Recent Developments in Electronics and Communication Systems
KVS Ramachandra Murthy et al. (Eds.)

doi:10.3233/ATDE221321

A Review on Spatial and Transform Domain Image Fusion Methods

Vella Satyanarayana[a,1], P. Mohanaiah[b]
[a]*Research Scholar, Department of ECE, JNTUCEA, Anantapur, Andhra Pradesh, India*
[b]*Professor, Department of ECE, N.B.K.R Institute of Science & Technology, Vidyanagar, Nellore, Andhra Pradesh, India*

Abstract: Image fusion aims to collect better information from an image obtained by combining two or more different images. Image fusion has many applications such as remote sensing, medical imaging, medical diagnosis, robotics, surveillance, and image enhancements. This article presents the strengths and weakness of recent arrivals in the literature on spatial and transform domain. A comparative analysis among recently existed literature of various types of image fusing methodologies. A generalized flow diagram for image fusion which is universally acceptable to all types of images such as medical images, visible images, infrared images, multi-focus images, multi-exposure images, hyperspectral image and multispectral images is depicted. Various effective qualitative and quantitative performance measures useful for image fusion with reference image and without reference image are also tabled. At last, recommendations are given as per current research requirements for better performance with decent complexity.

Keywords: Image fusion, Data fusion, Datasets, Fusion metrics, medical image fusion

1. Introduction

There have been numerous advancements in image analysis and image fusion methods for improved information collection in recent times. Image fusion aims to collect additional details from one image obtained by combining two different images. Image fusion has many applications such as remote sensing, medical imaging, medical diagnosis, robotics, surveillance, and image enhancements. Specifically, this sector's significant development with steady growth in the number of publications and efficiency of recently developed approaches has been observed in recent years [1]. A vital task in image fusion is selecting the fusion law for a particular application like multi-modality fusion, multi-focus fusion etc [2, 13]. It is observed that a single fusion rule is used for several fusion applications, such as the same rule for multi-focus image fusion and multi-modality image fusion. It is also observed in the literature, a single application of image fusion is used multiple fusion rules for combining image coefficients at different scales [3, 12]. Various approaches are used to fuse. Initially, raw data fusion is followed later for effectiveness shifted to features set fusion, for the betterment of existing fusion methodologies moved to decision level fusion. Different source images are displayed in the table 1 for the new researcher's reference. Various methodologies have existed for

[1] Corresponding Author, Vella Satyanarayana, *Research Scholar, Department of ECE, JNTUCEA, Anantapur, Andhra Pradesh, India*; E-mail: vellasatyanarayana414@gmail.com

Table 1. Multiple image fusion example source images

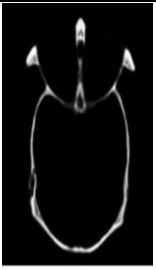
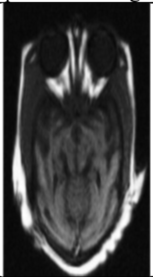
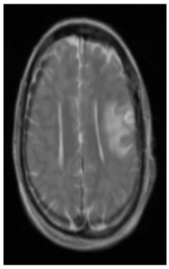
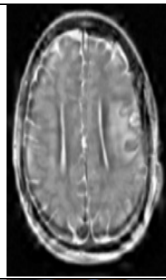
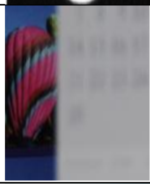
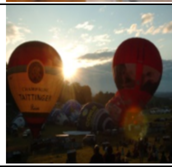
Medical images				
Multi focus images				
Multi exposure images				

image fusion in literature. It can be achieved in the Spatial Domain, Frequency domain (Transform domain), Deep learning-based methods [4, 11].

Regression-based methods, or combined hybrid methods. In the spatial domain, the fusion can be achieved using block-based, region-based, pixel-based. In block-based images, the source images are converted into nonoverlapping blocks. The blocks are fused using a threshold based adaptive fusion rule. Region-based image fusion is also similar to block-based image fusion, but here instead of dividing source images into blocks, the source images are divided into the region using segmentation [5, 6, 7, 20]. Many blocks-based image fusion and region-based image fusion methodologies are existed in literature, but they have their limitations. In pixel-based image fusion, the pixel of images are directly fused using the weighted average method (the intensity levels of the two pixels are averaged for fused images pixel intensity), Chose Maximum (In the two source image intensities, maximum intensity is selected for fused image), Choose Minimum (In the two source image intensities, the minimum intensity is chosen for fused image) and many other methods available [8, 9, 10].

