A Critical Review of Image Fusion Methods

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***Abstract* –** The need for image fusion is rising recently in image processing requirements due to the tremendous amount of acquisition systems. Fusion of images is defined as an alignment of important Information from diverse sensors using numerous mathematical models to generate a single composite image. In this paper, various state-of-art image fusion approaches of diverse levels with their pros and cons, various transform-based and spatial methods with quality metrics, and their applications in different areas have been discussed. Finally, this review has concluded many upcoming directions for different applications of image fusion.

key words – Image Fusion, Acquisition system, Diverse levels, Spatial methods.

1. Introduction

Image fusion is an emerging field for generating an Enlightening image with the integration of images found by different sensors for decision making [1]. The investigative and visual image quality can be improved by mixing different images. Effective image fusion is capable of protective vital Information by extracting all important Evidence from the images without producing any discrepancies in the output image. After fusion, the fused image is more appropriate for the machine and human perception. The first step of fusion is source image is mapped with respect to the reference image, and this process is called Image Registration. This type of mapping is achieved to match the equivalent image on the basis of confident features for further analysis. Image fusion and Image registration are apparent to generate valuable Information in several areas [2]. According to the literature, the number of scientific papers has been increased dramatically since 2011 and reached the peak of more than 26,000 in 2020 which can be demonstrated in Fig. 1.

This fast-growing trend can be recognized due to the enlarged demand for high-performance image fusion methods with low cost. Recently, various methods like multi-scale decomposition and sparse representation have been familiarized that bring several ways for educating the image fusion performance. There is an essential for a well-organized fusion method due to differences between corresponding images in numerous applications. For instance, numerous satellites are increasing nowadays to acquire aerial images with diverse spatial, spectral, and temporal determinations in the field of remote sensing. The image fusion is essentially a collection of image Information realized by several imaging parameters such as dynamic range or, aperture settings, the position of the camera or spectral response, or the use of polarization filters. With the help of suitable image fusion methods, the Information of interest is extracted from different images, which can further be used for driver assistance, traffic control, quality assessment or, reconnaissance. Several techniques of image fusion can be classified as pixel level, feature level, decision level. Pixel-level techniques for image fusion directly integrate the data from input images for further computer processing tasks [3]. Feature level techniques for image fusion contain the extractions of relevant features that are pixel intensities, edges, or textures that are combined to create supplementary merged features [4, 5].

