Unstructured Noise Removal for Industrial Sensor Imaging Unit by Hybrid Adaptive Median Algorithm

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Abstract

Thermal noise is the most common type of contamination in digital image acquisition operations, and is caused by the temperature condition of the industrial sensor devices used in the process. When it comes to picture improvement, removing noise from the image is one of the most crucial steps. However, in image processing, it is more critical to retain the characteristics of the original picture while eliminating the noise. Thermal noise removal is a challenging problem in image denoising. This article provides a strategy based on a Hybrid Adaptive Median (HAM) filtering approach for removing thermal noise from the image output of an industrial sensor. The demonstration of this proposed approach's ability, is to successfully detect and reduce thermal noise. In addition, this study examines an adaptive hybrid adaptive median filtering approach that has significant computational advantages, making it highly practical. Finally, this research report on experiments shows the high-quality industrial sensor imaging systems that have been successfully implemented in the real world.

Keywords: Noise model, industrial sensor, adaptive median filtering, thermal noise, non-local filtering

1. Introduction

The broadcast television, remote sensing by satellite, aircraft, radar, sonar, teleconferencing, computer communications, and facsimile transmission are all examples of image transfer in many industrial sensors' output. For educational and corporate materials, as well as for medical photographs utilized in the patient monitoring system, image storage is needed the most. Data compression is critical to digital image processing because of its vast range of applications [1-5].

When it comes to extracting information from noisy signals, numerous approaches have recently been developed that are easy to adapt and apply to two-dimensional images. Linear noise reduction methods were employed in the past. Although linear approaches are easy to understand mathematically, they perform poorly in many cases. Linear filters intended to eliminate noise from a signal with sharp edges, will also smooth off the edges. Linear filtering also fails to reduce signal-dependent noise and impulsive noise adequately. The use of a nonlinear or adaptive filter might be more appropriate in these situations [6-8]. Homomorphic filtering was one of the first nonlinear noise reduction methods to be utilised. This was used to remove noise that had a multiplicative effect. Figure 1 shows some sample infrared industrial camera unit.

Photo sensor for Industrial Unit

Smart Infrared Cameras for Industry 4.0

Figure 1. Industrial sensors imaging unit [32, 33]

As a cooling agent, mineral oil refined from crude petroleum is often used in all power transformers. Insulation and cooling are provided by transformer oil in power transformers [9, 10]. Due to age, transformer oil's characteristics have changed significantly. There may be internal or external forces that induce transformer failures. When it comes to cooling, the oil's chemical qualities play a huge role. The colour, viscosity, pour point, and fire point qualities of transformer oil are used to determine the quality of the oil. With an image which is a two-dimensional representation of an individual or unique characteristic, or distinct feature through images and visuals, information may be conveyed and transmitted effectively [11-13].

A clean picture may be taken or acquired if the appropriate light levels are present either artificially or naturally. Otherwise, digital image pre-processing is required to add the expected picture to the photographs. Images that have been filtered to remove distracting brightness information are more easily understood by humans and may be used in machine-to-machine interactions [14, 15].
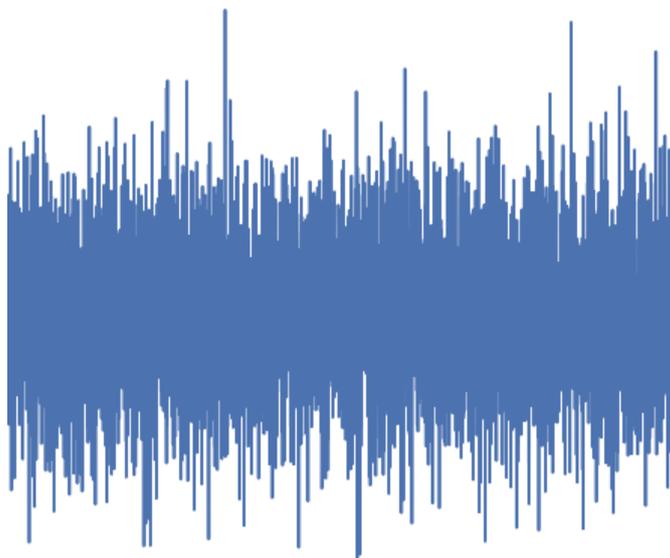
Figure 2. Unstructured thermal noise

