J Inf Process Syst, Vol.18, No.3, pp.319~331, June 2022
https://doi.org/10.3745/JIPS.01.0086

ISSN 1976-913X (Print)
ISSN 2092-805X (Electronic)

JOURNAL OF INFORMATION PROCESSING SYSTEMS JIPS

A Novel Approach to Enhance Dual-Energy X-Ray Images Using Region of Interest and Discrete Wavelet Transform

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Abstract
The capability to examine an X-ray image is so far a challenging task. In this work, we suggest a practical and novel algorithm based on image fusion to inspect the issues such as background noise, blurriness, or sharpness, which curbs the quality of dual-energy X-ray images. The current technology exercised for the examination of bags and baggage is "X-ray"; however, the results of the incumbent technology used show blurred and low contrast level images. This paper aims to improve the quality of X-ray images for a clearer vision of illegitimate or volatile substances. A dataset of 40 images was taken for the experiment, but for clarity, the results of only 13 images have been shown. The results were evaluated using MSE and PSNR metrics, where the average PSNR value of the proposed system compared to single X-ray images was increased by 19.3%, and the MSE value decreased by 17.3%. The results show that the proposed framework will help discern threats and the entire scanning process.

Keywords
Background Noise, Discrete Wavelet Transform, Dual Energy X-Ray Pictures, Image Fusion

1. Introduction

Image processing is dramatically getting more popular each day, and its importance in many application areas is proliferating. The techniques used for image processing are not only used to extract meaningful insights but also save computational cost and memory constraints [1]. Image processing is a process that is used to transform a picture into a digital format, and then actions are executed on it to obtain a clearer and improved picture or, sometimes, to draw out valuable information from that picture. This technique consists of an automatically adjustable change to be performed in the image and relies on authentically designed algorithms [2]. Image processing is a multidimensional area that overlaps with other fields like machine learning, human vision research, pattern recognition, and artificial intelligence. Image improvement is a crucial method in the field of image preprocessing. In earlier research, an amount

Manuscript received January 15, 2021; first revision May 12, 2021; second revision June 22, 2021; accepted July 13, 2021.
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of improved algorithms has been utilized in various image dispensation applications. On the other hand, the commercially used dual-energy X-ray mechanism is a system that utilizes two X-ray beams of different energies (with low- and high-voltage of 80 kV and 120 kV, respectively) to scrutinize the said entity and draw out information regarding the atomic composition and compactness of the item [3]. These commercial methods are constrained to have only the ability to resolve a particular complexity of corrupted images. Such as region of interest (ROI) can recover the precise region of attention. Likewise, discrete wavelet transform (DWT) can eliminate the background noise from the X-ray pictures. Conventional algorithms cannot provide a suitable significant image to fulfil the improved application demand. Consequently, such issues can be solved using image fusion. Image fusion is a technique that explicitly combines the information of interest from two or more images into a single informative and vivid image.

The objective of image fusion is to merge the input of many X-ray images into a fused X-ray image and produce a more vivid image to reveal more significant information than an individual image. Image fusion is an effective image processing technique and has been declared as one of the emerging ways of image enhancement for the last two decades. The technique has been used in many application areas of image processing, such as floodplain mapping, remote sensing, and medicine [4]. Image fusion is a technique based on image processing algorithms and is used to improve the information quality in an image while working on various images [5]. The record of the last few years shows that in a variety of image fusion methods, a type of fusion based on wavelet transform has been verified as a vital trend in the area of research due to its excellent results [6,7]. The image fusion of multi-resolution images using wavelet transforms often archives better results than the traditional techniques. The DWT is one of the most efficient methods of image fusion as this method provides rich information, and different experimental works have revealed that this method outperforms other methods of image fusion [1]. Image enhancement can be done using a variety of methods and techniques. In [8], the authors presented a modified fuzzy filter for reducing Gaussian noise. In this paper, they had focused on eliminating Gaussian noise only. Khan et al. [9] presented a genetic programming-based noise reduction approach for magnetic resonance imaging (MRI) images. In this work, the author claims that the proposed genetic programming can efficiently remove Rician noise. A DWT-based approach for the reduction of impulse and poison noise was presented in [4]. They aim to resolve blurriness and sharpness in corrupted X-ray images and to reduce the impulse as well poison noise in these images. Khan [10], presented an area of interest enhancement based on image fusion. In this work, they had focused on reducing impulse noise. In this paper, wavelet-based image fusion is used to improve degraded X-ray images, and the area of interest is utilized to boost the target region of the image. In order to get de-blurred, noise-free and sharp X-ray image sources, the sharpening, and enhancement techniques are discretely used with the similar tainted X-ray image. Subsequently, through a particular procedure within the wavelet domain, these two different sources of X-ray images are fused to acquire the improved X-ray picture. The research outcome shows our suggested framework remarkably enhances the corrupted X-ray pictures and synchronously offers suitable particulars and noise-free X-ray images.

