Image Fusion Conspectus

Shalini Dutta, Sudhakar S. Jadhav

Abstract*— *Technological advancements have brought extensive research in the field of Image Fusion. Image fusion is the process of amalgamation of relevant information from a set of input images into a single image which in turn is better informative, complete and accurate. This paper presents an overview of Image Fusion. The silhouette of the paper is anticipated to cover Image fusion right from its inception till the future research prospects. This covers the various fusion systems and techniques of image fusion such as Spatial Domain methods like Weighted Pixel Averaging, Select Maximum/Minimum, Principal Component Analysis (PCA), Frequency/Transform Domain methods like Pyramid Decomposition (Laplacian, FSD, Ratio, Gradient, Morphological), Discrete Wavelet Transform (DWT) and Artificial Neural Network (ANN) based image fusion. A comparative study of various image fusion techniques and their analyzed results are enlisted. Vivacious applications of image fusion also are highlighted as well. The compendium is concluded with the analysis of better approach as a result of the comparative study and the future scope of research perseveres.

Index Terms*— *Image Fusion, Discrete Wavelet Transform (DWT), Weighted Pixel Averaging, Select Maximum/Minimum, Principal Component Analysis (PCA), Pyramid Methods, Artificial Neural Network (ANN)

I. INTRODUCTION

The lexicon describes the word 'fusion' as 'blending of different things into one' meaning that fusion is the process or result of joining two or more things to form a single entity. As the meaning suggests clearly, 'Image fusion' hence is the fusion of different Images. In technical terms Image fusion can be defined as : 'The process of amalgamation of relevant information from a set of input images into a single image which in turn is better informative, complete and accurate'

In a nutshell, the goal of Image Fusion is:-

a.) To reduce the amount of data, to be input and to be analyzed.
b.) To retain the important information which is existent
c.) Inflecting and forming a new image which is suitable for human/machine perception and or for further processing task.

Evolution of image fusion was inevitable when aroused the need for an image containing details of all the relevant objects in focus. With the practical advent of various Image fusion techniques one could acquire series of camera captures having different focus settings and fuse them together producing a picture with the extended field depth.

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During the fusion process, each and every subtle visual details and information present in the set of input images must be inherited into the fused output image without the introduction of artifacts or noise. Image fusion is a part and parcel of Image Processing. Some of the major benefits we can reap of by fusing images are:-

1. Extended range of Operation.
2. Extended Spatial Temporal coverage
3. Reduced Uncertainty
4. Increased Reliability
5. Robust System Performance
6. Compact, almost accurate, precise and complete representation of Information.

II. INCEPTION OF IMAGE FUSION

The Image fusion is part and parcel of Data Fusion wherein the data is in form of arrays of numbers representing brightness, color, temperature, distance and other physical scenic properties. Birth of camera and the dawn of commercial photography lead to year 1839 to be declared as the practical year of photography. And the aftermath was the origin of image fusion which dates back to mid – eighties. The primitive report laying the foundation of Laplacian pyramid techniques in Binocular image fusion was done by Burt [5]. Burt and Adelson [6] later introduced a new approach based on hierarchical image decomposition; Adelson disclosed the use of a Laplacian technique in construction of an image with an extended depth of field from a set of images taken with a fixed camera having lenses with different focal lengths. Toet [7] used various pyramid schemes, which were mainly applied to fuse visible and Infrared images for surveillance purposes. Meanwhile Lillquist [8] also disclosed an apparatus for composite visible or thermal infrared imaging. The drastic leap was when the use of soft computing based neural networks in fusion of visible and infrared images was suggested by Ajjimarang [9]. Nandhakumar and Aggarwal [10] provided an integrated analysis of thermal and visual images for scene interpretation. Rogers et al. [11] described fusion of LADAR and passive infrared images for target segmentation. Simultaneously Li and Chipman et al. [12] proposed the use of Discrete Wavelet Transform. In the same era Koren et al. [13] described a steerable dyadic wavelet transform and Waxman and colleagues developed a computational image fusion methodology based on biological models of color vision and used opponent processing to fuse visible and infrared images. The need to combine visual range of data in robotics and navigation and to merge captured images at different locations and modalities for target localization and tracking in defense applications prompted further research in image fusion [1].