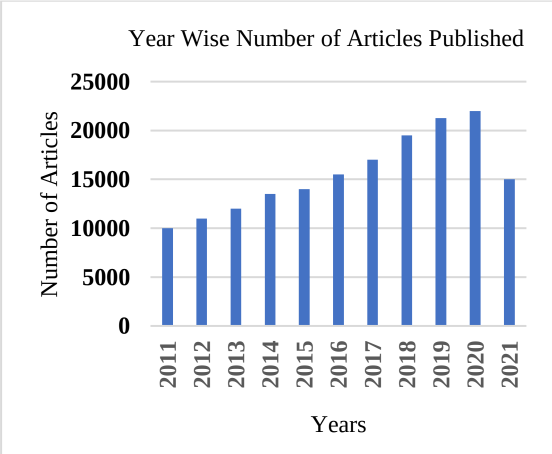

Fig.1 According to the literature, the number of articles linked to image fusion

For images, in Indecision level fusion techniques, the input images are treated one at a time for the extraction of Information [4]. There is a diversity of image fusion classifications based on the datasets such as multi-spectral, multi-focus, multi-sensor, multi-scale, and multi-temporal. In multi-focus techniques for image fusion, Information from numerous images of a similar scene is fused to become one composite image [6]. In addition, the multi-source and multi-sensor image fusion methods recommend greater features for representing Information that is not perceptible to a human visible system and is used for medical diagnosis applications. The Information produced from merged images can be active for the localization of abnormalities precisely [7]. The temporal modeling will stretch details of all clinical variable quantities and reduce the risk of Information failure [8]. The fast-growing trend can be a major influence of image fusion techniques having low cost and high performance. Currently, several techniques like sparse representation and multi-scale decomposition have been predicted that help in enhancing the image fusion performance [3]. Sparse representation is a philosophy of image representation, which is working on image processing tasks such as recognition, denoising, and interpolation [1]. The multi-spectral image is used for remote sensing that merges their features to get a clear image using consistent Information and spatiotemporal correlation [9]. Image fusion has grown to be an influential solution by merging the images captured through diverse sensors. Images of diverse types such as MRI, CT, infrared and visible are greater input images for multimodal fusion [1]. Currently, Deep learning is a very dynamic topic in image fusion. It has gained great success in this area for solving different types of problems such as image processing and computer vision. It is extensively used for image fusion [10]. Due to recent technological progressions, several imaging fusion techniques have been applied in many applications including video surveillance, remote sensing security, machine vision, and medical imaging. Still, there are a number of challenges related to image fusion that have to be discovered. Moreover, an accurate, appropriate, and consistent fusion technique is required for the various types of images for different areas that should be easily explainable to obtain better results. Besides, image fusion techniques must be strong against uncontrollable gaining conditions or inexpensive computation time in real-time systems as mis-registering is a major error found while fusing images. This paper presents an outline of various image fusion techniques with their applications in diverse areas. Also, many challenges, shortcomings, and benefits of image fusion techniques have been discussed.

2. Step-by-Step Process of Image Fusion

As discussed earlier, the aim of image fusion is to produce a merged image with the integration of information from more than one image. Figure 2 demonstrates the key steps involved in the image fusion process.

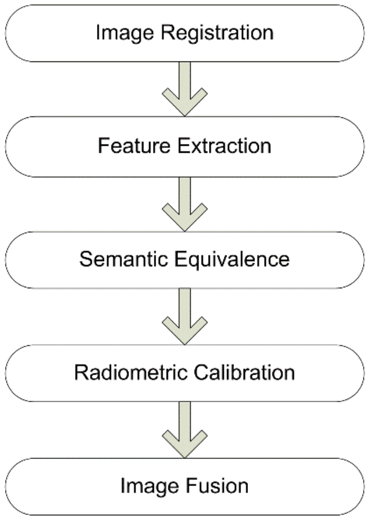

Fig. 2 Image Fusion Process

In extensive-ranging, the registration is measured as an optimization issue that is used to exploit the similarity as well as to reduce the cost. The Image registration procedure is used to align the succeeding features of several images with respect to a reference image. In this procedure, multiple source images are used for registering in which the original image is predictable as a reference image and the original images are united through a reference image. In feature extraction, the important features of registered images are extracted to produce numerous feature maps. The objective of the decision operator is to label the registered images with respect to pixel or feature maps, a set of decision maps are produced. Semantic equivalence found the decision or feature maps that might not pass on to a like object. It is employed to connect these maps to a common object to achieve fusion. This process is employed for the source obtained from a similar kind of sensors. Then, radiometric calibration is working on spatially aligned images. Afterward, the transformation of feature maps is performed on a normal scale to get the end result in a similar representation format. Finally, image fusion merges the consequential images into one resultant image covering an enhanced explanation of the image. The main goal of fusion is getting more Informative fused image [2].

3. Image Fusion Techniques

Image fusion techniques can be classified as spatial and frequency domains. The spatial technique deals with pixel values of the input images in which the values of pixels are manipulated to achieve a suitable outcome. Evaluation of the entire synthesis operations are using Fourier Transform of the image and then Inverse Fourier Transformer is