The remaining of this paper is organized as follows: Section 2 describes the proposed method for image enhancement. In Section 3, analyses about the proposed work are made. Section 4 is reserved for the experimental process of this work. In Section 5, the results are presented. Finally, in Section 6, the research work is concluded.

2. Proposed Methods

2.1 Discrete Wavelet Transform

DWT is a method that integrates the time and frequency domains, and specifically, it is just like a time-frequency depiction of a non-stationary signal. The time and frequency information can also be retrieved by short-time Fourier transform, but it has a limitation of fixed resolution problem that a wavelet transform overcomes, and due to this reason, the wavelet transform is a better approach. While using short-term Fourier transform, a signal is broken into small pieces that are assumed to be stationary. On the other hand, in wavelet transform, high pass filter and low pass filter are used to decompose the signal and produce two different versions, i.e., low pass (L) and high pass (H) versions. The low pass version of a signal can be more decomposed by passing it to a group of low pass (LL) and high pass (LH) filters again. In the same way, the high pass version can also be further decomposed. The decomposition process can be repeated for the time when some signal reaches a pre-defined reference level [11].

The wavelet transform process divides the signal or indication and renders several fundamental functions. These functions are attributed to the wavelet transform. In picture dispensation, wavelet is a multi-resolution method that helps us to examine the surface of the picture. Wavelets coefficients are applied like features vectors for categorization. The DWT technique transforms the pixels of an image into wavelets. The made wavelets are then used for wavelet-based compression and coding.

DWT is a low-productivity, proficient, less computational, and low-cost technique for resolving reciprocal highlights from computer images [12]. The DWT has been used in different applications areas such as engineering, mathematics, and computer science. Image processing is one of the practical applications where the DWT technique is used for noise removal [13,14]. The discrete wavelet transform method is utilized in the suggested framework to unravel highlights from low and high-energy X-ray photographs. The DWT algorithm is an enhancement of continuous wavelet transform (CWT) and is also said to be the mother wavelet transform. CWT is incessant with scales and shifts measurement to reach the mother wavelet transform [15]. It refers back to the actual valued wavelet, $\psi(x)$. For example, the definition of a square fundamental function, $f(x)$, is as under:

$$w\psi(p,q) = \int_{-\infty}^{\infty} f(x)p,q(x)dx \tag{1}$$

$$\psi P,q(x) = \frac{1}{\sqrt{p}}\ \psi\left(x - \frac{q}{p}\right) \tag{2}$$

where q is translation constraints, and p is scaled constraints in the above equations [16]. DWT is a linear alteration function converting the picture particulars into its frequency components known as an approximation and detailed components. Picture detailed can access from these components regarding horizontal, diagonal, and vertical sub-bands. It can merely gain using low and high pass filters. DWT has mainly two functions: the scaling functions and the wavelet functions. These two functions are dependent on the filters used in DWT as the low pass filter performs the scaling functions while the high pass filter performs the wavelet functions [1]. These two functions are orthogonal functions which divide the function space into a sequence of orthogonal high and low-frequency spaces. The coefficients (weights) connected with the scaling function are known as approximation coefficients and capture low-frequency information, while the coefficients known as detail coefficients capture high-frequency information associated with wavelet functions. Eqs. (3) and (4) express the following components.

