Image Fusion Methods: A Survey

**Saleha Masood[1], Muhammad Sharif[1], Mussarat Yasmin[1],Muhammad Alyas Shahid[1,*] and Amjad
Rehman[2]**

[1]*Department of Computer Science, Comsats Institute of Information technology WahCantt*
[2]*MIS Department CBA Salman bin Abdulaziz University Alkharj KSA*

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Abstract

Image fusion is an approach which is used to amalgamate the corresponding features in a sequence of input images to a single composite image that preserves all the significant features of the input images. Image fusion is also known as pan-sharpening. It is a method which is used to integrate and add the geometric detail of a high-resolution panchromatic (Pan) image and the information of color of a low-resolution multispectral (MS) image for the production of a high-resolution MS image. This methodology is mainly most important and significant for any large-scale applications. Image fusion classification based on its systems (models and algorithms) are considered and overviewed in this survey. The basic two algorithms categories are analyzed and compared to each other, in the analysis and discussion section the major points to be considered while performing image fusion are highlighted.

Keywords: Image fusion methods, Feature matching, Image resampling, Spatial Domain Fusion, Temporal Domain Fusion

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1. Introduction

The perception of fusing a sequence and series of images into a single image started in the past around the era comprising 1950's and 1960's, by means of the exploration on behalf of useful approaches of amalgamation pictures commencing numerous devices with the most common device called sensor to deliver a compound picture might be utilized to well classify ordinary and synthetic entities [1]. Expressions likeamalgamation, permutation, collaboration, incorporation, and numerous additional concepts that direct further or fewer the equivalent notions have since seemed in the fiction [2]. In the application of remote sensing communal, the succeedingdescription has been embraced:

"A formal framework in which means and tools for expressing the alliance of data are originating from different sources called Data fusion. It aims to obtain information of greater and better quality; the exact definition of 'greater quality' will depend upon the application" [3].

Image fusion, in general, a procedure through which two or extra imageries or pictures are joined into a solo image holding the significant structures and topographies from each of the original images [4]. The fusion of images is frequently essential for pictures attained through diverse mechanism modalities or acquired methods of the identical prospect or entities [5]. Significant solicitations of image fusion comprise medicinal processing of images for better diagnostic and interpretation of diseases, imaging in the context of analyzing microscopic details, remote sensing, engineering, computer sciences including computer vision and robotics. Fusion methodscomprise the modest technique of averaging pixels within the imageand moving towards furthercomplex and problematic approaches like PCA and imagefusion using the method of wavelet transforms in the process of image fusion [6]. Numerous image fusion methods might be renowned, contingent on whether the pictures are blended and mixed in the domain of 3-dimensional area or they are distorted into an alternativearea, and their alters fused [7].

1.1 The aim of the image fusion
The basic goals of performing image fusion method can be analyzed in the diagram of figure 1.
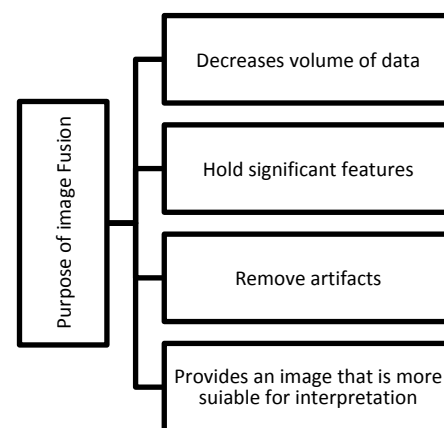

Fig 1. Aim of image fusion

2. Image Fusion Systems

There are two main kinds of image fusion systems, which are shown in **figure 2.**

Image Fusion Systems

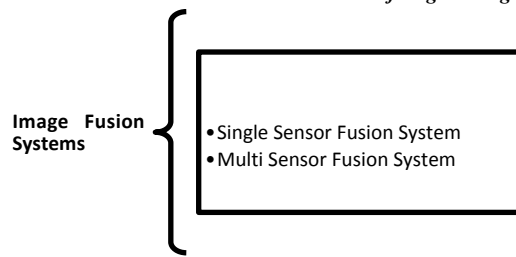- Single Sensor Fusion System
- Multi Sensor Fusion System

Fig 2. Image Fusion Systems

2.1 Single Sensor Fusion System (SSFS)

In the system where there is only one sensor, images are taken and captured using a single sensor, images are taken in a sequence of a particular scene and then the sequence of images is fused into a single image[8]. There is a major drawback of using a single sensor as it is sensor capability dependent so the problems can arise using a single sensor include in [9].