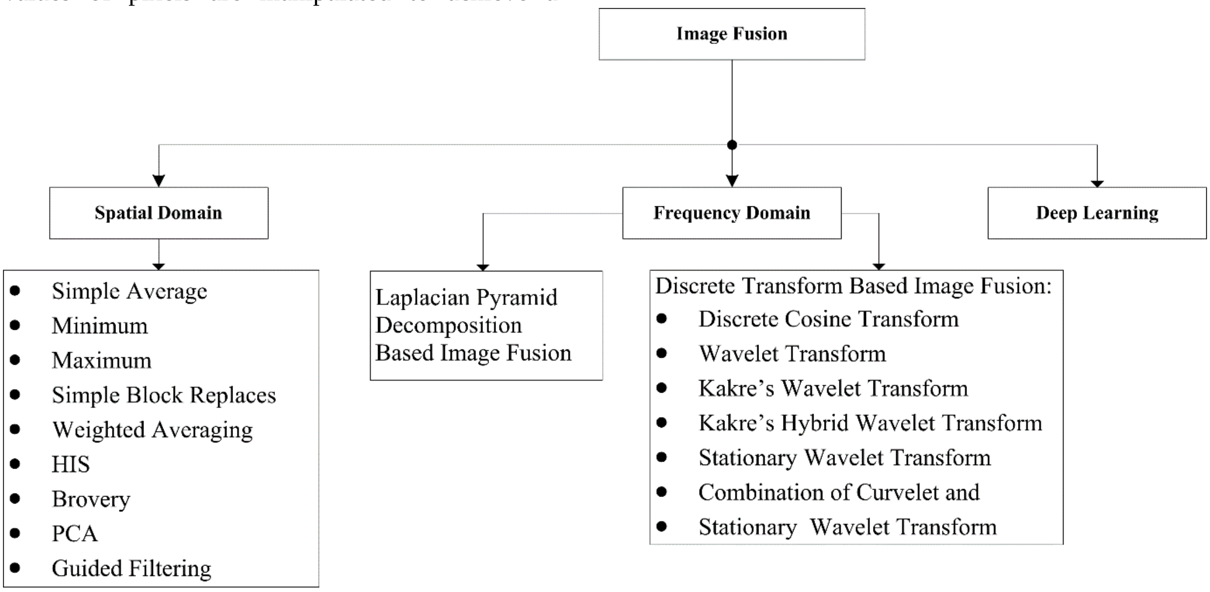

Fig. 3 Image Fusion Techniques

evaluated to get a resulting image. Other Image Fusion techniques are HIS, PCA, high pass filtering, and the Brovey method [11]. In image fusion Discrete transform fusion techniques are extensively used as compared to pyramid-based fusion techniques. Various types of Image Fusion techniques are shown in Fig. 3 [12].

3.1 Spatial Based Techniques

The Spatial based technique is a simple image fusion method consisting of Minimum, Maximum, and Max-Min, Simple Average and Simple Block Replace techniques [13] [14]. Table-1 shows the diverse spatial domain-based methods with their pros and cons.

3.1.1 Simple Average

Simple Average is a fusion technique used to combined images by averaging the pixels. This technique focused on all areas of the image and if the images are taken from the similar type of sensor, then it works well [15]. If the images have high contrast and high brightness then they will produce good results.

3.1.2 Minimum Technique

It selects the lowermost intensity value of the pixels from images and produced a fused image [13]. It is used for darker images [16].

3.1.3 Maximum Technique

It selects the pixels values of high intensity from images to produce a fused image [11].

3.1.4 Max–Min Technique

It chooses the averaging values of the pixels least and largest from the entire source images and produced the resultant merged image.

3.1.5 Simple Block Replace Technique

It adds pixel values of all images and takes the block average for it. It is based on pixel neighbouring block images.

3.1.6 Weighted Averaging Technique

It allotted the weights to every pixel in the source images. The resultant image is produced by the weighted sum of each pixel value in source images [18]. This method recovers the detection reliability of the output image.

3.1.7 Hue Intensity Saturation (HIS)

It is a basic fusion color technique that transformed the Red–Green–Blue image into HIS components and then intensity levels are separated with panchromatic (PAN) image. Spectral contains both hue and saturation Information and Spatial contains intensity Information of the image. It makes in the bands and has three multispectral bands Red–Green–Blue (RGB) of low resolution. In the end, the inverse transformation is executed to convert the HIS space to the original RGB space for getting fused image [11]. It is a extremely straightforward technique to combine the images features and delivers a high spatial quality image. It gives the best result in remote sensing images and major disadvantage is that it involved only three bands [22].

Table 1 shows the diverse spatial domain based methods with their pros and cons as per the literature review

Fusion Techniques	Advantages	Disadvantages
Averaging [13, 17]	Simple, easy to recognize and implement	Decreases the image quality and reduces noise into final fused resultant image. Produced blurred images. Not appropriate for real time applications
Minimum pixel value [13, 17]		
Simple block replacement [14]		
Maximum pixel value [13, 17]		
Max- min [14]		
Weighted averaging [17]	Improves the detection reliability	Enhances the SNR
Principal component based analysis [19, 20]	Simple and more efficient, high spatial quality, lesser computational time	Resulted in color distortion and spectral degradation
Hue intensity saturation[17]	Efficient and simple. high sharpening ability and Fast processing	Color distortion
Brovey [13]	Extremely straightforward and more efcient method. Faster processing time. Gives Red–Green–Blue images with superior degree of contrast	Color distortion
Guided filtering[21]	It performs well in image smoothing or enhancement, fash or no-fash imaging, matting or feathering and joint upsampling	On the sparse inputs it is not directly applicable. It has a common drawback; it may have halos near some edges like other explicit filters.

