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Image Fusion based on Integration of Wavelet and Curvelet Fusion Methods

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Abstract: ***In today's period, there is a great impact of image registration and image fusion on many fields such civilian and defense areas to retrieve exact information about the particular image. the process in which different images of the same scene are captured as input images and those are combined in order to improvise the fused image content which gives more information and is complete than any of the input images. Different methods of image fusion technique are principal component analysis (PCA), Discrete Wavelet transforms (DWT), curvelet transform. Principal component analysis (PCA) is a spatial domain fusion technique, which deals with image pixels to reduce multidimensional data sets to lower dimensions for analysis. Discrete Wavelet transforms (DWT) and curvelet transform is the transform domain methods to integrate the input images and extract the exact required information. Discrete wavelet transform(DWT) has an impressive reputation as a tool for image processing in image denoising and image fusion application.The Curvelet transform is suited for objects which are smooth away from discontinuities cross curves. The application of the curvelet transform in image fusion would result in better fusion results than that obtained using Principal Component Analysis (PCA) and Discrete wavelet transforms (DWT) The idea behind the current research is to exhibit the enhancement in image processing parameters by implementing fusion of curvelet and wavelet using simple average and weighted average fusion method .***

Keywords: Image Fusion, Spatial domain, Transform domain Principal Component Analysis (PCA), Discrete Wavelet Transform (DWT), Curvelet Transform.

I. Introduction

Image fusion follows the process in which integration of the relevant information from a set of input images of the same scene into a single image is done, where the fused image which is received as resultant is an extraction giving more information and complete than any of the input images. The goal of the image fusion algorithm is to take redundant and complementary information from the source images and to generate an output image which becomes more suitable for the purpose of human visual perception. The reliability and overall detail of the image are increased, because of the addition of analogous and complementary information. Image fusion requires that images be registered first before they are fused. Image Fusion makes it a lot of advantages on remote sensing, medicine, computer vision, military target detection and identification that it has overcome the blind spot in many fields of science and technical difficulties. Especially in computer vision, image fusion technology has greatly improved the accuracy of the identification.

Image Fusion Method and Techniques

Image fusion methods are broadly classified into two groups:

A. Spatial Domain
B. Transform Domain

A. Spatial Domain

In Spatial domain fusion method image pixels plays an important role, manipulations are done on image pixels to enhance the image quality. In these spatial variables i.e. intensity of pixels is varied through some mathematical calculations, such as selection of maximum intensity pixels are done from a set of source images and enhanced image is developed. Another way is by calculating mean values of pixels. High spatial resolution is the benefit of spatial domain image fusion techniques but it produces spatial distortion and blurs images when used which is the drawback of this technique.Different Techniques which falls under this group are:

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- Simple maximum
- Simple minimum
- Averaging
- Intensity-hue-saturation transform based fusion (IHS)
- Principal component analysis (PCA)

B. Transform Domain

In transform domain fusion, initially, Fourier transform method is applied on source images which are to be fused and to regain the resultant image inverse Fourier transform method is applied.Disadvantages encountered on spatial fusion method such as Spatial distortion problem or blurring problem can be sorted efficiently through transform domain as transformed coefficients provide appropriate information from the source image. Various techniques of frequency domain are:

- Wavelet transform
- Curvelet transform
- Contourlet Transform
- Nonsubsampled Contourlet Transform

II.Literature Survey

Much of the research and work has been done in the field of image fusion using wavelet and curvelet fusion technique.

H. Hariharan, A. Koschan and M. Abidi described the Direct Use of Curvelets in Multifocus Fusion. In this effort, a data-driven and application-independent technique to combine focal information from different focal planes is presented. Fusion is performed on medial and peripheral curvelets by relevant fusion rules and the fused image combines information from different focal planes while extending the depth of field of the scene. The main contribution in this effort is the direct use of curvelets in combining multifocal images. And it is concluded that direct curvelet fusion method exhibits improved global sharpness.

