# Image Fusion: A Review

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## Abstract

At the present time, image fusion is considered as one of the types of integrated technology information, it has played a significant role in several domains and production of high-quality images. The goal of image fusion is blending information from several images, also it is fusing and keeping all the significant visual information that exists in the original images. Image fusion is one of the methods of field image processing. Image fusion is the process of merging information from a set of images to consist one image that is more informative and suitable for human and machine perception. It increases and enhances the quality of images for visual interpretation in different applications. This paper offers the outline of image fusion methods, the modern tendencies of image fusion and image fusion applications. Image fusion can be performed in the spatial and frequency domains. In the spatial domain is applied directly on the original images by merging the pixel values of the two or more images for purpose forming a fused image, while in the frequency domain the original images will decompose into multilevel coefficient and synthesized by using inverse transform to compose the fused image. Also, this paper presents a various techniques for image fusion in spatial and frequency domains such as averaging, minimum/maximum, HIS, PCA and transform-based techniques, etc.. Different quality measures have been explained in this paper to perform a comparison of these methods.

**Keywords:** Image Fusion, Fusion Methods,  Spatial Domain Fusion, Transform Domain Fusion, Image Quality.

## Introduction

In many situations a single image cannot describe the scene accurately, because the scene is usually taken using more than one sensor. Only a single image is more appropriate for human or machine processing, therefore it is significant to fuse all the images from different sensors to form a single image with all relevant information. With the spreading of image processing, image fusion has been a significant subject in several associated areas such as computer vision, remote sensing, object detection, medical imaging, image classification [1]. The term fusion refers into a method extracting of information that is gained in several areas. Data fusion deals with data and information from different sources to achieve enhanced information for decision making. Data fusion can be defined as a multidisciplinary field that contains several domains. The objective of data fusion is joining related information from two or more data to form a single data that is more accurate than the separate data. There are some terms related to data fusion like data combination, decision fusion, data aggregation, multisensory data fusion [2]. Image fusion can be defined as a manner of mixing the information from a set of images to form one image and produce a fused image that is more complete and informative than the original images. The purpose of image fusion is construct a fused image output that supplies the information which is more reliable and more suitable. The general definition of image fusion is the blending of two or more various images to form a new image by implementing a suitable algorithm [3]. The goal of image fusion increases corresponding information from various sources into one new image. The term fusion means extracting the information in different domains. A good fusion is getting on information from the original images and the resulted image without any changeability [4].

The fusion algorithm must satisfy the following requirements:

- It keeps on important features of the original image without loss of detail infused image.

- It prevents any artifacts in the image as noise [5].

The fusion process can apply at various levels of information representation is signal level, pixel-level and feature level. Signal level fusion merges set of signals that have an identical general design. At pixel level (image-level) combines a set of pixels of images in order to make the fusion decision like maximum, minimum and average pixels. While infusion based on the feature level, the information will be extracted from source images individually and then merged based on original image features. Infusion based on decision level, the information will extract from each source image individually and then the decisions are made for each input channel.These decisions are fused to produce the final decision [3,6].

Image fusion can be distinguished by the following categories:

- Multi-view fusion: Images are the same modal and time, but in various conditions are shown in Figure 1.


**Figure 1. multi view image fusion [3]**

- Multimodal fusion: Images are different modalities: MRI, visible, infrared, ultraviolet, etc. as shown in Figure 2.

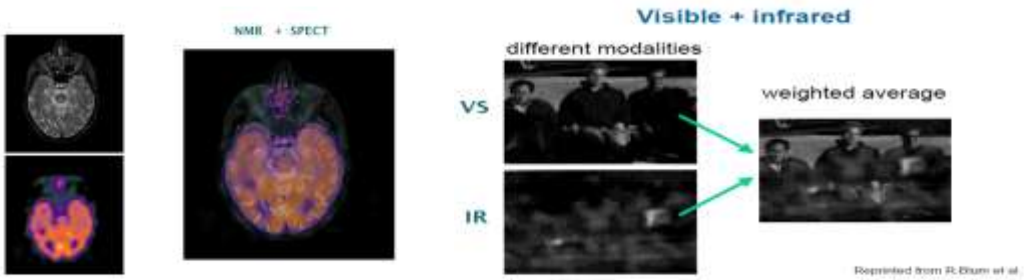


**Figure 2. multimodal image fusion [3]**

- Multi-temporal fusion: images are taken at various times, but with same modality are shown in Figure 3.

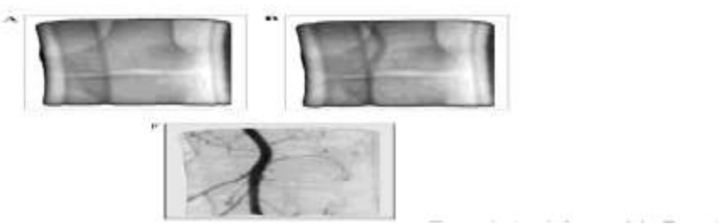

**Figure 3. multi temporal image fusion [3]**

Multi focus fusion: images of a 3D scene will be taken frequently with different central length as shown in Figure 4.

- Fusion for image Deconvolution (restoration): Where each image involves a true region and degradation region, which removes the degradation part by using the fusion process is shown in Figure 5 [3].