2.Literature Survey:

Image Energy-based fusion provides a better amount of structural information. Hongpeng proposes it for different image modalities such as fusing infrared and visible images and fusing medical images. In 2018, Xin Jin et al. suggested a multi-focus image fusion on Gray images and colour images with two fusion rules (average fusion rule and maximum fusion rule) using LSF, PCNN, LPT [17]. The complexity of this IF method is acceptable with better performance. Yang et al. proposed a IF method based on DWT which having good spatial and spectral localization in fused image but it contain shift variant nature and spatial inconsistency and halo artifacts at edges [1, 2, 3, 16]. A generalized NSST-based pulse-coupled neural network (S-PCNN) has been suggested by Hajer Ouerghi . This approach transforms images from PET into components of YIQ. Just MRI images and the Y components of PET images given to the NSST transform. Using local energy and weight region standard deviation the lower sub bands are fused [18, 19]. The S-PCNN fuses the HF coefficients with the adaptive connection strength coefficient excitation. By this approach, authors can get an efficient fused image with less colour distortion and more structural information [4,, 14, 15].

Table 2. Related work spatial and transform domain image fusion methods

Reference and Authors	Application	Domain	Methods used	Comments	Performance
Wei L et al, [27]	Medical Diagnosis	Transform	DWT and PCA	Good quality is observed in spatial domain fused image	Entropy-7.24 PSNR 67.08
Y Kim et al [28]	MS, PAN image fusion	Transform	MTF, SPCA	Efficient with respect to spatial structures	NA
Azzawi A et al [29]	Medical Diagnosis	Transform	ICA, WT	Though it is quick procedure the fused image consists noise	SD-41.2832 IE 4.9546
Baihong Lin et al., [30]	Hyperspectral image and multispectral image fusion	Spatial	GMM	No need for image Registration but computationally high	NA
Vijayarajan R, Muttan S [31]	Medical Diagnosis	Spatial	Pixels, PCA	Good quality is observed in spatial domain fused image but pixels suffers with graphic outline	EN-7.20 PSNR-26.86
Yong Yang et al., [32]	Multi Focus image fusion	Spatial	RSR, PCNN, Morphological Operators	The complex algorithms consume much time	NA
Zhang L Et al [33]	Medical Diagnosis	Spatial	PCA	Possibility of spectral deterioration	PSNR-76.44 SD-45.23
Huihui Song et al., [20]	Spatiotemporal fusion	Spatial	NLM - CNN, SR - CNN	Atmospheric conditions much effect efficiency of algorithm	NA

3.Generalized flow diagram:

Effective fusion process makes effective fused image and leads to effective collection of information form it. However, the fusion stages rely on conceptual understanding of input source image modalities. A single fusion process can work for all modalities but not effective for all. The source images can be any modality like medical images, visible images, infrared images, multi-focus images, multi-exposure images, hyperspectral image and multispectral images. The flow diagram of generalized image fusion methodology can be seen in figure 1. The pre-processing helps to register the given source images into same size and remove/reduce noise in source image so it makes it simple to further processing on the source image. The source images are converted into approximation coefficients and detail coefficients using various decompositions such as DWT, NSCT, SWT, NSST, Curvelet Transform. The decomposition method may downgrade source image resolution in the coefficients and represent most of the source images energy in it.