3.1.8 Brovey Transform Technique

Gillespie et al. suggested Brovey Transform in 1987. It is a direct technique for merging data from more than one sensor. It incapacitates the three band problems. It consistent the three multispectral bands used for RGB towards append the intensity and brightness into the image [12]. It includes an RGB color transform technique that is recognized as color normalization transform to avoid drawbacks of the multiplicative technique [11]. It is helpful for visual Understanding but generates spectral distortion [22]

3.1.9 Principal Component Analysis (PCA)

It is a statistical method on the basis of orthogonal transformation. It converts a set of observations of a possibly correlated variable into principal components that are set of linearly uncorrelated variables. The main drawback of PCA is spectral degradation and color distortion [9].

3.1.10 Guided filtering

It works as a boundary smoothing and preservative operator similar to the respected bilateral filter. It has improved performance near the boundaries. It has a hypothetical link with Laplacian matrix, and it is a fast and non-estimated linear time algorithm, whose density is independent on the mask size. This filter is more efficient and active in graphics and computer vision applications with joint up sampling, haze removal, detail smoothing and noise reduction [24]. Image Fusion is also used in medical field to identity the various diseases. In which article, author perform experiment on brain images and prove that Guided filter delivers better results as compared to multi-resolution singular value decomposition technique and Principal Component Analysis [23].

3.2 Frequency Domain

Frequency domain techniques decomposed the multiscale coefficients from the input images [25]. Spatial distortion can be stimulated by the frequency method. Table 2 lists the several techniques based on frequency domain with their pros and cons.Table 2 shows the diverse frequency domain based methods with their pros and cons as discussed by several authors

3.2.1 Laplacian Pyramid Fusion Technique

For image fusion, it uses the interpolation sequence and Gaussian pyramid for multi-resolution analysis. Saleem et al. have reported an improved image fusion technique using a contrast pyramid transform on multi-source images [26]. But it is suffered by the drawback of extraction capability which can be overcome by multi-scale decomposition. Further, Li et al. improved the gradient pyramid multi-source image fusion method which attains high band coefficient with the aid of gradient direction operator [9].

3.2.2 Discrete Transform Fusion Method [13]

Discrete transform fusion technique takes composite images. Firstly, if the images are colored then RGB (Red–Green–Blue) components of the multiple images are detached subsequently, discrete transformation on images is applied and then the average of multiple images is computed an inverse transformation is applied at the end to get a fused image. DWT (Discrete wavelets transform) is a better image fusion method as compared to other fusion methods like Laplacian pyramid method, Curvelet transforms method etc [39].

Table 2 shows the diverse frequency domain based methods with their pros and cons as discussed by several authors

Fusion Techniques	Advantages	Disadvantages
Laplacian/Gausian pyramid [27, 28]	Provides better image quality of a representation for multi focus images	Provide almost same result. Number of breakdown levels affects the Image Fusion result
Low pass pyramid ratio [29]		
Morphological pyramid [28]		
Gradient pyramid [30]		
Filter subtract decimate [30]		
Discrete cosine transform (DCT) [31]	Decomposed images into series of waveform and used for real time applications	Low quality fused image
Discrete wavelet technique with Haar fusion [32]	Produced better quality of fused image with good SNR. Reduced the spectral distortion	Merged image has fewer spatial resolutions
Kekre's wavelet transform fusion [33, 34]	Used for any size of images and its fnal fused result is more Infrmative	Computationally complex
Kekre's hybrid wavelet based transform fusion [45, 46]	It gives better results	It cannot be used images integer power of two
Stationary wavelet transform (SWT) [37, 38, ,44]	Give better result at level 2 of decomposition	Time consuming process
Stationary wavelet transform (SWT) and Curvelet Transform	Suitable for real time applications	Very time consuming process

3.2.3 Discrete Cosine Transform (DCT) In image fusion, DCT has many types like DCTcm (DCT contrast measure), DCTe (DCT energy), DCTma (DCT magnitude), DCTch (DCT contrast highest), and DCTav (DCT average) [29]. This technique does not give a better result with the size of the block less than 8×8. In the DCT domain, DCTav is straightforward technique and basic method of image fusion. DCTe and DCTma methods well performed in image fusion.