The first and most significant drawback is the capability of the sensor as they are designed only for some specific conditions and scenarios so the capability problem introduces further issues including resolution, circumstances under which it can work and the dynamic range under which the sensor can work[10].

2.2 Multi-Sensor Fusion System (MSFS)

In the case of a MSFS, numerous sensors are utilized for the purpose of taking and capturing images [11]. A sequence of images is captured with different sensors which are then fused into a single image that presents all in focus image. MSFS of images was basically introduced to overcome the drawbacks of single sensor fusion system and thus offers a number of benefits over single sensor image fusion system [12]. These benefits include:

2.2.1 Benefits:

The welfares of MSFS of images are comprised of:

i. As when we were talking about multiple sensors we said that different sensors operate under different conditions and thus providing a capability of operating under various conditions, as a result, increasing the range of conditions under which the system can operate and thus provides more effective and efficient image fusion system [13-14].

ii. Different sensors have a diverse range of temporal and spatial characteristics so combining information from various sensors will result in increased range of temporal and spatial characteristics within the fused image [15].

iii. Important information and features from multiple images taken from multiple sensors are fused into a single image so the probability of uncertainty and error in the resultant image is far less as compared to the image fused using a single sensor image fusion system [16].

iv. There will be are duction in noise factor in the fused image and the reliability factor will increase providing a high-quality image [17].

v. The multi-sensor fusion system provides redundancy in numerous quantities that can support in structures strength [18]. In a circumstance when one or additional sensors stop working or the concert of a specific sensor fails, the method can rely on the additional sensors within the system [19].

vi. A dense and more appropriate representation of information and important features is possible through the use of multiple sensors as all the important features are stored in a single imageinstead of storing each feature separately [20-21].

3. Why Image Fusion?

Multi-sensor statisticsblend has converted into a criticism which stresses further all-purpose standard clarifications to a quantity of solicitation circumstances [22]. Numerous conditions in image dispensation need both great three-dimensional and spectral evidence in a sole image [23-24]. It is significant in the domain of remote sensing [25]. Conversely, the tools are not proficient of offering such info either throughstrategy or for the reason of analysis restrictions [26]. One conceivable answer on behalf ofthis problem is the fusion of images [27].

The process of fusing images allows the combination of diverse statistics foundations [28]. The merged image might have corresponding three-dimensional and spectral perseverance features [29]. On the other hand, the ordinary methods of image fusion can alter the spectral facts of the multispectral data while incorporationof images [30].

4. Literature Review

If we analyze the domain of image fusion we can see that huge work has been done in this context ranging from the spatial domain to temporal domain in the image fusion prospect. Starting from the one of the most common application of image fusion i.e. remote sensing [31] the approach basically makes use of multiple sensors to detect the error in the cotton plants. Image fusion using the concept of pixels and wavelet is presented in [32].Details of image fusion applications in the domain of remote sensing are presented in [33]. Another major application of image fusion is in the medical imaging. The fusion of MR images through the use of long and short axis is presented in [34].Similarly, the fusion of liver images can be analyzed in [35]. Another major application where image fusion is more applicable and is applied is the area of image enhancement; pattern selective color fusion is an example in this regard [36]. In the case of remote sensing the concept of multi-spatial and spectral details of images is really important [37]. A wavelet-based image focus fusion can be analyzed in [38]. Comparative image fusion is presented in [39]. Contour based transform is another category of image fusion [40]. Image fusion using the concept of DWT is the most widely and advantageous approach as it offers a number of advantages in the context of fusing images [41]. DWT with the combination of the multi-focus concept is presented in [42]. The concept of Multispectral and Panchromatic in the image fusion process can be analyzed in [43]. Fuzzy logic is another branch of image fusion [44]. The application of image fusion in the transportation system is presented in [45]. The analysis of image fusion algorithm being used is another important concern in the prospect of image fusion [46]. Feature fusion is also performed in the image fusion category as the corresponding features in the sequence of images into a solo composite image are the basic goal of