$$dj\ +1[p]=\sum_{n=-\infty}^{+\infty}\ h[n-2p]aj[n] \tag{3}$$

$$aj+1[p]=\sum_{n=-\infty}^{+\infty}\ l[n-2p]aj[n] \tag{4}$$

In the above equations, dj and aj allude to the detail coefficients and estimation coefficients of the wavelet function and the functions $h[n-2p]$, $[n-2p]$, signify high and low pass filter's coefficient correspondingly. Initially applying DWT, the Wavelet transform function is executed on low and high-energy X-ray pictures, and then, a fusion decision map is produced through the assumption of the group of fusion rules. A fused wavelet coefficient map is created by taking the wavelet coefficient of the source X-ray photograph. At last, inverse DWT (IDWT) is used to achieve the merged X-ray picture [17].

The wavelet transform method is quite different from the simple Fourier transform as the wavelet transform approach can provide knowledge about the time as well as frequency-domain of an image signal. The short-term Fourier transform can also extract information about time and frequency, but the wavelet transform performs better as it can deal with the fixed resolution problems that are occurred due to the short-time Fourier transform [11]. The local information extracted using wavelet transform about image signals helps in the extraction of disturbing information out of power signals. The wavelet transform approach can be applied using various types of wavelet functions. In literature, it was established that the Daubechies wavelet (db4) function is effective in cases of power signals analysis. The db4 function was effective due to its similar shape to power disturbance signals [18]. The number of levels for multi-resolution analysis is another parameter for calculating detail coefficient. The detail coefficients are prone to noise after a specific number of levels. In the different levels, the features that are taken from higher-level coefficients are mostly associated with features taken from lower-level coefficients and do not increase the value of the classification system.

2.2 Area of Interest Enhancement

A ROI is the selected area of an image to be filtered out, or some operations are to be made. A set of ROI objects for creating ROIs of different shapes are circles, ellipses, polygons, rectangles, and hand-drawn shapes. When an ROI is created, one can utilize ROI object properties to customize the functioning and appearance of the created ROIs.

After getting a noise-free merged picture, it is requisite to enhance the contrast of the complete picture or the exact area for the noise decreasing procedure [19]. Histogram equalization can be used to remove noise from the picture and for the enhancement of the picture; however, the drawback of histogram equalization is that it brightens every pixel inside the picture, and for a while, the brighter region of the picture acquires brighter [20]. The histogram specification technique can be used for picture improvement; however, this technique also has a few drawbacks and complications. The technique used here for the enhancement of image contrast is the area of interest enhancement. The block diagram of the ROI enhancement approach is shown in Fig. 1. The filtering of ROI is to apply a filter on a specific area of an image. While ROI filtering, a method known as "the create Mask" is applied for generating a binary mask for the area of interest of an object [21]. A filter is then applied to the region of the binary mask. The region of interest is filtered out using the roifilt2 (https://www.mathworks.com/help/images/ overview-of-roi-filtering.html), the function of MATLAB.

The roifilt2 specifies an input grayscale image to be filtered, a binary mask image that describes the ROI, and a filter. The roifilt2 function takes an image and produces another image with filtered values for all those pixels of the binary mask where it has 1s in it. Also, the generated image contains unfiltered values 0s in the binary mask. The filtered and unfiltered process of the pixels is known as "masked filtering."

Fig. 1 shows the region of interest enhancement for the fused de-noised X-ray image. In the first place, a fused de-noised image is taken for enhancement, and the area of interest is selected for enhancement. Then, the exact area is filtered out so that more clear enhancement can be made. An ROI technique "roifilt2" function is then applied to enhance the specific area.