1.1 Motivation

During the collection and transmission of data, the interactive system's data signal will be distorted by noise. As a result, it is difficult to perform additional feature identification and target tracking analysis on images with random noise present. The present denoising method has to be improved in order to enhance the sensor's output image quality of the interactive system and assure the accuracy of the interaction in real time scenario.

2. Structure of the Article

The following is the structure of this research article: Previously published researches on image noise reduction algorithms for a variety of domain photographs are presented in Section 3. Section 4 describes a hybrid approach for removing thermal noise from the output picture of industrial sensors that have been presented. The discussion of the acquired and experimental final output outcomes is presented in Section 5. The last part brings the present research effort to a close and discusses potential future expansions.

3. Preliminaries

Based on the HOS sequence, Hassouni et al. eliminated picture noise. A region-recursive estimating approach was used to calculate the motion trajectories [16]. On the basis of the similarity (periodicity) of images characteristics, Buades et al. developed a nonlocal average denoising technique. For texture creation prior to this, the image's periodicity was employed primarily [17].

These approaches, which are utilised for compressed sensing, feature extraction, pattern recognition, and denoise picture denoising have been the subject of much study and progress in recent years. Denoising benefits of the technique have grown increasingly apparent as mathematical theory and image processing technology have progressed, and it is currently one of the most widely used denoising algorithms. Improved NLM algorithms, such as those that divide pixel areas in order to preserve more picture structure information, have been developed by several academics [18]. As an example, in the area of medical image recognition, the patch based NLM method was utilized in [19]. Despite its simplicity, the computation of the NLM method was not straightforward. As a result, it takes a lot of computation time to calculate the similarity weight. As a result, finding out how to delete pixels with low correlation while keeping the noise reduction effect will lead to actual performance gain in the NLM algorithm. The salt and pepper noise can't be effectively filtered out by the NLM algorithm [19].

Noise might be formed due to the imperfection of the equipment used in picture processing. The data are degraded by the interference that occurs during transmission. Transmission errors and compression may also lead to noise. It is possible to add a wide range of sounds, such as dark current noise, which is caused by the thermally produced electrons at sensor locations. As a result, images must be denoised in order to recover their original quality. To reduce digital picture noise, a variety of techniques may be used. However, choosing the right strategy is critical to achieving the intended outcome [20].

Although Yang and colleagues' model assumes the greatest value for pixels affected by positive and negative impulsive interference noise, it was an anomaly that has to be taken into account. Using a noise model, to apply median filtering to pixels, is finding out whether their values are equal (or nearly equivalent) to the maximum or lowest value. Thus, it was possible to attain a decent result [21].