image fusion [47]. The combination of wavelet and fuzzy logic concept for image fusion is presented in [48]. A novel approach by taking into account the concept of multi-focus for image fusion can be analyzed in [49]. Using curvelet transforms for the image fusion is an important method in the process of fusing images [50]. Evaluating the spatial and spectral details of images after applying an image fusion technique is an important step[51]. Guided filtration process for image fusion is presented in [52].Multimodal and multi-temporal image fusion method can be analyzed in [53]. ICA independent component analysis approach can also be utilized for performing a fusion of sequence of images [54]. Quantitative analysis of image fusion algorithm is another major area of concern [55]. The application of image fusion in the context of signal processing is presented in [56]. Region segmentation and spatial frequency can be the two important factors in the process of multi-focus image fusion [57]. The fusion of region and wavelet-based image fusion is presented in [58].

5. Image fusion Models

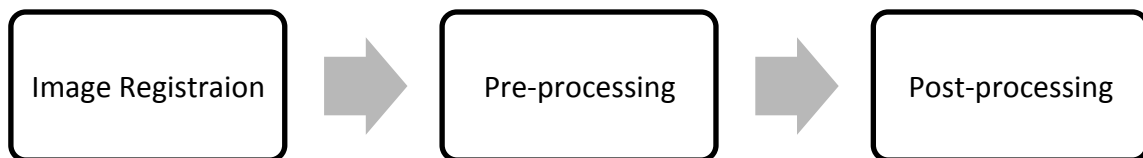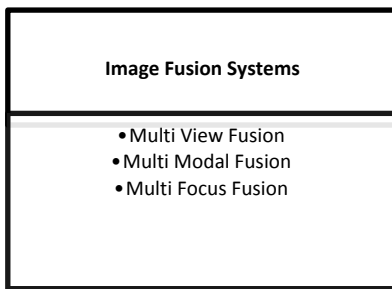There are three types of image fusion models, which are given in **figure 3.**

Image Fusion Systems

- Multi View Fusion
- Multi Modal Fusion
- Multi Focus Fusion

Fig 3. Image Fusion Models

5.1 Multi-View Fusions
The multi-view approach of image fusion has the characteristic to mergenumerous 3D data of the equivalent importance and matching samples by commencing diverse viewpoints within a single resultant image.

5.2 Multi-Modal Fusions
In the case of multimodal image fusion various models are combined and fused into a single image [59].

5.3 Multi Focus Fusions
The approach of multi-focus fusion of images merge and blend the important details and features from two or more images into a single image resulting in an image that is all in focus image[60]. It means that every feature or object in the output image has a proper focus [61-62].

In a situation where one site encompasses substances in diverseexpanse, the camera might be dedicated to every piece of information within the image one afterward the further, generating a group of images [63]. Then, by means ofimage fusion, a picture with superioremphasisover entire zone might be produced.

6. Basic Steps of Image Fusion

There are three basics steps which are carried out in the process of image fusion [64]. These steps are mentioned in **figure 4.**

Image Registraion → Pre-processing → Post-processing

Fig 4. Image Fusion Basic Steps

6.1 Image Registration
The process of image registration aligns the sequence of images in order to overlap the corresponding features and details correctly [65].