3.2.4 Discrete Wavelet Transform (DWT) Method

DWT method decomposes the two or more images into numerous high and low-frequency bands [40]. This method diminished the spectral distortion in the resultant fused images by making the good signal to noise ratio with fewer spatial resolution as compared to the pixel-based method. Wavelet fusion performed greater to the spatial domain fusion method with respect to minimizing the color distortions [15].

3.2.5 Kekre's Wavelet Transform (KWT) Method Kekre's Wavelet Transform method is

found from Kekre's transforms [41]. It can produce KWT matrices of ((2 N)*(2 N)), ((3 N)*(3 N)),…., ((N2)*(N2)) from Kekre's transform method matrix [42]. The fused image is far good than other methods.

3.2.6 Kekre's Hybrid Wavelet Transform (KHWT) Method

KHWT technique has been derived from hybrid wavelet transforms. Many authors recommended that kekre-hadamard wavelet method gives more brightness. Hybrid kekre-DCT wavelet method gives respectable results. In this method, the best two matrices are collective into a hybrid wavelet transforms method. It cannot be used images integer power of two [35].

3.2.7 Stationary Wavelet Transform (SWT) Method

DWT method has a drawback of translation invariance and Stationary Wavelet Transform overcome this problem [43]. This technique delivers a better output at decomposition level 2 and time inefficient process [37] [38] [44]. SWT derived from DWT method and is a new type of wavelet transform method with translation invariance. It delivers enhanced analysis of image facts. The next second invention curvelet transform method is furthermore suitable for 2-D image edges.

3.2.8 Curvelet Transform Method

Stationary Wavelet Transform methos has a better characteristic in time–frequency. It can achieve well result for developing in smooth. The second generation Curvelet is a new multi-scale transform; it breaks the drawbacks of wavelet method in representing directions of boundaries in the image [45, 45–47].

3.3 Deep Learning

Another technique which is utmost widely used for image fusion is Deep Learning in several domains. Various deep learning based image fusion methods have been existing for multi-exposure image fusion , multi-focus image fusion, multi-modal image fusion, hyper-spectral (HS) image fusion, and multi-spectral (MS) image fusion, showing several advantages. In another way, deep learning and case-based reasoning techniques are used with image fusion to improve the outcome of segmentation. Artificial intelligence used to improve the results of segmentation and its implementation done on kidney and tumour images. This procedure completes in three layers: Fusion layer, Segmentation layer, Data layer [48].

4. Leading Applications in Diverse Domains

In current years, Image Fusion has been broadly used in many different applications such as medical diagnosis, remote sensing, surveillance and photography. Here, various issues and challenging are discussed related to different fields [3].

4.1 Medical Domain Applications

Harvard Medical School has provided a brain image dataset of recorded Computerized Tomography (CT) and Magnetic Resonance Imaging (MRI). Figure 6 illustrate an example of image fusion in medical diagnosis by fusing CT and MRI. MRI is used to capture the soft tissue structures like the heart, eyes, and brain and the CT is used for capturing the bone structures with high spatial resolutions. The CT and MRI can be used collectively with image fusion methods to enhance accuracy and sensible medical applicability. The main challenging of this field is also talented as below.

(i) Lack of medical crisis oriented image fusion methods: The main reason of image fusion is to contribution the improved clinical results. The clinical crisis is still a big challenge and nontrivial responsibilities in the medical field.

(ii) Objective image fusion performance estimate: The main difficulty in this field is how to evaluate the image fusion performance. There are diverse clinical issues of image fusion, which chosen the image fusion effect may be fairly dissimilar.

(iii) Mis-registration: The inaccurate registration of objects suffered from poor performance in the medical field. Figure 4 shows the fusion of MRI and CT images. In this, the fusion of images is achieved by the guided filtering based technique with image statistics.