4. Proposed Method

4.1 Un Structured Noise model

There are two types of structured noises: those that are predictable and those that are unpredictable and aperiodic in nature. Noise with a constant amplitude, frequency, and phase is known as stationary. Structured noise is the result of electrical components interfering with one other. Figure 2 depicts the unstructured noise variance that is used in the study. Unstructured sounds in the noisy domain such as thermal noise is studied. The extra noise detection is included in this research work to get better reconstruction of image which has been shown in Figure 3. The used noise may also be referred to as electronic noise since it is generated by amplifiers or detectors while they continue to operate. Thermal vibrations of atoms and the distinct character of the radiation of heated things are also natural causes [22].
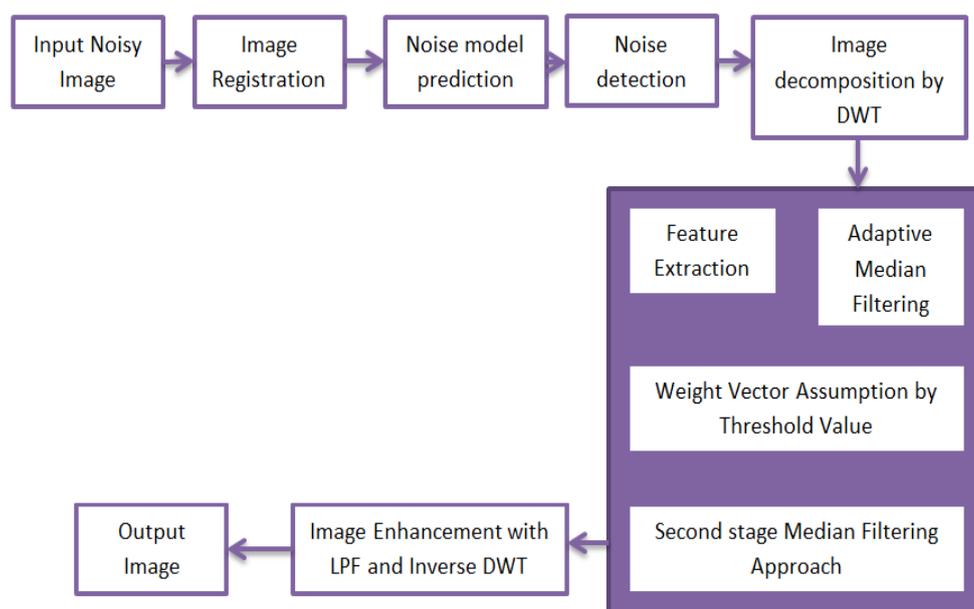
Figure 3. Proposed framework for hybrid adaptive median filtering approach

It's common for digital photographs to be distorted by this kind of noise. Because of this, the thermal noise model is fundamentally built and characterized by its PDF or normalized histogram about grey values. Real-world circumstances are accurately approximated in the mathematical model.

4.2 Noise Detection

The noise model explains that noise is seen in the captured and sent image, throughout the process of image acquisition and transmission. As a result, understanding the noise model

is a critical step in the image processing process. Image denoising, on the other hand, is an essential step in the image processing process. It is clearly known that, it is unable to carry out denoising activities, unless there is an understanding of the noise model. Structured and unstructured noises are the two types of noise that may be found in a communication line. Low-rank noise is another name for structured noise. Lower-dimensional noise models are preferable in signal processing, since they are easier to handle [23-26].

In addition, this model is translated into the physical system's entire rank measurement space. Because of this low rank and structure depending on physical system, it is said that in the measurement space, the noise that results has a low rank. The following equations are examples of the unstructured noise model.

Step 1:

$$y(i) = x(i, j) + n(i)$$

$$y(i) = H(i, j) * \theta(k) + s(i, j) * n(i)$$

where i=rows, j=columns, y(i) is received image; H is transfer function of the system, s is subspace, t is ranking, θ is angle parameter, n(i) is random noise. Then the DWT takes place to extract the features or decomposition of image features from the noise detected image.

4.3 Noise Removal Algorithm

A novel approach for removing noise has been devised in which the value grows while it remains constant at the thermal noise level. External parameters (k) are employed to evaluate noise density when the rise in value occurs. Square windows are used to reduce noise pollution. The first step is to construct two new matrices from the pixels that enter the window. In the first matrix, the horizontal and vertical neighbors of the center pixel create the first row and column. The window serves as the second matrix in the system. The mean and standard deviation of the freshly formed matrices are determined. Finally, two new equations are utilized to discover a new pixel value whether the noisy pixel value is inside or beyond the range specified in it. Mean and standard deviation are used to determine the new pixel value [27-30].

4.3.1 Considering adaptive median value

Adaptive median value is used if the window size is smaller than the maximum grey value of the window that is replaced.

