Clinical Integration of Positron Emission Tomography (PET) and Magnetic Resonance Imaging (MRI) for Enhanced Medical Image Fusion

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Abstract— *Medical image fusion enhances image reliability by integrating key data from multiple sources. This paper introduces a fusion method using NSST (Non-Sampled Shearlet Transform) in the transform domain. Entropy analysis, based on PCNN (Pulse Coupled Neural Network), is employed to optimize fusion. The proposed algorithm prioritizes high-information bands for fusion, resulting in superior image quality. NSST and PCNN are applied to fuse MRI and PET images, ensuring comprehensive data integration.*

I. INTRODUCTION

Advancements in medical imaging equipment offer diverse modalities such as X-ray for bone display, Computed Tomography (CT) for hard tissue visualization, Magnetic Resonance Imaging (MRI) for soft tissue depiction, and Positron Emission Tomography for physiological and pathological insights. Medical image fusion enhances diagnostic accuracy by consolidating information from different imaging modalities, facilitating easier diagnosis. Moreover, image fusion finds applications in various fields including space research, defense, and remote sensing. Transforming images from the time domain to the frequency domain enables efficient analysis. Wavelet Transform, a multi-resolution image decomposition tool, separates images into detailed and approximation coefficients, capturing different image features through frequency sub-bands. Discrete Wavelet Transform (DWT) efficiently handles 1-D singularity, offering improved spectral content, albeit with limited directionalities and time invariance issues. To address these, Shifted Wavelet Transform (SWT) or un-decimated DWT is employed. Various fusion algorithms are developed based on these transforms, with the proposed edge and energy method outperforming average and maximum techniques. This method leverages high-edge information and energy from decomposed bands, yielding superior fusion results.

1.1 DWT

The wavelet transform evaluates signal compatibility with wavelets, yielding higher transform values for matched signal-wavelet pairs and lower values otherwise. It's instrumental in discerning regional characteristics within images. Discrete Wavelet Transform (DWT) decomposes images into bands via decimation, achieved through successive 1-D transforms along rows and columns. This decomposition yields sub-bands half the size of the original signal, implemented through scaling. DWT facilitates multi-resolution analysis, with the LL band resembling a spatial image while higher bands capture diverse frequencies. The decomposition and reconstruction of the image is done by using 'db2'. The 2-D wavelet is given as

$$\varphi_{\phi}(j,u,v) = \frac{1}{\sqrt{N \times N}} \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f(x,y)\, \phi_{j,u,v}(x,y) \quad (1)$$

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where as scaling function is