6.2 Pre-Processing:
In the procedure of image fusion, the basic aim of this step is to make the images more suitable for the algorithm of image fusion. [66-67]

6.3 Post-Processing:
This step is basically dependent on the kind or category of the display being used in the fusion process. Another dependability of this process involves the inclination of a human operator. [68]

6.4 Image Registration:
The image registration is the main and basic step performed in the image fusion system [69].The process of image registration in image fusion works on the fact that the

conditions under which a sensor operate, its resolution, the distortion of lens or the rate of frames can never be anticipated to counterpart with the other so it follows the principle to match the pixels among the images to map the similar features in the resultant fused image [70].
The general and most utilized method used for this purpose encompasses rotation or the geometric transformation [71]. Other methods that are also applicable involve affine, projective and polynomial methods but they are considered as progressive global approaches [72].Straightforward geometric translation or rotation is the simplest technique.
Image registration is performed indifferentstepswhich are mentioned in **figure 5**.

6.4.1 Feature detection
The Process basically detects the corresponding similar features within the images which are to be fused in a single image.

6.4.2 Feature matching
Here in this step, the similar corresponding features detected in the sequence of images are matched to each other. The

step is performed by finding the correspondence between the detected features.

6.4.3 Transform model estimation
The mapping function is used to perform the transformation step so here in this step the parameter and the types of the estimation model to be used are figured out.
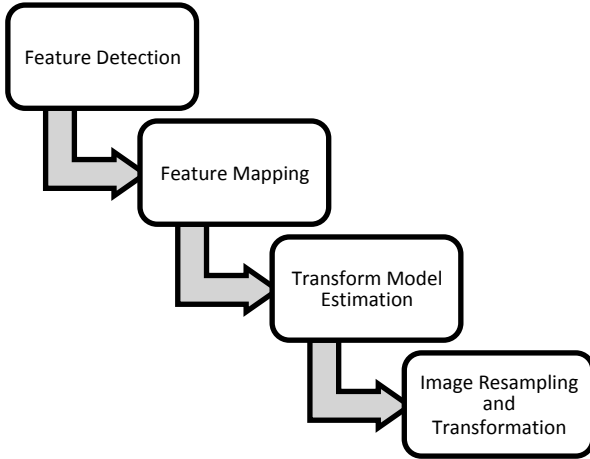
Fig 5. Image Registration steps

6.5.4 Image resampling and transformation
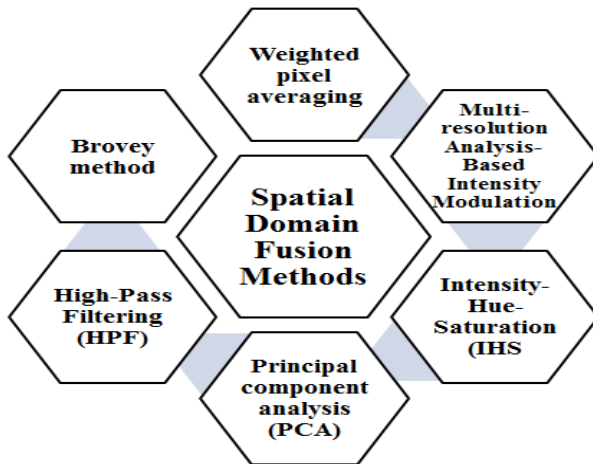The image which is sensed in the previous step is basically transformed in this step [73-74].

Fig 6. Spatial Domain Fusion Methods

7. Image Fusion Classification

Image fusion methods can be divided into two major domains which include [75]:
- Spatial Domain Fusion
- Temporal Domain Fusion

7.1 Spatial Domain Fusion Methods:
A Spatial Domain Fusion Method is shown in **figure 6.**
Here is a brief overview of each method under the category of spatial domain fusion methods.

7.1.1 Weighted pixel averaging:
Weighted pixel averaging approach under the spatial domain of the image fusion is the simplest method in this prospect. The basic formula of performing this operation is:

$$F (x, y) = W_A * A (x, y) + W_B * B (x, y)$$

Where in the above equation W_A, W_B variables are scalars

The basic advantage offered by this approach is that it has the potential to lessen or decrease the present noise or artifacts within the source of image [76]. But while decreasing the noise present in the image it also destroys the significant features of the image [77].
The resultant image by the process is a low contrast image that gives a washed-out look.

