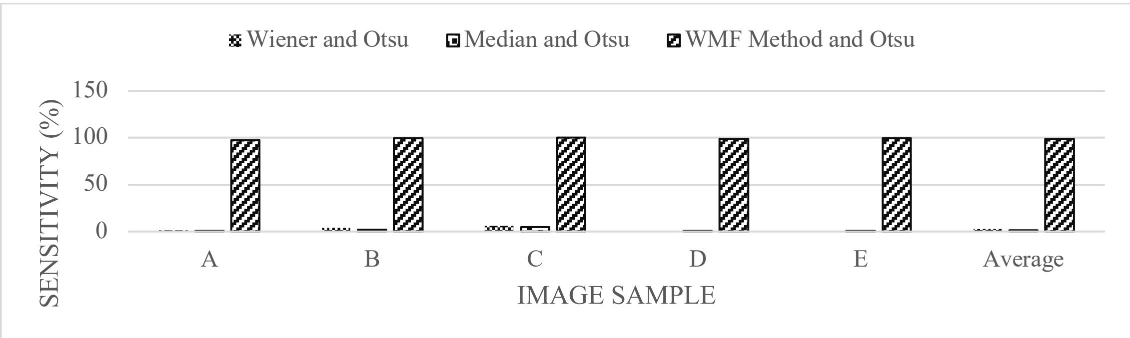


Fig. 9. Comparison between Wiener, Median, and WMF Methods with Otsu's thresholding application based on sensitivity (%)

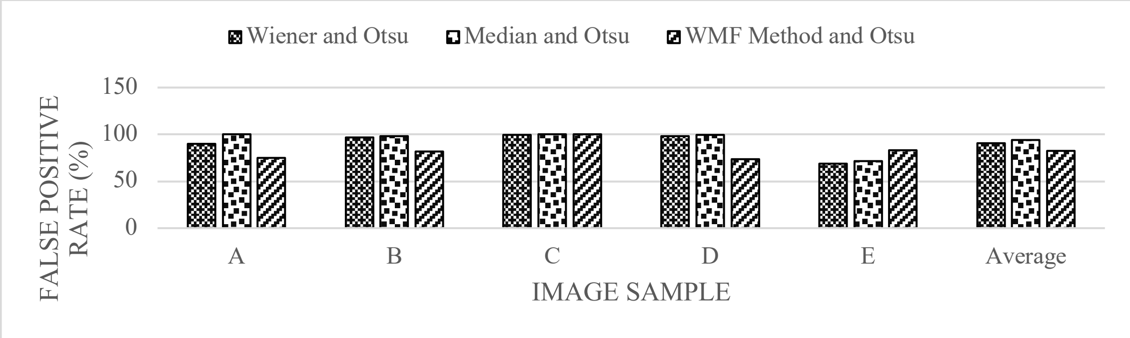


Fig. 10. Comparison between Wiener, Median, and WMF Methods with Otsu's thresholding application based on false positive rate (%)

For Otsu's thresholding, the overall percentage result of the proposed method in terms of accuracy is 80.2934%, for sensitivity is 99.1513%, and the false positive rate is 82.6265%. Based on Otsu's result, it is proven that the proposed fusion de-noising technique effectively reduces the noise in the electrical tree images. On the other hand, referring to the Wiener and Median results from Otsu's thresholding, the Figure 8 displays a completely lower number for the indicating parameters.

According to Niblack's algorithm, the result from the Figure 11 illustrates that the overall percentage result in terms of accuracy is 79.5855%, for sensitivity is 92.0085%, and finally for false positive rate in Niblack is 61.0065%. Referring to the Wiener and Median findings from Niblack's thresholding table, the number of accuracies, sensitivity, and false positive rates are significantly smaller.

This proposed method indicates improvement based on the image obtained. By referring to Figures 11 to 13, the segmentation images have made several improvements compared to the ground truth image of the electrical tree. Based on observation, the electrical tree branches are clearer and easier to track. Meanwhile, the ground truth image has lost some of the branches during the segmentation process and is only left with the width branch of the tree. The result was also compared to the Wiener and Median filter applied with the thresholding segmentation Otsu and Niblack based on the following figures.

