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Electrical Tree Image De-Noising using Threshold Wavelet Transform and Wiener Filter

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ABSTRACT

Electrical treeing occurred in solid dielectric materials, especially in electrical application with high voltage. The occurrence of electrical tree happens when high electric fields applied, causing tiny channels or paths to form. The main issue during the data collection process is the changes of lighting, making it difficult to study the tree's propagation length, fractal dimension, and growth rate due to corrupted images. This research aims to analyse electrical tree structure images in XLPE material using a CCD camera and develop image de-noising techniques to suppress noise on the electrical tree image. The performance was then analysed using the Otsu thresholding algorithm for accurate segmentation. The methodology was divided into four phases: sample preparation, experimental setup, image pre-processing in MATLAB, and testing four de-noising filters: Wiener, median, NLM, and Gaussian. The Wiener filter with higher PSNR, SNR, and RMSE was selected and using superimposed method, both threshold wavelet transforms and wiener was combined to eliminate the noise. Finally, the proposed method of superimposed was tested with the Otsu thresholding method to evaluate accuracy, sensitivity, and specificity of the combination filter. Based on the analysis of PSNR, SNR, and RMSE, the performance of the threshold wavelet and Wiener filter (TWWF) de-noising technique improves the image quality of the electrical tree structure. Thus, for the Otsu thresholding segmentation algorithm analysis, it also had the highest values in terms of accuracy, sensitivity, and specificity.

1. Introduction

Electrical treeing is a phenomenon that occurs in solid dielectric materials, such as insulating materials used in high-voltage electrical equipment. It is a form of electrical breakdown that can lead

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to the gradual formation and growth of tree-like structures within the dielectric material [1]. When high electric fields are applied to the dielectric material over an extended period, electrical treeing may occur. It typically starts as microscopic channels or paths within the material, resembling the branches of a tree. These channels can develop due to impurities, voids, or defects present in the material, or due to mechanical stress or other factors [2]. In time, the channels can grow and branch out, making a complex network that goes all the way through the insulating material. This is called "electrical treeing" because it looks like the branches of a tree. As the trees grow, they can diminish the dielectric strength of the material, resulting in partial discharges, increased leakage currents, and ultimately the insulation's failure [3].

Electrical treeing is a significant concern in high-voltage applications, such as power transmission and distribution systems. It can occur in various types of insulating materials, including polymers and composite materials. To mitigate treeing, careful material selection, design considerations, and periodic maintenance and testing of insulation systems are essential [4]. An electrical tree grows through three stages: start, propagation, and escape [2]. Charges from high-voltage electrodes or partial discharges (PD) are involved in the process of an electrical tree starting up. During the electrical tree propagation stage, current spikes are seen when PD happen in a tube or channel filled with gas. During the runaway stage, a small number of channels show an increasing rate of growth towards the ground electrode. The shape and growth of electrical trees depend on both external and internal factors in insulating materials [5-7].

While to study the electrical tree characteristic, electrical treeing data was collected in the form of images. Hence, several factor can affect the images of electrical treeing during the experiment process. Noisy images of electrical tree may disturb the analysis of electrical tree characteristic. Familiar noise that usually occurred in digital image data are divided into three types of noise; additive, multiplicative, and impulse noise. Even though the occurrence of noise in images data are mainly to degrades the image data values, however, difference noise cause difference effect on image and data.

Besides, some important image details are hidden, causing problems with subsequent processing such as segmentation, and edge detection. Noise also reduces the ability of human observation to diagnose objects more thoroughly. There are multiple numbers of noise in image enhancement that occur due to various reasons that may corrupt the signal. The characteristics of noise signal as well as its probabilistic features can distinguish it [8].

Hence, to correctly analysis the images of electrical tree characteristic, the application of image de-noising is considered important and supported by [9] state that the de-noising method in digital image processing is required to decrease the noise while maintaining the image features such as edges, corners, and other sharp structures. The image de-noising techniques can be classified into two different domains under traditional filters, which is known as spatial and transform domain. Spatial domain the divided into two types; linear filter and non-linear filter. Linear filters consist of mean and wiener filter, are used for both general purpose tasks such as image or video contrast enhancement, de-noising, and sharpening. Furthermore, linear filter work as well for object or feature specific tasks like target matching and feature enhancement.

Spatial filters apply low pass filtering to groups of pixels, assuming that noise is concentrated in the higher frequency range of the spectrum. Normally, spatial filters reduce noise to a great level, but at the cost of blurring images, which obscures picture edges and make the picture become invisible. Therefore, non-linear filters can remove multiplicative noise without the need to identify it. Several nonlinear filters have recently been created; median and weighted median filter [10].