The area of interest is filled and updated using the 'roifill' method. The roifill method is effective in editing X-ray images and removing unnecessary information. The method fills the area of interest by predetermined values on the boundary of the area. The areas of interest are when chosen by mouse, and the roifill retrieves an X-ray image according to the chosen filled area of interest [21]. In this work, the roifill method was used for filling and updating the area of interest of the input dual-energy X-ray images.

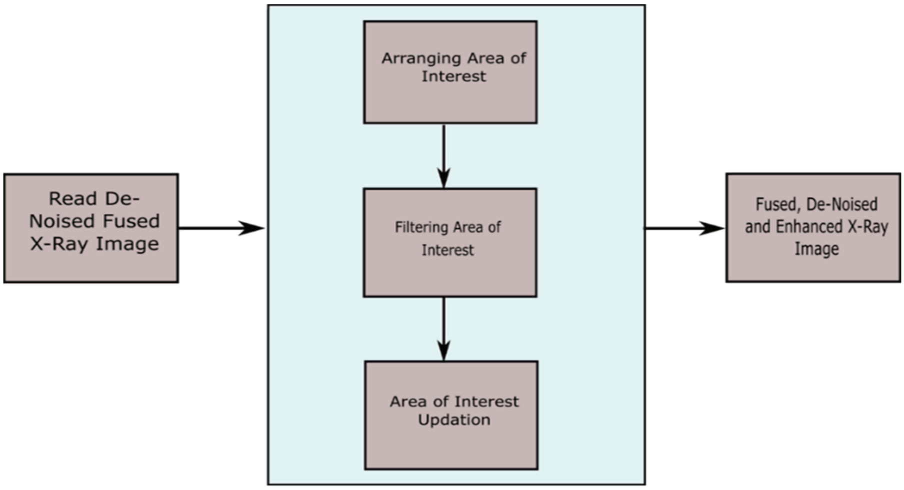


Fig. 1. Region of interest enhancement.

2.3 Image Enhancement Algorithm using the DWT Image Fusion and Area of Interest Algorithm

Generally, X-ray images that are debased with Poisson noise are made de-blurred and given low contrast. Poisson noise occurs while the predetermined amount of photons possessing energy is not capable enough to detect statistical fluctuations in measurement [19]. The particles are known as "photons" in an optical gadget and "electrons" in the electronic circuit. Apart from other digital pictures, X-ray picture noise affects the boundaries of the item and pixels intensity values that generate ambiguity for the system to distinguish items and for the administrator to make a decision [22]. DWT and ROI enhancement approaches are used for the contrast enhancement of the target area in the picture; the suggested approach, based on Wavelet is associated with ROI to attain the desired outcomes. This model significantly supports the checking process when we are going to discriminate threats and the entire process of screening, as is obvious from the empirical outcomes. However, the "X-ray" pictures are still blurred, noisy, and show low complexity because of fewer photons penetration, arbitrarily dropping photons, thickness of object matter, detector size matter, and changing analogue to digital. Background noise in the X-ray image denotes needless information, which gets worse the picture quality, for instance, if the normal picture "$f\ (i,j)$" having noise "$n\ (i,j)$", Then the noisy picture "$g(i,j)$" will be articulated in the following equation [23].

$$g(i,j) \ = f\ (i,j) + n\ (i,j) \tag{5}$$

Thus, our proposed framework filter is the eventual filter used for background noise tainted pictures. Resting on the opposing, though sharpening cannot extremely enhance picture contrast; however, this processing vastly improves details of the edges via employing the dissimilar operation of the Laplace operator [4]. Therefore, the entire connection of the DWT and ROI approaches materializes in picture improvement. A technique for the reduction of Background noise in X-ray pictures utilizing a discrete wavelet transform is intended. The fundamental restriction to this scheme is that it passes through a filter every pixel among a Wiener filter if they are tainted or not. Several research studies contain worked on Poisson noise in a diverse field [23]. These studies design a framework to remove the background noise with wavelet transform and to enhance the target area of the image. The proposed DWT algorithm uses the above-mentioned harmonizing feature utilizing image fusion id to get image free of background noise, de-blurred, and improve the boundaries of tainted X-ray pictures concurrently. The sketch map of the proposed framework is exposed in Fig. 2, and the flow of process is explained below.

