STM JOURNALS
Journal of Artificial Intelligence Research & Advances
ISSN: 2395-6720(online)
Volume 3, Issue 1
www.stmjournals.com

Brief Review of Medical Image Fusion Techniques Based on Hybrid Intelligence

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Abstract
An image fusion combines complementary images from multiple images such that the fused image is more suitable for further processing tasks or specific application. The goal of image fusion is to integrate complementary multi sensor, multi temporal and/or multi view data into a new image containing more information for proper medical diagnosis and different application tasks. The purpose of this paper is a survey of image fusion algorithms based on soft computing.

Keywords: *Medical image fusion, fuzzy logic, neural network, soft computing, wavelet transform, intelligence edge detectors*

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INTRODUCTION
Image fusion is the process of combining two or more aligned images. Each input image contains information of the same scene but the important information present in the images is spread across several images and will be complementary in nature. The fused image will contain the essential features of all the images and it is more useful than any of the input images. Various types of images are fused together to obtain useful information. Therefore image fusion is used in many areas. Broadly image fusion is classified by two ways namely spatial domain (time domain) and frequency (transfer domain) techniques.

However, each and every image fusion technique can be classified by spatial or frequency domain. Image fusion can also be classified based on:

(i) Level of abstraction
(ii) How data is entered
(iii) Single sensory fusion
(iv) Multi-sensory fusion

By level of abstraction, image fusion can be classified further:

(i) Pixel level fusion: Fusion is performed pixel by pixel.
(ii) Feature level fusion: Features are extracted from both the images and best features appear in the fused image.
(iii) Decision level fusion: Fusion of high-level information where decisions are based on the outputs from individual sensors.

- Pixel level fusion combines information from different source images and produces a single fused image that is the core of the system. Typical sensor combinations include: visible light (VL) and infrared (IR), millimeter waves (MMW) and IR, synthetic aperture radar (SAR) and IR, multispectral (MS) and panchromatic (Pan), and computerized tomography (CT) and magnetic resonance imaging (MRI).
- Feature level fusion refers to combining different feature vectors that are obtained by either using multiple sensors or employing multiple feature extraction algorithms on the same sensor data.
- The decision level methods represent the highest level of processing where information fusion can take place. In this class, the decisions of each single classifier are fused in order to generate the final decision, according to a given policy.

By how data is entered, image fusion can be classified further:

(i) Multi-view fusion
(ii) Multi-modal fusion
(iii) Multi-focus fusion
(iv) Multi-temporal fusion

- In the multi-view fusion, images of the same modality taken at the different view and under same conditions are fused. Goal of this fusion is to create 3D model.
- In multi-modal fusion, images of the different modalities like X-ray, CT, MRI, visible, infrared, ultraviolet, etc. are fused. Goal of this fusion is to emphasize band-specific information.
- In multi-focus fusion, images of the different or same modalities like X-ray, CT, MRI, visible, infrared, ultraviolet, etc. are fused. Goal of this fusion is to emphasize band-specific information as well as make all the objects in focus.
- In multi-temporal fusion, images of the same scene taken at different times (usually of the same modality) are fused. Goal of this fusion is the detection of changes.

By single image fusion uses one sensor but multi temporal scenes to fuse images and multi sensor image fusion uses multiple sensors to fuse images.

The task of image fusion is to make many salient features in the new image such as regions and their boundaries. Several situations in image processing require high spatial and high spectral resolution in a single image. Most of the available equipment is not able to provide such data convincingly. The image fusion techniques allow the integration of different information sources. The fused image can have complementary spatial and spectral resolution characteristics. Various approaches have been developed for performing image fusion, each with their own merits and limitations. Though it is infeasible to develop a robust approach to handle all the types of image fusion, techniques are available to cater to the specific type of image fusion. In the recent years, many algorithms based on hybrid intelligent systems are developed for medical diagnosis and computer assistance, patient monitoring and patient care [1-5].

