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Comparative Analysis of Medical Images Fusion Using Different Fusion Methods for Daubechies Complex Wavelet Transform

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Abstract: The fusion of data for medical imaging has become a vital issue in many medical fields such as radiotherapy. This paper clarifies the concepts and relationship between image fusion methods based on wavelet transform. Fusion experiments are performed on CT scan and MRI Medical images for 81 different combinations of approximation(cA) and detail(cD) coefficients based on Daubechies (db) complex wavelet transform.This paper compares the influence of all combinations quantitatively on the results of image fusion in detail. Experimental results show the worst and best fusion performances are given by UD-UD and LR-Min fusions respectively.

Keywords: Image fusion, wavelet transform, multisource image, spatial frequency, Wavelet transform, multimodal medical image fusion, Medical imaging, Daubechies complex wavelet transform, Fusion metrics, Phase information.

I. Introduction

Image fusion is the process by which two or more images are combined into a single image for retrieval of vital information from these images [1]. The fusion of images is often required for medical images acquired from different instrument modalities such as X-rays, computed tomography (CT), magnetic resonance imaging (MRI) and positron emission tomography (PET) of the same objects. For image fusion a number of research studies have been reported in the literature [2-4]. The Fusion techniques include the method of pixel averaging or complicated methods such as principal component analysis and wavelet transform fusion. Pixel based methods [5][6] are the most commonly used for image fusion. Pixel level image fusion method is easy to implement and images contain original information. In recent years image fusion methods based on wavelet transform have been widely used. A simple image fusion algorithm based on wavelet transform is proposed in reference [7]. The wavelet transform decomposes the image into spatial frequency bands at different scales such as low-high, high-low, high-high and the low-low band. The average image information is given by the low-low band [8]. Due to spatial orientation, other bands contain directional information. Higher absolute values of wavelet coefficients in the high bands correspond to salient features such as edges or lines [9]. The common element idea in almost all of them is the use of wavelet transform to decompose images into a multi resolution scheme [10-11]. Gonzalo Pajares et.al. [12] presents an image fusion tutorial based on wavelet decomposition, i.e. a multi resolution image fusion approach. Lahouari Ghouti [13] presents the use of balanced multi wavelets for image fusion. Gemma Piella [14] presents an overview on image fusion techniques using multi resolution decompositions. MRI images provide much greater contrast of soft tissues of brain than CT images , while brightness of hard tissues such as bones is higher in CT images but soft tissues cant' be seen . In this paper image fusion of CT & MRI images has been carried out using Daubechies complex wavelet transform for different wavelet coefficients i.e. high-scale, low-frequency components(approximation wavelet coefficient) and low-scale, high-frequency components (detail wavelet coefficient) and their combinations in MATLAB environment. This paper further quantitatively evaluates the fused images quality through two performance measures Standard Deviation (SD) and Entropy (EN). This paper is organized as follows; Section II gives the wavelet transform based image fusion briefly. Section III defines the two image fusion performance evaluation criterion, Standard Deviation (SD) and Entropy (EN). Comparative Experimental Results are presented and discussed in Section IV .The conclusion is mentioned in Section V. Appendix contains all the fused images.

II. Wavelet Transform Image Fusion

The basic image fusion scheme is shown in Fig. 1. The first step is to compute the wavelet transforms of images. Wavelet transform image fusion method decomposes an image into various sub images based on local frequency content and by choosing the salient wavelet coefficients; a composite multi-scale representation is built. Since larger absolute wavelet transform coefficients correspond to sharper brightness changes, a common integration rule is to select, at every point in the transform domain, the coefficients whose absolute values are higher. In this way the fusion takes place in all the resolution levels and the more dominant features at each scale are preserved in the new multiresolution representation. Subsequently with some specific rules of decision or weighting, a new image is constructed by performing an inverse wavelet transformation. In wavelet transformation, at each level of decomposition process the image size is halved in both spatial directions which lead to a multi-resolution signal representation, due to sampling. The formation of fusion pyramid is the most important step for fusion.