A Median filter is the most basic nonlinear filter that examines each pixel in the image individually and compares it to its neighbours to determine whether it is representative of its surroundings.

Rather than merely replacing the pixel value with the mean of nearby pixels value, the median of those values is used instead. Non-data adaptive and data-adaptive basis functions are two types of functions. A small number of researchers mostly focus on non-data adaptive transformations because it is more often used. Thus, wavelet approaches characterise such signals far better than the original domain or transformations with global basis elements, such as the Fourier transform. However, there is limitation on using the wavelet domain since it relies on the wavelet base selection thus may cause image shown in the wavelet domain cannot be present clearly if the selection is done are unfit.

The application of image de-noising in digital images are recognise to be critical role played due to the future analysis on the images data that may become disarray with a corrupted images data. Hence, several cased was studied in difference applications. In a case study of wavelet transform [11] the post-processing de-convolution is applied to improve the de-noising algorithm. In this study, the researcher created a blur function to corrupt the original image to present the performance of the basic wavelet-based image de-noising technique. The benefit of the proposed approach is demonstrated as the reconstruction of de-noised pictures from the nonnegative Garrote Curvelet shrinkage rule and UDW coefficients Experimental. The results show that this strategy improves image quality and reduces MSE, particularly when the image is affected by substantial AWG noise.

While for wiener filter, it combines a low pass and a high pass filter which resulted to it functioning actively in the presence of additive noise in the image. Wiener filter performs a de-convolution also known as high pass filtering operation to invert motion blurring, as well as compression operation to remove additive noises [12]. In this study, both inverse and wiener filters are applied to the corrupted image then comparisons are made. The result of the study shows that in absence of noise, both filters function well in reconstructing the original image from its degraded counterpart. However, when additive noise is present, the wiener filter outperforms inverse filtering in terms of restoration.

Hence, based on previous research study, the filtering method with the application of superimposed to enhance the effectiveness of both wiener and threshold wavelet transform are proposed. Finally, to evaluate previous founding for the effectiveness of proposed filtering method, the Otsu's thresholding segmentation is then applied to study the tree growth (length and width) for image reconstruction in terms of accuracy, sensitivity, and specificity.

2. Methodology

This part discussed the methods and contents of the research design employed to carry out the study. Thus, offer the research procedures and stages of the experiment in material for sample selection, data collecting, image pre-processing, image post-processing, and data analysis.

The research starts off by developing cable insulation sample using XLPE material, then the experiment setup consists of Ogura® needle, CCD camera, microscope, and HV function generator to detect the electrical tree. Once the electrical tree formation detected, the data was collected in video form then converted into image sample to measure the electrical structure images in XLPE.

Then, the image de-noising technique is developed to suppress the unwanted signal on the electrical tree image using median filter in pre-processing stage for accurate segmentation of tree structures based on PSNR, SNR and RMSE parameter. Next, image segmentation was implemented, the type of thresholding segmentation was pick based on the frequency of the segmentation from previous research. Finally, the evaluation of the develop de-noising was done based on accuracy, sensitivity, and specificity of the parameter.

2.1 Sample Preparation

This experiment uses XLPE insulation material and a stainless steel plate mould as shown in Figure 1. The bead is arranged on the plate, covered with plastic, and hot-pressed for 10 minutes at 1000 psi. The bead is then cold-cooled for 10 minutes at room temperature. The Ogura needle electrode is embedded in the XLPE insulation sample, which is cut into rectangular forms. The sample is heated at 120°C for 2 minutes in a thermo-scientific oven. Only samples without mechanical stress and voids were used in the experiments [3,13-18].

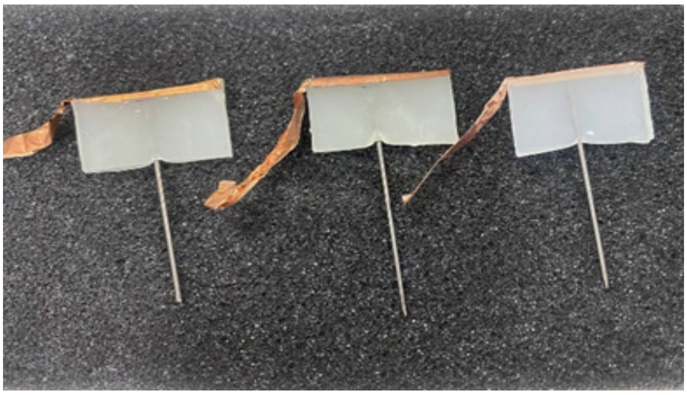


Fig. 1. Sample of XLPE with Ogura® needle

2.2 Experimental Setup

In Figure 2, an optical microscope, a CCD camera, a test cell, a high-voltage AC source, and a monitor are all required components of the experimental setup for testing electrical trees. The apparatus consists of a high-voltage transformer with a frequency of 50 Hz and a voltage of 140 kV, as well as a limiting resistor and a capacitive divider. Accelerated electrical branching is achieved by the needle-plane electrode arrangement. Mineral oil has been poured into the testing chamber so that there will not be an exterior discharge or a creeping flashover [9,15,16-20].