Soft Computing is considered important in artificial intelligence. It is the use of inexact solutions to computationally hard tasks. It is tolerant of imprecision, uncertainty, partial truth, and approximation. In effect, the role model of soft computing is human mind. Soft computation techniques have been applied to various fields. Computer vision, machine perception and image processing are one of them. Most of problems in these fields have become much easier to solve by applying these technologies which include fuzzy system, the bio-inspired evolutionary algorithms, neural networks, rough set model which are currently attractive topic in wide variety of bioinformatics research areas. Moreover, the development of new intelligent system is often resulting of hybridization of different learning and adaptation of soft computing techniques. Such new approach can be used to address the limitations of individual techniques. Soft Computing is dedicated to system solutions based on soft computing intelligent approach techniques. It provides rapid dissemination of important results in soft computing technologies, a fusion of research in evolutionary algorithms and genetic programming, neural science and neural net systems, fuzzy set theory and fuzzy systems, and chaos theory and chaotic systems. Soft Computing encourages the integration of soft computing techniques and tools into both every day and advanced applications. To emulate more efficiently human mind, intelligent system is linking the ideas and techniques of soft computing with other disciplines like image processing. Hybrid intelligent is a combination of intelligent tools and techniques that make sense in a theoretical and practical basis for performing in a competitive way when compared to simple intelligent techniques. It can be framed either by integrating two or more intelligent systems, which maintains the identity of each methodology, or by fusing one system into another or by transforming the knowledge representation of one intelligent system into another form with the characteristic of the another intelligent system [6-10, 15].

Medical image fusion is a very emerging research field in recent decade. Major application domain under diagnosis are brain, breast, prostate and lungs. Various combinations of modalities MRI, X-ray, CT, PET, SPECT and Ultrasound are fused for tumor identification, organ analysis, change of detection and assessment of medical condition. Involving intelligence techniques in existing medical image fusion methods can be much worthy in rapid medical diagnosis, human endeavors of artificial intelligence and machine perception [11, 12].

LITERATURE REVIEW

Neuro-Fuzzy Approach for Medical Image Fusion

Das and Kundu have proposed frequency domain image fusion using non-subsampled contourlet transform (NSCT) to decompose both desired spatially registered images into low frequency and high frequency sub-bands [13]. Low and high frequency sub-bands of both the images are fed to the pulse coupled neural network, pulse coupled neural network (PCNN) is emulated from cat's visual cortex system which is very effective for image processing tasks where in the contourlet transform is inspired by human visual system. From the PCNN-related literature [14], we know that the linking strength β reflects the pixel's (coefficient) characteristics, and should be adaptive to the importance (significance) of the corresponding pixel (coefficient). Fuzzy logic is used to compute β.

To use a novel fuzzy-based technique to adaptively set the value of β by estimating each coefficient's significance (importance) in the corresponding image. If a coefficient's local average energy (LAE) is large or its local information entropy (LIE) is large, then the coefficient has more importance in the image. Considered $LAE_{s,d}^{I}(i,j)$ and $LIE_{s,d}^{I}(i,j)$ as the representations of a coefficient's local average energy and its local information entropy, respectively. The fuzzy membership values $\mu_1(B_{s,d}^{I}(i,j))$ and $\mu_2(B_{s,d}^{I}(i,j))$ correspond to $LAE_{s,d}^{I}(i,j)$ and $LIE_{s,d}^{I}(i,j)$ respectively. Low and high sub-band of both images are fed to the PCNN, and then at the output they are fused based on B value which is dependent on (β). Finally the inverse non-subsampled contourlet transform is performed to get fused image.

Medical Image Fusion Based on Hybrid Intelligence

Kavitha and Chellamuthu have proposed hybrid intelligence medical image fusion technique using ant colony optimization and pulse coupled neural network [15]. Swarm intelligence is used to optimize the edge detection and edge enhancement of objects in images that are fed to the pulse coupled neural network. As show in block diagram below (Figure 1), desired spatially registered both images are gone through optimization edges and enhancement by ant colony optimization then both the images are fed to pulse coupled neural network (PCNN) which is emulated from cat's visual cortex system which is very effective and developed for image processing tasks. At the end, maximum fusion rule is applied from both output images of PCNN to get the final fused image.