1. The wavelet approach, ROI filter, and sharpening are applied independently to get two corresponding sources of X-ray pictures (i.e., sharpened and free of noise X-ray picture).
2. Utilizing a fast DWT approach, decompose the sharpened and noise-free X-ray picture.
3. To obtain fused coefficients, the detailed and approximate coefficients of the DWT decomposition are fused correspondingly through different rules.
4. Using IDWT, the picture from the fused coefficients is rebuilt, and a clear, more informative image is produced.

Fusion rules carry out an important function in image fusion, and researchers have developed several fusion rules for a variety of applications [4,6]. Special rules are used in the new research to manage the detail and approximate coefficients, correspondingly. Let K and L represent the two sources of X-ray images—the sharpened and de-noised X-ray images. Moreover, F specifies the merged result of K and L. The following equation (Eq. 6) is used for the approximate coefficients.

$$F(i,j) = \ \alpha K(i,j) \ + \ (1 - \ \alpha)\ L(i,j) \tag{6}$$

where α acts as a weight coefficient that can alter the section of K and L to manage the blurriness of the fused X-ray picture. It has been empirically experienced that scale 4 can give a pleasing outcome for merging sharpened and noise-free X-ray pictures consistent with different picture circumstances. In future, we aim to develop an adaptive algorithm that will determine the value of α. The following fusion rule (Eq. 7) is used to merge the detail coefficient.

$$F(i,j) = \alpha K(i,j) + (1-\alpha)L(i,j) \quad (7)$$

Fig. 2 shows the overall fusion process of dual-energy X-ray images. In this figure, high and low-energy images are given as input to the system. In the next step, the wavelet approach and sharpening are applied independently to get two corresponding sources of X-ray pictures. Then DWT approach is used to decompose the sharpened and noise-free X-ray picture. Some fusing rules are then applied to get the detailed and approximate coefficients of the DWT fused image. Finally, IDWT is applied to rebuild the picture from the fused coefficients.

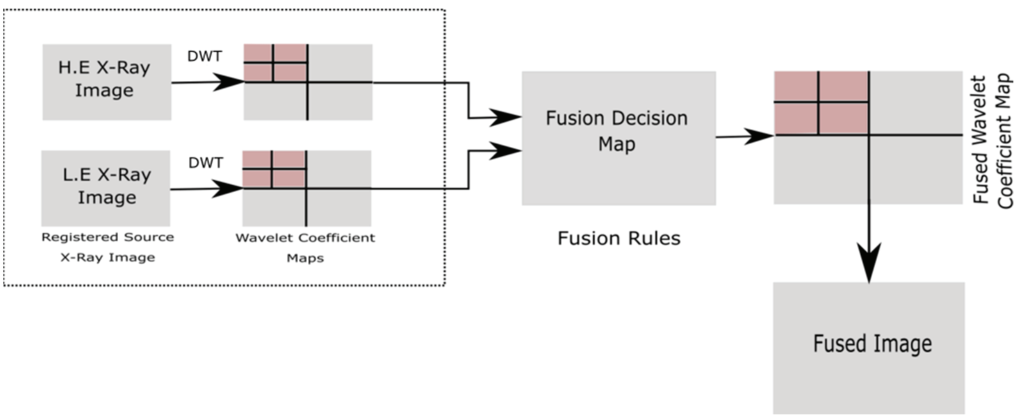


Fig. 2. Fusion process of dual-energy X-ray image [12].