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III. IMAGE FUSION SYSTEMS

We have two popular Image Fusion Systems which are:-

A. Single Sensor – Only one sensor will capture a complete sequence of images and then the captured images will be fused together into one single image. The capability of sensor hence can pose as a limitation.

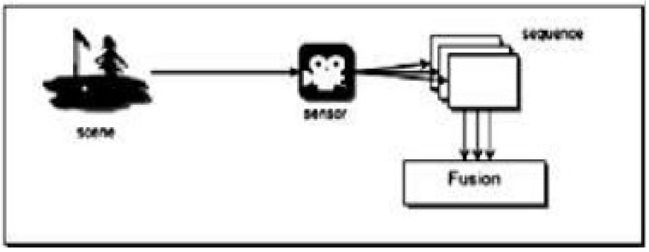

Figure 1. Single Sensor Image Fusion System

B. Multi Sensor – Multiple sensors will capture a complete sequence of images and then the captured images will be fused together into one single image, hence overcoming the limitation of single sensor system

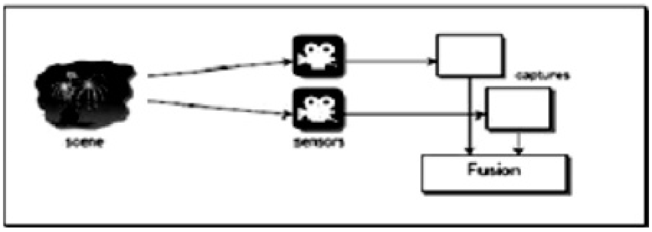

Figure 2. Multi Sensor Image Fusion System

Image fusion algorithms can be categorized into different levels as low, middle, and high/ pixel level, feature and decision levels.

Pixel Level fusion: deals directly with the pixels obtained at the imaging sensor outputs. Pixel intensity values of the source images are averaged pixel by pixel. This works in spatial or transform domain

Feature Level fusion: deals with the extracted features from the source images. The image is segmented into contiguous regions and those regions are fused together based on the comparable physical properties of the scene.

Decision Level fusion: this uses the output of the initial object detection and classification as inputs to the fusion algorithm to perform data integration. Both feature level and decision level image fusion may result in inaccurate and incomplete transfer of information. The pixel averaging in the pixel level fusion leads to undesired side effects in the resultant image. Recently researchers have recognized that it is more meaningful to combine objects or regions rather than pixels [1]. The region based algorithm has many advantages over pixel based algorithm like it is sensitive to noise, better contrast, less affected by mis-registration but at the cost of complexity.

IV. IMAGE FUSION TECHNIQUES

Image fusion techniques can be broadly classified as follows:-

1. Spatial Domain Fusion
    - 1.1 Weighted Pixel Averaging
    - 1.2 Brovey Method
    - 1.3 Principle Component Analysis (PCA)
    - 1.4 Intensity Hue Saturation (HIS)
2. Transform Domain Fusion
    - 2.1 Laplacian Pyramid
    - 2.2 Curvlet Transform
    - 2.3 Discrete Wavelet Transform (DWT)
3. Artificial Neural Network based image fusion