Novel Hybrid Approach for Multi-Focus Image Fusion using Fuzzy Logic and Wavelets

Myna and Prakash have proposed multi-focus hybrid intelligence image fusion method based on wavelet transform and fuzzy logic, where desired source images have been decomposed in frequency domain by wavelet transform [16]. Wavelet decomposition of the images is used due to its inherent multi-resolution characteristic. Discrete wavelet transform (DWT) has been used in the proposed approach to reduce the size of the image at each level. An image of resolution $2^k x 2^k$ pixels at level L reduces to size $2^{k-1} x 2^{k-1}$ pixels at level L+1. At each level the image is decomposed into four sub images obtained by applying low-pass filter L and a high-pass filter H working along the image rows and columns.

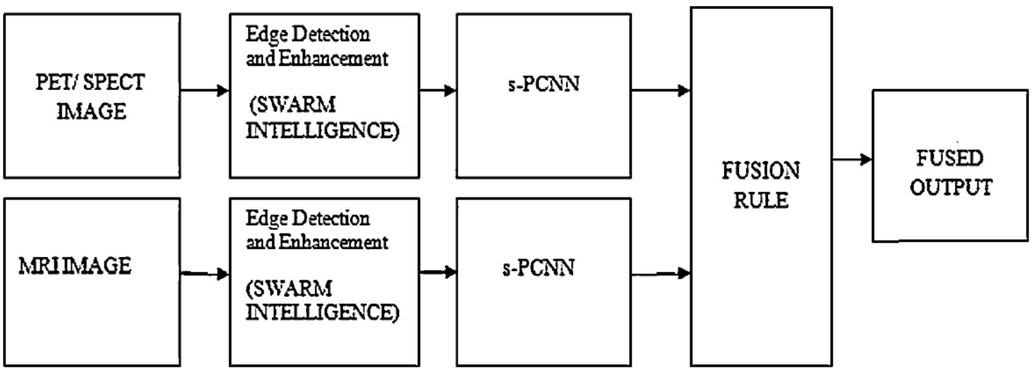

Fig. 1: *Hybrid Intelligence Image Fusion [15].*

Mamdani type fuzzy inference system which comprises of two inputs and one output is used; the two inputs represent the pixel values from two input images.

The Fuzzy inference system (FIS) uses the rule base and evaluates the fuzzified output. Mamdani FIS uses maximum value to evaluate OR operator in the rule and minimum value to evaluate AND operator. The logic is that a very dark or very bright pixel comes from the in focus region. Highest priority is given to the very dark and the very bright values. The priority decreases from left to right for the dark pixels and from right to left for the bright pixels. When two pixels belonging to two input images are compared, the one with the higher priority is considered to come from the in-focus part. The priority assigned to the eight membership functions. The output is a fuzzy value and is defuzzified using centroid method to get fused image. More about Fuzzy + Wavelet & Neuro-Fuzzy + Wavelet based image fusion can be found at [17].

Quality Assessment Parameters for Iterative Image Fusion Using Fuzzy and Neuro Fuzzy Logic and Applications

Rao *et al.* focused on comparison of image fusion methods among fuzzy logic, neuro-fuzzy logic, iterative fuzzy logic and iterative neuro fuzzy logic [18, 19]. All fusion methods are performed at pixel level in spatial domain. Fuzzy sets are to represent spatial information in images along with its imprecision, operations recently generalized to fuzzy sets in order to manage spatial information. Seven membership functions are defined for 255 intensity pixel color values for both images therefore 49 IF-THEN rules are intuitively created. Whereas in neuro fuzzy logic based image fusion neuro-fuzzy refers to combinations of artificial neural networks and fuzzy logic. In neuro fuzzy based image fusion the fuzzy membership value is trained by neural network. In iterative fuzzy and neuro fuzzy based image fusion an iteration behavior for the processed fused image is carried out further with number of input images. Output fused image can be formed by defuzzification.