Xuelong HU1, Huimin LU and Living ZHANG, Seiichi SERIKAWA describes A New Type of Multi-focus Image Fusion Method Based on Curvelet Transforms. In this after analyzing the classical multi-focus image fusion method, they use the maximum local energy method to calculate the energy of two images. Firstly, coefficients of two different focus images by curvelet transform; secondly, select the low-frequency coefficients by maximum local energy, and through a sliding window, obtained output the Maximum energy pixel information. Then the high-frequency coefficients are gotten by the absolute maximum method; finally, the fused image was obtained by performing an inverse curvelet transform. Compared with the wavelet transform, it exhibits high directional sensitivity and is highly anisotropic.

Jianwei Ma and Gerlind Plonka describes Curvelet Transform in this paper. The curvelet transform is a multiscale directional transform that allows an almost optimal non-adaptive sparse representation of objects with edges. In this article, a review on the curvelet transform is presented, including its history beginning from wavelets, its logical relationship to other multiresolution multidirectional methods like contourlets and shearlets, its basic theory and discrete algorithm The multiresolution geometric analysis technique with curvelets as basic functions is verified as being effective in many fields.

GUO Chao-Feng and LI Mei-Lian presented An Improved Image Denoising Algorithm Based on Wavelet Transform Modulus Maximum This paper proposes an improved image denoising algorithm, which uses a piecewise cubic spline interpolation algorithm to reconstruct wavelet coefficients after denoising based on Modulus Maximum Principle first, and then recompose the image using the mallet algorithm. Using the piecewise cubic spline interpolation algorithm to the de-noise image, the image obtains higher SNRP and smaller MAE. In addition, the piecewise cubic spline interpolation algorithm is simple and convenient. The experiment proves that the piecewise cubic spline interpolation algorithm is effective.

Deepak Kumar Sahu, M.P.Parsai presented a paper on Different Image Fusion Technique This paper presents a literature review on some of the image fusion techniques for image fusion like primitive fusion (Averaging Method, Select Maximum, and Select Minimum), Discrete Wavelet transforms based fusion, Principal component analysis (PCA) based fusion etc. Comparison of all the techniques concludes the better approach for its future research. This review results that spatial domain provides high spatial resolution. But spatial domain has image blurring problem. The Wavelet transforms is the very good technique for the image fusion provides a high-quality spectral content. Finally, this review concludes that an image fusion algorithm based on a combination of DWT and PCA with a morphological processing will improve the image fusion quality.

Ms. V.P.Sawant described Fusion Algorithm for Images based on Discrete Multiwavelet Transform. The discrete wavelet transform (DWT) is more compact, and able to provide directional information in the low-low, high-low, low-high, and high-high bands, and contains unique information at different resolutions. Image fusion based on the DWT can provide better performance than fusion based on other multiscale methods. Multiwavelets are an extension from scalar wavelets and have several advantages over scalar wavelets for image processing.

Vishal P.Tank, Divyang D. Shah, Tanmay V. Vyas, Sandip B. Chotaliya Manthan S. Manavadaria described An Image Fusion Based On Wavelet And Curvelet Transform. In this paper, it has been put forward an image fusion algorithm based on wavelet transform and second generation curvelet transform. The wavelet transform does not represent the edges and singularities well. So the second generation curvelet transform is performed along with the wavelet transform and the image fusion is done. It includes multiresolution analysis ability in Wavelet Transform, also has better direction identification ability for the edge feature of awaiting describing images in the Second Generation Curvelet Transform

A. Pure, Neelesh Gupta, Meha Shrivastava described A New Image Fusion Method based on Integration of Wavelet and Fast Discrete Curvelet Transform this paper describes the curved shapes of images and analyses feature of images better. This paper uses MRI and CT images for fusion which contains complementary information helpful for diagnosis of disease. The fusion

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results obtained from proposed method are analyzed and compared visually and statistically with different types of wavelets used in image fusion. The results of proposed method are efficient and improve the Entropy, PSNR, Mean, STD and MSE. The proposed method can be helpful for better medical diagnosis.

Sweta K. Shah and Prof. D.U. Shah has presented the Comparative Study of Image Fusion Techniques based on Spatial and Transform Domain. This paper presents two approaches to image fusion, namely Spatial Fusion and Transform Fusion. This paper describes Techniques such as Principal Component Analysis which is spatial domain technique and Discrete Wavelet Transform, Stationary Wavelet Transform which are Transform domain techniques. Performance metrics without reference image are implemented to evaluate the performance of image fusion algorithm. Experimental results show that image fusion method based on Stationary Wavelet Transform is remarkably better than Principal Component Analysis and Discrete Wavelet Transform.