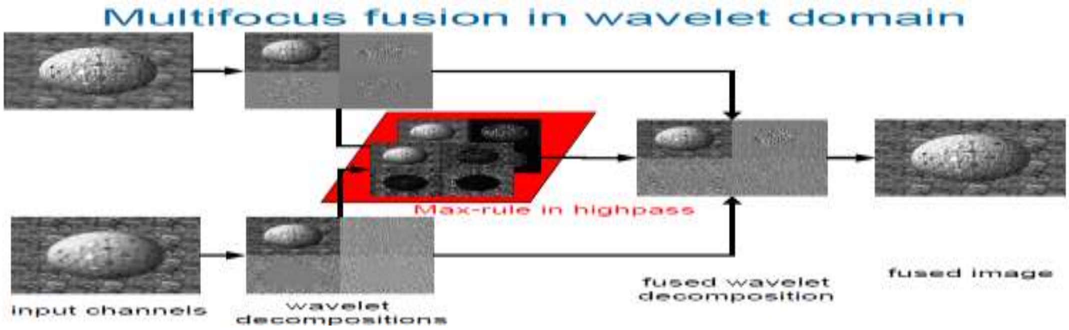


**Figure 4. multi focus image fusion [3]**

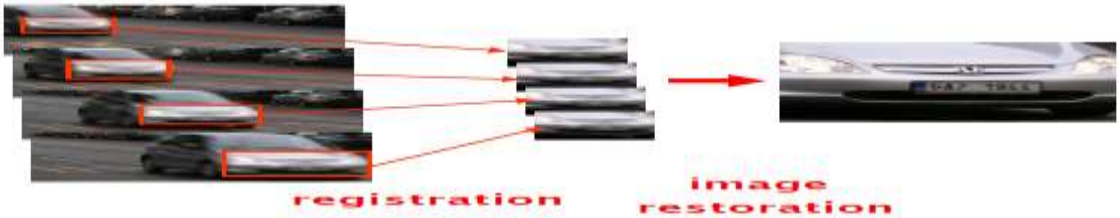


**Figure 5. image restoration for fusion [3]**

The fusion process is applied based on characteristics of a set of regions of input images, such as, contrast, shape and texture. The fusion process is applied in the spatial and frequency domain is shown in Figure 6 [6].

**Related Work**

Different kinds of the method are offered in this section, which are used for image fusion.

• Krishnamoorthy *et al.* [7] designed a comparative study of image fusion algorithms. They used three types of algorithms are the basic fusion, the pyramid, and the DWT algorithms. They showed that fused images with her wavelet would give the best result, approximately 63.33% of the time from any other algorithm.

• Choodarathnakara *et al*. [8] presented the valuation of fusion methods on remote sensing imagery. They compared between these techniques PCA, BT, MT, and DWT. They concluded the DWT fusion method gives the best result from other techniques.

• Sahu *et al*. [9] presented an image fusion by different methods and they used simple fusion methods as (Averaging, Maximum and Minimum), discrete wavelet transform, principal component analysis (PCA). They compared of these techniques and they concluded that image fusion by using DWT and PCA together would enhance the image quality.

• Jawale *et al.* [10] designed the implementation of image fusion technique using wavelet transform. They used 54 types of wavelet, 9 fused rules and compared to the fusion of many images. The fused image results from better goodness as well as similarity towards the single images. They show the best wavelet family is Haar, and the best fusion rule is Mean-Max. Since the similarity measures of the images were all more than 0.999, the fused images they got were nearly identical to the original images. It is much more precise.

• Zhu *et al.* [11] presented image fusion using wavelet for medical images. They implemented CT image and MRI image and they choose variance and average wavelet. They showed that this technique was better than the weighted maximum, local energy and regional variance fusion rules.

• C. Pavithra and S.Bhargavi [12] proposed a fusion of two images based on wavelet. They used the join between the gradient criterion and the smoothness criterion. They showed the use of both gradient criteria and smoothness criteria together gave better results from than using them separately. The gradient guarantees the existence edges in the images while the smoothness guarantees that the regions of regular density in the fused image minimize the effect of noise.

• Mandhare *et al.* [13] prepared image fusion using proven transform and wavelet transform. They used (averaging, multiplicative, Brovey and DWT) methods. They showed that image fusion by multiplicative and wavelet methods give higher spatial resolution and spectral than the original images.

• Rani *et al.* [14] proposed image fusion using discrete wavelet and multiwavelet. They used maximum fusion rule for using image fused. They concluded that multiwavelet analysis can give better performance than wavelet analysis.

• Mishra *et al.* [15] discussed image fusion MRI and CT by using wavelet transform. They performed the wavelet transform and different fusion rules like maximum, minimum and average methods on the images. They concluded that maximum method gives results better through least MSE and highest PSNR values.

• Tawade *et al.* [16] proposed image fusion by using wavelet. They concluded using fusion wavelet method and weighted will acquire a well fusion image of CT/PET compare to CT or PET separately. They exactly notice the unhealthy part in human body. Wavelet transform was same to human system, so the result showed improvement in visualization and interpretation.