$$\phi_{j,u,v}(x,y) = 2^{j} \phi(2^{j} x - u, 2^{j} y - v)$$

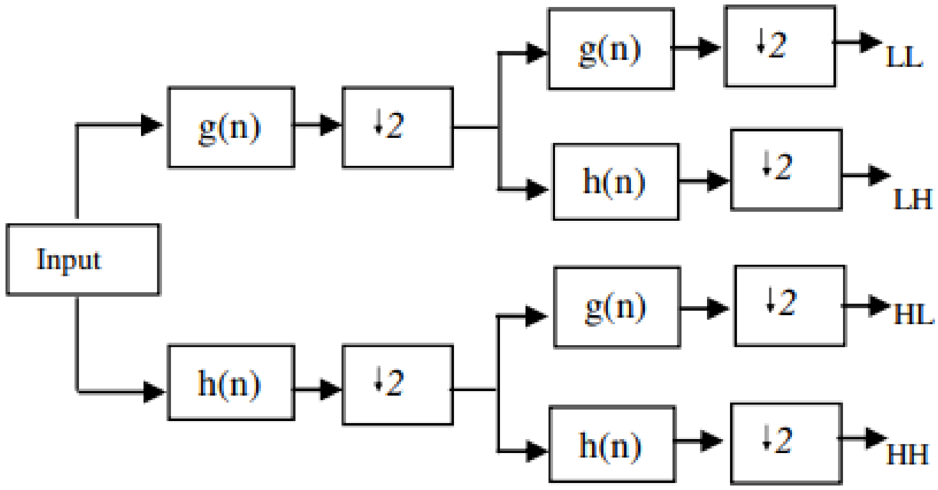


Figure 1: DWT Decomposition

1.2 SWT

The SWT is called as un-decimated DWT, it does by up sampling the signal instead of down sampling by adding zeros in between the filter coefficients [5]. The algorithm in which the zeros are added in between the filter coefficients is called as 'trous' which means with holes. In SWT the decomposed image will give sub-bands with one approximation coefficients and three detailed coefficients of the images. The size of the sub-bands will be same as the size of the original or input image. The approximation coefficients of images from the undecimated algorithm are therefore represented as the levels in a parallelepiped[6], with the spatial resolution of the image becoming coarser at every higher level so the size of the sub-band remains the same the 2D-SWT is on the idea without using the decimation. It applies the Discrete wavelet transform but without the down sampling during the decomposition and applies up-sampling during the reconstruction by using inverse transform. To be précised, it applies transform at every point of the image and saves the detailed coefficient and uses low frequency information at every level[5].

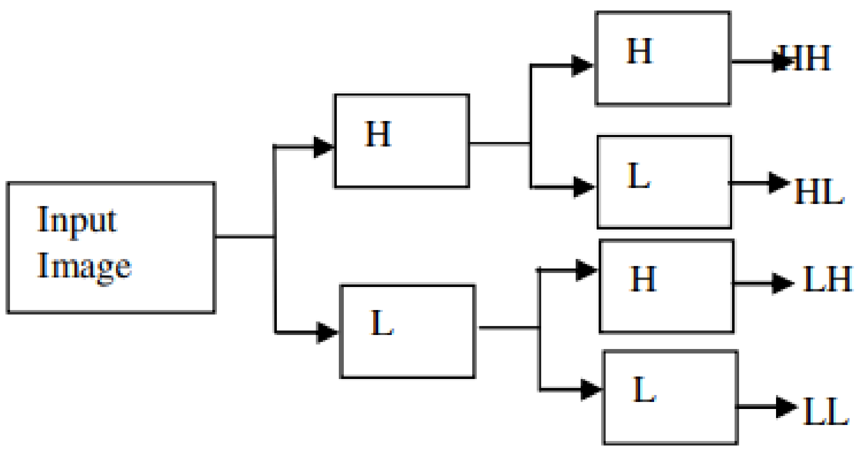


Figure 2: SWT Decomposition

1.3 Proposed NSST and PCNN

1.3.1 NSST:

Shearlets possess a distinctive blend of features: a straightforward mathematical structure derived from affine systems theory, optimal sparsity in representing a wide range of images and multidimensional data, and directionality controlled by shear matrices rather than rotations. This unique property enables a unified framework for both continuous and discrete settings, making it advantageous for digital implementations. Shearlet decomposition finds successful applications in numerous fields such as applied mathematics and signal processing, including operator decomposition, inverse problems, edge detection, image separation, and restoration. The Non-Sub-Sampled Shearlet Transform (NSST) enhances 2-D structural capturing compared to traditional multi-scale transforms, offering improved fusion information and reduced sensitivity to misalignment. Additionally, NSST exhibits lower computational complexity than the Non-Sub-Sampled Contourlet Transform (NSCT). As a result, NSST excels in various image fusion applications, providing high-quality spectral content, stronger selectivity in anisotropic direction, higher computational efficiency, and additional information regarding geometric singularities like edges and discontinuities, surpassing NSCT in versatility and performance.

1.3.2 PCNN:

ChatGPT

Pulse-coupled neural networks (PCNNs), originally inspired by the visual cortex of cats, are highly efficient models in image processing. Over the last decade, they've found extensive application in various tasks like image segmentation, feature generation, face extraction, motion detection, region growing, and noise reduction. PCNNs function as two-dimensional neural networks, with each neuron corresponding to a pixel in the input image, receiving color information (e.g., intensity) as external stimuli. These neurons are interconnected with neighboring ones, exchanging local stimuli. An internal activation system accumulates these stimuli until surpassing a dynamic threshold, generating a pulse output. Through iterative computations, PCNN neurons produce temporal series of pulse outputs, containing crucial information from input images, applicable in tasks like segmentation and feature generation. Notably, PCNNs exhibit robustness against noise, independence from geometric variations in input patterns, and the ability to handle minor intensity variations, presenting significant advantages over conventional image processing techniques.

1.4 Proposed Algorithm

For performing the fusion rules firstly, we need two different input images, here I considered the MRI, PET images of the same source. The pre-processing for the input images has been done by making the size of all the input images to be same i.e., 256*256 .