Medical Image Fusion: A Survey of the State of the Art

James *et al.* have proposed the state of art of medical image fusion [20]. Medical image fusion is used for diagnosis, monitoring and analysis. The aim of this review is to provide medical image fusion review based on:

(i) Widely used image fusion method
(ii) Imaging modalities and
(iii) Organs that are under study

The main modalities that are used in medical imaging are:

(i) MRI-Medical Resonance: It uses strong magnetic field to create image of interest of organ. The soft tissue structure in organ such as brain, heart, breasts, prostate, gynecological problems and eyes are imagined with high accuracy as a major application domain. The major disadvantage of MRI is its relative sensitivity to movement. The MRI image can be fused with CT, PET or SPECT for particular interest diagnosis.
(ii) CT-Computed Tomography: It is an X-ray computerized axial tomography, from different angles it can make cross sectional images of specific area allowing user to see inside bone structure without cutting. It has a high imaging resolution, and is used for brain, lungs, prostate, liver and breasts as major application domains. Its limitation is limited tissue characterization. CT image can be fused with MRI, PET, SPECT and Ultrasound.
(iii) PET-Positron Emission Tomography: It is nuclear medicine imaging based on gamma wave. Molecular imaging is often seen as an advantage of PET images. It is costlier than SPECT and has less artifacts due good sensitivity. The resolution limits of PET images are one of the main challenges and radiation side effects. Major application domains of PET are brain, breasts, prostate, lungs, liver tissue, bone marrow, and cancer diagnosis and tumor detection.
(iv) SPECT-Single-photon Emission Tomography: It is also nuclear medicine imaging based on gamma wave. It is widely used to study blood flow of tissues and organs such as brain, prostate, lungs, breasts, liver tissue, bone marrow, cancer diagnosis, oral cancer diagnosis. It has artifacts due to if the sensitivity is high. It is fused with MRI, CT and PET for particular interests.

Ultrasound: It is sonar based medical imaging with low cost and has known no side effects. It

is widely fused with MRI, CT, PET and SPECT for interests such as brain, breasts, prostate and gynecological problems.
Figure 2 shows the summary of the two stages involved in medical image fusion methods. The two stages of any classical image fusion method are: Image registration and Fusion of relevant features from the registered images. The detail current trends about image registration and fusion is explained in [21]. Table 1 shows the summary of the major medical image fusion methods, the modalities that these methods are applied and the applications in medical imaging studies.

Multi-Modality Medical Image Fusion using Discrete Wavelet Transform
Bhavana and Krishnappa have emphasized the multimodal image fusion approach based on wavelet transform and fuzzy c-means clustering for medical images PET and MRI [22]. MRI and PET images are used as input source images. PET image is firstly decomposed into its intensity hue saturation (IHS) transform and thus the information of high activity region is differentiated from the low activity region of PET image by making use of hue angle obtained from the IHS transform. Pre-processing stage involves removal of noise and enhancing the input images using Gaussian filter. Filtering is used mainly to smoothen or sharpen the input images. High activity and low activity regions of PET image carry more anatomical and spectral information, respectively. Hence both the high activity and low activity regions are decomposed by applying 4-level DWT transform to obtain high and low frequency coefficients. Then high frequency coefficients of PET and MR images using averaging method are fused and the inverse DWT is performed to obtain the fused result of high frequency output. Similarly by combining low frequency coefficients of PET and MR images into a complete set of wavelet coefficients and performing the inverse DWT, we can obtain the fused result for the low activity region. In order to get better structural information, Fuzzy c-means clustering is used and to avoid color distortion, color-patching is also done. Finally fused image is extracted and displayed with less color distortion and without losing any structural information. More about wavelet related image fusion can be found at [23].