• Agarkar *et al.* [17] prepared efficiency MRI and CT images fusion methods. They extended the hybrid approach of image fusion by using a curvelet transform method with wavelet transform to achieve improving the performance. They employ a fast curvelet transform method with wavelet transform to the speed of this method.

**Spatial Domain Image Fusion**

It is one of the pixel level fusion methods that is efficient and easy to implement. The weighted average is the simplest approach of the image fusion that uses of the pixel intensity of the corresponding pixels of original images. Image fusion can be computed according to Equation (1).

$$IF = \Phi (I1, I2,..., IN) = \alpha 1I1 + \alpha 2I2 + ... + \alpha NIN \quad (1)$$

The techniques of spatial domain include Averaging, select maximum/minimum method, Bovey transforms, Intensity hue- saturation method (IHS), High pass filtering method (HPF), Principal component analysis method (PCA) as shown in Figure 6. Spectral degradation is one of the drawbacks of spatial domain fusion [5,18].

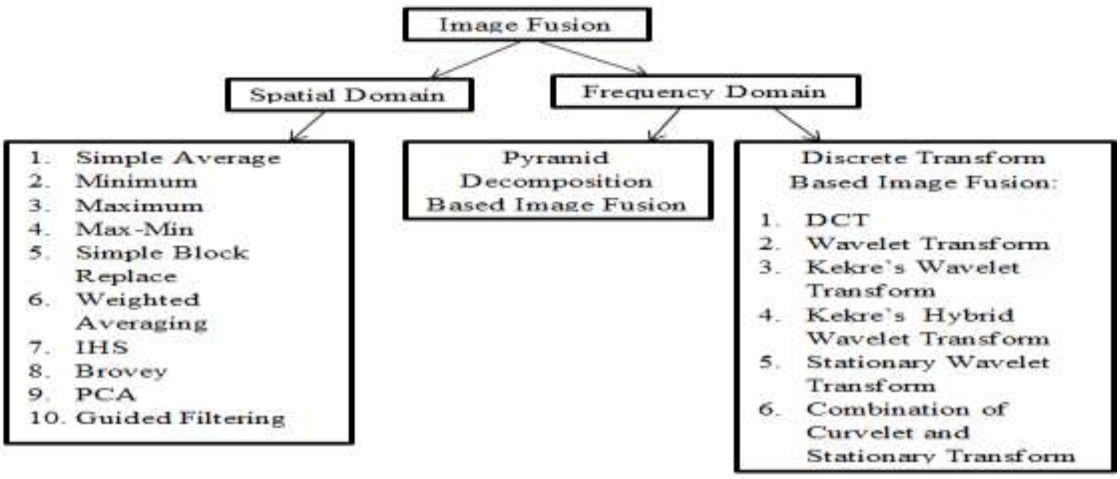


**Figure 6: Image Fusion Techniques [6]**

### Average Pixel image fusion

The fusion process is done on a pixel basis. For example consider two input images *I1*(x,y) and *I2*(x,y) that are required to be fused and *If*(x,y) be the fused output image. The process of merging *I1*(x,y) and *I2*(x,y) into *If*(x,y) is called Image Fusion. Figure 7 illustrated a pixel-based image fusion algorithm [18].

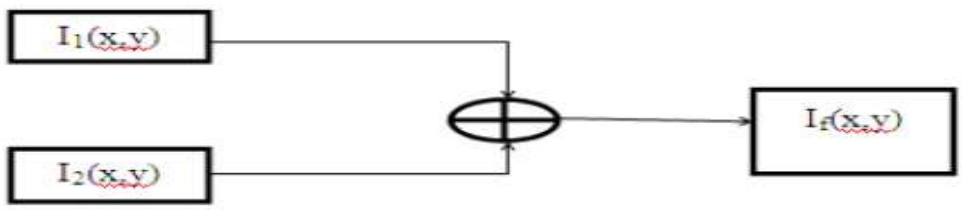


**Figure 7. Information flow of average pixel based image fusion [18]**

### Select maximum/minimum method

It is a nonlinear operation because it uses a maximum or minimum operator. The pixel with minimum intensity is selected from the corresponding pixel of the input images and is used as the resultant pixel. So every pixel in the fused image will contain pixels with minimum intensity. In the same method, the pixel with maximum intensity is selected from the corresponding pixel of the input images and for every pixel position the pixel of the fused image will be the pixel of the corresponding position from the input set of images having the highest pixel intensity value [19,20].

Figure 8 illustrated select maximum/minimum image fusion algorithm according to Equations (2) and (3).

$$I_f\,(x,y) = \max(I1(x,y),\, I2(x,y)) \qquad (2)$$

$$I_f\,(x,y) = \min\,(I1(x,y),\, I2(x,y)) \qquad (3)$$

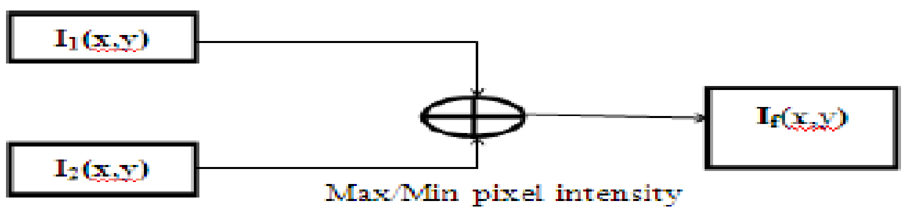


**Figure 8.. Information flow of select maximum/minimum image fusion algorithm [19]**

### Weighted Average Method

In this method, the fused image is achieved by taking the weighted average intensity of corresponding pixels from both the original images according to Equation (4) [20].

$$F(i,j) = \sum_{i=0}^{m} \sum_{j=0}^{n} W\, A(i,j) + (1-W)B(i,j) \qquad (4)$$

Where A(i, j) and B(i,j) are input images.