- Step-1: - Applying transform to the input images which decomposes the input image to sub-bands namely Low pass and Band pass Band
- Step-2: -Applying proposed fusion rule that is calculating the entropy information of the low level subband and calculating the energy for the other sub-bands. In the proposed algorithm based on the neural network is calculated by using the PCNN.
- Step-3:Finally, the image will be fused based on the MRI and PET images.

II. LITERATURE REVIEW

2.1 Multimodal Medical Image Fusion using NSCT and DWT Fusion Frame Work

K. Koteswararao, K. Swamy – 2019

Image fusion is a pivotal process that extracts vital details from multiple images, consolidating crucial information into a single composite image. Fusion can occur in either spatial or transform domains, with this study focusing on both to optimize performance. NSCT-based fusion selects important bands using the energy of decomposed bands, while DWT-based fusion employs a similar approach. The resulting fused images from NSCT and DWT are further combined using spatial domain techniques, considering ESOP values for fusion. Extensive experiments conducted on numerous medical images demonstrate the proposed method's efficacy in producing perceptually meaningful results. Performance assessment utilizes metrics such as entropy, edge-based similarity measures, and quality of mutual information. The research integrates two medical images (CT, MRI), preprocesses them, merges them using wavelet and NSCT transformations with energy fusion techniques, and finally combines them in the spatial domain for the desired output. This comprehensive approach ensures that all essential information from the two medical images is incorporated into the final output. The study's outcomes, analyzed qualitatively and quantitatively across various CT and MRI images, showcase significant enhancements in performance parameters. Furthermore, image fusion finds wide-ranging applications in remote sensing, space research, defense, and medical imaging, further highlighting its remarkable improvements in various domains.

2.2 A Review Of Quality Metrics For Fused Image

Author: Jagalingam Pa, Arkal Vittal Hegde - 2020

Image fusion is the process of combining high spatial resolution panchromatic (PAN) image and rich multispectral (MS) image into a single image. The fused single image obtained is known to be spatially and spectrally enhanced compared to the raw input images. In recent years, many image fusion techniques such as principal component analysis, intensity hue saturation, brovey transforms and multi-scale transforms, etc., have been proposed to fuse the PAN and MS images effectively. However, it is important to assess the quality of the fused image before using it for various applications of remote sensing. In order to evaluate the quality of the fused image, many researchers have proposed different quality metrics in terms of both qualitative and quantitative analyses. Qualitative analysis determines the performance of the fused image by visual comparison between the fused image and raw input images. On the other hand, quantitative analysis determines the performance of the fused image by two variants such as with reference image and without reference image. When the reference image is available, the performance of fused image is evaluated using the metrics such as root mean square error, mean bias, mutual information, etc. When the reference image is not available the performance of fused image is evaluated using the metrics such as standard deviation, entropy, etc. The paper reviews the various quality metrics available in the literature, for assessing the quality of fused image.

2.3 Medical Image Fusion using NSCT

K. VeeraSwamy1, B. Ashwanth - 2020

Image fusion is a process of extracting needed or important useful information from two or more images and fusing into a single or one image. This process results to a better image which contains more detailed information compared to the source or input images. General fusion techniques are not considering the edge and energy information which is very important information in the image. The fusion techniques using average and maximum rule techniques fail to fuse important edge information present in the source images. Further, energy available in the source images is also not considered. Hence, quality of the fused image is affected. To address these problems, edge and energy-based technique is explored. In this paper we are comparing the average and maximum fusion rule and Edge and Energy fusion rule for NSCT (Non-Sub-sampled Contourlet Transform) and comparing this transform with DWT and SWT. We are using the PET (Positron Emission Tomography) and MRI(Magnetic Resonance Imaging) images as the source images. The performance is assessed using metrics called Entropy

2.4 Image Fusion using NSCT Theory and Wavelet Transform for Medical Diagnosis

Anju P J, Dr.D.Loganathan - 2016

Image fusion is the process of combining relevant information from two or more images to produce a single fused image. Medical image fusion is mainly a multi modal image fusion where images from different modes such as Computed Tomography (CT), Magnetic Resonance Image (MRI), Positron Emission Tomography (PET) etc. are fused for diagnosis purpose. The classification of image fusion is wide and vibrant. Some of the popular medical image fusion methods are discussed and comparative study is made. A new method for medical image fusion which combine Nonsubsampled Contour let Transform (NSCT) and wavelet transform is proposed.