7.1.2 Brovey Transformations
The brovy transformations carry out the task of image fusion by taking into account the factor of chromaticity transform [78-80].Applications where images are to be fused into a single composite image by taking the sequence of images through diverse sensors then brovy transformations are considered to be the simplest and most applicable approach. As in such a case, there exists limitation of three bands so the aim of BT is to standardize the various spectral i.e. 3-dimensional bands for the display of RGB. Another reason why BT is the most applicable method is such a condition is that.
They add the component of brightness and intensity in the resultant fused image by performing multiplication of the result with the anticipated data [81].

7.1.3 High-Pass Filtering (HPF)
HRPI and LRMIs are the two major factors in this regard as they are combined to acquire the factor of HRMIs [82-84],performing this task is the basic and vital aim of high pass filtering in the image fusion process.
The basic workflow of HRF is comprised of acquiring the information with high frequency. This information is projected by performing the process of filtration where high pass filter is used to filter the HRPI. The similar task can be performed by subtracting the LRPI from the native HRPI. The approach offers the advantage that 3-dimensional details present in the image are preserved. The reason is that as it holds the high-frequency details of the images so the details of spectral and spatial domains are connected or contained within the high and low-frequency information [85].

7.1.4 Principal component analysis (PCA)
PCA, in general, a mathematical approach that makes use of transformations based on an orthogonal factor. The orthogonal feature results in a group of linear values that are acquired by converting a group of opinions from conceivably connected variables. The linear values being acquired are also called the principal components. The proportion of these principal components should be that they are supposed to be equal or less than the variables which are original within the images. In the prospect of multivariate analyses PCA is the easiest and simplest form [86-87].

7.1.5 Intensity-Hue-Saturation (IHS)
The IHS method under the spatial domain of image fusion makes use of traditional transformations comprised of three orders which are basically extended to a new domain or arbitrary order [88]. The advantage offered by this approach is that the computation of composite image in image fusion is a fast mechanism. Together with this advantage it also has the ability to combine a massive collection of data quickly by utilizing the data from multi-spectral resampled statistics.

But while performing this blend it distorts the original colors present within the images [88].

7.1.6 Multi-resolution Analysis-Based Intensity Modulation

The origins of MRAIM were introduced by Wang [90]. The basics of this approach rely on the GIF approach. The advantage offered by this approach is that a case where the ratio is present as a random integer, performing fusion using this approach will provide optimal results.

7.2 Temporal Domain Fusion Methods

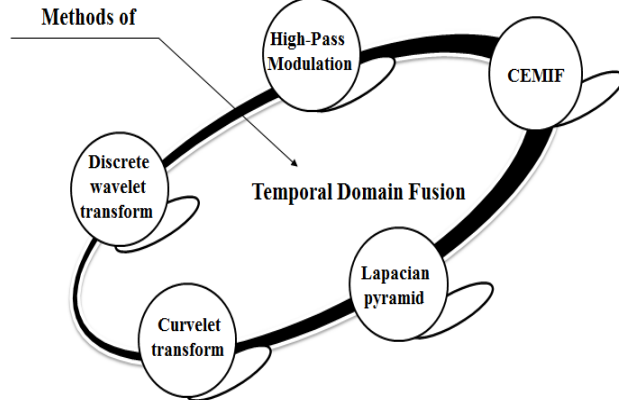A complete and elaborated Temporal Domain Fusion Method is shown in **figure 7**.

Fig 7. Temporal Domain Fusion Methods

Here is a brief overview of each method under the category of temporal domain fusion methods.

7.2.1 High-Pass Modulation

HPM [91] makes use of modulation coefficients in order to handover the information contained within the high-frequency domain to the LRMIs. The use of modulation coefficients in the HPM equals the proportion among the LRPI and the LRMIs.

The corresponding precise approach is expressed in [92].