4.3.2 Changes in existing procedure for hybrid process

The pixel is initialized through the matrix values with i and j. The grey values may be kept in the interval if the lowest grey value is more than or equal to the highest grey value; otherwise, the median value replaces the full grey value.

Step 2: if output <= threshold value; then add d=d+1

If weight vectors == adaptive median value; then reconstruct the output image with the value.

Step 3: Reconstruct the extracted features through interpolation by IWT.

Step 4: simple construction of Low Pass Filter (LPF) to enhance image for better clarity.

5. Results and Discussion

Figure 4 depicts the results of a denoising test. The input Lena grayscale image in Figure 4(a) processed by proposed HAM algorithm and it has been shown in 4(d). And other algorithms (WT, NLM) processed images in Figure 4 (b & c) are shown here.
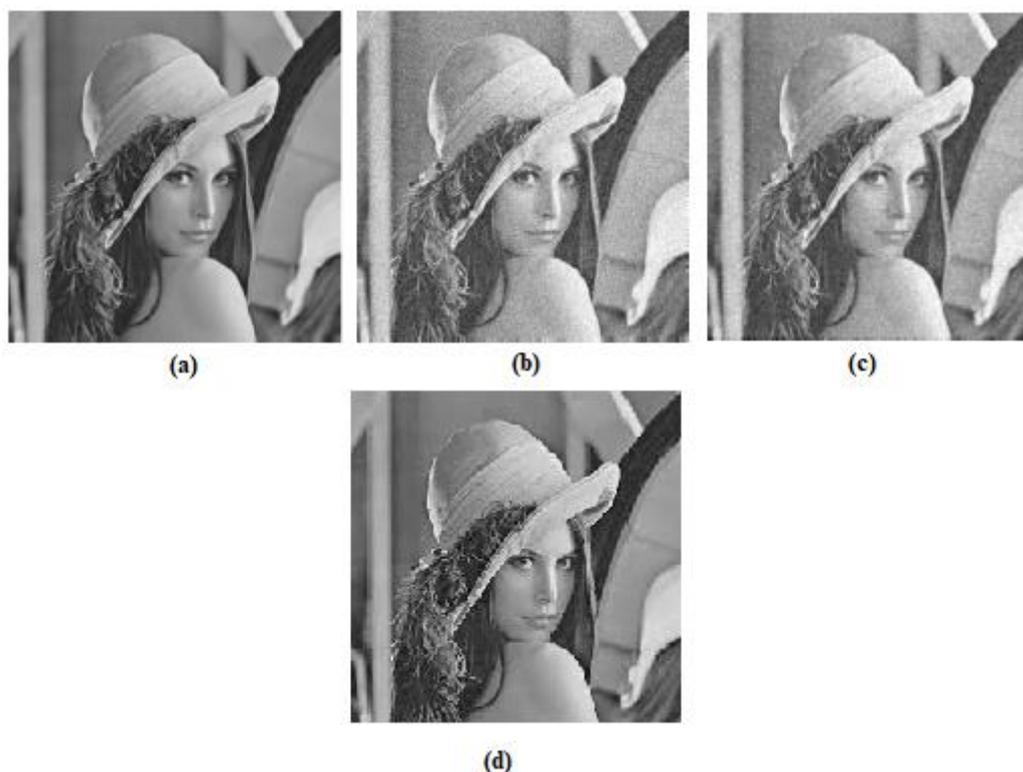
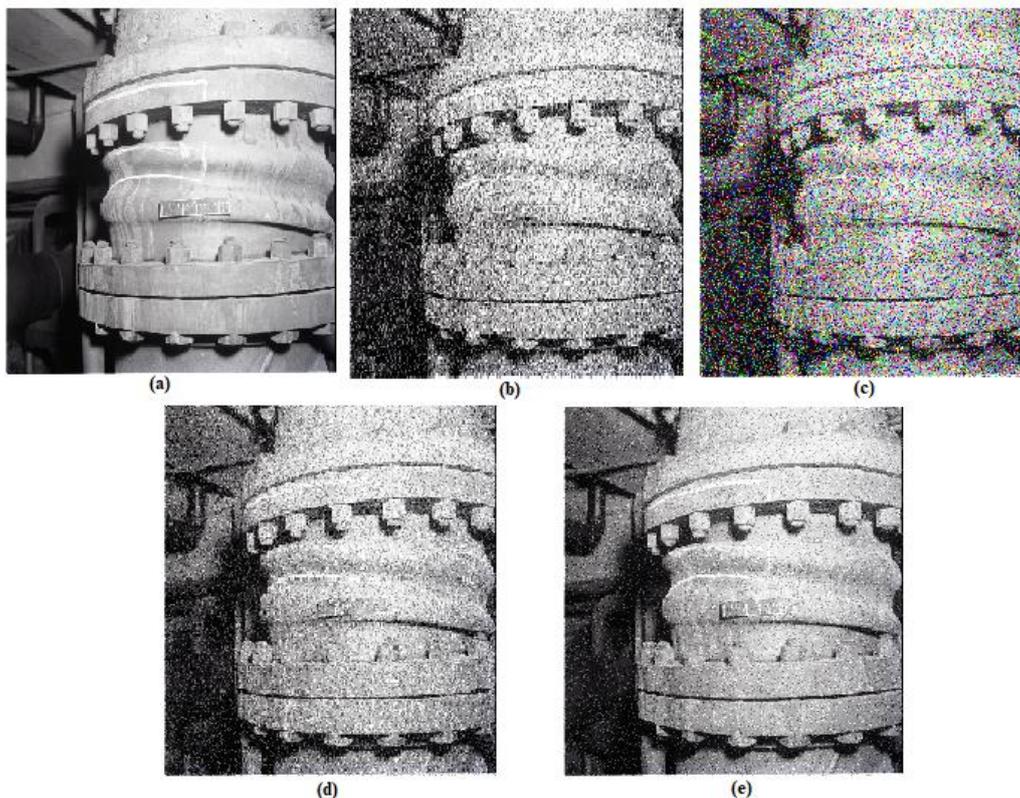**Figure 4.** Denoising of Lena image by various methods