F(i,j) is fused image

W is weight factor.

***Principal Component Analysis (PCA)*** Karl Pearson was invented Principal component analysis in 1901. PCA is similar to IHS transform, the advantage of the PCA method over IHS method is that a random number of bands can be utilized. This is one of the most popular methods for image fusion. Principal component analysis (PCA) is a vector space transform used to reduce sets of data to lower dimensions for analysis PCA is widely used in data compression and pattern matching without much loss of information. PCA is a statistical procedure that uses to transform a set of observations of correlated data into a set of values of linear uncorrelated data named principal components as is shown in Figure 9 [19, 21].

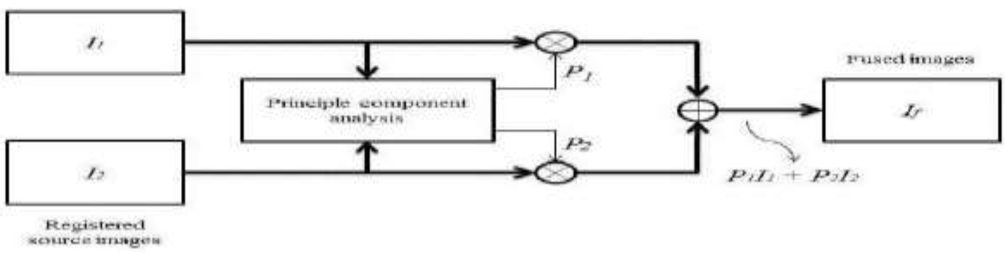


**Figure 9. Diagram of PCA algorithm [21]**

***Intensity Hue Saturation***

It is a method that effectively separates spatial (intensity) and spectral (hue and saturation) information from an image. This method converts a color image from RGB space to the I (intensity) H(hue) and S(saturation) components color space.

$$\begin{bmatrix} I \\ V1 \\ V2 \end{bmatrix} = \begin{bmatrix} 1/3 & 1/3 & 1/3 \\ -\sqrt{2}/6 & -\sqrt{2}/6 & 2\sqrt{2}/6 \\ 1/\sqrt{2} & -1/\sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Then the intensity is replaced with a high spatial resolution image. In this method three multispectral bands R, G and B of low resolution. Finally, apply an inverse transformation to transform from IHS space to the original RGB space and formation the fused image according to the following linear transformation as is shown in Figure 10 [20, 22].

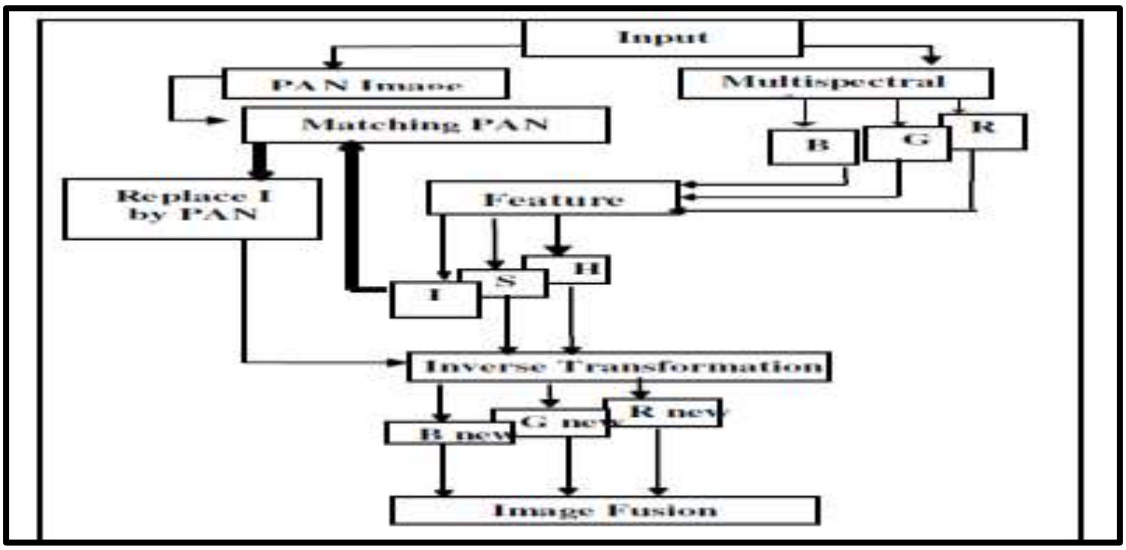


**Figure 10. Intensity Hue Saturation fusion process [22]**

**Brovey Transform Image Fusion**

Brovey transform is a simple technique to combine data from different sensors. It contains on three bands only. The purpose of it is normalize the multispectral bands utilized for RGB shown to increase the brightness or intensity to the image.