7.2.2 CEMIF

The origins of this approach were projected by Xydeas and Petrovic. The foundation of this approach relies on the concept of multi-resolution contacting a lessen number of variables. The CEMIF is an adaptive approach [93]. The advantage offered by this approach is that it reduces the complexity and difficulty involved in the computational step within the multi-resolution approaches. The major examples under this category involve wavelet transform and Pyramid of Laplacian. It also has the ability to hold the quality of the image after performing the fusion process. The decomposition that is being kept presents an easy form of conventional Gaussian-Laplacian pyramid approach.

7.2.3 Pyramidal Method

The Pyramidal method under the category of the temporal domain of image fusion makes use of a data structure that is comprised of a sequence of band pass or the low pass copies of the original image. In such a case every copy presents statistics of diverse scale. The advantage offered by this approach is that it results in a high contrast, more clear and attractive and sharp image by preserving the basic and significant features of the images in a single composite image [94].

7.2.4 Laplacian Pyramid

When talking about the pyramid of the image we discussed that is basically comprised of copies of the band and low pass filters with each band presenting a different level and scale information of the image. Here in the case of a pyramid, the density is being decreased in steady phases. Another feature of the pyramid is that in a series of images each next image is a filtered version of its previous image. The resultant image presents the image at the lowest level with the equivalent scale of the native image. The image at the lowest level encompasses the resolution details at the highest level [95].

7.2.4.1 Laplacian:

The basic goal of laplacian method is to acquire the reduced form of the original image by making use of the filtration of the original image using the low pass filter. Similarly, the next image in the pyramid is the reduced version of its previous image and this process goes on till the last image in the sequence of images. In parallel to this process averaging the levels on after another is carried out[96]. The basic formula to perform this function is given below:

$$g_l(i,j) = \sum_{m=-2}^{2} \sum_{n=-2}^{2} w(m,n) g_{l-1}(2i+m, 2j+n)$$

Here in the equation, N denotes the number of levels within the pyramid and the dimension of Lth level is denoted through the variables.

7.2.5 Wavelet Transform method

The discrete sampling of wavelets is the basic function performed by the DWT. The advantage offered by this approach is its tendency to favor of handle the temporal resolution [97]. Another significant advantage offered by DWT is that holds information of location together with the details of frequency factor. The domain comprised of applications of DWT is massive enoughthat it encompasses areas including mathematics, engineering, robotics science and computer science. Another major solicitation of DWT is in the domain of signal processing.

7.2.5.1 Algorithm

The basic working of DWT method encompasses a 2 level DWT of every picture within the sequence of input images. The corresponding subbands comprised of high-frequency details are then utilized to choose the merged or blended edge details in the low pass filtration process. A window of 3x3 is utilized to calculate the mean and standard deviation in order to figure out the edge statistics. The final output is acquired by means of using the inverse of DWT on the wavelet coefficients being fused [98].

There are a number of advantages which are offered by the use of DWT. They are capable of handling diverse resolutions of images it also offers a way to acquire new coefficients from the sequence of input images. And as a result provides with a wide variety of coefficients. The resultant image that is achieved by the inverse of DWT holds the information that is combined in the fused image [99].

7.2.6 Curvelet Transform

Curvelettransforms [100-103]is one of the major image fusion methods under the temporal category of image fusion.

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It is basically a non-adaptive method. The aim of the method is to represent multi-scale details of the objects in the images. It is a generalized version of Fourier transform. The generalization that is being made is comprised of two additional features including spatial frequency [104-105] and the location of the objects in the images. The basic application of curvelet method is in the domain when the objects within the images contain the minutest scale length. The examples that can be considered here include text, geometrical figures and lastly the most common application

area cartoons. The sparser or dense results can be acquired by using a right type of image [106].