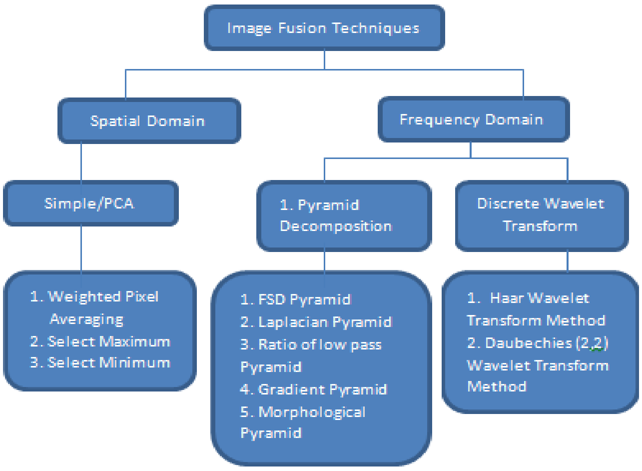

Figure 3. Image Fusion Techniques Contour

4.1 SPATIAL DOMAIN FUSION

Spatial domain techniques directly deal with the image pixels. We manipulate the pixel values to achieve the desired consequence. Simple fusion algorithms perform a basic operation like pixel selection, addition, subtraction or averaging. While PCA is a mathematical tool which is often used to reduce multidimensional data sets to lower dimensions for analysis. Following is the running list describing a few of the famous Spatial Domain techniques:

4.1.1 Weighted Pixel Averaging

Averaging is one of the trivial methods wherein the resultant image is obtained by every corresponding pixel in the input images. But simply averaging the pixels never gives the desired fused image so, one needs to perform fusion as a weighted superposition of all input images. This algorithm is a way of obtaining an output image with all regions in focus. First one has to add the value of the pixel P(i , j) of each image and this sum is then divided by 2 to obtain the average. The average value is then assigned to corresponding pixel of the output image and is repeated for all pixel values as given in equation (1):

$$K(i,j) = \{ W_A * X(i,j) + W_B * Y(i,j) \} / 2 \qquad (1)$$

Where X (i , j) and Y (i , j) are pixel values of two input images, and W_A and W_B are scalars.

4.1.2 Select Maximum/ Minimum

As the name suggests this is a selection process, among the set of corresponding pixels in the input image the pixels with the maximum intensity is chosen for the final resultant image when it is select maximum and the pixels with the minimum intensity is chosen in case of select minimum. The value of pixel P (i , j) of each resultant image is taken and compared to corresponding pixel of other image in the input set and the greatest/lowest value is assigned to corresponding pixel as shown in equation (2) and equation (3) :

$$I_F = \max \{ abs(I_A), abs(I_B) \} \qquad (2)$$

$$I_F = \min \{ abs(I_A), abs(I_B) \} \qquad (3)$$

Thus in a nutshell this algorithm chooses the in-focus regions from each input image by choosing the greatest/smallest value for each pixel, resulting in highly focused output.

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4.1.3 Principal Component Analysis (PCA)

PCA also known as Karhunen-Loeve transform or Hotelling transform is a vector space transform, which reveals internal structure of data in an unbiased way. This mathematical rather statistical tool transforms a multivariate dataset of inter correlated variables into dataset of several uncorrelated linear combinations called principle components, of original variables. First principal component accounts for as much of the variance in the data as possible and each succeeding component accounts for as much of the remaining variance as possible [2]. A new set of orthogonal axes is generated, reducing the redundancy of image data. In this method optimal weight factor is added to each pixel value of all the source images and then the weighted average is calculated to produce the final fused image at the same pixel location. Hence this technique finds its usage in image classification, image encoding, image data compression, image enhancement, pattern recognition and image fusion.

4.2 FREQUENCY/TRANSFORM DOMAIN FUSION

In Frequency domain fusion the image is first transformed to frequency domain using the Fourier transformation, all enhancements operation to modify the image properties such as brightness, color, sharpness, contrast, grey levels are performed on the Fourier transform of the image and then Inverse Fourier transform is performed to get the resultant image. Aftermath will be the fused image with the pixel values in accordance with the transformation function which was applied on input values.