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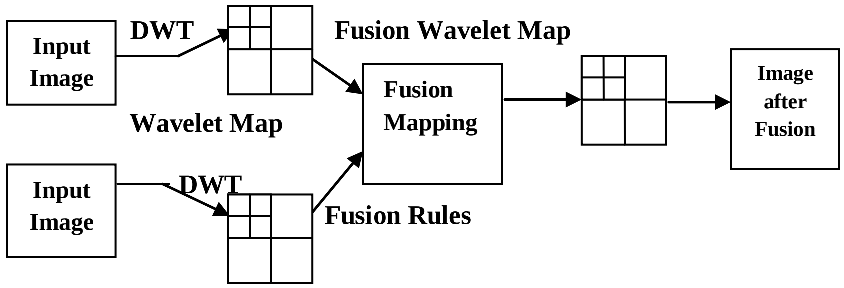


Fig.1 Wavelet Transform Process

The image fusion process is performed by using wavelet toolbox in Matlab. The steps for Image fusion using a wavelet tool box are –

Step 1. Load the CT and MRI Medical Images.

Step2. Perform the wavelet decompositions. Use the wavelet and level menus located on the upper right; determine the wavelet family, the wavelet type, number of levels and type of wavelet coefficient to be used for the analysis.

Step 3. Merge the two images after decompositions.

Step 4. Restore the new image using image fusion. The new image produced by fusion clearly exhibits features from the two original ones.

III. Performance Assessment

The wavelets share some common properties, but each wavelet also has a unique image decompression and reconstruction characteristics that lead to different fusion results. The general requirements of an image fusing process are that it should preserve all valid and useful pattern information from the source images, while at the same time it should not introduce artifacts that could interfere with subsequent analyses. The performance measures used in this paper provide quantitative comparison among different fusion schemes, mainly aiming at measuring the definition of an image.

A. Standard Deviation (SD)

The standard deviation is the most common measure of statistical dispersion, which measures the contrast in the fused image and evaluate how widely spread the gray values in an image. Standard deviation denotes the deviation degree of the estimation and the average of the random variable. This metric is more efficient in the absence of noise. So, the larger the standard deviation, the better the result.

An image with high contrast would have a high standard deviation.

$$\sigma = \sqrt{\sum_{i=0}^{L}\left(i-\bar{i}\right)^2 h_{I_f}(i)}, \cdots \bar{i} = \sum_{i=0}^{L} i h_{I_f}$$

Where $h_{I f}(i)$ is the normalized histogram of the fused image and L is number of frequency bins in histogram.

B. Entropy (EN)

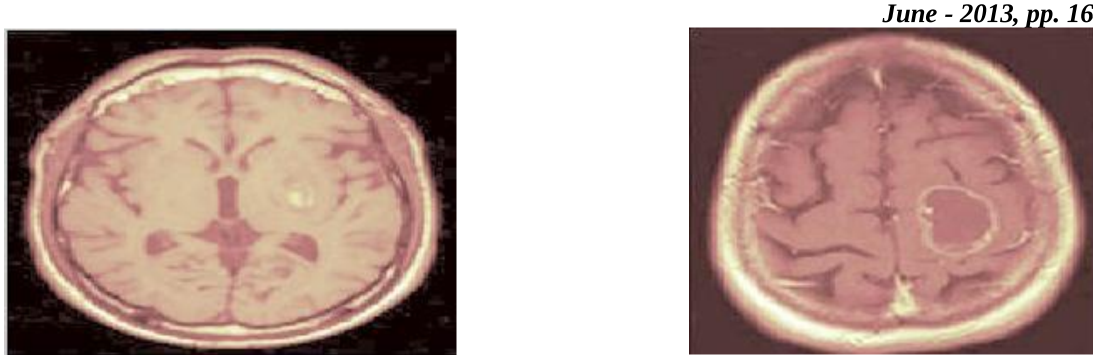
Entropy is an index to evaluate the information quantity contained in an image. If the value of entropy becomes higher after fusing, it indicates that the information increases and the fusion performances are improved. Entropy is defined as

$$E = -\sum_{i=0}^{L-1} p_i \, log_2 \, p_i$$

Where L is the total of grey levels, $p = \{p_0, p_1 \ldots p_{L-1}\}$ is the probability distribution of each level.