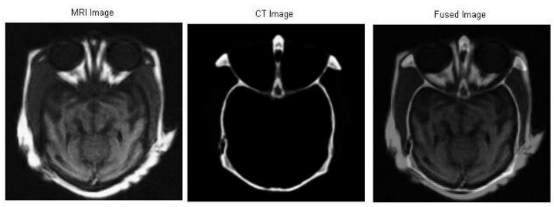

Fig. 4 Examples of IF in medical diagnosis domain. (a) MRI (b) CT (c) Fused image

4.2 Remote Sensing Applications

In accumulation to the modalities discussed above, it has various image fusion techniques such as Synthetic Aperture Radar, ranging and light detection and moderate resolution imaging spectroradiometer that have been valuable in image fusion applications. Byun et al. have given the area based image fusion scheme for combining multispectral , panchromatic, and synthetic aperture radar images [1]. Chronological data fusion and high spatial approach is used to crop synthetic Landsat imagery by combining Landsat and moderate resolution imaging spectroradiometer data [1]. Furthermore, the synthesis of air-bone hyper spectral and Light Detection and Ranging (LiDAR) data is investigated recently by a combination of spectral Information. Several datasets have been provided by Earth imaging satellites like Worldview-2, Quick bird, and IKONOS for the applications of pansharpening. Co-registered hyper-spectral and multispectral images are more complex to find as compared to multispectral and panchromatic images. Also, air-bone hyper-spectral data and LiDAR are accessible. For occurrence, the IEEE Geoscience and Remote Sensing Society Data Fusion 2013 and 2015 Contests have distributed plentiful hyper-spectral, light and color detection and ranging data for research purposes. In this domain application, numbers of satellites are mounted to acquire remote sensing images with varied spatial, temporal and spectral resolutions. Moreover, in this area, classification and change detection has been provided that by Earth products or Google Maps that are effectively useful to construct the imagery seen. This is a supplementary difficult problematic as compared with pansharpening, the multichannel multispectral image contains both spatial Data and spectral Data. Therefore, pansharpening is unsuitable or incompetent for the IF of hyperspectral and multispectral images. The prime challenge in this domain is accomplished as below:

(i) Spatial and spectral distortions: The image datasets frequently reveal differences in spatial and spectral structures which causes more distortions with spatial or spectral artifacts during image fusion.

(ii) Mis-registration: The next most important challenge in this field is how to reduce the misregistration rate. The remote sensing input images are frequently obtained from acquisitions, diverse times or spectral bands. Even the panchromatic and multispectral [51] datasets providing by a similar platform, the one or more sensors may not produce accurate results in the same direction; their gaining moments may be diverse. Therefore, in order to resolve this, prior to image fusion, the images are required to be registered. Equally, registration is the challenging process because of the dissimilarities between input images as they are provided with diverse acquisitions. Figure 5 shows the fusion of Panchromatic and Multi-spectral images that is attained by the Principal Component Analysis (PCA) transformation correspondingly.

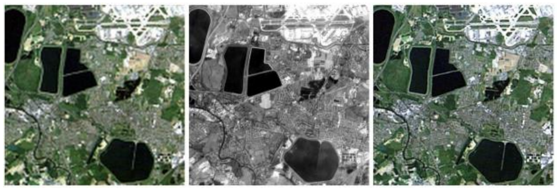

Fig. 5 Examples of Image Fusion in remote sensing domain. (a) noise free MS image (b) PAN image (c) Fused image.

4.3 Surveillance Domain Applications Figure 6 illustrates examples of image fusion in the surveillance domain that is infrared and visible images fusion. Its high temperature makes it able to “see in the night” even without enlightenment as it is sensitive to objects. Infrared images [50] give bad spatial resolution and it can be overcome by fusion technique by the visible and infrared image. Furthermore, the fusion of visible and infrared images has been introduced for another surveillance domain problem in face recognition, image dehazing, and military reconnaissance. The main challenges of in this domain are as:

(i) Computing efficiency: In this domain, effective image fusion algorithms should merge the Information of innovative images to get the final resultant image. In these domains usually engages continuous real-time monitoring.

(ii) Imperfect environmental conditions: The major difficulty in this domain, the images may be acquired at defective circumstances. Due to the weather and enlightenment condition, the input images may contain under-exposure and serious noise. Fusion of visible and infrared image is shown in Fig. 6a, b. In this outline, the fusions of both images are achieved by the guided filtering and image statistics.