3. Analysis

Initially and most importantly, the imperative feature of the proposed approach is to find out the Background noise in tainted pixels, and then the DWT approach is used to restore the picture. Image fusion possesses the capability to eradicate background noise from X-ray pictures. The complexity and computational time will be enhanced by separating the low- energy and high-energy X-ray pictures, whereas to deal with these issues, the author uses an image fusion process.

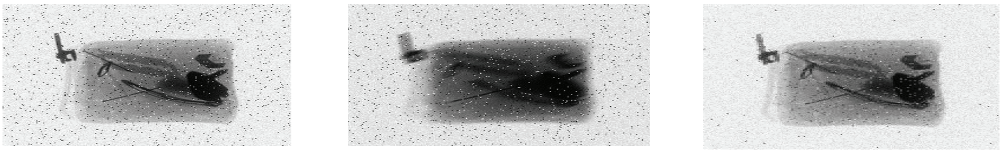
Secondly, the DWT approach is imposed on every pixel in the initial phase/iteration. The low-energy pictures and high-energy X-ray pictures are uploaded and decomposed using DWT to obtain approximation and detail coefficients, and fusion rules are then used to acquire fused approximate and detail coefficients. In the end, IDWT is used to obtain the merged X-ray images.

After the fusion, occasionally, it is required to enhance the image due to the process of reducing noise. In earlier research, the approach used for picture improvement was histogram equalization. The limitation of the histogram equalization is that it brightens every pixel in the picture, and for a while, the brighter region of the picture achieves extra brightness. The histogram specification technique has also been used by the researcher previously to enhance the contrast in the picture; however, it also has a few restrictions and complications [22]. Herein the proposed framework, we applied an easy technique known as ROI enhancement to improve contrast in the picture. The roifilt2 is used in this work that specifies; an input grayscale image that is to be filtered, a binary mask image that describes the ROI, and a filter. The roifilt2 function takes an image and produces another image with filtered values for all those pixels of the binary mask where it has 1s in it. Also, the generated image contains unfiltered values 0s in the binary mask. The filtered and unfiltered process of the pixels is known as "masked filtering." The roifilt2 is effectively suitable in cases when the return data is of the same range as of the original image.

4. Experimental Process

The proposed approach for image enhancement was conducted on a Core i5 system with 8 GB RAM and implemented using MATLAB R2020a. The dataset for system evaluation contains 40 X-ray images having noise and baggage. In this section, first of all, we will see the results of the baggage image adjustment approach that how it enhances the quality of digital images and then in the second part, we will observe the global contrast enhancement using referenced image approach. The testing set that contains 40 images of size 256*256 (Figs. 3 and 4) and 512*512 (Figs. 5 and 6) are infected with different background noise densities. Note that we have shown the sample of just 13 images (evaluation results) for a clear presentation of the results.

Fig. 3 shows the background and impulse noise wavelet-based fusion of 256*256 pixels images of the bag containing blades, where Fig. 3(a) represents high-energy X-ray image of the bag containing a blade, Fig. 3(b) shows low-energy X-ray image, and Fig. 3(c) shows the fused image of the low and high-energy images.



(a) (b) (c)

Fig. 3. Background and impulse noise wavelet-based fusion of images of the bag containing blades: (a) high-energy X-ray, (b) low-energy X-ray, and (c) fused X-ray.

Fig. 4 shows the background and impulse noise wavelet-based fusion of 256*256 pixels images of a bag that contains guns; Fig. 4(a) represents a high-energy X-ray image of a bag containing a gun, Fig. 4(b) shows the same image having low energy while Fig. 4(c) represents a fused image of both low and high-energy images.