IV. EXPERIMENTAL RESULTS

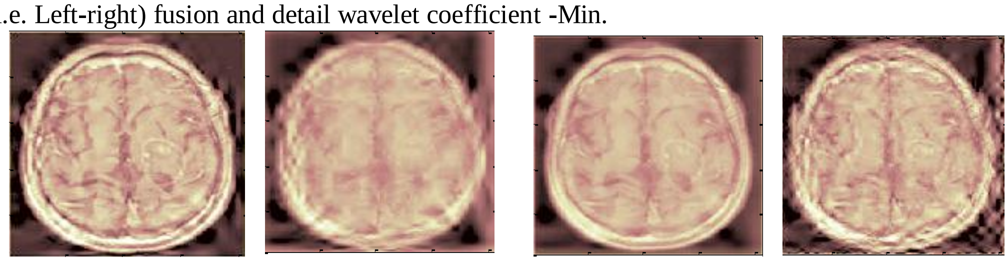
The CT and MRI medical images (Fig. 2) are used in this fusion experiment. The set of 09 approximation and detail coefficients (Max, Min, Mean, Rand, Linear, UD fusion, DU fusion, LR Fusion, and RL Fusion) and their 81 combinations are used in the study.



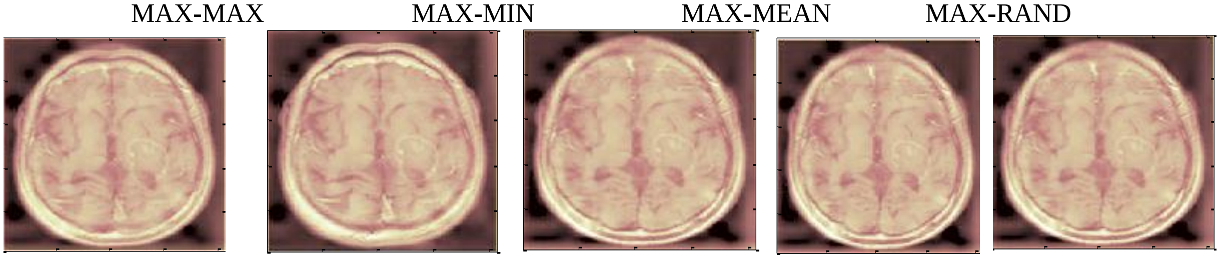
(a) (b)

Fig. 2 Original medical images to be fused (a) CT image (b) MRI image

The fusion performance for each combination is evaluated by using the standard deviation (SD) and Entropy (EN) as performance measures. The fusion results (Table I and Fig.3) in Matlab environment clearly show that many of the fusion methods produced results that had lower measures of effectiveness (Standard Deviation and Entropy) than their input images. The lowest SD and EN values were associated with approximation Wavelet Coefficient- UD (i.e. Up-Down) fusion and detail wavelet coefficient-UD fusion. The highest relative SD and EN values were obtained with approximation Wavelet Coefficient- LR (i.e. Left-right) fusion and detail wavelet coefficient -Min.