8. Applications

There are a number of applications of image fusion system. These applications can be analyzed in **figure 8.**
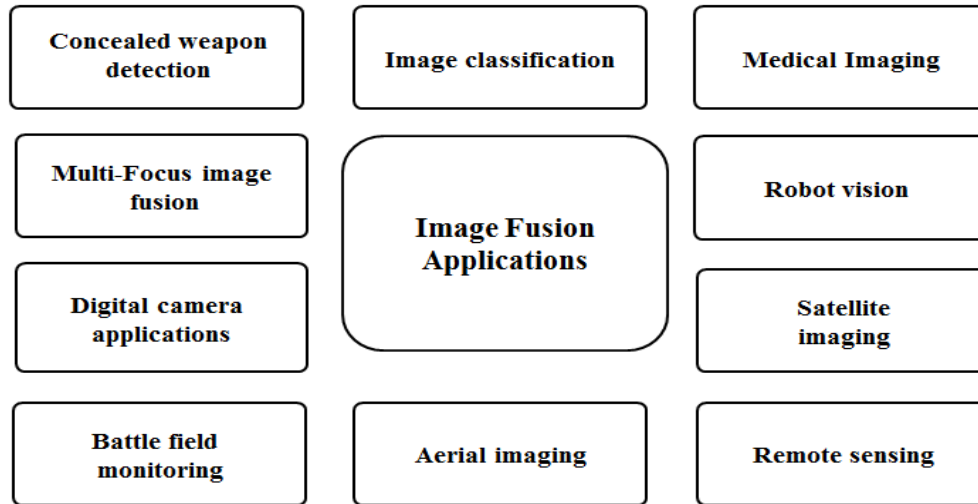

Fig 8. Image Fusion Applications

9. Analyses and Discussion

The overview of the image fusion approaches in the spatial and temporal domainsadduces a number of issues. This method / approachshould be considered while performing the image fusion process. Each method has its own strengths and weaknesses. The basic points are analyzed below:

With the passage of time, the requirement to merge the effective and significant features from multiple image sources increased as using a single sensor for capturing a sequence of images resulted with a number of limitations and drawbacks. Image fusion process works by representing information that is represented at different levels within a single image. A more effective move that can be taken in this regard is to categorize the different level of information within the images into a single image. This categorization can be comprised of a level, providing info about signal than a level describing feature followed by a level of symbolic representation and so on[107].

The analysis and concentration on the concept of pixel level approach of fusion basically result in an all in one combined image of a sequence of images [108]. When it is the case that a sequence of images are presented and important features are to be combined into a single image then it is considered that the solution can be presented by a human operator but the possible answer to such operation is image fusion. The quality of image fusion process should be that it should preserve all the necessary and significant features from a sequence of images into one composite image called the fused image [109]. The process of the image should be effective enough that after combining and blending important features from several images it should not result in inconsistency and artifacts in the resultant image. The orientation and location of an entity or substance

within the images are the most significant factor so while performing the process of image fusion it is supposed to be invariant to the rotation and shift factor. Another factor that creates a problem when fusing a number of images is the factor of uniformity and strength of temporal feature [110].

The factors that can create the distraction in the visual process of humans are being sensitive to stirring light spurs, time reliant disparity alterations familiarized through the process of image fusion. So in order to get results which are more consistent and uniform two factors should be handled with care. These factors include temporal stability and temporal consistency [111-113].The reason of temporal stability is that the changes occurred in the gray level while merging must be caused by the gray levels within the images, not by the process of fusing the images [114]. The sequence which is being combined and merged into a single composite image should be stable and uniform. The consistency of temporality is that changes that are being introduces in the gray levels of the images should appear in the resultant image without any change of contrast factor [115].

10. Conclusion

The aim of the survey was to analyze the basic process of image fusion collectively with its categorization based on its modals systems and algorithms. The analysis showed that huge work has been done in the domain of image fusion but still there is enormous room for new and innovative work in this context. The analysis also has shown that every algorithm in this context has its own strengths and weaknesses. An Analyst may observe clearly, no image fusion technique is superior over another; the selection and

effectiveness of a particular method are dependent on its application. According to research point of view, it can be concluded that PCA based image fusion techniques result in a better-enhanced image without altering the spatial and spectral details of the image. The wavelet based approaches are suitable in the applications where original values of RGB components are to be saved. And wavelet based approaches results in less distortion in the image. Lastly,proven transformations resulted in sharper images but alter the

original colors of the image by making dark areas of image darker and white areas whiter in the resultant image.

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