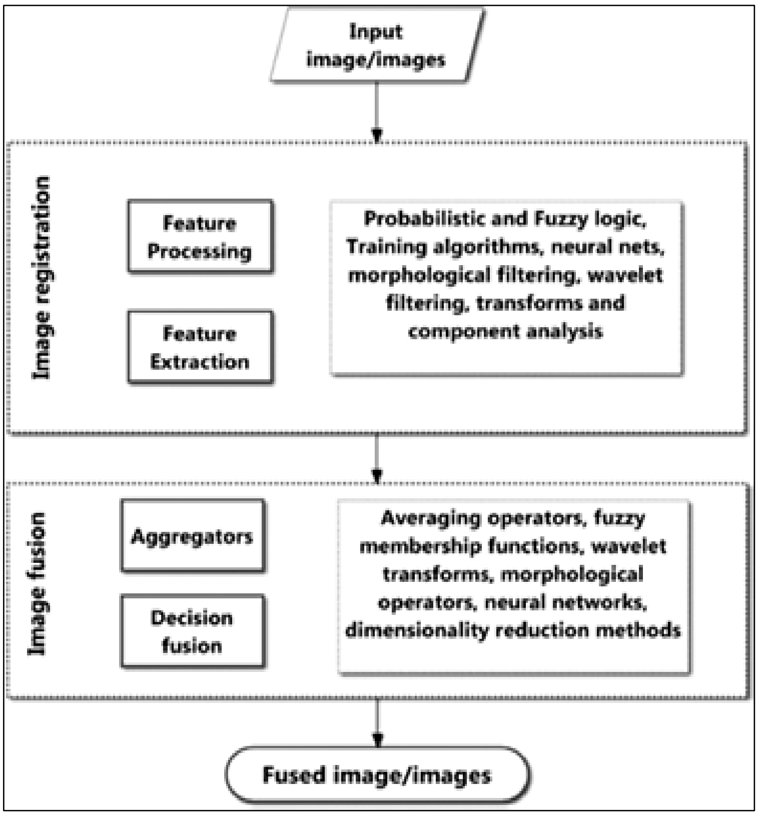

Fig. 2: *Flow of Image Fusion [20].*

Table 1: *Major Medical Image Fusion Methods and its Applications [20].*

Methods	**Modalities**	**Applications**	**Image Fusion Strategies**
Morphology	MRI, CT	Brain diagnosis	Morphology filters and pyramids
Knowledge	MRI, CT PET, Ultrasound, Mammogram	Segmentation, Micro-calcification diagnosis, Tissue classification, Brain diagnosis, Classifier fusion, Breast cancer tumor detection, Delineation and recognition of anatomical brain object and Medical image retrieval	Knowledge learning systems, Expert systems
Wavelet	CT, PET, MRI, Mammograms, MRA, fMRI, SPECT, Ultrasound	Pseudo coloring super resolution, Medical diagnosis, Feature level image fusion, Lifting scheme, Segmentation, 3D conformal radiology treatment planning and Color visualization	Wavelet transform, Multi resolution analysis, Discrete wavelet transform, Stationary wavelet transform, Dual tree discrete wavelet transform, Lifting wavelet transform, Multi-wavelet transform
Artificial neural network	CT, PET, MRI, Mammograms, MRA, fMRI, SPECT, Ultrasound	Feature generation, Classification, Fusion, Micro-calcification diagnosis, Breast cancer detection, Medical diagnosis, Cancer diagnosis	Coupled neural networks, Clustering neural network, Fuzzy neural networks, Wavelet neural networks
Fuzzy logic	CT, PET, MRI, Mammograms, MRA, fMRI, SPECT, Ultrasound	Brain diagnosis, Cancer treatment, Image segmentation and integration, Maximization Mutual Information, Deep brain simulation, Brain tumor segmentation, Image retrieval, Spatial weighted entropy, Feature fusion, Multimodal image fusion, Ovarian cancer diagnosis	Image fuzzification, Modification of membership values, Image defuzzification, Fuzzy combination operators, Neuro-fuzzy networks

RELATED WORK

Das and Kundu have conducted the experiment results of novel medical image fusion using neuro-fuzzy with NSCT are carried out in five different datasets of images: CT/MRI, MRI/MRA, FLAIR/DWI, PET/MR, and PET/CT [13]. Each group of results are also compared with various methods; regional variance multi-wavelet fusion, fusion using pulse coupled neural network, fusion using pulse coupled neural network with NSCT, fusion using multiscale contourlet transform, effective wavelet transform, neuro-fuzzy hybrid medical image fusion counterlet transform, neuro-fuzzy hybrid medical image fusion curvlet transform. Performance evaluation is done by measuring spatial frequency, entropy, and standard deviation. The effects of the different fusion rules, as well as the new techniques to compute the PCNN parameters can improve the present technique.