(a) (b) (c)

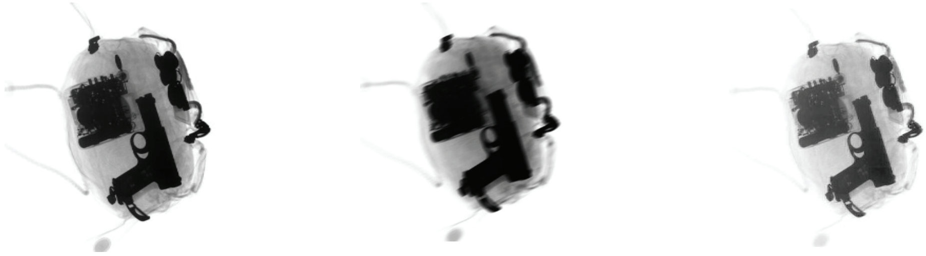
Fig. 4. Background and impulse noise wavelet-based fusion of images of the bag containing guns: (a) high-energy X-ray, (b) low-energy X-ray, and (c) fused X-ray.

Fig. 5 shows the background and impulse noise wavelet-based fusion of 512*512 pixels images of a bag that contains blades. The images were high-resolution and we tested the performance of our proposed approach using the high-resolution as well as low-resolution images. It can be seen in Figs. 3 and 5 that our proposed approach can perform well in both 256*256 and 512*512 pixels images. Fig. 5(a) represents a high-energy X-ray image of a bag containing a blade and Fig, 5(b) shows the same image having low-energy, while Fig. 5(c) represents a fused image of both low and high-energy images.

(a) (b) (c)

Fig. 5. Background noise wavelet-based fusion of 512*512 pixels images of the bag containing blades: (a) high-energy X-ray, (b) low-energy X-ray, and (c) fused X-ray.

Fig. 6 shows the background and impulse noise wavelet-based fusion of high-resolution images containing guns. The images shown in this figure are of 512*512 pixels quality. Fig. 6(a) represents a high-energy X-ray image of a bag containing a gun and Fig. 6(b) shows the same image having low-energy, while Fig. 6(c) represents a fused image of both low and high-energy images.



(a) (b) (c)

Fig. 6. Background noise wavelet-based fusion of 512*512 pixels images of the bag containing guns: (a) high-energy X-ray, (b) low-energy X-ray, and (c) fused X-ray.

Figs. 3–6 shows the fusion process of different low energy and high-energy X-ray images of 256*256 and 512*512 resolution quality. The fusion process was made using the proposed approach presented in this paper. The results show that the proposed approach can fuse the images with more clarity and objects (blades/guns) can be examined easily after de-noising the images.

5. Results

The results were evaluated using mean squared error (MSE) and peak signal-to-noise ratio (PSNR). The MSE metric is used to measure the average squared difference between the predicted value and the actual value. The low values of MSE show more accurate estimation and hence more effective evaluation results. The MSE values of fused images in comparison with individual X-ray images are shown in Fig. 7. Moreover, the PNSR metric was used for evaluating the performance of the proposed dual X-ray image enhancement approach. PSNR is used to measure the quality of an image. The high values of PSNR show that image enhancement is made in a better way. Fig. 8 represents that the PNSR values of the proposed approach are higher than individual X-ray images.

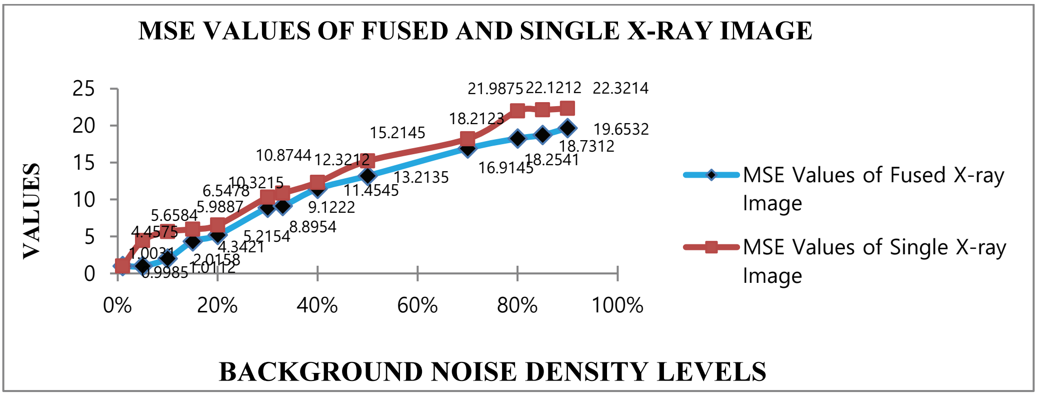


Fig. 7. MSE values of fused and single baggage X-ray picture.