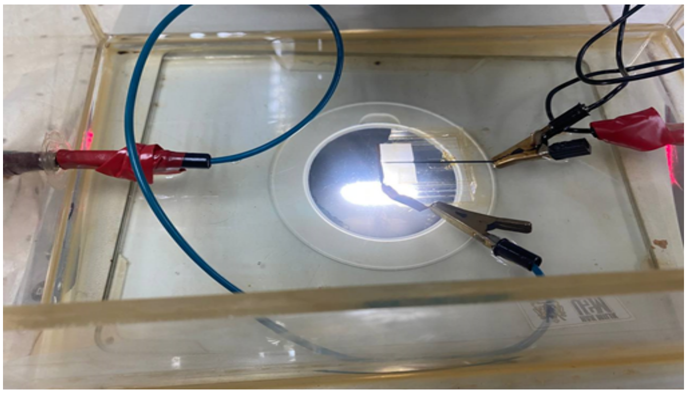


Fig. 2. The Needle-plane Setup in the Test Chamber Filled with Mineral Oil

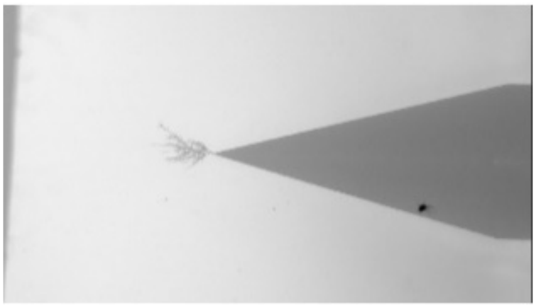
An Electrical stress is applied to cable samples until the tree inception voltage (TIV) is reached in order to evaluate the cables. Images of the tree are taken by a CCD camera, which are then sent to a real-time microscope digital imaging system to be transmitted and displayed on a monitor. The length of the electrical treeing is measured and recorded, and the shape of the electrical treeing for each sample is captured in each instance.

2.3 Image Pre-Processing

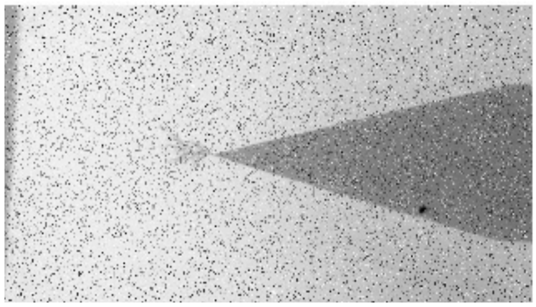
Image pre-processing, including de-noising, is crucial for data acquisition. Electrical tree images are collected and presented in colour, with different background colours and random noises. Raw image data is pre-processed in MATLAB to improve efficiency and ease mining. Ogura needle-generated images are enhanced with noise, and colour images are converted to grayscale images for easier processing (as shown in Figure 3).

The data used in the study came from a previous HV laboratory, and the focus of the study is on de-noising techniques for electrical tree images. From time zero until the formation's destruction, video footage of the tree being formed was gathered and later converted into still images. An examination of the tree's dimensions and characteristics revealed that it was most frequently a pine-like conifer. The images had noise added to them in order to test the robustness of the de-noising algorithm as well as its performance. There were a variety of noise levels that were examined, ranging from 0.01 to 0.10.

Considered the random noise that casually appeared during the process of image data collection. Salt and pepper noise was proposed and applied on the original image that had been converted into greyscale to corrupt the images. Five sample images namely as Image sample A, Image sample B, Image sample C, Image sample D, and Image sample E.



(a) Grey scale image



(b) Noisy (salt and pepper) image

Fig. 3. Sample of grey scale image and noisy image of electrical tree

The experiment consisted of adding noise in the form of salt and pepper to the initial image, which caused the image to become noisy. In order to eliminate unwanted noise, MATLAB was used to evaluate and compare four different approaches. De-noising techniques aim to improve image characteristics and retrieve relevant data. The edges, corners, and masses of an image are removed, and then the pixel values are boosted using kernel convolution. Image quality can be improved using de-noising techniques, which also make it possible to conduct more precise data analysis in the context of future studies.