4.2.1 Filter Subtract Decimate (FSD) Pyramid

FSD Decomposition phase consists of Low pass filtering, subtracting the low pass filtered input images and form the pyramid and decimate the input image matrices by halving the number of rows and columns neglecting every alternate row and column [1]. While Recomposition phase includes undecimating the mage matrix by duplicating every row and column, Low pass filtering with 2*W and matrix addition of the same with the pyramid formed in corresponding level [1].

4.2.2 Laplacian Pyramid

This method follows all the steps as that of FSD Pyramid just one additional low pass filtering is performed with 2*W. In this the difference image L_k at level k is obtained by subtracting an image up-sampled and then low –pass filtered from level k+1 from the Gaussian image Gk at level k [1]. Efficiency of FSD pyramid is hence more than Laplacian pyramid as the up-sampling step is skipped.

4.2.3 Ratio Pyramid

Ratio pyramidal method is also based upon FSD pyramid method. A minor difference is present in the decomposition phase in which case, after low pass filtering, instead of subtracting here pixel wise ratio is calculated.

4.2.4 Gradient Pyramid

This also follows FSD Pyramid method but since it is gradient so directional filters are involved. The decomposition phase includes two low pass filters, along with them four directional gradient filters namely horizontal, vertical and diagonal filters are involved. So it is a bit similar to Laplacian pyramid also in a way simply replacing Laplacian pyramid with combined gradient pyramid.

4.2.5 Morphological Pyramid

Decomposition phase comprises of two levels of filtering – image opening viz. the combination of image erosion followed by image dilation and image closing which is the other way round. The closing and opening roundtrips results into removal of noise from the image. Rest all steps are same as that of FSD pyramid.

4.2.6 Discrete Wavelet Transform (DWT)

Wavelets are finite duration oscillatory functions with zero average value [14] having finite energy. Here we deal with the superposition of wavelets or basically two functions – Father Wavelet / Scaling function and Mother wavelet / wavelet function which undergoes dilation or contractions (scaling) and shifts (translational) operations to produce self-similar family of wavelets. This transform decomposes the image into low-high, high-low, high-high spatial frequency bands at different scales and low-low band at the coarsest scale [2]. DWT is a multi-scale and multi resolution approach [16][18]. It allows the image decomposition in different kinds of coefficients preserving the image information [2]. After the coefficients are merged the final fused image is obtained by performing inverse DWT.

4.3 ARTIFICIAL NEURAL NETWORK (ANN) BASED FUSION METHOD

ANN based method employs a nonlinear response function that iterates many times in a special network structure in order to learn the complex functional relationship between input and output training data. It is more powerful and self-adaptive method of pattern recognition.

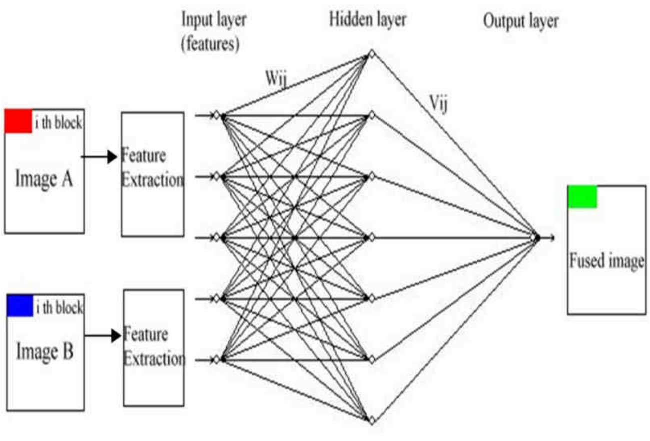

Figure 4. Schematic diagram of ANN based fusion

Here the two registered images are decomposed into several blocks with size M and N. Then, features (spatial frequency, visibility and edge) of corresponding blocks are extracted, and normalized feature vector incident to neural networks can be constructed. Then some vector samples are selected to train the NN. Once trained, the ANN model can remember a functional relationship and be used for further calculations. For these reasons, ANN concept has been adopted to develop strongly nonlinear models for multiple sensor data fusion. An ANN is a universal function approximator that directly adapts to any nonlinear function defined by a representative set of training data. [3]