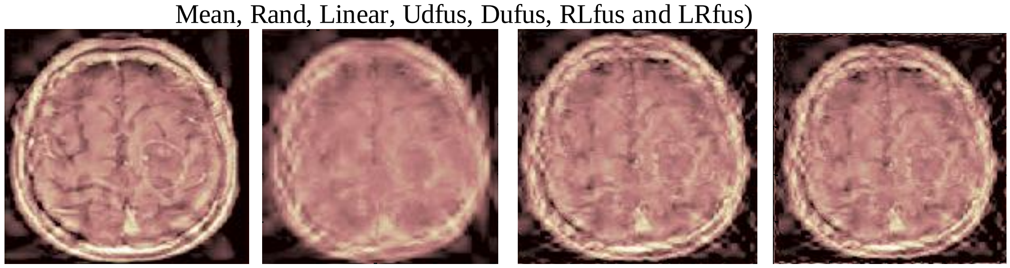


MAX-MAX MAX-MIN MAX-MEAN MAX-RAND

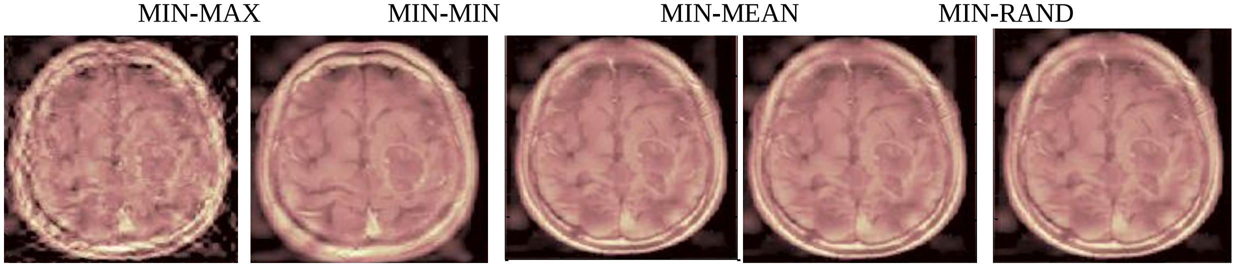


MAX-LINEAR MAX-UDFUS MAX-DUFUS MAX-RLFUS MAX-LRFUS

Fig 3. (a) Image fusion results for medical images with approximation coefficient (Max) and detail coefficients (Max, Min, Mean, Rand, Linear, Udfus, Dufus, RLfus and LRfus)



MIN-MAX MIN-MIN MIN-MEAN MIN-RAND



MIN-LINEAR MIN-UDFUSION MIN-DUFUSION MIN-RLFUSION MIN-LRFUSION

Fig 3. (b). Image fusion results for medical images with approximation coefficient (Min) and detail coefficients (Max, Min, Mean, Rand, Linear, Udfus, Dufus, RLfus and LRfus)

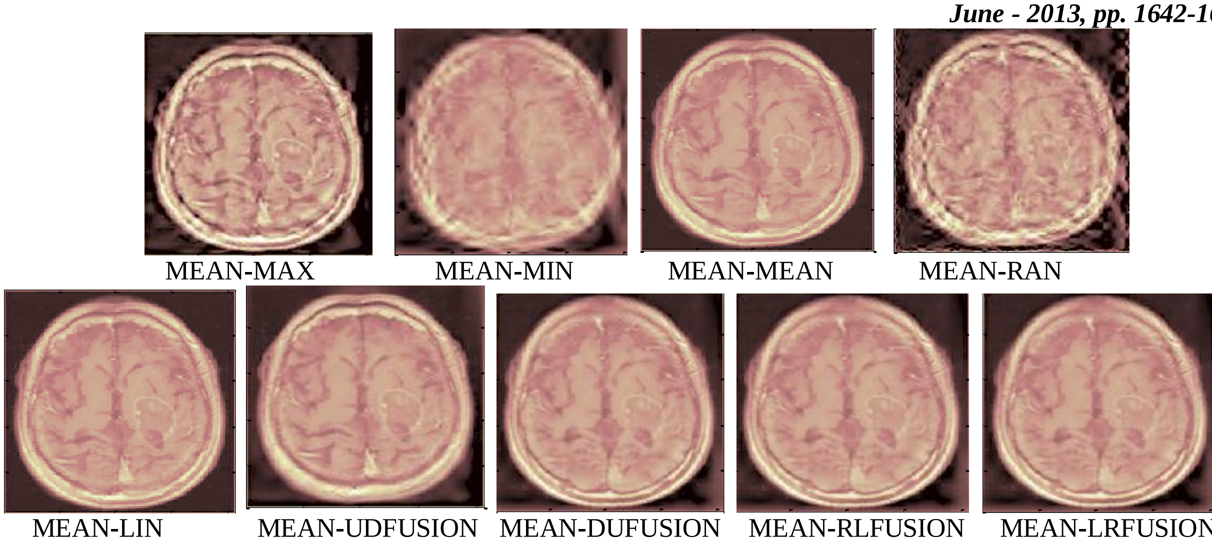


Fig 3. (c). Image fusion results for medical images with approximation coefficient (Mean) and detail coefficients (Max, Min, Mean, Rand, Linear, Udfus, Dufus, RLfus and LRfus)