(a) (b) (c)

Fig. 6 Examples of Image Fusion in surveillance domain. (a) Visible image (b) Infrared image (c) Fused image

4.4 Photography Domain Applications Figure 7 illustrates examples of image fusion in the photography field, the fusion of multi-focus images. It is not possible for all objects with varied distances from camera due to its restricted depths to be all-in-focus within a single shot of cameras. Due to the restricted depths of the camera, it is not possible to be all-in-focus within a single shot of cameras for all objects with varied distances. To overcome this, the multi-focus image fusion method is used to merge several images with a similar scene having diverse focus points for generating an all-in-focus resultant image. This resultant compound image can well defend the significant information from the source image. It is more require in several image processing tasks and machine vision. In Fig. 7, the data sources used in the photography domain. The various challenges which are faced in this domain are:

(i) Effect of moving target objects: In this domain, multi-focus, and multi exposure images are constantly provided by diverse times. In these circumstances, during the capturing process moving objects may become visible in diverse locations. The moving objects might produce inconsistencies into the fused image.

(ii) Relevance in consumer electronics: In this, images are taken from various shots with diverse settings of the camera. The task is to combine the multi-exposure and multi-focus image [50] fusion methods into consumer electronics to produce a compound image of high quality in real-time. Image fusion of multi-focus images (Fore-focus image and Back-focus image) is shown in Fig. 7a, b. In this outline, image fusion of multi-focus images is attained by guided filtering based technique and image.

(a) (b) (c)

Fig. 7 Examples of Image Fusion in photography domain. (a) Back-focus Image (b) Fore-focus image (c) Fused image

4.5 Applications in Other Domains Many other applications that are used for fusion like object recognition, tracking, object detection etc.

5 Discussion

Despite the numerous constraints which are handled by several researchers, still number of research and development in the field of image fusion is growing day by day. Image fusion has numerous open-ended difficulties in different domains. The main objective is to discuss the current challenges and future trends of image fusion that arise in several domains, such as medical diagnosis, surveillance, remote sensing, and photography are analyzed in the fusion developments. This paper has discussed various spatial and frequency domain methods as well as their performance evaluation measures. Simple image fusion techniques cannot be used in authentic applications. hue intensity saturation, PCA [49], and Brovey methods are computationally capable, high-speed and tremendously straightforward but lead to in distortion of color. Images fused with Principal component analysis have a spatial benefit but resulted in spectral degradation. The guided filtering is an easy, more suitable for real-world applications and is computationally efficient process. In image fusion outcome, the quantity of decomposition levels disturbs the pyramid decomposition. Every algorithm has its own advantages and disadvantages. The main challenge faced in remote sensing field is to decrease the visual distortions subsequently fusing hyperspectral (HS), panchromatic (PAN), and multi-spectral (MS) images. This is because source images are captured using different sensors with comparable platform but do not focus on a similar direction as well as their gaining moments are not exactly the same. The dataset and its accessibility signify a restriction that is challenged by many researchers. The progress of image fusion has increased its concentration in colored images and its enhancement. The object of color contrast enhancement is to produce an attractive image with bright color and clarity of the visual scene. Recently, researchers have used neutrosophy in image fusion, used to remove noise and to enhance the quality of single photon emission tomography (SPET), positron emission tomography (PET), computed tomography (CT), and magnetic resonance imaging (MRI) image. This integration of neutrosophy with image fusion give rise to better visibility and noise reduction of the fused image. Deep learning is the growing trend to develop the robotic application. It extremely applied in several applications such as speech recognition, face recognition, object detection and medical imaging. The integration of quantitative and qualitative measures is the accurate way to determine which particular fusion technique is better for certain application. The numerous challenges which generally are faced by researchers is to design image transformation and fusion approaches. Also, the lack of effective image depiction methods and broadly recognized fusion evaluation metrics for performance evaluation of image fusion techniques is also of great concern. However, the recent progresses in machine learning and deep learning based image fusion shows a huge potential for future improvement in image fusion.

7 Conclusion

Recently, the area of image fusion is attracting more consideration. In this paper, various image fusion techniques with their pros and cons, different methods with state-of-art have been discussed. Different applications like remote sensing, medical image, surveillance, and photography images have been discussed with their challenges. Finally, the different evaluation metrics for image fusion techniques with or without reference has been discussed. Therefore, it is concluded from survey that each image fusion technique is intended for a specific application and can be used in various combinations to acquire better results. In future, new deep neural networks-based image fusion techniques will be developed for various fields to improve the efficiency of fusion procedure by implementing the algorithm with parallel computing unit.

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