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V. COMPARATIVE ANALYSIS OF FUSION TECHNIQUES

TABLE 1: Fusion Techniques compared and analyzed theoretically

Domain	Fusion Technique/Algorithm	Advantages	Disadvantages
Spatial	Simple Average[2][20]	Simplest method of image fusion	This method doesn't give guarantee to have a clear object from the set of images.
	Simple Maximum [19]	Resulting in highly focused image output obtained from the input image as compared to average method	Pixel Level methods are affected by blurring effect which directly affect on the contrast of the image
	PCA [21]	PCA is a tool which transforms number of correlated variable into number of uncorrelated variables, this property can be used in image fusion	But Spatial domain fusion may produce spectral degradation.
Transform	DWT [16][17][19]	The DWT fusion method may outperform the standard fusion method in terms of minimizing the spectral distortion. It also provides better signal to noise ratio than pixel based approach.	In this method final fused image will have less spatial resolution.
	Combine DWT , PCA[18][20]	Multilevel fusion where the image undergoes fusion twice using efficient fusion technique provide improved results. Output image contained both high spatial resolution with high quality spectral element.	This method is complex in fusion algorithm. Required good fusion technique for better result.
	Combination of Pixel & Energy Fusion Rule[15]	Preserves boundary information and structural details without introducing any other inconsistencies to the image	Complexity of method increases.
Artificial Neural Network based Image Fusion[3]		Learning capability of neural networks makes it feasible to customize the image fusion process. Multiple I/O frameworks make it to be a possible approach to fuse high dimension data.	Very Complex method

VI. APPLICATIONS

Image fusion finds its wide spread applications in various fields. Its applications are growing every moment. Contemporary era entails vivacious Image Fusion applications, some of which are enlisted as follows:-

1. Medical Imaging – In medical diagnostics and treatment nowadays fused images are created using multiple images from single or multiple modalities such as MRI,PET,CT. Also image fusion is used in computer assisted surgery and spatial registration of 3-D surface.

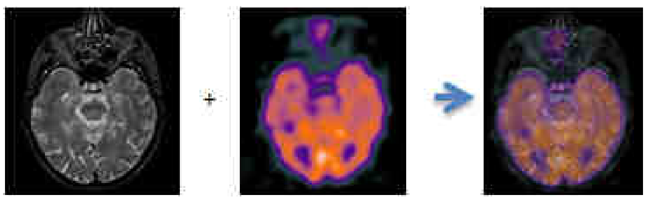

Figure 5. NMR + SPECT fused image in medical diagnostics

2. Remote sensing- The remote sensing satellite imaging also is a trend of the era. Image fusion is useful in object identification, classification and change detection from analyzing the satellite images. The SPOT PAN Satellite provides high resolution (10m pixel) panchromatic data. While the LANDSAT TM satellite provides low resolution (30m pixel) multispectral images. Image fusion attempts to merge these images and produce a single high resolution multispectral image. Standard merging methods involve RGB and Intensity-Hue-Saturation (IHS) transformation. Remote sensing application of image fusion proves quiet important at the time of natural disaster like flood detection, or to analyze the global climate and predict accordingly.