Four existing de-noising filter are proposed to run the test in MATLAB software, Wiener, Median, NLM and Gaussian filter were deconstructed to test, and comparison was made accordingly in term of PSNR, SNR and MSE as follows.

$$PSNR = 20 \log_{\left(\frac{max}{mse}\right)} 2 \tag{1}$$

Peak Signal to Noise Ratio (PSNR) is an evaluation metric that determines the Signal to Noise Ratio (SNR) between the original image and an image with noise of the same dimension M×N in Decibels (dB).

SNR is a parameter that is independent of noise type, but its results and usability are highly dependent on how the image is degraded. SNR is useful with uniformly random noise such as gaussian, but it performs poorly with localised and nonlinear degradation like threshold degradation or loss of a specific area.

$$MSE = \frac{1}{MN} \sum_{i}^{M} = 1 \cdot \sum_{j}^{N} 1(x(i,j) - \ddot{x}(i,j)) \quad (2)$$

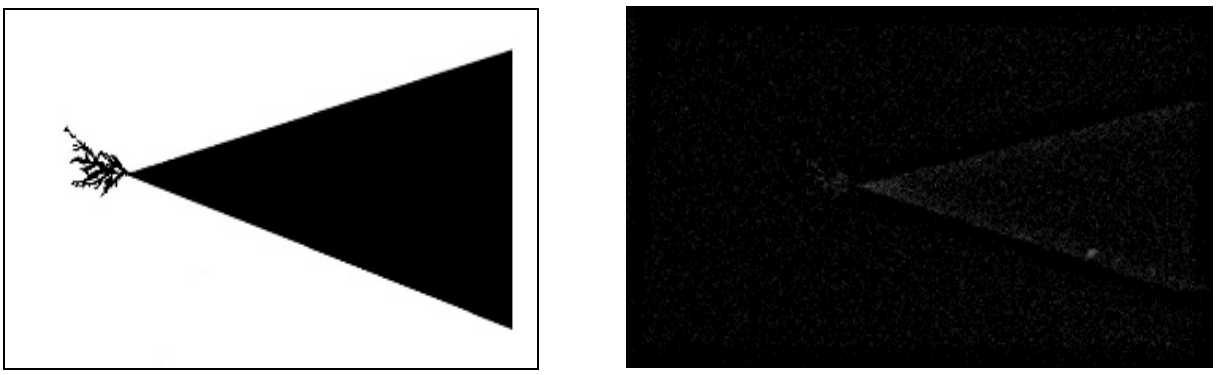
MSE is a digital image processing evaluation metric that is the average squared difference between the actual and measured values.

Difference window size was tested on the image sample, the purpose of testing two sizes of window 3x3 and 5x5 was to determine the best size to be practice in this research. The window size should be determined by examine the problem and situation at hand.

2.4 Superimposed Between Thresholding Wavelet Transform and Wiener Filter

The study focuses on digital picture processing using grayscale, a technique that reduces processing power and improves image quality. The study uses a Wiener window with 3x3 dimensions and a 5x5 window, with an extra layer and two 3x3 levels for precision. Normalisation is used to adjust pixel values and bring the image back to the standard range of perception. Dark field image reduction and bright field image normalisation are used to make the imaging method more consistent. The mean and standard deviation of the group are determined by a different window size.

Figure 4 shows the ground truth and TWWF image. The Wiener filter and thresholding wavelet are combined after normalisation, reducing noise and uneven backgrounds. De-noising is recommended to reduce noise and uneven backgrounds. Segmentation thresholding methods are used to evaluate the algorithm's success. The study compared four filters and used the proposed filter to improve image performance. After the normalisation process is complete, the thresholding wavelet and the Wiener filter are superimposed. In order to test the suggested method, segmentation thresholding algorithms are utilized, and the GIMP image editing programme is used to extract a ground truth image so that the original binary image may be compared with the suggested filter approach.



(a) Ground truth image (b) TWWF image

Fig. 4. Ground truth image and TWWF image of the sample

2.5 Thresholding Algorithm Image Segmentation

The input to these thresholding algorithms is often a grayscale image and a threshold. A binary image is produced as a consequence. When a pixel in the input image has an intensity greater than a threshold, the corresponding output pixel is marked as white (foreground), and when the intensity of the input pixel is less than or equal to the threshold, the output pixel location is marked as black (background). The de-noising method is used in this study along with Otsu's thresholding technique. To detect an electrical tree development for picture reconstruction using a treeing technique, a proposed thresholding purpose is presented.