This technique creates the development of a user automated tool. It was established to avoid the disadvantages of the multiplicative procedure. It is a mixture of arithmetic operations and normalizes the spectral bands [23].

**Artificial Neural Network**

Artificial Neural networks (ANN) have found in pattern recognition. It is used as a nonlinear response function. It uses Pulse Coupled Neural Network (PCNN) which contains a feedback network. This network is divided into three parts called the receptive part, the modulation part, and the pulse generator. Each neuron corresponds to the pixel of the original image. The advantage of this method is in terms of hardiness against noise, independence of geometric differences and ability of bridging secondary intensity variations in input patterns. Pulse Coupled Neural Network has biological significance and utilized in medical imaging as this technique is possible and provides real time system performance as is shown in Figure 1 [22, 24].

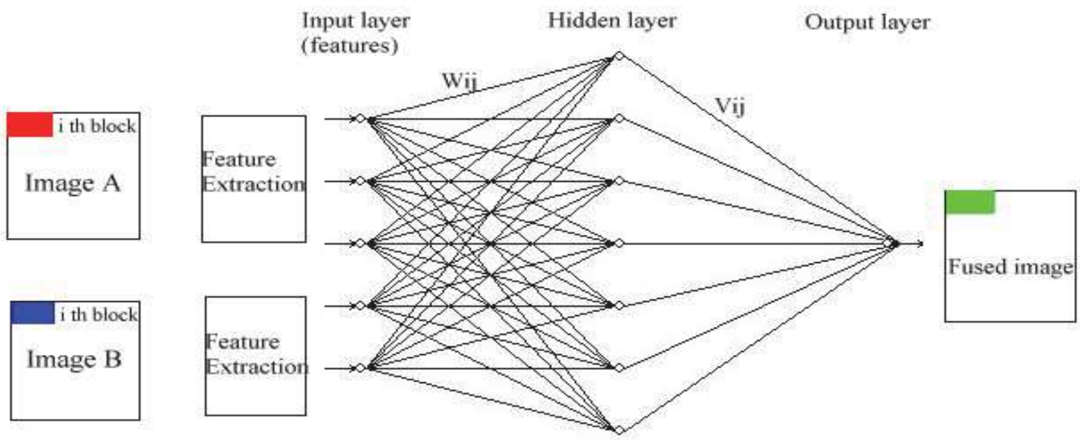


**Figure 11. Schema of the ANN-based image fusion method [24]**

**Fuzzy logic based Methods**

Fuzzy logic employs in various environments for designing a number of different applications as image processing. Fuzzy logic presents a logical system differs from the traditional logical system. In case that there does not find any mathematical relations between elements through image processing, fuzzy logic is used to resolve the problem of ambiguity. Fuzzy image processing consists of three main phases: image fuzzification, modification of membership values, and de-fuzzification (if required). Fuzzy logic based multi-focus image fusion used in many techniques as a simple rule-based if-then system, pixel clarity and salience map of the gradient, the index of fuzziness as is shown in Figure 12 [2, 25].

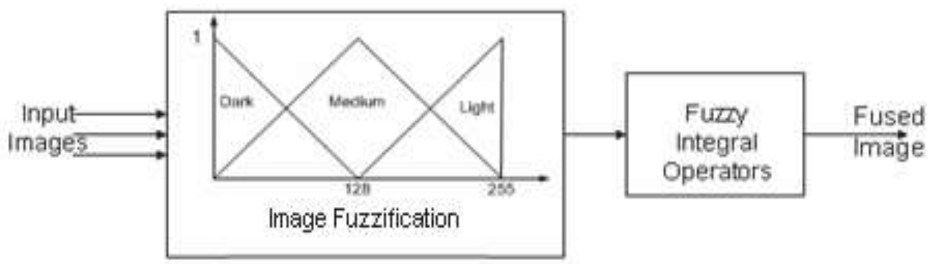


**Figure 12. Block diagram of fuzzy logic image fusion [2]**

### Transform Domain Image Fusion

In the frequency domain, the image is transferred into a frequency domain that means, the Fourier Transform of the image is calculated first. Then perform the Inverse Fourier transform to get the resultant image. The original images in the frequency domain will decompose into multilevel coefficient and synthesized by using an inverse transform to compose the fused image [5].

### Wavelet-Based Image Fusion

Wavelet transform is a domain transform method. It is a more common method used for image fusion. The discrete wavelet transform decomposes the original images into four sub bands by the filters with each level K, called approximation coefficients, vertical details, horizontal details, and diagonal details. The processing wavelet coefficients of each level are the input of the next level. The fused image is gained by utilizing IDWT process. Wavelet transform allow for analysis the images by using different levels of accuracy. Discrete wavelet transform tends for choosing the distinguishing features of an image. Wavelet transform is used in different areas such as image fusion, texture analysis, feature detection, data compression etc. Discrete transform based fusion scheme is shown in Figure 13 [18,26].