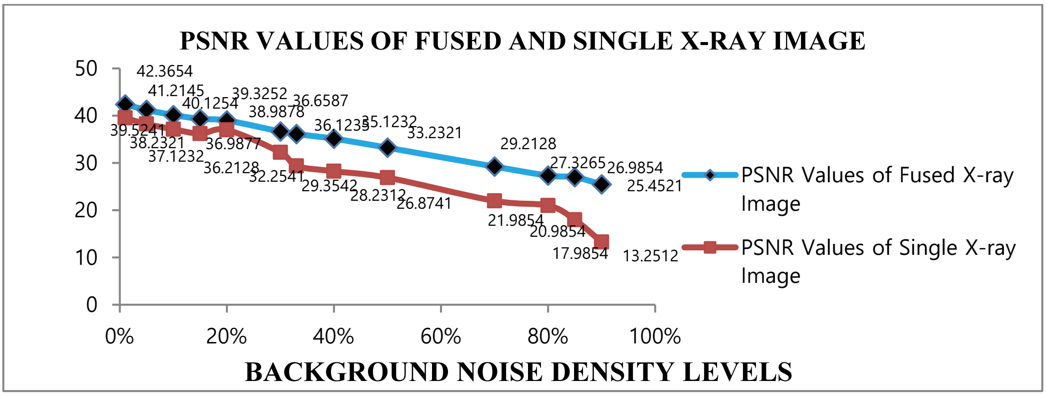


Fig. 8. PSNR values of individual and fused baggage X-ray picture.

Fig. 7 shows the MSE values of fused and single baggage X-ray images. It is clear from this figure that the MSE values of fused X-ray images are smaller than that of the individual X-ray images. Note that smaller MSE values show better clarity and are considered to be a more informative image.

Fig. 8 shows the PSNR values of individual and fused baggage X-ray picture. In this figure, it is clear that the proposed system can enhance dual-energy X-ray images with better PNSR values and the improvement in PNSR values shows that the newly fused images will be more clear and informative as compared to the individual images.

The results presented in the above figures disclose that the proposed framework of image enhancement provides excellent results as compared to comparative approaches. It is clear from the evaluated results that our proposed approach for X-ray image enhancement using ROI and DWT achieves better PNSR values for all the images.

6. Conclusion

This research work has put forward a reliable, new, and fast technique to remove background noise and to enhance the contrast of a particular region of an image. An empirical, novel, and proficient algorithm based on image fusion were proposed to inspect the issues such as the background noise, blurriness, or sharpness in the image, and such other regressive effects which curbs the quality of dual-energy X-ray pictures. The proposed approach was evaluated using MSE and PSNR values and the comparison of the fused images with individual images shows that the proposed approach produces more informative and noise-free images. From the experiments, it is obvious that the proposed framework removes the background noise and increases the contrast of the targeted area within no time computation and intricacy. The remarkable improvement of the suggested framework is that it is straightforward and can be seen faster than other techniques in hand. The proposed wavelet transform and ROI-based image enhancement approach can be utilized as a real application for the examination of different X-ray images.

Acknowledgement

This research was supported by Dr. Aurangzeb Khan who is working as an associate professor at the University of Science and Technology, Bannu, Pakistan. We thank him for his guidance and support during conducting the various experiments and the report.

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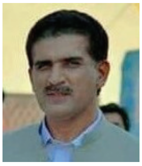

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