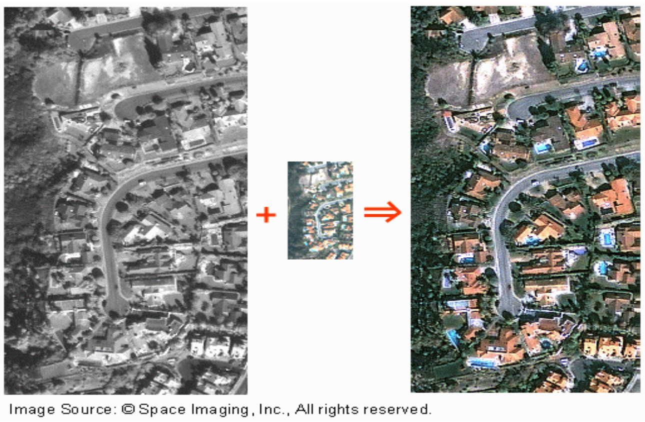

Figure 6. Image pan-sharpening with input images obtained from space imaging, and the output is the resultant fused image

3. Robotics – Intelligent Robots require motion control, feedback from environment from visual tactile, force/torque, and other types of sensors, intelligent

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viewing control, automatic target recognition and tracking, stereo camera fusion are all one of the potential applications of image fusion []

Figure 7. Octavia the fire-fighting robot of US Navy that works on Image fusion principles to understand gesture, recognize target and localize fire and extinguish it with compressed air/water supply.

4. Manufacturing and Microscopic Imaging – Electronic circuit and component inspection, 3-D modeling and product surface measurement and inspection and other tasks related to manufacture process monitoring are also influenced drastically by image fusion.

Figure 8. Image fusion based 3 D Modeling

5. Biometrics – Image fusion solves one of the most researched challenges of Face/Iris recognition. Now the regular attendance systems are also developed based on biometrics. Image fusion is hence finding huge acceptance and credits worldwide being the basic technology behind biometrics. Also helps in achieving better security standards.

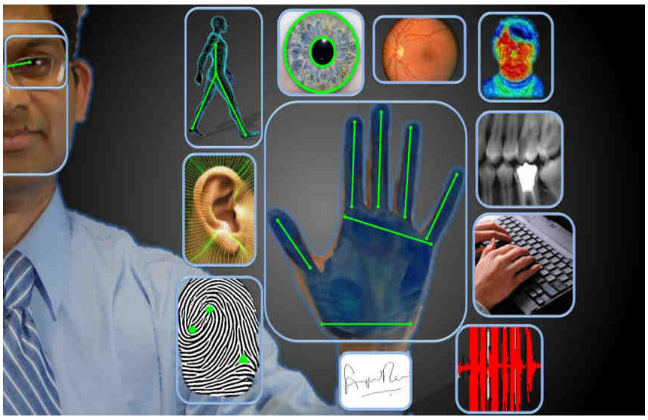

Figure 9. Image fusion the spine of Biometrics (Face/Palm/Iris recognition)

6. Surveillance and Navigation applications for both military and domestic purposes – Defense personnel started using image fusion long ago. The usage of image fusion in battle field monitoring, concealed weapon detection, night flying/sailing guidance for pilots and sailors and detection, tracking and identification of ocean/air/ground target/event dates back to decades. With the advent of emerging and more accurate image fusion techniques the surveillance and navigation applications are achieving success.

Figure 10. Navy Graphical Data and Image Fusion System

VII. CONCLUSION

This paper presents an overview of Image fusion. On the basis of the study it was found that selection of fusion algorithm is problem dependent and every technique has set of pros and cons and to remove those various other techniques are proposed. In a nutshell one could figure out that spatial domain provide high spatial resolution but suffer from image blurring problem. On the other hand wavelet transforms is a good technique which provides a high quality spectral content. But a good fused image comprising of valuable information is in turn a hybrid of spatial and transform domain combinations like DWT and PCA implemented together in which case the performance alleviates compared to singleton techniques implementation. Ushering in the new era is the application of soft computing based image fusion techniques ANN based image fusion is a promising technique with which one can anticipate more accurate analysis and prediction with regards to the fused image. ANN based fusion is finding acceptance in several applications of image fusion nowadays like robotics, artificial intelligence, biometrics. Regarding image fusion research, DWT and PCA with morphological processing and reduced complexity and better implementation of ANN based fusion might be the future trends to ponder upon.

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