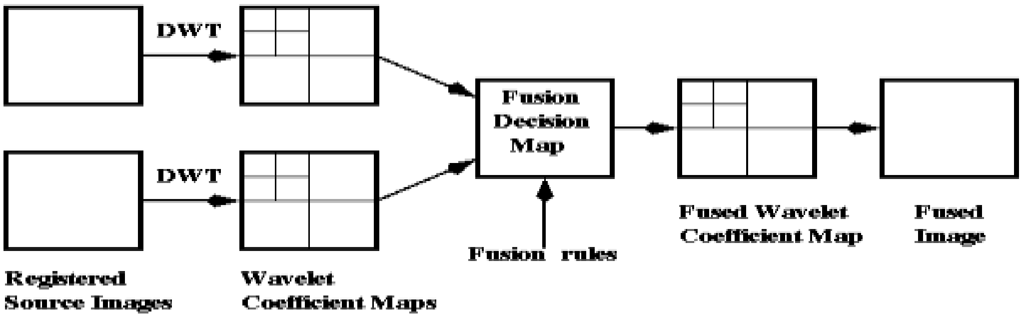


**Figure 13. Diagram of discrete transform based image fusion [18]**

### Stationary Wavelet Transform (SWT)

The stationary wavelet transform is very similar to the discrete wavelet transform but it differs from than discrete wavelet transform is that the process of downsampling is suppressed that's why stationary wavelet transform is translation invariant. The process of downsampling in stationary wavelet transform is suppressed and hence this transform is considered to be translation invariant unlike discrete wavelet transform. Transform is performed at each point of the image and the coefficients are kept; low-frequency information alone is used at each level of the transform is shown in Figure 14 [6,26].

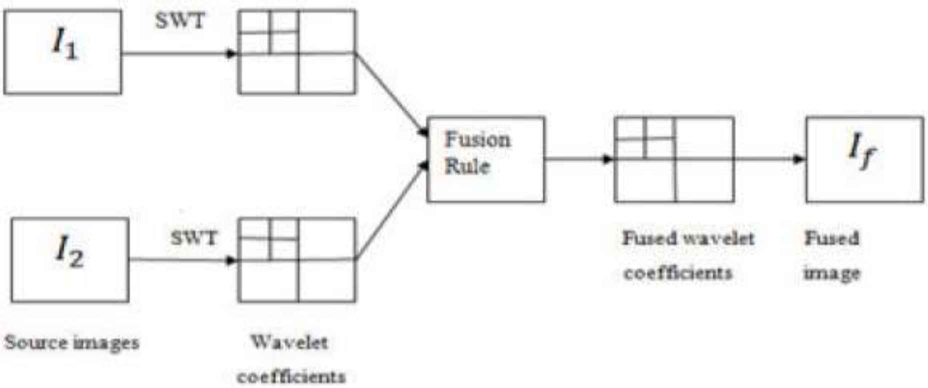


**Figure 14. Diagram of stationary wavelet transform based image fusion [6]**

### Curvelet Transform Based Image Fusion

In curvelet transform, the basis function is in the form of curve i.e.. It is a multi-scale transform that works on image in anisotropic way. Which gives the best approximation with less curvelet coefficient in a reduced amount of time compared to wavelet transform. Figure 15 illustrates the decomposition of the input image into sub-bands followed by the spatial partitioning of each sub-band(i.e., each subband is decomposed into blocks). The ridge lets transform is then applied to each block [26,27] .

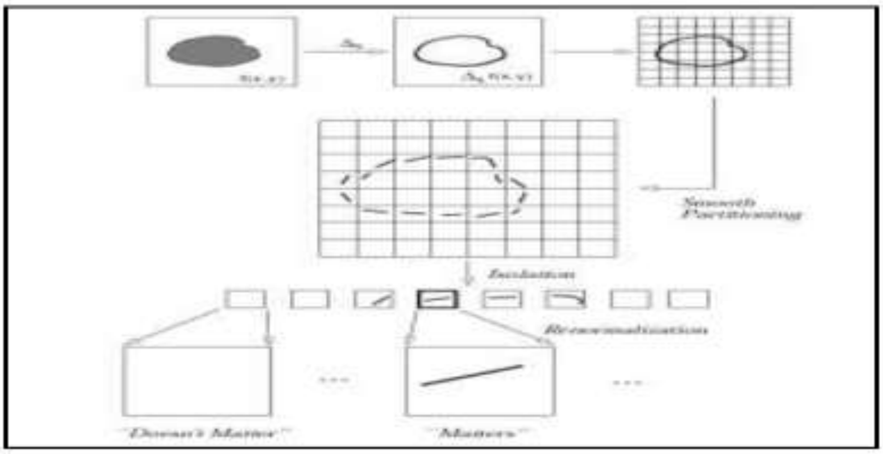

**Figure 15. Diagram of curvelet transform [27]**

### High Pass Filtering

The high pass resolution of multispectral images is gained from high pass filtering. The high-frequency information that is obtained from the high-resolution panchromatic image is added to the low resolution multispectral image to get the resultant image. It is achieved either by filtering the high-resolution panchromatic image or by the original (High-Resolution Panchromatic Image) HRPI and subtracting (Low-Resolution Panchromatic Image) LRPI from it. The spectral information limited in the low-frequency information of the high-resolution multispectral image is preserved by this method [3,28].