2.5 Intelligent Multimodal Medical Image Fusion with Deep Guided Filtering

B. Rajalingam, Fadi Al-Turjman, R. Santhoshkumar & M. Rajesh- 2020

Medical image fusion is a synthesis of visual information present in any number of medical imaging inputs into a single fused image without any distortion or loss of detail. It enhances image quality by retaining specific features to improve the clinical applicability of medical imaging for treatment and evaluation of medical conditions. A big challenge in the processing of medical images is to incorporate the pathological features of the complement into one image. The fused image presents various challenges, such as existence of fusion artifacts, hardness of the base, comparison of medical image input, and computational cost. The techniques of hybrid multimodal medical image fusion (HMMIF) have been designed for pathologic studies, such as neurocysticercosis, degenerative and neoplastic diseases. Two domain algorithms based on HMMIF techniques have been developed in this research for various medical image fusion applications for MRI-SPECT, MRI-PET, and MRI-CT. NSCT is initially used in the proposed method to decompose the input images which give components of low and high frequency. The average fusion rule applies to NSCT components with low frequency. The NSCT high frequency components are fused by the law of full fusion. NSCTs high frequency is handled with directed image filtration scheme. The fused picture is obtained by taking inverse transformations from all frequency bands with the coefficients obtained from them. The methods suggested are contrasted with traditional approaches in the state of the art. Experimentation proves that the methods suggested are superior in terms of both qualitative and quantitative assessment. The fused images using proposed algorithms provide information useful for visualizing and understanding the diseases to the best of both sources' modality.

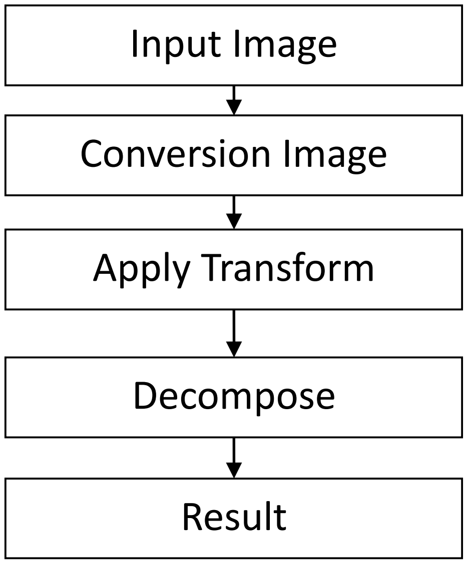
III. PROBLEM STATEMENT

- In our existing method, the Paper present medical image fusion in transform domain by using DWT (Discrete Wavelet Transform) and SWT (Stationary Wavelet Transform).
- The edge and energy rule for the decomposed bands of DWT, SWT based image fusion are performed.
- The new fusion rule gave less performance to obtain the fused image.
- Entropy is used to assess the performance of the existing method of the system.
- The two images (MRI, PET) are used for the fusion by using DWT, SWT by using the image processing.
- But, in our existing method the fusion not come in accurate results.

DISADVANTAGES

- Fusion not in proper way
- Inefficiency
- Less performance

IV. METHODOLOGY



4.1 Input Image

The input images consist of two types: MRI images and PET scan images. MRI scans are particularly useful for imaging the brain, spine, soft tissue of joints, and the interior of bones. They're employed in diagnosing various conditions including brain tumors, traumatic brain injury, developmental anomalies, multiple sclerosis, stroke, dementia, infections, and the underlying causes of headaches. On the other hand, PET scans involve administering a special dye containing radioactive tracers, either orally, through inhalation, or via injection into a vein, depending on the area of examination. These tracers are absorbed by certain organs and tissues, highlighting areas of higher chemical activity. PET scans provide insights into organ and tissue functionality, including blood flow, oxygen consumption, glucose utilization, and more, by detecting bright spots indicating increased chemical activity.

4.2 Conversion Image

Here, the conversion part takes place the grey scale conversion of the image. To implement the algorithm to the input image, first to convert the gray scale image.