Shriniwas T. Budheswar described Wavelet and Curvelet Transform based Image Fusion Algorithm. In this paper, implementation of image fusion algorithm using wavelet and curvelet transform has been described and practical results are compared with several algorithms When the standard deviation value of images of curvelet and wavelet are compared, it is higher for the wavelet transforms. These indicate that wavelet transform is efficient in representing the contrast information. The same can be confirmed by using visual inspection of the fused images. The edges are sharper for curvelet based image than wavelet-based image while contrast for wavelet is better than curvelet based method. These prove that curvelet transform can represent the curves efficiently than wavelet transform and wavelet has better capability to represent texture, contrast information than curvelet.

Author	**Year**	**Method/ Technique**	**Remark**
H. Hariharan, A. Koschan and M. Abidi	2009 (IEEE)	Curvelet transform	Curvelet transform is done on multifocal images
Xuelong HU1, Huimin LU and Living ZHANG, Seiichi SERIKAWA	2010 (IEEE)	Curvelet transform	Determines new type of multi-focus image fusion method based on curvelet transform
Jianwei Ma and Gerlind Plonka	2010 (IEEE)	Curvelet transform	A review on the curvelet transform is presented, including its history beginning from wavelets, its logical relationship to other multi-resolution multidirectional methods
GUO Chao-Feng and LI Mei-Lian	2010 (IEEE)	Wavelet transform	Determines An Improved Image Denoising Algorithm Based on Wavelet Transform Modulus Maximum.
Deepak Kumar Sahu, M.P.Parsai	2012		a literature review on some of the image fusion techniques for image fusion like primitive fusion, Discrete Wavelet transform based fusion, Principal component analysis (PCA)
V.P. Sawant		Wavelet transform	A paper on fusion algorithm based on discrete wavelet transform (DWT)
Vishal P.Tank, Divyang D. Shah, Tanmay	2013	Wavelet and	Describe that the wavelet transform does not represent the

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V. Vyas, Sandip B. Chotaliya Manthan S. Manavadaria		curvelet transform	edges and singularities well. So the second generation curvelet transform is performed along with the wavelet transform
A. Pure, Neelesh Gupta, Meha Shrivastava	2013	Wavelet and fast discrete curvelet transform	This paper uses MRI and CT images for fusion which contains complementary information helpful for diagnosis of disease.
Sweta K. Shah and Prof. D.U. Shah	2014	Principal compone nt analysis and wavelet transform	This paper presents two approaches to image fusion, namely Spatial Fusion and Transform Fusion
Shriniwas T. Budheswar	2014	Wavelet and curvelet transform	In this paper, implementation of image fusion algorithm using wavelet and curvelet transform has been described and practical results are compared with several algorithms

III.Methodology

A.Principal Component Analysis (PCA)

A vector space transform often used to reduce multidimensional data sets to lower dimensions for analysis is called Principal Component Analysis (PCA). In other words, PCA transforms the number of correlated variables into uncorrelated variables called principal components. In this method, a weighted average of Images to be fused is calculated. The weights for each source image are obtained from the Eigenvector. The objective of PCA is to reduce dimensionality by extracting the smallest number of components that result for most of the variation in the original multivariate data and conclude the data with little loss of information which can be neglected to get the best resultant image. Fusion of images using PCA algorithm are discussed as follows.

1. The column vectors are generated from the input image matrices.
2. The covariance matrix of the two column vectors produce are calculated
3. The diagonal elements of the 2x2 covariance matrix contain the variance of each column vector with itself, respectively.
4. Eigen values and the Eigen vectors of the covariance matrix are calculated.
5. Corresponding to the larger Eigen value normalize the column vector by dividing each element by mean of Eigen vector.
6. The output values of the normalized Eigen vector are the weight values which are respectively multiplied with each pixel of the input images. Sum of the two scaled matrices calculated in last step will be fused image matrix.

The fused image is: I= P1I1+ P2I2.