The peak signal-to-noise ratio (PSNR) is often used to quantify visual noise and its formula is as follows:

$$PSNR = 10 * \log\left(\frac{255^2}{MSE}\right)$$

$$MSE = \frac{1}{M * N}\sum_{i=1}^{N}\sum_{j=1}^{M}\left[I(i,j) - \hat{I}(i,j)\right]^2$$

$$Correlation = \frac{\sum_{i,j}(y_{i,j} - \mu_y)(x_{i,j} - \mu_x)}{\sqrt{\sum_{i,j}(y_{i,j} - \mu_y)^2 \sum_{i,j}(x_{i,j} - \mu_x)^2}}$$

The greater the PSNR indicates, the better is the denoise effect. Many performance measures, such as brightness, contrast, and structural similarity [31], may be used to assess the industry sensor image's authenticity. The overall image fidelity of the industry sensor image is assessed using the PSNR in this study. Figure 5 shows industry sensor's imaging denoising procedure. 5(a) shows high quality image. 5(b) shows industry sensor's image with thermal noise. 5 c, d & e show denoised images by various algorithms such as WT, NLM and proposed HAM respectively.


Figure 5. Denoising of industry sensor's image by various methods [34]

The proposed HAM method, the nonlocal median-based algorithm, and the wavelet transform domain algorithm are compared. Table 1 shows the performance measures of various filtering methods.