The threshold technique is commonly employed to separate bright and dark zones. Hence, a grayscale image is transformed to a binary image by setting all pixels below a specified threshold value to ‘0’ and all pixels above that value to ‘1’ [21]. Finally, the de-noising technique is compared based on the thresholding segmentation algorithm in terms of accuracy, sensitivity, and specificity. Figure 5 shows the TWWF image segmentation using Otsu Threshold Wavelet Algorithm for Sample E.

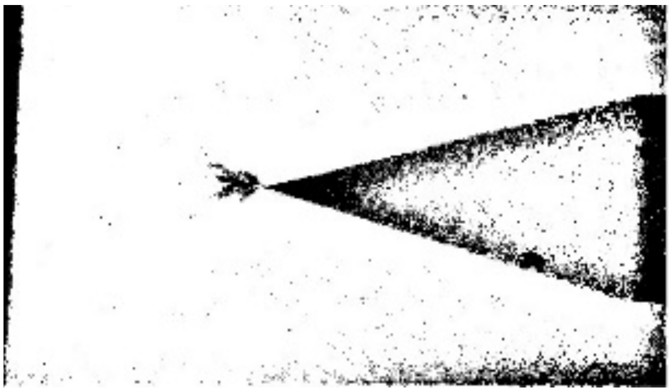


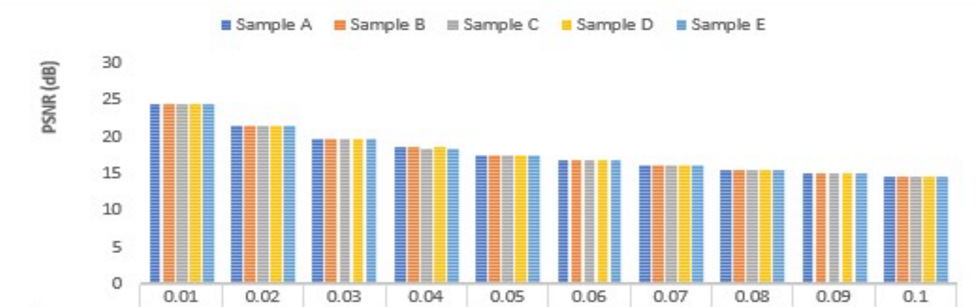
Fig. 5. TWWF Image Segmentation using Otsu Threshold Wavelet Algorithm for Sample E

3. Result and Discussions

After discussing the methodology from the previous chapter, this chapter continued by providing the result. Image acquisition and pre-processing took place from the first part of the methodology. Hence, the final decision was made from all the images tested, and 0.10 had higher noise intensity which suited the most to study the de-noising techniques. Furthermore, PSNR, SNR, and MSE values for each noisy image were evaluated. The different between all ten values can be seen in a decrement arrangement for PSNR and SNR.

The first part of the methodology included image acquisition and pre-processing. Furthermore, the salt and pepper noise image Sample A, B, C, D and E were chosen to find PSNR, SNR and RMSE with the noise density from 0.01 until 0.10.

The different between all ten values can be seen in a decrement arrangement for PSNR, SNR and RMSE parameter. Figure 6, 7 and 8 show the value of PSNR, SNR and RMSE of noise image which Salt and Pepper noise for Sample A, B, C, D and E.



	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1
Sample A	24.4911	21.4783	19.7452	18.4943	17.5027	16.7192	16.0322	15.448	14.9907	14.5106
Sample B	24.4546	21.5017	19.6936	18.4982	17.515	16.7133	16.0514	15.4744	14.9556	14.4963
Sample C	24.4992	21.4883	19.7593	18.4634	17.5139	16.7156	16.0289	15.4831	14.957	14.5142
Sample D	24.4529	21.541	19.7016	18.4875	17.496	16.7214	16.0476	15.4726	14.9655	14.4969
Sample E	24.4862	21.4648	19.7484	18.4571	17.5283	16.7159	16.0526	15.4701	14.9708	14.4771

Noise Density (dB)

Fig. 6. PSNR (dB) value versus Noise Density for Sample A, B, C, D, E

The data showed that the noise density value (0.10) significantly impacted image deconstruction. At 0.10 noise density, PSNR values were lower, indicating deconstructed images. The higher PSNR indicates best image presented according to the past research founding [22].