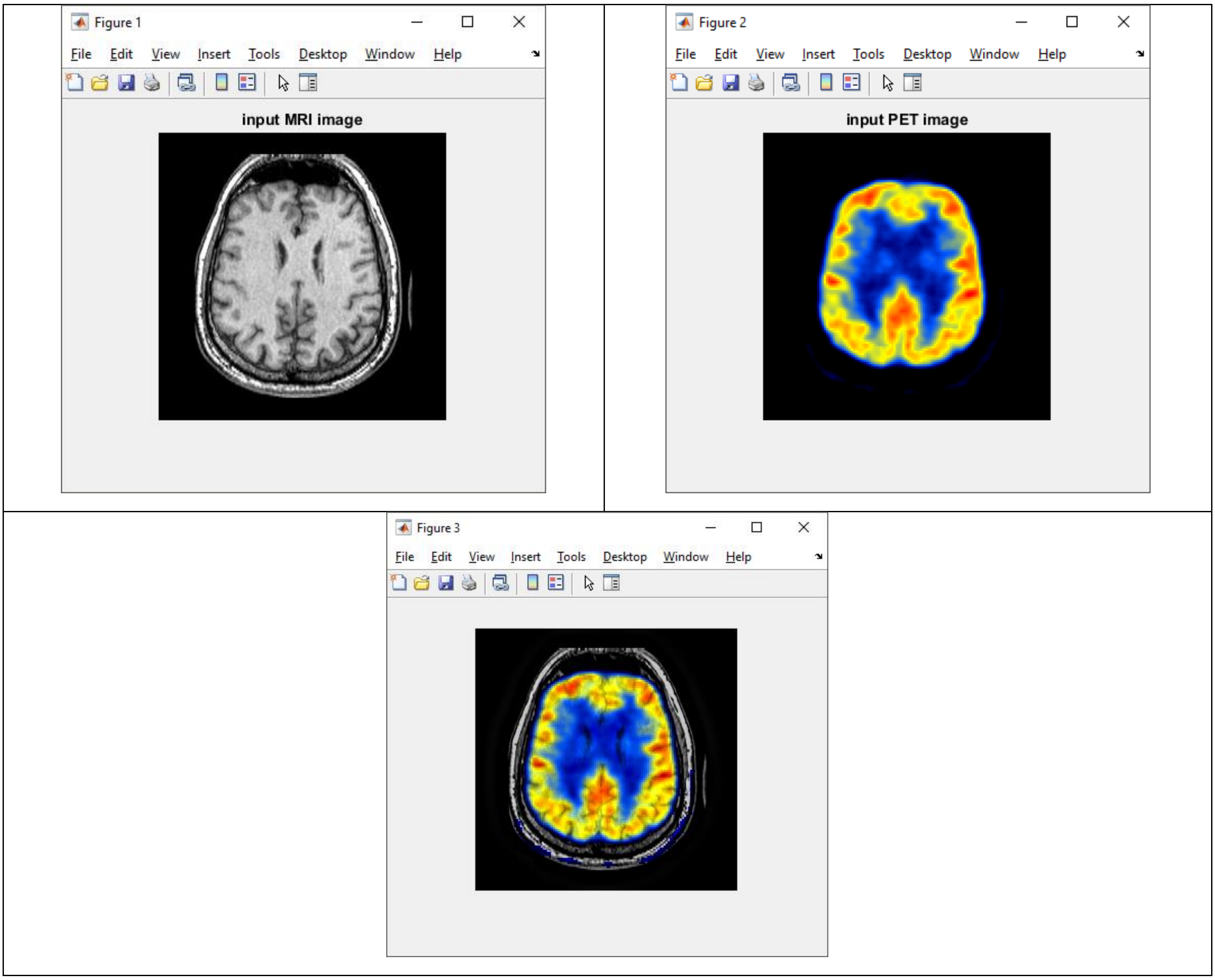
4.3 Apply Transform

After, complete the conversion techniques, next to apply the transform based on the NSST. A NSST is one type of technique is used in the Image Processing Toolbox. Also it have very good technique for the image fusion provide a high quality spectral content, Hence NSST has stronger selectivity of anisotropic direction, higher computational efficiency. A non-sub-sampled shearlet transform (NSST) is found to be best algorithm for image fusion.

4.4 Decompose

After, to apply the transform then to decompose the image into some level based on the Pixel range of the system. Here, the 5 times to decompose the image based on the input requirement. Decompose image obtained the some band based upon the low pass and band pass of the system. Next, to calculate the entropy based on the mean, median and gradient value. Finally, the entire image will be reconstructed based on the input requirement. The Results will be shown the Fused image of the system.'

V. IMPLEMENTATION



VI. CONCLUSION

The fusion of images using PCNN and NSST occurs in the transform domain, with LL and higher bands selected based on input from two images. Entropy, derived from parameters like mean, median, and pixel gradient, guides the selection process. This method can be further enhanced by decomposing images into multiple levels. Experimental evaluations utilizing NSST and PCNN demonstrate superior performance compared to alternative techniques.

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