Table 1. Performance measures of various method

| Image	Method	PSNR	MSE	Correlation
Sample infrared image of Industry 4.0	Wavelet Transform Domain	31.1	0.431	0.72
	NLM	32.7	0.274	0.81
	Proposed HAM	46.23	0.0039	0.96
Lena	Wavelet Transform Domain	36.3	0.1102	0.80
	NLM	39.2	0.0192	0.91
	Proposed HAM	49.92	0.0023	0.97

In order to compare the denoising impacts of each approach, a separate polluted picture is created. Before comparing the two photos, varying levels of thermal noise is added. Industrial sensor output images are degraded by various thermal noisy patterns frequently. A Lena image contaminated by thermal noise is denoised as shown in Figure 4.
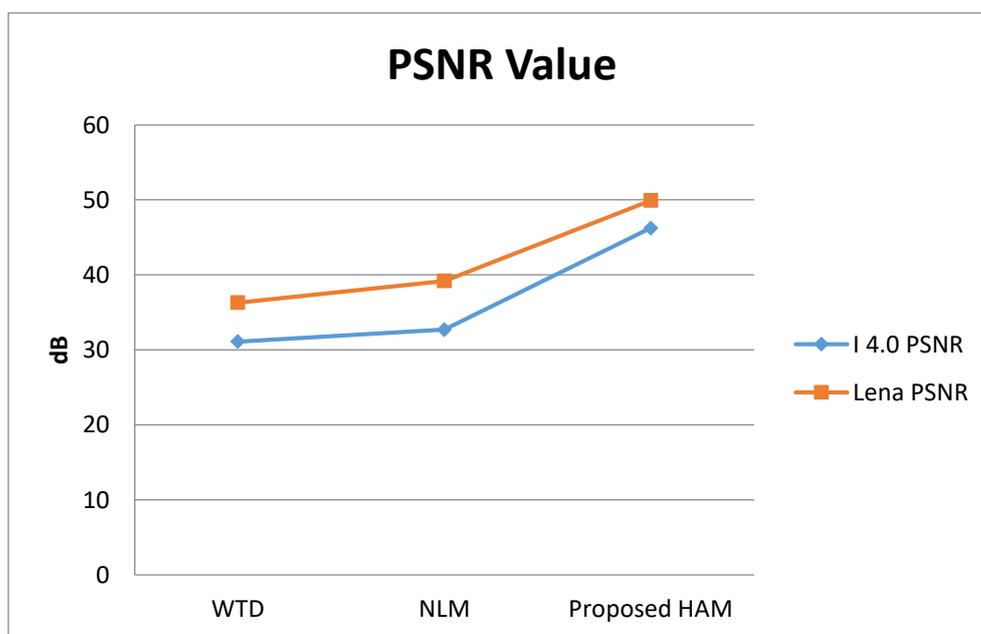
Figure 6 (a). PSNR differences among the two images
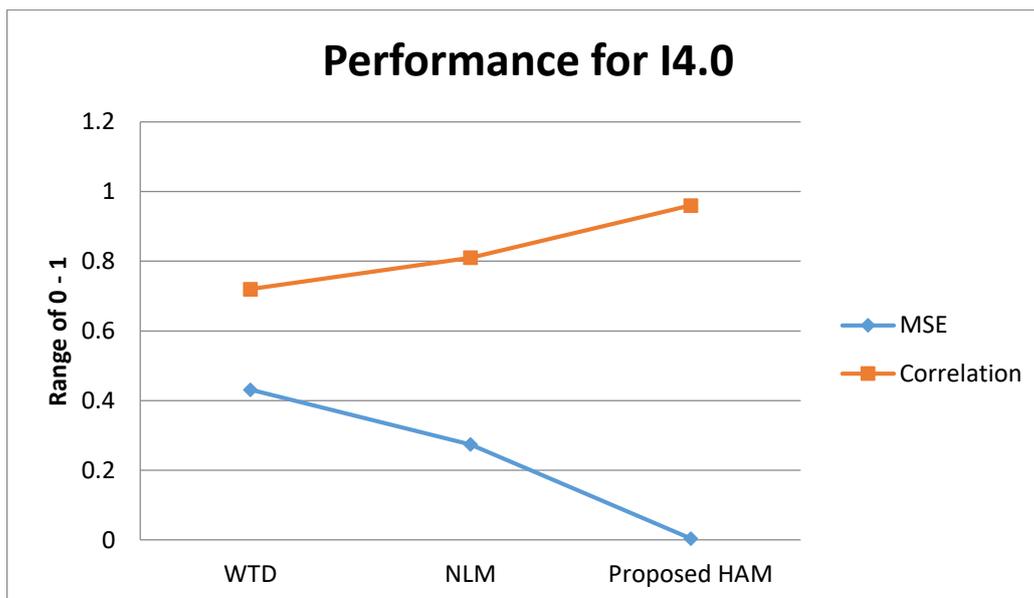
Figure 6 (b). Performance of I4.0
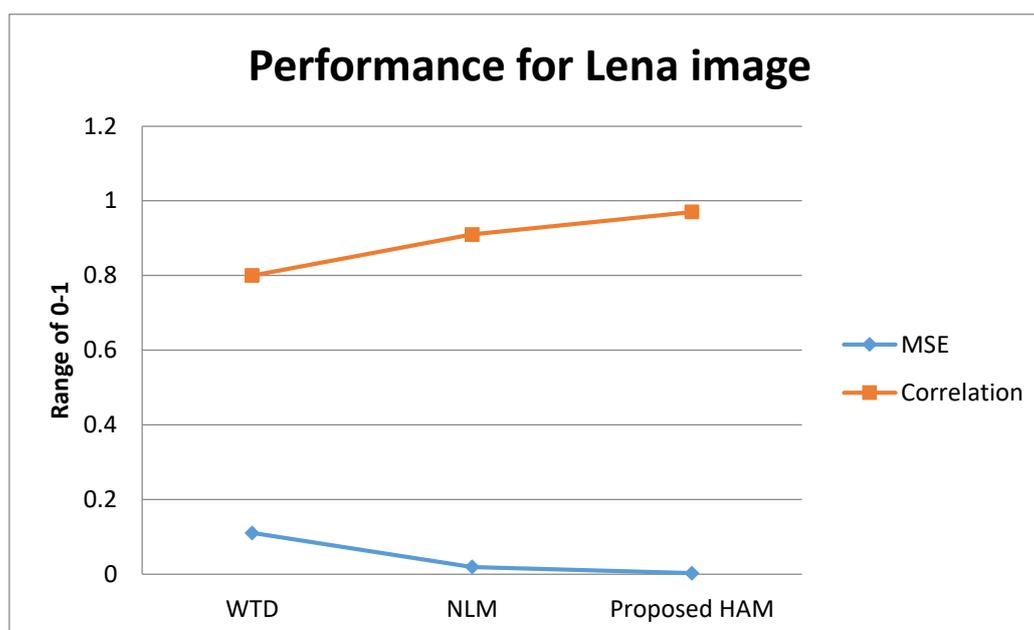
Figure 6 (c). Performance of Lena image

Figure 6. Performance chart for various denoising algorithm

This paper proves that the proposed hybrid adaptive median-based method has strong denoising performance against thermal noise in industrial sensor output and natural photos, as shown in the above Figures 4, 5 and 6 with the proof in Table 1. The exact placement of the interactive system calibration interface is successfully enhanced using the upgraded NLM algorithm, and the interactive point positioning is correct, further proving the usefulness of the method.

6. Conclusion

Thus, the proposed Hybrid Adaptive Median (HAM)-based image denoising based on natural and industrial sensor imaging infrared is provided and analyzed here. Adaptive median filtering offers good edge-preserving features with DWT and is often used in image processing. It was compared to more conventional filtering systems, such as median filtering and wavelet filtering in the transform domain. The next study will investigate the method for color image processing effects and to enhance the algorithm to minimize the time spent on image denoising to reduce the interaction latency for any industrial imaging sensors in the future. Since the fitness function is generated by the genetic algorithm, this technique has the potential to become more efficient in the future by possibly improving the efficiency of the suggested method by optimizing the fitness function of the genetic algorithm.

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