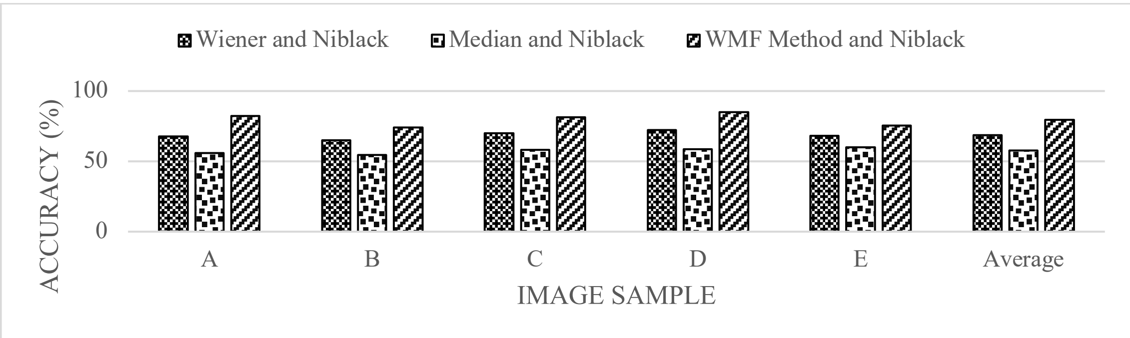


Fig. 11. Comparison between Wiener, Median, and WMF Methods with Niblack's thresholding application based on accuracy (%)

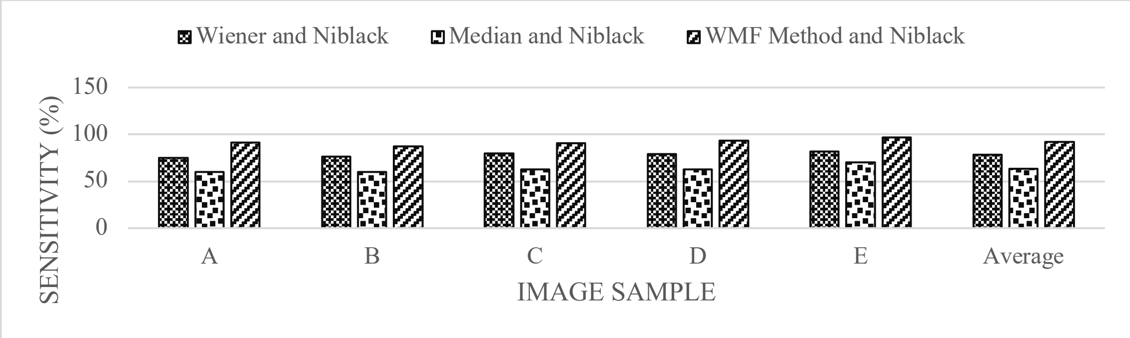


Fig. 12. Comparison between Wiener, Median, and WMF Methods with Niblack's thresholding application based on sensitivity (%)

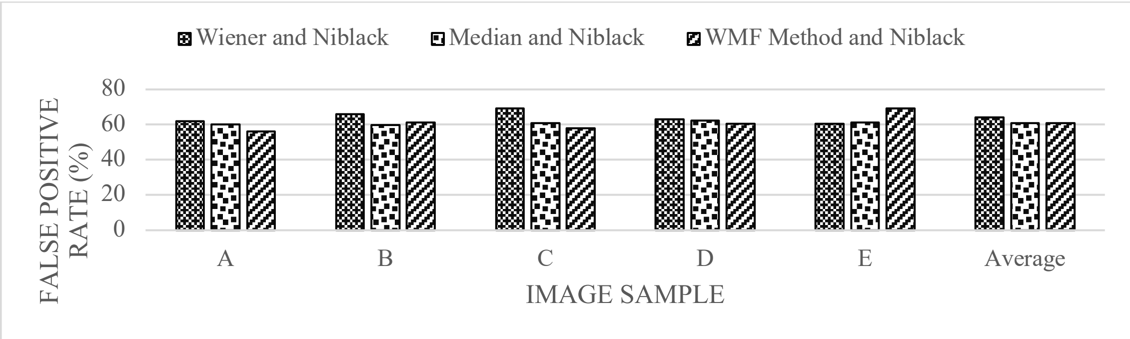


Fig. 13. Comparison between Wiener, Median, and WMF Methods with Niblack's thresholding application based on false positive rate (%)

According to the result collected, the Wiener and Median have low performance compared to the WMF method, with an accuracy value of 4.5025% and 3.1267% compared to 80.2934%. The gap between the existing filter and the WMF method is between 75.7909% and 77.1667%. Other than that, sensitivity exhibits similar results with accuracy; Wiener and Median have a small number, 2.4696% and 1.4774%, compared to the WMF method, 99.1513%. The false positive rate, also known as the miss rate, is the probability that the test will miss the true positive. Hence, lower values of the false positive rate demonstrate better probability during the prediction of the real image. Referring to the result data from the following Figures 13, Wiener and Median suggest a higher value than the WMF method: 90.6120%, 93.7962%, and 82.6265%.