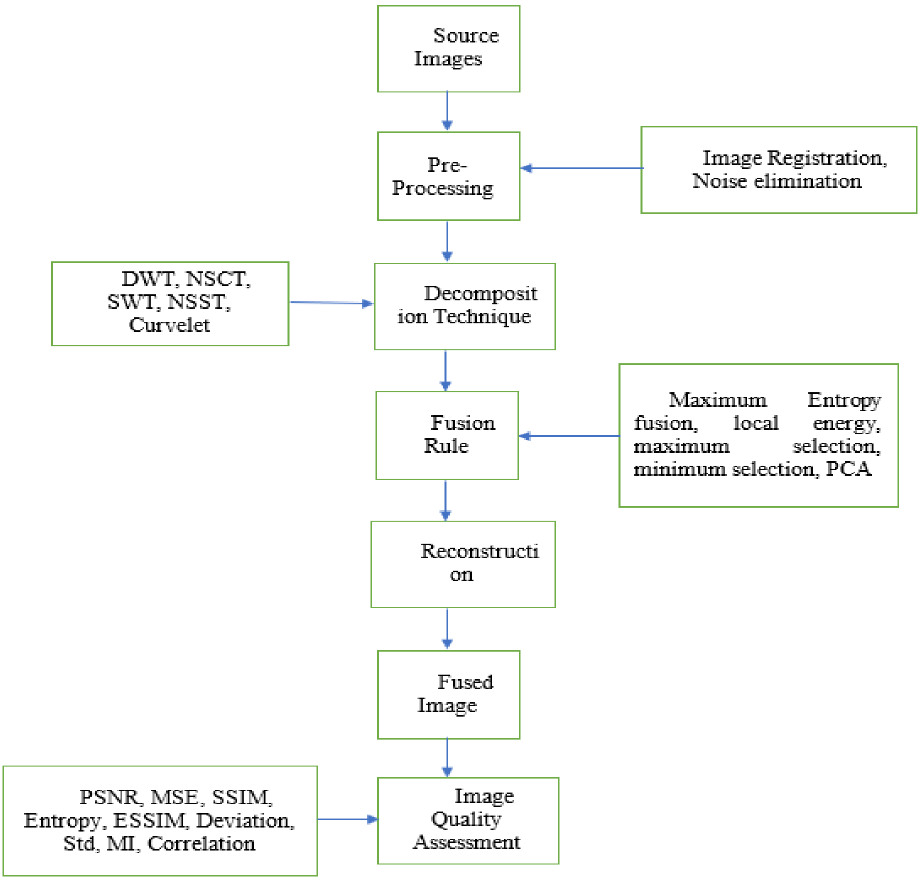


Figure 1: Generalized Flow Diagram of Image Fusion

4.Quality assessment techniques of Image Fusion:

There are two standard methods to assess the output of fused images are qualitative analysis and quantitative analysis. The fused image is compared to the input images in qualitative analysis. It attests to the fused image's accuracy utilising different statistical criteria in terms of spatial detail, graphical patterns, object size, colour, spectral information, etc. The objective assessment interpretation is a quantitative analysis that can surpass the impact of humans' incorrect vision judgment to allow the metrics to measure the efficacy of image fusion mathematically. In Quantitative analysis, there are two types of approaches, one is metric measurements with reference image (SSIM, MI, CC, PSNR, SNR, RMSE) and other one is metric measurements without references (Fusion Quality Index, Entropy, Standard Deviation). Most used performance measure for all sort of image fusions are presented in table 3.

Table 3. Performance measures of image fusion

Name of Metric	Formula	**Value for best performance**
RMSE	$RMSE=\sqrt{\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\left(Ir(i,j)-if(i,j)^2\right)}$	Lower (Close to Zero)
SNR	$SNR=10\log_{10}\left(\frac{\sum_{i=1}^{M}\sum_{j=1}^{N}(I_r(i,j))^2}{\sum_{i=1}^{M}\sum_{j=1}^{N}(I_r(i,j)-I_f(i,j))^2}\right)$	Higher value
PSNR	$PSNR=20\log_{10}\left(\frac{L^2}{\sum_{i=1}^{M}\sum_{j=1}^{N}(I_r(i,j)-I_f(i,j))^2}\right)$	Higher value
CC	$CC=\frac{2C_{rf}}{c_r+c_f}$	Higher value (CloseTtoT+1)
MI	$MI=\sum_{i=1}^{M}\sum_{j=1}^{N} hI_rI_f(i,j)\log_2\left(\frac{{}^{h}I_rI_f(i,j)}{{}^{h}I_r(i,j){}^{h}I_f(i,j)}\right)$	Higher value

5.Conclusions and Future Directions:

Image fusion is a technique of fusing multiple images for better information and a more accurate image than source images. It has many applications in remote sensing, medical imaging, medical diagnosis, robotics, surveillance, and image enhancements. In this paper discussed, recent arrivals on image fusion pros and cons are discussed briefly and tabled. Though good progress seen in recent years on image fusion, there is a need for addressing many issues in it. Source images Mis registration effects severely on the fused image, and it may vary the original information in the fused image. Particular focus is needed for fusing boundary regions in some fusion applications like multi-focus images, multi-exposure images and medical images. Almost all of the existing fusion methodologies are working for a single application like multi-focus images for medicine or multi-focus images for biology, so there is a need for efficient proposals on multi-application image fusion methods from researchers. A flow diagram for image fusion which is generally applicable to all forms of images is introduced. Qualitative and quantitative fused image quality metrics are discussed.