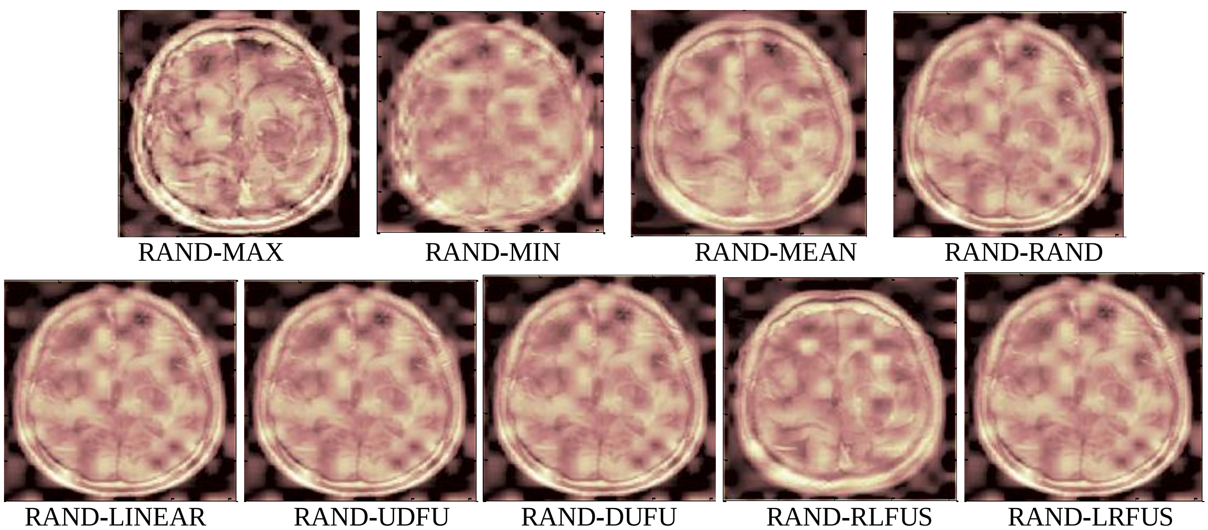


Fig 3. (d). Image fusion results for medical images with approximation coefficient (Rand) and detail coefficients (Max, Min, Mean, Rand, Linear, Udfus, Dufus, RLfus and LRfus)

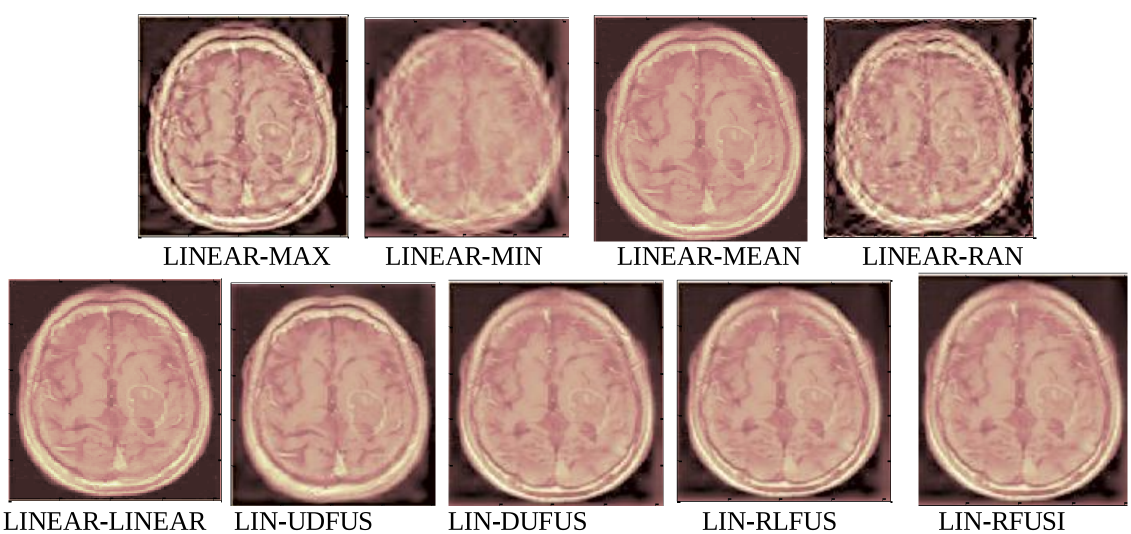
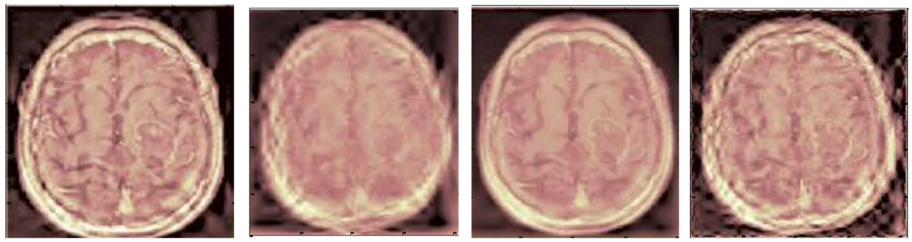
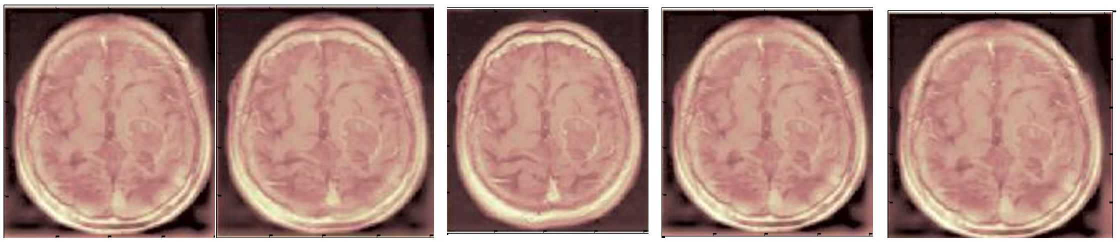