### Pyramid Techniques

Image pyramids can be called as a model for the binocular fusion for the human visual system. By creating the pyramid structure an original image is signified in various levels. A composite image is designed by applying a pattern selective method of image fusion. Firstly, the pyramid decomposition is implemented on each original image. All these images are integrated to form a composite image and then apply inverse pyramid transform to get the resultant image. Image fusion is carried out at each level of decomposition to form a fused pyramid and the fused image is obtained from it [24].

### Discrete Cosine Transform

Discrete cosine transform has created significance for the compressed images in the form of MPEG, JVT etc. In discrete cosine transform, the spatial domain image is transformed into the frequency domain image. This method is divided the images into three parts as low frequency, medium frequency and high frequency. Average illumination is signified by the DC and the AC values are the coefficients of high frequency. The image is divided into the blocks of with the size of 8*8 pixels. The image is then grouped by the matrices of red, green and blue and transformed to the grayscale image [3,24].

**Table 1. Comparison between some of techniques of image fusion**

| No. | Image fusion method | Domain | Advantage | Disadvantage |
|---|---|---|---|---|
| 1 | Average Pixel image fusion | Spatial | This method is very simple, easy to understand and implement. | It reduces the resultant image quality consequently by introducing noise into the fused image. It leads to unwanted side effects like reduced contrast. |
| 2 | Select Minimum/ Maximum | | This method is very simple, easy to understand and implement. | These methods produce blurred output, which in turn affects the contrast of the image. Therefore, these techniques are not suitable for real-time applications. |
| 3 | Intensity Hue Saturation (IHS) | | This method is very simple, computationally efficient and faster processing and high sharpening ability. | It only processes three multispectral bands and results in color distortion |
| 4 | Principle component analysis (PCA) | | This method is very simple, computationally efficient, faster processing time and high spatial quality. | Results in spectral degradation and color distortion |
| 5 | Brovey transform (BT) | Frequency | very simple, efficient and faster. It creates RGB images with higher degree of contrast. | Results in color distortion |
| 6 | Wavelet Based Image Fusion | | It provides a good quality fused image and better Signal to Noise Ratio. It also minimizes spectral distortion. | The fused image has less spatial resolution. |
| 7 | Stationary Wavelet Transform (SWT) | | This method provides a good result at level2 of decomposition | It is time-consuming |
| 8 | Curvelet Transform (CT) | | This algorithm is very well suitable for real applications. | It is time-consuming |
| 9 | Discrete Cosine Transform (DCT) | | It minimizes the complexity and this algorithm can be utilized for real applications. | in this method, if block size is less than 8x8 fused image is not of well quality. |

**Objectives of Image Fusion Schemes**

The goal of it is to study the meaning of image fusion in image processing. The aims of image fusion can be categorized into the following sections:

- **Image sharpening**: it is considered as one of the key goals of image fusion for increasing the spatial resolution of the original image. It is a challenging field of remote sensing, which has become more related to high spatial-resolution satellites and spectral sensors.

- **Feature enhancement:** Image enhancement is a process improvement the original image in such a method that the output image is more appropriate for interpretation by the humans. In some cases, properties in the image may be distorted noise or blur. Through the use of detailed information from other sensors and fusing this information into one the image will be enhanced features the image.

- **Robotic vision:** Robotic vision is one of significant sensor utilized in the scope of robotics for improving the robot vision. Self-localization is considered as one of the more issues in robotic vision by which a robot identifies its location. Most of these sensors fail to provide reliable results because low signal to noise ratio measures and other sensory problems.

- **Biomedical applications:** The term of Image fusion becomes common within medical diagnostics and treatment. Image fusion is used with multiple images of a patient and overlaid or merged for providing additional information. Fused medical images may be generated from a set of images from the same modality or by merging information from a set of modalities such as magnetic resonance image (MRI), computed tomography (CT), positron emission tomography (PET), and single-photon emission computed tomography (SPECT). Image fusion offers an analysis tool that facilitates the categorization and discovering of illnesses from several methods (modality) such as MR or CT images, etc.

- **Clutter removal:** The satellite images is one of the types multi-spectral images that taken by image sensors that are covered with cloud or fog during bad weather.On several cases in the areas of sensing, the real scene can be covered with clutter or clouds. By image fusion methods was cleared out the cloud, blue and noise [29,30]**.**

**Applications of Image Fusion**

- The fusion process is used in object detection for maximizing the amount of information extracted from the satellite image can be found in fused images. A fusion process basically usages in remote or satellite image range to the suitable view of satellite vision.

- Fusion method uses in medical imaging through Location/identification of tumors, abnormalities and disease, where disease should examine through an imaging vision by spatial and frequency domain.

- Image fusion method used in military field as detection, tracking, identification of ocean (air,ground) target/event, concealed weapon detection, and Battle-field monitoring. where all the perspectives utilized to identify threats based on performance.

- The fusion process is effectived in machine vision that used to visualize the two states for the human vision.

- Fused images used in the robotics field to object location/recognition, guide the locomotion of the robot and analyze the frequency differences in the images.

- In artificial neural networks used 3d image fusion where the focal length differs based on wavelength conversion is shown in Figure 16 [3,31].