Experiments of Kavitha and Chellamuthu are carried out with ten datasets of PET/MRI and SPECT/MRI images and the results are compared with fusion based on genetic algorithm, fusion based on modified pulse coupled neural network and fusion based on neuro-fuzzy logic [15]. The performance evaluation of results is carried out objectively as well subjectively. Objective evaluation is carried out by fusion metrics entropy, standard deviation, average gradient, mutual information, structural similarity index metric, correlation coefficient, bias, and universal image quality index. It can be concluded that values of fusion performance metrics are improved compared to other three methods and radiologist found it useful in detection of lesion for proper diagnosis. The computational time is not much significant that anti-colony optimization takes little while time to compute in detect and enhancement of edges. Computational time can be optimized by using different intelligence edge detectors like bee colony and genetic algorithms or changing parameters in ant colony optimization. The fusion technique also can be improved by using different fusion rules.

Experiment of Myna and Prakash is conducted on two datasets; one where the reference image is available and second where the reference image is not available [16]. When the reference image is available the performance evaluation of the fused image is carried out by performance parameters root mean square error, mean absolute error, percentage fit error, signal to noise ratio, peak signal to noise ratio, correlation, mutual information measure, universal quality index, structural similarity measure. When the reference image is not available the evaluation metrics used are standard deviation, entropy, cross entropy, spatial frequency, fusion factor, fusion symmetry, fusion quality index and fusion similarity metric. Also this algorithm is compared with simple averaging fusion method, principal component analysis fusion method and wavelet transform fusion method. This technique can be improved by choosing different number of combinations of membership functions, different fuzzy rules and different wavelet related transform. This method can also be developed for color, multimodal and multiple images for medical diagnosis as well as remotely sensed images.

Experiment of Rao *et al*. is conducted on landmine and medical images dataset with evaluation parameters image quality index, mutual information measure, fusion factor, fusion symmetry, fusion index, root mean square error, peak signal to noise ratio, entropy, correlation coefficient, and spatial frequency [18]. Results have showed that iterative based fuzzy and neuro-fuzzy image fusion methods performed well. Methods can be improved by changing fusion fuzzy rules as well as choosing different combination of membership functions. These methods can be further developed for multimodal, multiple and color images for medical diagnosis and remote sensing. Also these methods can be extended for image classification and video fusion.

The survey by James *et al.* states various techniques used in medical image fusion based widely used techniques, medical modalities and organs under study [20]. The image fusion User Interface Tool can be developed for the research as well as commercial medical application purpose.

The technique presented by Bhavana and Krishnappa have compared with HIS+RIM fusion method and experiment is conducted on PET and MRI images a total of three sets of brain diseases like PET normal axial, PET normal coronal, PET Alzheimer, MRI normal axial, MRI normal coronal and MRI Alzheimer constitute the experimental dataset for fusion [22]. Performance evaluation is carried out with fusion metrics mean square error, peak signal to noise ratio, average gradient and spectral discrepancy. For medical fusion, this method can also be evaluated with other modalities MRI-CT, MRI-SPECT, PET-Ultrasound. Moreover, to preserve edges better, complex wavelet and contoulet transform can be used. Various performance evaluation metrics for image fusion are explained in [24–29].

CONCLUSION

In the conclusion, study of various hybrid intelligent techniques for medical image fusion are surveyed. Soft computing components are used with different combinations to make intelligence image fusion technique better. Many of them show effective result in performance but still need to improve the present state for better medical diagnosis. Such as in spatial domain, developing fuzzy and neuro-fuzzy based image fusion algorithm for multiple, multimodal and color images by changing fuzzy rules and choosing combinations of membership functions. Pulse coupled neural network can be used with different edge detectors. In frequency domain, different parameter computation methods for pulse coupled neural network can be used. In wavelet based transform, fuzzy rules can be used to fuse frequency coefficients with intelligence edge detectors.

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Cite this Article
Bodana Vaibhav K. Shah Jheel J. Brief review of medical image fusion techniques based on hybrid intelligence. *Journal of Artificial Intelligence Research & Advances*. 2016; 3(1): 8–15p.