Finally, the conclusion can be made that the WMF method proves that it is more effective in reducing the noise in the image while securing the electrical tree branches based on the results data. The thresholding results are depicted in the following Figures. Otsu's thresholding presents a set of data that is incredibly higher compared to Niblack thresholding. Meanwhile, Otsu's thresholding is usually applied to automatic image thresholding. In the simplest form, the algorithm returns a single intensity threshold separating pixels into foreground and background. Furthermore, based on the observations, Otsu's thresholding presents a clear background compared to the Niblack threshold.

Table 1
The fusion de-noising result of five selected electrical tree images

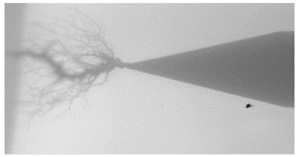
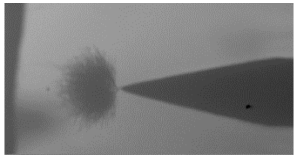
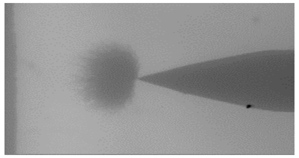
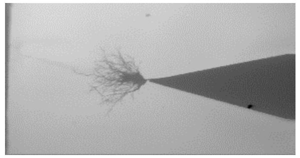
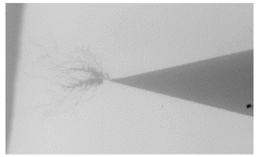
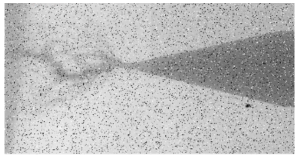
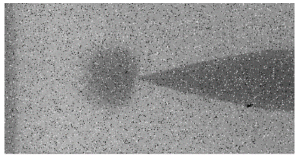
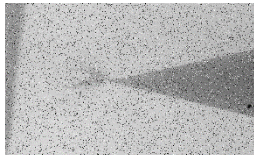
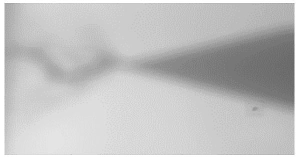
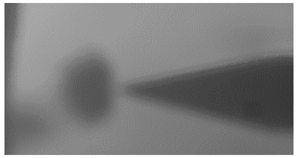
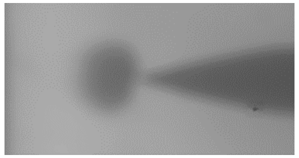
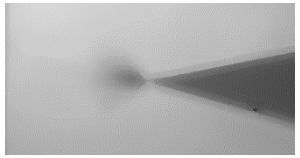
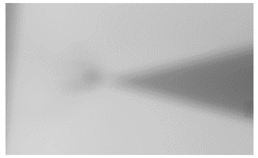
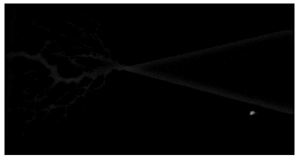
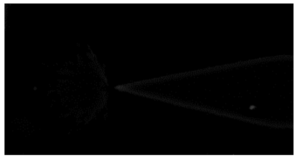
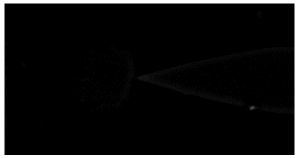
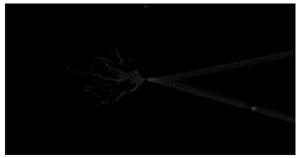
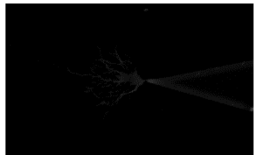
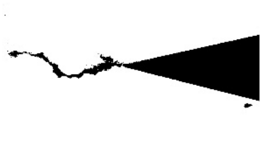
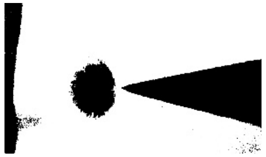
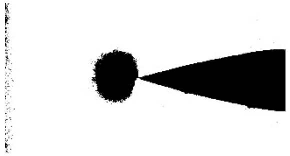
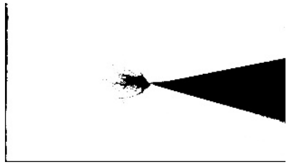
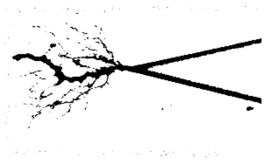
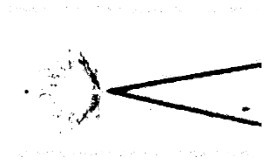
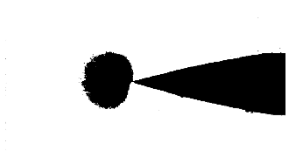
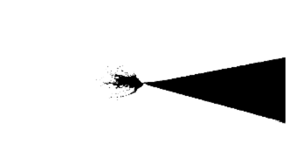
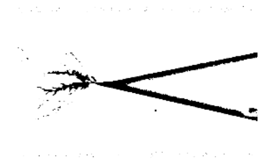
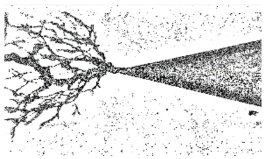
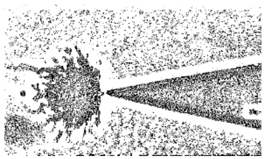
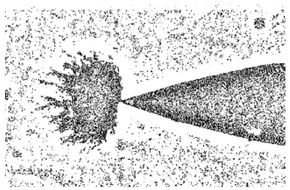
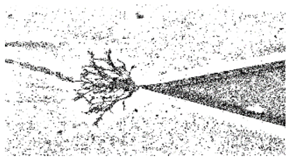
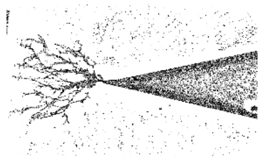
Image Type	Image sample A	Image sample B	Image sample C	Image sample D	Image sample E
Grayscale					
Noisy Image					
Background Normalization					
WMF Method					