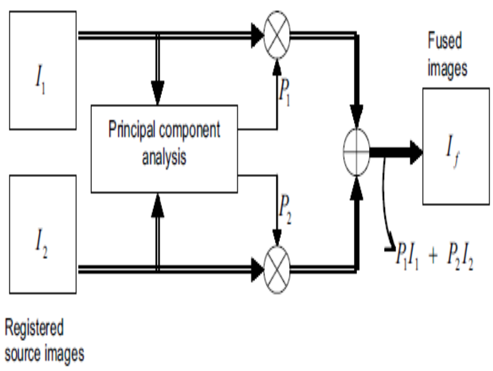

Figure 1: Image Fusion by PCA

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C. Discrete Wavelet Transform(DWT)

The Discrete Wavelet Transform (DWT) is based on sub-band coding which is found to yield a fast computation of Wavelet Transform. The discrete wavelet transform is a multiscale (multiresolution) approach well suited to manage the different image resolutions. In wavelets, the signal is projected on a set of wavelet functions. Wavelet provides good resolution in both time and frequency domains. In wavelet-based transform, the signal is divided into scaled (dilated or expanded) and shifted (translated) versions of the chosen mother wavelet or function. Implementation of the wavelet transform is easy and it reduces the computation time and resources required.

Using discrete wavelet transform in image process input or original images are multi differentially decomposed into sub-images in different spatial and frequency domain and transform the coefficient of sub-image. In DWT, the projecting information in signal appears in high amplitudes and the receding information appears in very low amplitudes. By discarding this receded information data compression is acquired. The wavelet transforms enables high compression ratios with good quality of reconstruction.
The DWT uses low-pass and high-pass filters, h (n) and g (n), to expand a digital signal. They are referred to as analysis filters. The dilation performed for each scale is now achieved by a decimator. After each level of decomposition, four bands of data is produced for 2-d images in which one is low-frequency district (LL) and three high-frequency districts (LH, HL, HH) as depicted in the figure.

1, 2, 3-Decomposition level
L-Low frequency band
H-High frequency band

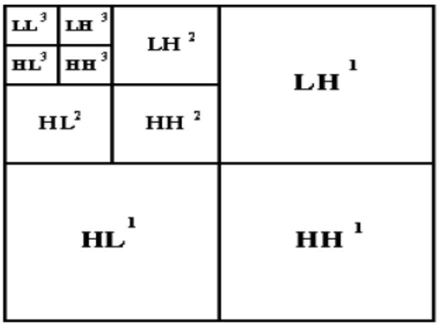

Figure 2: Wavelet Decomposition

D. Curvelet Transform

The curvelet transform is a multiscale directional transform that allows an almost optimal non-adaptive sparse representation of objects with edges. Curvelet transform was introduced by candles and Donoho in the year 2000 which is suited for objects which are suited for curved surfaces. To analyze local line or curve singularities, a partition of the image is considered, and then the ridgelet transform is applied to the obtained sub-images. Curve discontinuities are handled efficiently by curvelet transform as they are designed to handle curves using only a small number of coefficients. Curvelet transform was extended to the fields of edge detection and image denoising. Curvelet transform can represent appropriately the edge of image and smoothness area in the same precision of inverse transform. Steps involved in Curvelet transform is as follows:

1. The image P is split up into three sub-bands Δ1, Δ2 and P3 using the additive wavelet transforms.
2. Tilting is performed on the sub-bands Δ1 and Δ2
3. The discrete Ridge let transform is performed on each tile of the sub-bands Δ1 and Δ2.

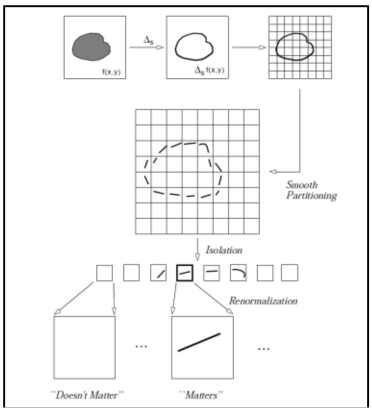

Figure3: Overview of Organization of the Curvelet Transform

IV. MODIFIED IMAGE FUSION ALGORITHM

Fusion of Wavelet and Curvelet by Simple Average and Weighted Average

1. Read the blur images (i. e I1 and I2) captured from two different cameras or sensors.

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2. Check if the two images are same in size if the image size is not same then resizing the images to keep both images of the same size. (resize function is used)