	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1
Sample A	22.4942	19.4813	17.7482	16.4973	15.5057	14.7222	14.0352	13.451	12.9937	12.5137
Sample B	22.4595	19.5065	17.6985	16.503	15.5199	14.7182	14.0563	13.4792	12.9605	12.5011
Sample C	22.5046	19.4937	17.7647	16.4688	15.5193	14.721	14.0343	13.4884	12.9624	12.5196
Sample D	22.4566	19.5447	17.7053	16.4912	15.4997	14.7251	14.0513	13.4764	12.9692	12.5006
Sample E	22.488	19.4666	17.7502	16.4589	15.5301	14.7177	14.0544	13.4719	12.9726	12.4789

Noise Density (dB)

Fig. 7. SNR (dB) value versus Noise Density for Sample A, B, C, D, E

Figure 7 shows the data that the noise density value (0.10) significantly impacted image deconstruction. At 0.10 noise density, SNR values also lower, indicating deconstructed images.

	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1
Sample A	15.2049	21.5093	26.2592	30.3267	33.9942	37.2033	40.2652	43.0667	45.3947	47.9743
Sample B	15.2689	21.4514	26.4155	30.3132	33.946	37.2285	40.1764	42.936	45.5785	48.0537
Sample C	15.1907	21.4845	26.2166	30.4346	33.9503	37.2185	40.2806	42.8931	45.5712	47.9547
Sample D	15.272	21.3545	26.3914	30.3505	34.0204	37.1938	40.1941	42.9445	45.5268	48.0503
Sample E	15.2281	21.4797	26.3056	30.3636	33.9436	37.2294	40.0799	42.9049	45.5186	48.0591

Noise Density (dB)

Fig. 8. RMSE (dB) value versus Noise Density for Sample A, B, C, D, E

Based on Figure 8, shows the higher values resulted in greater error, making 0.10 noise density an excellent choice for image deconstruction experiments. In this study, five electrical tree images were all in grayscale.

The salt and pepper noise was used to corrupt the images. All of the functions were written and tested using the MATLAB software. Figure 9, 10 and 11 shows the value of PSNR, SNR and RMSE of filter image for Sample A, B, C, D and E.

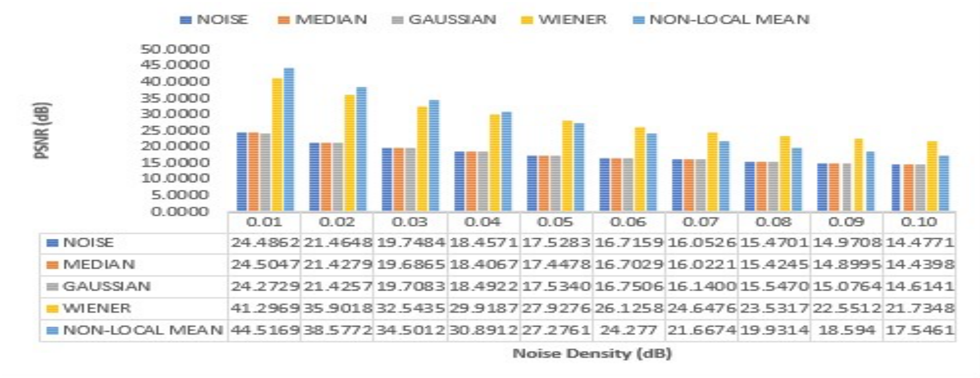


Fig. 9. Filters Comparison of PSNR (dB) Values for Salt and Pepper Noise

Based on the comparison above, it shows that the best choice of filter is Wiener with highest PSNR value took into consideration. Hence, it is reasonable to conclude that Wiener filter shows quite better performance compare to median, Gaussian, and NLM filters. Therefore, a higher PSNR value indicates better image quality and noise reduction.

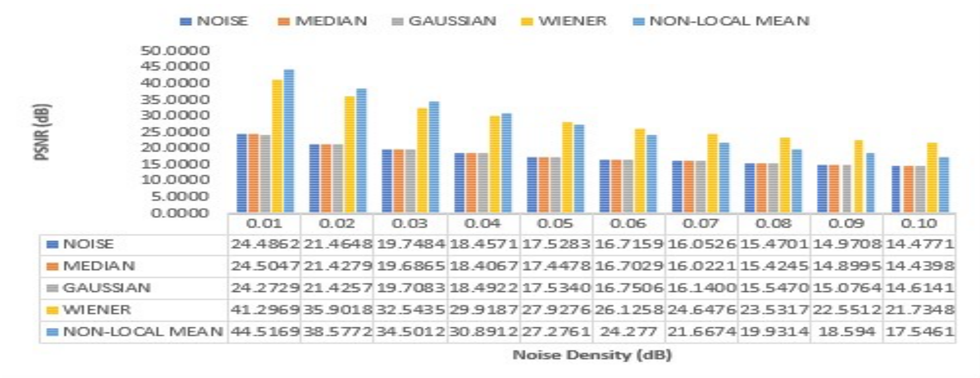


Fig. 10. Filters Comparison of SNR (dB) Values for Salt and Pepper Noise

While the Figure 10 shows the graph of SNR values for the Wiener filter are higher than the median, Gaussian, and NLM filters that were tested. It is also even higher than the noise value. The highest SNR value indicates a stronger signal relative to the noise.