Fig 3. (e). Image fusion results for medical images with approximation coefficient (Linear) and detail coefficients (Max, Min, Mean, Rand, Linear, Udfus, Dufus, RLfus and LRfus)

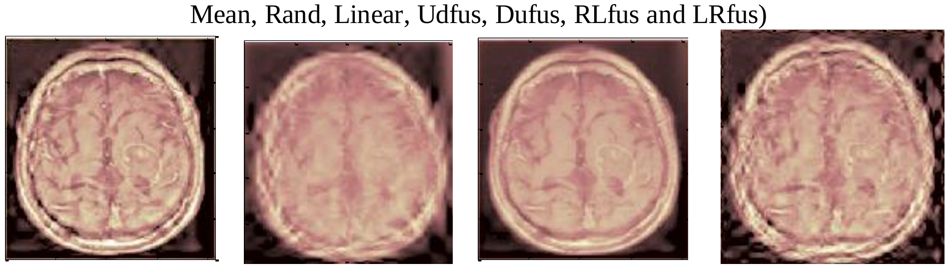


UDFUS-MAX UDFUS-MIN UDFUS-MEAN UDFUSIONRAND

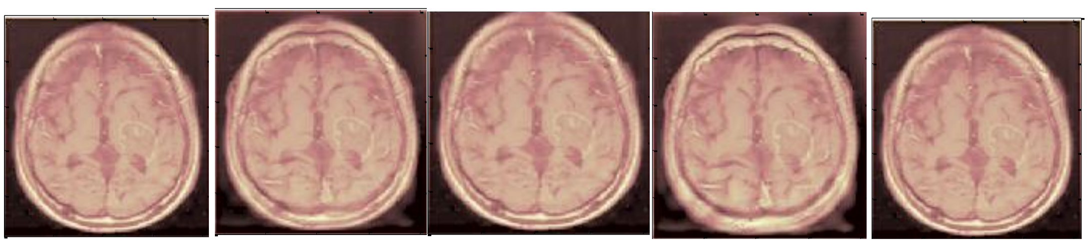


UDFUS-LIN UDFUS-UDFUS (WORST IMAGE) UDFUS-DUFUS UDFUS-LRFUS UDFUS-RLFUS

Fig 3. (f). Image fusion results for medical images with approximation coefficient (Udfus) and detail coefficients (Max, Min, Mean, Rand, Linear, Udfus, Dufus, RLfus and LRfus)