3. Apply Gaussian filter on both the input images Equation of Gaussian function

$$G(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

4. Perform Wavelet decomposition or signal decomposition (LPF and HPF filter bank is used)
5. Deriving wavelet coefficients using Wavelet basis function

$$W_{a,b}(f(x)) = \int_{x=-\infty}^{\infty} f(x)\psi_{a,b}(x)dx$$

$$\psi_{a,b}(x) = \frac{1}{\sqrt{a}}\psi\left(\frac{x-b}{a}\right)$$

Dilation factor a = 2m
Translation factor b = n2m
Where m and n are integers.

6. Perform IDWT Inverse discrete wavelet transform on both the images.
7. Tilting and driving approximation component P3 of original image

$$P = \sum_{i-1}^{n-1} \Delta 1 + Pn$$

8. Deriving the basis function for Ridgelet transform and find Ridgelet transform
- The ridgelet basis function is given by:

  Ψa, b, θ(x1, x2) =a-1/2ψ ((x1cosθ+ x2sinθ-b)/a)

  for each a>0, each bϵR and each θϵ [0, 2π]

- Ridgelet coefficients of an image f(x1, x2) are represented by:

  Rf (a, b, θ) = ∫ Ψa, b, θ (x1, x2) f(x1, x2) dx1 dx

  Curvelet coefficients are obtained.

9. Perform Simple average by given formula

f (i, j) = x (i , j) + y(i , j) / 2

10. Perform Weighted average by given formula

f (i, j) = w1 * x (i, j) + w2 * y (i , j) / 2

Where w1, w2 ∈ (0 , 1)

11. Last, to compare the results of Spatial and Frequency Domain with proposed method - Fusion of Wavelet and Curvelet by Simple Average and Weighted method, in terms of PSNR and MSE.

Flow of Proposed Work

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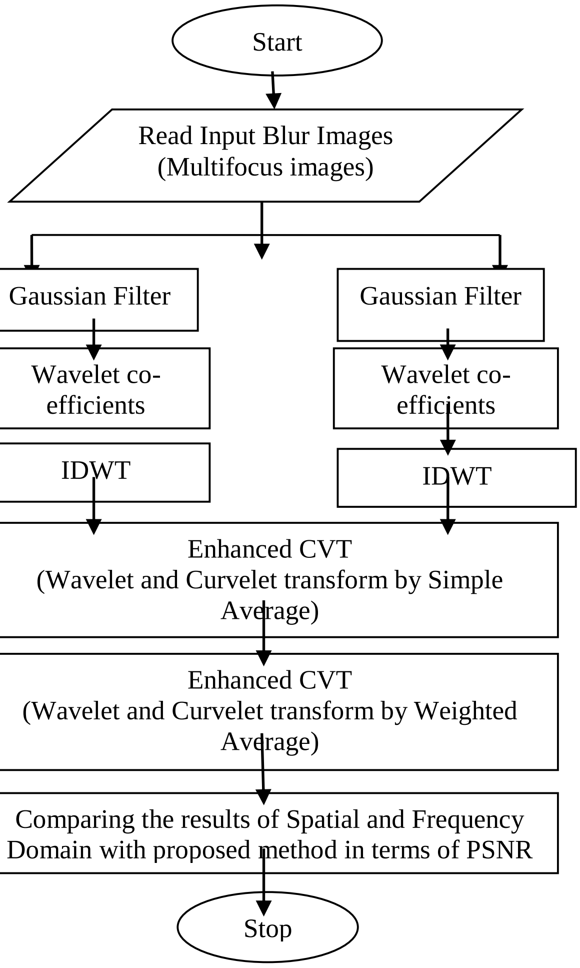

V.EXPERIMENTAL RESULTS

Experimental results of different technique such as PCA, Wavelet transform, Curvelet transform and proposed image fusion method for fusion and their comparison are shown below:

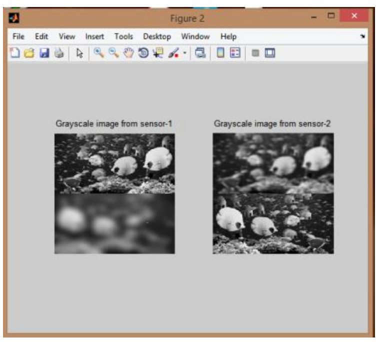

Figure 4: Gray scale image

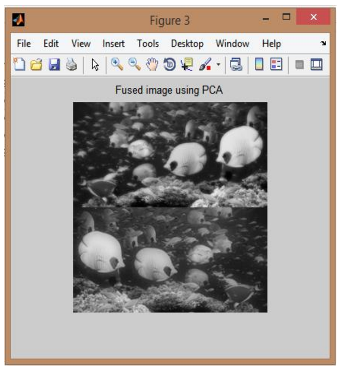

Figure 5: Fusion Image by PCA

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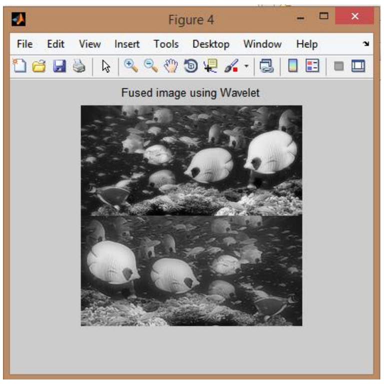

Figure 6: Fusion Image by Wavelet

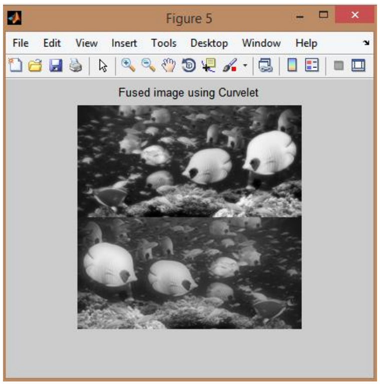

Figure 7: Fusion Image by Curvelet

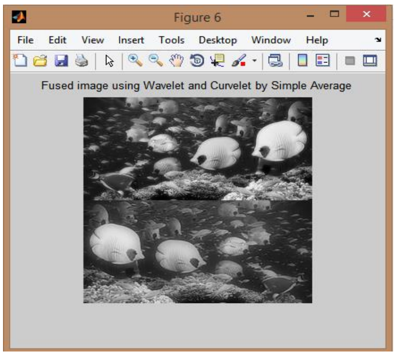

Figure 8: Fusion Image by Simple Average

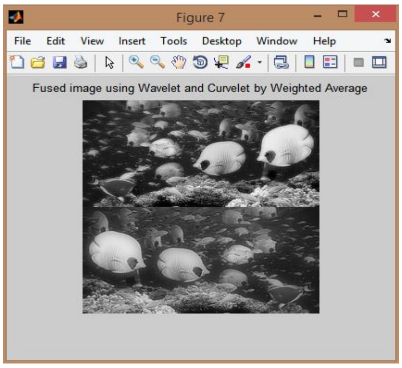

Figure 9: Fusion Image by Weighted Average

Quantitative Analysis of fusion methods:

	PCA		**Wavelet**	
	PSNR	**MSE**	**PSNR**	**MSE**
Image-1 and IDEAL	67.147	0.0125	67.147	0.0125
Image-2 and IDEAL	72.169	0.0039	72.169	0.0039
FUSED IMAGE and IDEAL	72.278	0.0038	73.227	0.0031

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A. PCA and Wavelet

	Curvelet		**Modified algorithm Fusion of Wavelet and Curvelet Using Simple Average**		**Modified algorithm Fusion of Wavelet and Curvelet Using Weighted Average**	
	PSNR	**MSE**	**PSNR**	**MSE**	**PSNR**	**MSE**
Image-1 and Ideal	67.147	0.0125	67.147	0.0125	67.147	0.0125
Image-2 and Ideal	72.169	0.0039	72.169	0.0039	72.169	0.0039
Fused Image and Ideal	71.948	0.0042	69.733	0.0020	79.275	0.0015

B. Curvelet and proposed method

CONCLUSION

With the help of experimental results on multi-focus images, it has been proved that a weighted average fusion using Curvelet in comparison to simple Curvelet-based image fusion will increase the PSNR and reduce the MSE compared to all other methods.

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