Table 2
The fusion de-noising result of five selected electrical tree images

Image Type	Image sample A	Image sample B	Image sample C	Image sample D	Image sample E
Ground Truth Image					
WMF Method and Otsu					
WMF Method and Niblack					

4. Conclusions

The paper titled "Image De-noising Based on Fusion Technique for Electrical Tree Structure in High Voltage Cable Insulation" addresses a critical issue in the field of electrical power systems. Electrical treeing is a phenomenon that can lead to significant damage in power systems, causing downtime, revenue loss, and potentially compromising human safety. This study aims to deepen our understanding of electrical tree morphology and the formation of treeing, with a particular focus on developing a de-noising technique to improve the analysis of electrical tree images. The research proposes a novel approach called the "fusion de-noising technique." This technique aims to remove unwanted noise from electrical tree images to enhance the accuracy of analysis. It achieves this by combining two existing filters, the Wiener filter and the Median filter, which have been previously tested and proven effective. Additionally, the study incorporates three different thresholding segmentation algorithms, namely Otsu and Niblack, to evaluate the performance of the proposed de-noising method.

The primary focus of this research is on the de-noising aspect of electrical tree image analysis. The study evaluates the proposed method's performance based on three critical metrics: accuracy, sensitivity, and false positive rate. The results of the analysis reveal that the proposed fusion de-noising technique effectively eliminates noise from the images while preserving the integrity of the electrical tree branches. One notable finding is the comparison of accuracy between the de-noising techniques, including Wiener, Median, and the proposed WMF (Wiener-Median Fusion) method. The percentage difference in accuracy indicates that the WMF method performs less effectively than the others, with higher values suggesting room for improvement. Similarly, the sensitivity results show that the WMF method has the highest sensitivity among the tested techniques, indicating its effectiveness in detecting relevant features in the images.

However, it is crucial to note that a lower false positive rate is desirable to ensure the acceptability of a de-noising method. In this aspect, the WMF method consistently outperforms the others, demonstrating the lowest false positive rate values. This implies that the WMF method excels in reducing noise while maintaining the accuracy of electrical tree branch detection. The application of the Niblack segmentation method also supports the conclusion that the WMF method is more effective in reducing noise in the images while securing the electrical tree branches. Overall, the research provides valuable insights into the development of a fusion de-noising technique that can improve the analysis of electrical tree structures, contributing to the reliability and safety of high voltage cable insulation in power systems.

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