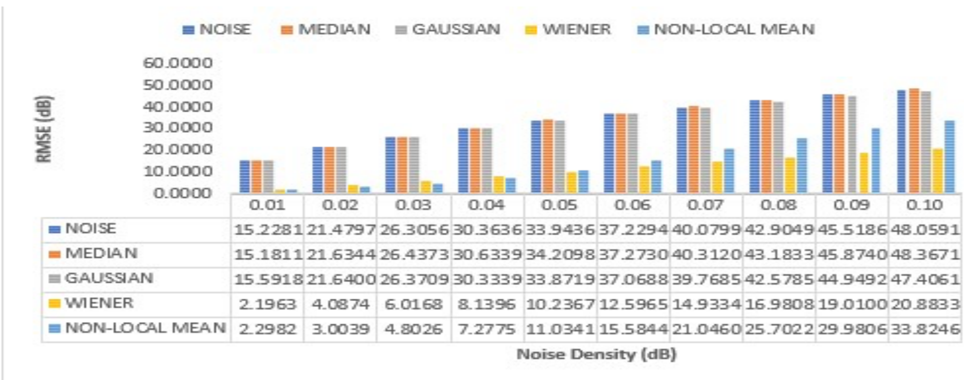


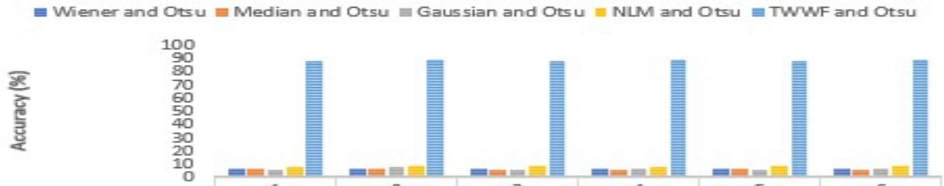
Fig. 11. Filters Comparison of RMSE (dB) Values for Salt and Pepper Noise

Besides, the RMSE values of the Wiener filter are lower than those of other filters that were tested, which represents higher performance with a lower error value and indicates better de-noising accuracy. The Wiener filter outperforms median, Gaussian, and NLM filters in reducing noise in electrical tree images.

However, it is not ideal for eliminating noise due to the de-blurring approach. Two de-noising techniques were developed to improve the filter's performance: the Wiener filter and threshold wavelet transform (TWT) de-noising.

The Wiener filter underwent normalisation and a superimposed technique with the TWT method. The proposed combination de-noising technique was evaluated based on accuracy, sensitivity, and specificity.

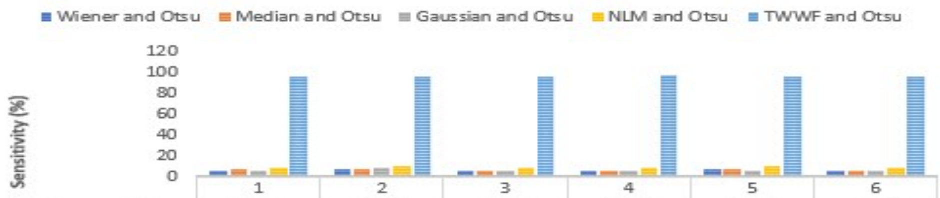
Figure 12, 13 and 14 present the results of the Otsu's thresholding algorithm.