References

[1] Liu W, Huang J, Zhao Y. Image fusion based on PCA and undecimated discrete wavelet transform. InInternational Conference on Neural Information Processing 2006 Oct 3 (pp. 481-488). Springer, Berlin, Heidelberg.

[2] Kim Y, Kim M, Choi J, Kim Y. Image fusion of spectrally nonoverlapping imagery using SPCA and MTF-based filters. IEEE Geoscience and Remote Sensing Letters. 2017 Oct 31;14(12):2295-9.

[3] Al-Azzawi N, Abdullah WA. Medical image fusion schemes using Contourlet transform and pca bases. Image fusion and its applications. 2011 Jun 24:93-110.

[4] Lin B, Tao X, Duan Y, Lu J. Hyperspectral and multispectral image fusion based on low rank constrained Gaussian mixture model. IEEE Access. 2018 Mar 19;6:16901-10.

[5] Vijayarajan R, Muttan S. Discrete wavelet transform based principal component averaging fusion for medical images. AEU-International Journal of Electronics and Communications. 2015 Jun 1;69(6):896-902.

[6] Yang Y, Yang M, Huang S, Ding M, Sun J. Robust sparse representation combined with adaptive PCNN for multifocus image fusion. IEEE Access. 2018 Apr 3;6:20138-51.

[7] Zhang L, Dong W, Zhang D, Shi G. Two-stage image denoising by principal component analysis with local pixel grouping. Pattern recognition. 2010 Apr 1;43(4):1531-49.

[8] Adu J, Xie S, Gan J. Image fusion based on visual salient features and the cross-contrast. Journal of Visual Communication and Image Representation. 2016 Oct 1;40:218-24.

[9] Karsanina MV, Gerke KM, Skvortsova EB, Ivanov AL, Mallants D. Enhancing image resolution of soils by stochastic multiscale image fusion. Geoderma. 2018 Mar 15;314:138-45.

[10] Hou R, Nie R, Zhou D, Cao J, Liu D. Infrared and visible images fusion using visual saliency and optimized spiking cortical model in non-subsampled shearlet transform domain. Multimedia Tools and Applications. 2019 Oct;78(20):28609-32.

[11] Yang B, Jing ZL, Zhao HT. Review of pixel-level image fusion. Journal of Shanghai Jiaotong University (Science). 2010 Feb;15(1):6-12.

[12] Meher B, Agrawal S, Panda R, Abraham A. A survey on region based image fusion methods. Information Fusion. 2019 Aug 1;48:119-32.

[13] Meher B, Agrawal S, Panda R, Abraham A. A survey on region based image fusion methods. Information Fusion. 2019 Aug 1;48:119-32.

[14] Yadav SP, Yadav S. Image fusion using hybrid methods in multimodality medical images. Medical & Biological Engineering & Computing. 2020 Apr;58(4):669-87.

[15] Liu R, Liu J, Jiang Z, Fan X, Luo Z. A bilevel integrated model with data-driven layer ensemble for multi-modality image fusion. IEEE Transactions on Image Processing. 2020 Dec 14;30:1261-74.

[16] Zhou T, Ruan S, Canu S. A review: Deep learning for medical image segmentation using multi-modality fusion. Array. 2019; 3–4: 100004.

[17] Tan W, Thitøn W, Xiang P, Zhou H. Multi-modal brain image fusion based on multi-level edge-preserving filtering. Biomedical Signal Processing and Control. 2021 Feb 1;64:102280.

[18] Guo R, Shen XJ, Dong XY, Zhang XL. Multi-focus image fusion based on fully convolutional networks. Frontiers of Information Technology & Electronic Engineering. 2020 Jul;21(7):1019-33.

[19] Zhang Q, Liu Y, Blum RS, Han J, Tao D. Sparse representation based multi-sensor image fusion for multi-focus and multi-modality images: A review. Information Fusion. 2018 Mar 1;40:57-75.

[20] Zhang Y, Chen L, Zhao Z, Jia J. Multi-focus image fusion based on cartoon-texture image decomposition. Optik. 2016 Feb 1;127(3):1291-6.