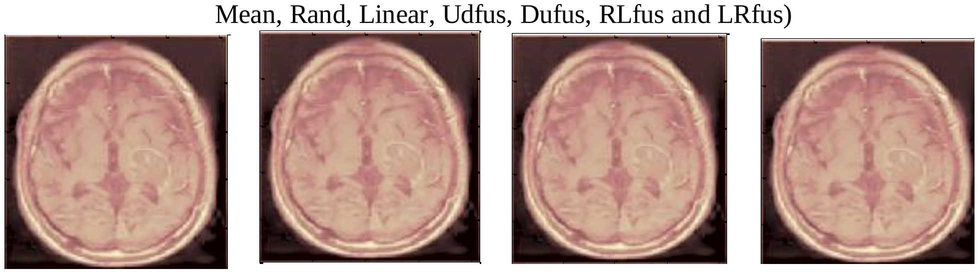


DUFUS-MAX DUFUS-MIN DUFUS-MEAN DUFUS-RAND

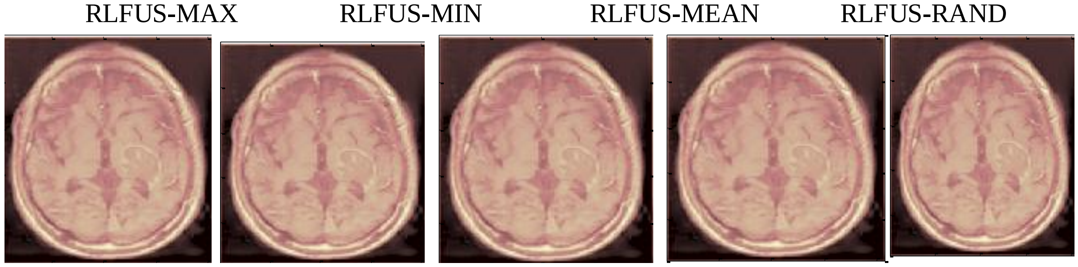


DUFUS-LIN DUFUS-UDFUS DUFUS-DUFS DUFUS-RLFUS DUFUS-LRFUS

Fig 3. (g). Image fusion results for medical images with approximation coefficient (Dufus) and detail coefficients (Max, Min, Mean, Rand, Linear, Udfus, Dufus, RLfus and LRfus)



RLFUS-MAX RLFUS-MIN RLFUS-MEAN RLFUS-RAND



RLFUS-LIN RLFUS-DUFUS RLFUS-UDFUS RLFUS-RLFUS RLFUS-LRFUS

Fig 3. (h). Image fusion results for medical images with approximation coefficient (RLfus) and detail coefficients (Max, Min, Mean, Rand, Linear, Udfus, Dufus, RLfus and LRfus)

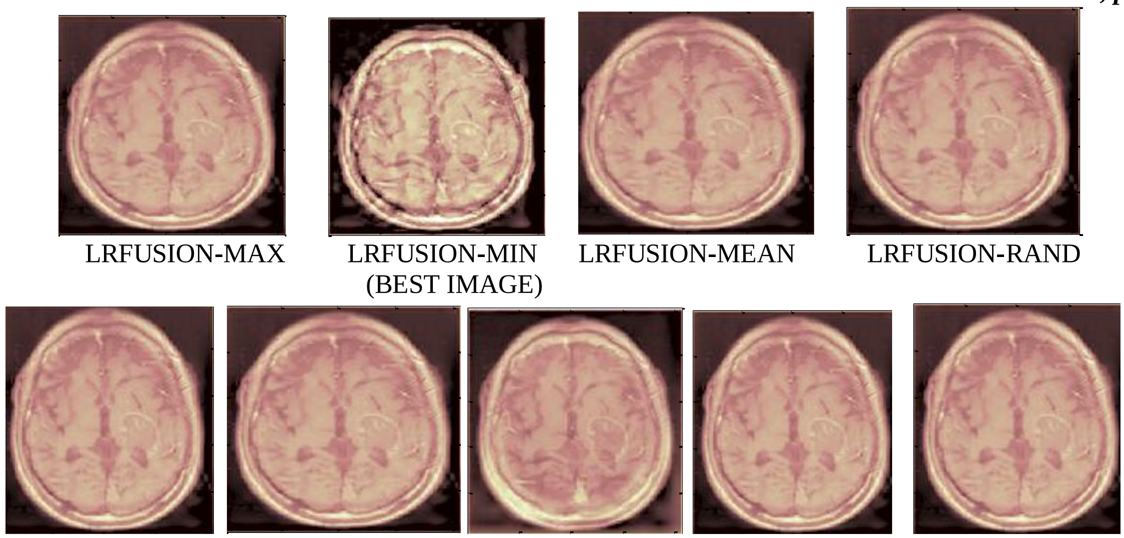


Fig 3. (i). Image fusion results for medical images with approximation coefficient (LRfus) and detail coefficients (Max, Min, Mean, Rand, Linear, Udfus, Dufus, RLfus and LRfus)