	1	2	3	4	5	6
Wiener and Otsu	6.9805	6.873	7.063	6.8146	6.839	6.914
Median and Otsu	6.5168	6.6801	6.3419	5.7865	6.4713	6.3593
Gaussian and Otsu	6.1392	7.7822	5.625	6.5494	6.175	6.4542
NLM and Otsu	8.1696	9.0866	8.6976	8.4812	9.016	8.6902
TWWF and Otsu	88.2194	88.7143	88.1243	89.6812	88.5346	88.6548

Fig. 12. Filter Comparison of Accuracy (%) Values using Otsu's Thresholding Algorithm

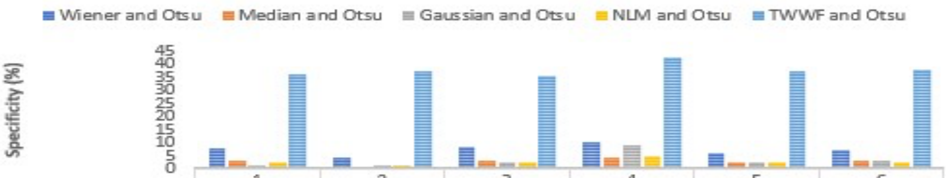
For Otsu's thresholding algorithm, the overall percentage result of the proposed method in terms of accuracy is 88.6548%. According to the results collected, the Wiener, median, Gaussian, and NLM filters have low performances compared to the TWWF method, with accuracy values of 6.9140%, 6.3593%, 6.4542% and 8.6902% compared to 88.6548%, respectively.



	1	2	3	4	5	6
Wiener and Otsu	6.8927	7.2446	6.8541	6.2304	6.9476	6.8339
Median and Otsu	7.0012	7.4867	6.8098	6.0156	7.0942	6.8815
Gaussian and Otsu	6.8557	8.6941	6.136	6.1465	6.6955	6.9056
NLM and Otsu	9.0476	10.2025	9.6134	9.0865	10.0133	9.5927
TWWF and Otsu	96.1394	95.9681	96.1674	97.5768	96.1504	96.4004

Fig. 13. Filter Comparison of Sensitivity (%) Values using Otsu's Thresholding Algorithm

Referred to Figure 13, the overall percentage result of the proposed method in terms of sensitivity is 96.4004%, while the value sensitivity shows similar results with accuracy, the Wiener, median, Gaussian, and NLM filters have quite slight differences of 89.5665%, 89.5189%, 89.4948% and 86.8077% compared to the TWWF method 96.4004% respectively.



	1	2	3	4	5	6
Wiener and Otsu	7.5614	4.2372	8.4213	10.3129	6.107	7.328
Median and Otsu	3.3146	0.9591	3.2997	4.4145	2.2723	2.852
Gaussian and Otsu	1.4028	1.3142	2.3019	8.962	2.6661	3.3294
NLM and Otsu	2.3651	1.1724	2.742	4.8573	2.2935	2.6861
TWWF and Otsu	35.865	37.2668	35.8227	42.4053	37.2006	37.7121

Type of Filter

Fig. 14. Filter Comparison of Specificity (%) Values using Otsu's Thresholding Algorithm

Besides, Figure 14 shows the overall result of the proposed method for specificity. Referred to the presented figure, the highest value for TWWF is at 42.4053 %, whilst other filter for the same sample shows quite low values at 4.8573 %, 8.962 %, 4.4145 %, and 10.3129%. This indicates the performance of TWWF filter is clearly best fit to eliminate the noise.

Thus, the proposed methods showed an improvement with the results when wiener filter combined with thresholding wavelet transform method. The essence of images is improved in terms of noise reduction by using the combination of TWT and Wiener filter together to preserve the edges and recover more details of the original images; the results were better than using a wavelet transform or Wiener filter solo.

4. Conclusions

The research study focuses on the de-noising of electrical tree images using threshold wavelet transforms and Wiener filters. The study aims to understand the damage caused by electrical treeing on power systems, which can impact downtime, revenue loss, and human safety. Five tree sets were extracted for study purposes, and the study aimed to accumulate electrical tree structure images using a CCD camera. The study tested five sets of images using filters such as median, Wiener, Gaussian, and NLM filters. The Wiener filter showed exceptional performance, with higher PSNR and SNR values compared to median, NLM, and Gaussian filters. The MSE result was also lower than the rest of the filters.

The study presented a combination de-noising approach using the Thresholding wavelet transform and Wiener filter to remove undesired noise from electrical tree images. The proposed method efficiently eliminates noise while securing electrical tree branches. The results showed high accuracy and sensitivity, while specificity was lower compared to Wiener, NLM, and median filters. The TWWF method proved its effectiveness in securing small branches, demonstrating its suitability for the study's objectives.

Finally, to prove the effectiveness of the propose approach, an Otsu's thresholding algorithm was proposed by evaluate the three parameter, accuracy, sensitivity, and specificity. Based on the parameter, the propose filter method prove to have better performance compare to the existing filter with accuracy value at 89.6812 % higher compare to Gaussian filter accuracy at 6.1392 %. Meanwhile, the accuracy proves to be higher at 97.5768 % and specificity at 42.4053 %.

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