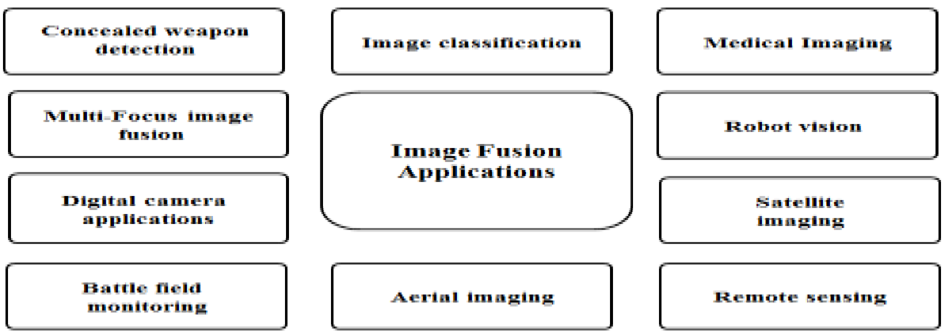


**Figure 16. image fusion applications [32]**

**Image Quality Metrics**

Image quality can be defined as a feature of an image that processes the image corrupted compared to a pure image. Performance metrics are used essentially to measure the possible benefits of fusion and also used to compare results gained using various algorithms [5].

***Mean Square Error (MSE)***

It is used to measure of the differences between values of the input image and fused image divided by dimensions of the image according to Equation (5).

$$\text{MSE}=\sum_{i=0}^{n-1}\sum_{j=0}^{m-1}\frac{(s(i,j)-f(i,j))2}{n*m} \quad (5)$$

Where n and m are the dimensions of image.

s(i,j) is the pixel values of the original image.

f(i,j) is the pixel values of the resulted image.

The value of MSE must be as small as possible [9].

**Peak Signal to Noise Ratio (PSNR)**

It is the ratio between the maximum possible power of an image and the power of corrupting noise that affects the fidelity of its representation. PSNR calculates from the following Equation:

$$\text{PSNR}= 10*\log_{10}\left(\frac{255^2}{MSE}\right) \quad (6)$$

In order that computing PSNR should calculate the mean square error (MSE) in the beginning. The value of PSNR must be as large as possible [9].

**Root Mean Square Error(RMSE)**

RMSE is computed as the root mean square error of the corresponding pixels in the input image and the fused image. The smaller RMSE is the better the fusion. *RMSE* calculates by Equation (7).

$$\text{RMSE}= \sqrt{\sum_{i=0}^{n-1}\sum_{j=0}^{m-1}(s(i,j)-f(i,j))2} \quad (7)$$

Where n and m are the dimensions of the image.

s(i,j) is the pixel values of the original image.

f(i,j) is the pixel values of the resulted image [33].

**Correlation Coefficient**

This measure defines the amount of the relationship between two variables only is always the value of this metric between -1 and 1. If the value of the correlation coefficient is positive, the correlation is directly proportional this means any increase in the value of the variable first lead of the high value of the second variable, while if the value of the correlation coefficient is negative, the correlation to be inversely this means any increase in the value of the first variable lead to a decrease in the value of the second variable. A value close to +1 means that the two images are very similar, while a value close to -1 indicates that they are highly dissimilar. Equation (8) computes the correlation between Fk, Mk as it follows:

$$CC = \frac{\sum_i^M \sum_j^N (F_K(i,j) - \overline{F_K})(M_K(i,j) - \overline{M}_K)}{\sqrt{\sum_i^M \sum_j^N (F_K(i,j) - \overline{F_K})(M_K(i,j) - \overline{M}_K)^2}} \quad (8)$$

Where FK is the fused pixel, MK is the original pixel, M and N are the dimensions of the images [34,35].

## Conclusions

This paper explains different techniques of spatial and frequency domain for the fusion image and their performance evaluation parameters. The techniques of spatial domain provide high spatial resolution but they have an image blurring problem. To overcome this problem we use transform domain, such as the wavelet method and morphological processing with it. Every algorithm has some advantages and drawbacks. Simple techniques of image fusion like averaging and minimum/ maximum produce noisy, blurred and low contrast images. These techniques cannot be used for real-time applications. Principal component analysis and Intensity Hue Saturation are very simple, computationally efficient and fast algorithms but they cause in color distortion. Images are fused by PCA algorithm have a high spatial quality, but it results in spectral degradation. Discrete wavelet transform minimizes spectral distortion. DWT can't well capture the long edge and the curve of the image due to the isotropic nature of the wavelet transform. Curvelet transform can solve the blurring of edges and details in wavelet image fusion, but it has no well performance of the local variation of the image. Wavelet and Curvelet transform don't have translation invariance because of translation invariance. SWT transform can keep on the description of the detail components of images and can preserve the details of the original image compared to the ordinary wavelet transform. But, Combination of SWT and Curvelet fusion algorithms preserved the advantages of the both, reserved image detail and profile information such as edge and effectively avoided block effect based on wavelet transform the fusion algorithm and image detail performance deficiencies based on the curvelet transformation method.

## Conflicts of Interest

The authors declare that no conflict of interests exists in what regards this work.

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