Fig 3. (a)- (i) Image fusion results for medical images (CT and MRI) with different approximation and detail coefficients.

V. Conclusions

In this paper, a Matlab based fully automated wavelet tool box method for CT and MRI medical image fusion is used. The synthesized image has the merits of both CT & MRI scanned images. In this paper, 09 kinds of wavelet coefficients and therefore 81 kinds of wavelet-based fusion methods are compared. The standard Deviation (SD) and Entropy (EN) has been used as image fusion evaluation criterion for quantitative analysis of image fusion results. The Matlab fusion results (Table I and Fig. 3) clearly show that many of the fusion methods produced results that had lower measures of effectiveness (SD and EN) than their input images. The highest relative SD and EN values were associated with approximation Wavelet Coefficient- LR and detail wavelet coefficient -Min. The comparative analysis of image fusion techniques allows in selecting the best fusion method and therefore one can obtain better visualization of the fused image.

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Table 1: Quantitative evaluation results of the 81 different image fusion schemes in Figure 3

DETAIL COEFFICIENTS / APPROXIMATION COEFFICIENTS		MAX	MIN	MEAN	RAND	LINEAR	UD_FUSION	DU_FUSION	LR_FUSION	RL_FUSION
MAX	**SD**	64.7655	51.1922	54.6393	57.8598	54.6393	56.5693	55.3885	55.3885	55.3885
	EN	0.2551	0.1244	0.0854	0.2260	0.0854	0.0786	0.1493	0.1493	0.1493
MIN	**SD**	62.5843	46.0790	50.9674	54.7850	50.9674	53.4161	51.3673	51.3673	51.3673
	EN	0.6812	0.4141	0.6117	0.5885	0.6117	0.5724	0.6219	0.6219	0.6219
MEAN	**SD**	62.4055	47.0200	51.0889	54.8862	51.0889	53.5308	51.8821	51.8821	51.8821
	EN	0.4997	0.0887	0	0.3257	0	0.2209	0.1803	0.1803	0.1803
RAND	**SD**	65.4499	52.8104	56.0639	61.2995	55.0942	58.6955	57.3155	57.3155	57.3155
	EN	0.5398	0.3703	0.3748	0.4668	0.3666	0.4494	0.5047	0.5047	0.5047
LINEAR	**SD**	62.4055	47.0200	51.0889	55.8026	51.0889	53.5308	51.8821	51.8821	51.8821
	EN	0.4997	0.0887	0	0.3710	0	0.2209	0.1803	0.1803	0.1803
UD FUSION	**SD**	62.7025	48.2334	52.0260	52.0260	52.0260	**53.8946**	52.9678	52.9678	52.9678
	EN	0.4839	0.0922	0.1686	0.1686	0.1686	**0.0017**	0.3056	0.3056	0.3056
DU FUSION	**SD**	64.1289	48.4785	53.0015	56.7187	53.0015	55.5106	53.2291	53.2291	53.2291
	EN	0.5231	0.2298	0.3092	0.3991	0.3092	0.3355	0.2269	0.2269	0.2269
LR FUSION	**SD**	53.6153	**72.5367**	53.6153	53.6153	53.6153	53.6153	53.6153	53.6153	53.6153
	EN	0.3248	**0.6956**	0.3248	0.3248	0.3248	0.3248	0.3248	0.3248	0.3248
RL FUSION	**SD**	53.6153	53.6153	53.6153	53.6153	53.6153	53.6153	53.6153	53.6153	53.6153
	EN	0.3248	0.3248	0.3248	0.3248	0.3248	0.3248	0.3248	0.3248	0.3248

